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The Impact of Technological Change in Agriculture on Production, Resource Use and the Environment: Towards an Approach for Ex Ante Assessment

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PREFACE

The purpose of this working paper is to provide some additional insights on the process of transforming agricultural R and D resources into food and other agricultural products and the related resource and environmental issues. Emphasis will be placed on providing guidelines and information expected to be useful for the further planning and execution of the IIASA research project on "Limits and Consequences of Food Production Technologies".[1]

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[1] For a description of the project see: IIASA, Research Plan 1980-1984 and Jaroslav Hirs, An Approach to the Investigation of Limits and Consequences of Food Production Technologies (draft), IIASA, Laxenburg, 1979.

ACKNOWLEDGEMENTS

Acknowledgement is due to a number of persons at IIASA for providing ideas and suggestions useful for this paper. In particular, I want to thank Jaroslav Hirs from the Food and Agriculture Program (FAP), and Harry Maier, Jennifer Robinson and Rolfe Tomlinson from the Management and Technology Area (MMT), for some very interesting and useful interchange of ideas related to the topic of this paper. The joint FAP-MMT collaboration stimulated significantly the preparation of this paper.

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THE IMPACT OF TECHNOLOGICAL CHANGE IN AGRICULTURE ON PRODUCTION, RESOURCE USE AND THE ENVIRONMENT: TOWARDS AN APPROACH FOR *EX ANTE* ASSESSMENT

Per Pinstrup-Andersen

INTRODUCTION

This paper focuses on issues expected to be important in the efforts to better understand, assess and model the process of technological change in agriculture. In accordance with the goals of the overall project the emphasis of this paper is placed on the interaction between technological change and food production, resource use and environment. A short description of each of the major elements of the process and how the elements interact will be accompanied by a brief overview of the relevant empirical evidence and the most successful models and estimation methods used in recent empirical studies. Finally, suggestions will be made on the further project development with emphasis on the modeling efforts.

The adoption process and the impact of technological change on agricultural production, resource use and environment will be discussed. Furthermore, agricultural research and development, including testing and diffusion of new technology, will be treated.

The remainder of this note is divided into seven parts. A brief discussion of the problem area and the needs for policies and strategies for technological change in agriculture are presented first. Then follows a presentation of an overall framework for the process in question. Demand and supply factors in agricultural R and D and the related decision-making issues are discussed in the third section. Then attention will be given to the adoption process (section 4), and the interaction between technological change in agriculture and food production (section 5), resource use (section 6), and environment (section 7).

PROBLEM AREA

The food and nutrition problems of the world require no explanation here. Although it may be argued that current world food production is sufficient to provide an adequate diet for all, the fact is that current distribution of available foods is such that large segments of the world population suffer from insufficient food intake. Furthermore, there is little reason to expect that the distribution of currently available quantities of food among countries and intra-country population groups will improve significantly in the near future. Changes in food distribution must come about primarily through additional food supplies.

Increasing incomes will result in increases in food demand. Unless paralleled by supply increases of the same magnitudes, such demand increases will result in upward pressures on food prices which, in turn, may reduce food intakes among low-income families because these families already spend a large proportion of their incomes on food and other necessities. Of course, if considerable income increases are obtained by these families, the net effect on their food intake may be positive. However, except for a few countries, there are no indications that poor families will gain even their proportional share of total income growth. In addition to the effect of income expansions, the future food demand will be affected by population growth. Thus, assuming no significant changes in existing income distribution, food production must be expanded considerably in the future just to avoid a worsening of the current food and nutritional situation. Estimates of the required annual growth rate for food production in market oriented developing countries are in the order of four percent (IFPRI and FAO). The majority of such production increases must come about through expanded yields per unit area while area expansions will contribute a smaller and decreasing proportion of required future production increases. Yield increases may be obtained in a variety of ways. However, the key to sufficiently large and self-sustaining yield increases is technological change. While other measures such as increasing use of traditional inputs may increase yields, they will in most cases do so only at increasing costs per unit of output. Technological change, on the other hand, may increase yields at reduced per unit cost and thus make additional food available at lower prices.

A large portion of absolute as well as relative poverty is found in the agricultural sector. Thus, improving the food and nutritional situation through cheap food policies is not a feasible alternative because low food intakes are closely associated with poverty. Failure to reduce poverty in rural areas will, in addition to the hardships it causes among the rural population, result in a continuation of the migration from rural to urban areas at rates that exceed the labor absorbing capacity of the non-agricultural sectors and, thus, contribute to increasing poverty outside the sector. On the other hand, expanding food availability through higher food prices will be harmful to the urban poor, i.e., those not deriving their incomes directly from agriculture. Again, expanded food production at reduced per unit cost appears to be the only viable solution.

Food production is - as any other production activity - resource using. Technological change may greatly affect the resource use pattern. Rapid changes in the prices of some resources, e.g., fuel energy and fertilizers, during recent years and prospects of absolute resource scarcity and negative environmental impacts have raised some serious questions regarding the current and predicted future path of technological change in agriculture. The need to assure that the path that will actually be followed in future technological change will pay due attention to relative and absolute resource endowment, environmental issues, future food demand and other relevant issues is becoming more obvious. While some argue that relative resource and output prices accompanied by minor adjusting policy measures will assure that the optimal path for society will be followed, others would argue that the market mechanism is grossly inefficient to guide the future path of technological change. Still others argue that relying exclusively on the market forces for guiding the future technological development would lead to disaster from the point of view of environment and depletion of non-renewable resources.

The time horizon required for the guidance of R&D and the resulting technological change in agriculture is long relative to the time horizon implied in the reaction of market forces. Thus, market signals for changing the technological path may not come about sufficiently early to assure that the required change is obtained at the most appropriate point in time. The time lag between changes in R&D strategies and the resulting impact in technological change at the farm level may be considerable while relative market prices would tend to react to immediate changes in demand and supply factors including changes in relative resource scarcity. Thus, rapid and abrupt changes in resource or product prices requiring immediate substitutions among inputs or outputs may not be reflected in the path of technological change for many years to come. As farmers become more experienced with technological change, the time requirements may be somewhat reduced. On the other hand, increasing complexity of modern technology may extend the time period needed to produce the desired technology.

Input and output price distortions which create differences between social and private costs of inputs and outputs are another factor which makes market forces less effective in guiding technological change. Existing market conditions may not reflect the true social value of the various inputs and outputs. Furthermore, externalities to the individual firm may imply that certain social costs are not reflected by the market forces. Negative environmental effects may represent such a case.

The above was focused on market oriented economies. In centrally planned economies, decisions on input and output prices must also reflect the desired long run technological change in addition to a series of other efficiency and equity goals. The need for the relevant information to assure optimal policies, including the choice of price levels, is no less essential in these countries.

Thus, irrespective of the economic and political system, national research and technology strategies must aim at assuring the desired long run path of technological change in agriculture through the introduction and/or maintenance of the appropriate policy measures. Similarly, because of the interdependence among countries regarding scarce resources, environment and food production and trade there is a need for an international strategy for the overall technological change in agriculture.

But to establish and/or maintain effective strategies and policies on technological change, a priori information on the consequences of alternative technological developments is essential. The desired characteristics of new technology must be specified in order to establish priorities in R&D and to choose among available technological alternatives. Let us, therefore, turn to a discussion of how the relevant a priori information regarding the consequences on food production, resource use and environment may be obtained.

GENERAL PROCESS FRAMEWORK

A general and grossly simplified process framework is illustrated in Figure 1. Decision-making on R&D priorities and activities are influenced by a series of R&D demand and supply factors. The results of R&D expected to be useful for and of interest to the potential user (the farmer in the case of agricultural production technology) are fed into some diffusion mechanism which, if successful, will lead to technology adoption by the appropriate farmers or other users. While decisions regarding R&D rest with the executing agency - in the case of the majority of agricultural research this is some government agency - the decision to adopt a given technology is made by the individual farmer or, in the case of collective and state farms, by the body responsible for the administration of the particular farm or farms.

Adoption or non-adoption will have consequences for (1) decision-makers on adoption/non-adoption (farmers), (2) other groups in society, e.g., consumers and farm labor, and (3) society at large, e.g., some types of environmental impacts. The consequences will, in turn, motivate farmers to make further adjustments in the production process including possible changes in technology adoption. Furthermore, in cases where the diffusion mechanism is - or can be - controlled by farmers or farm groups, the consequences may lead to changes in this mechanism. Finally, farmers may attempt to influence future R&D activities.

Similarly, the consequences of technological change may motivate government to introduce policy measures and modify existing ones to adjust current and future consequences to better achieve society's goals or goals of particular groups in society.

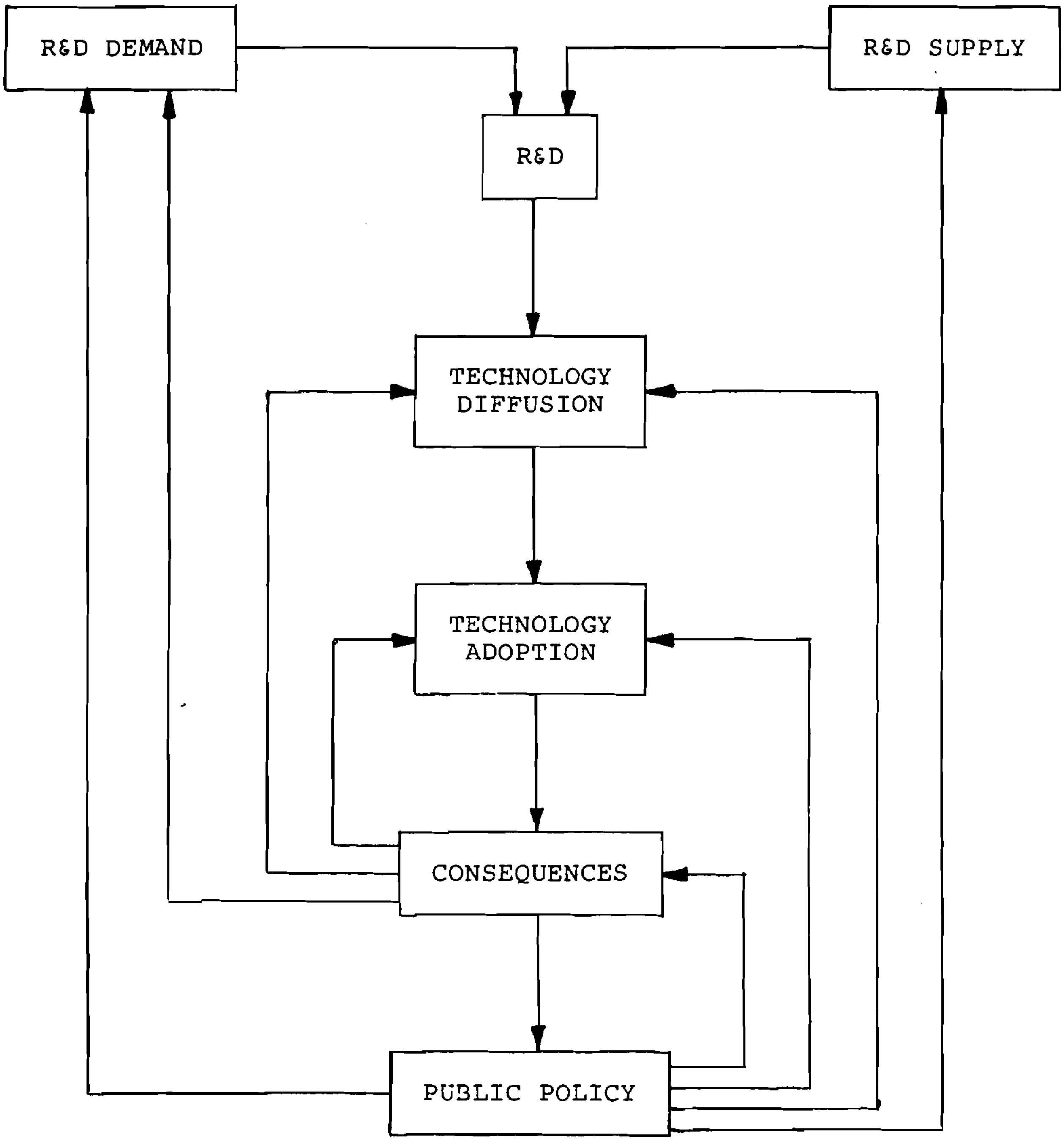
R&D DEMAND
R&D SUPPLY
R&D
TECHNOLOGY DIFFUSION
TECHNOLOGY ADOPTION
CONSEQUENCES
PUBLIC POLICY

Figure 1

Such policy measures may influence any or all of the elements in the process. For example, government may influence future R&D through research supply and/or demand factors (these factors will be further discussed in a subsequent section), it may influence the diffusion or adoption processes or it may alter the consequences of technology already adopted. The latter would have particular reference to measures aimed at counteracting undesirable environmental or distributional effects.

In the subsequent sections, each of the elements mentioned here and shown in Figure 1 will be discussed in more detail.

R&D FOR AGRICULTURE

A large majority of agricultural research is financed and carried out by public institutions. The role of publicly financed research in the overall agricultural research effort is largest in developing countries and smallest in North America. Thus, it is estimated that only 2.2 percent of total agricultural research in Asia is carried out by the private sector. This figure increases to 2.9 percent for Africa, 5.1 percent for Latin America, 10.8 percent for Western Europe and 25.4 percent for North America.[2] Because of its relative importance this discussion will be aimed primarily at public research.

The decision-making process in publicly funded agricultural research has received very little formal research attention. As a result, while the workings of the decision-making process within any given research institution may be well understood, a more generalized body of knowledge on the topic is lacking.[3] The actual workings of the decision-making process is heavily influenced by organizational and management structures. These structures are somewhat better understood, although the magnitude of formal analytical work on agricultural research organization and management is also rather limited.[4]

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[2] James K. Boyce and Robert E. Evenson. Agricultural Research and Extension Programs. ADC, New York, 1975.

[3] Illustrations of some aspects of the decision-making process in selected agricultural research institutions in Latin America are presented in: Per Pinstrup-Andersen and F.C. Byrnes (eds.), Methods for Allocating Resources in Applied Agricultural Research in Latin America. Series CE-11, CIAT, Cali, Colombia, November, 1975. Recent innovations and suggestions for improvements in the decision-making process are discussed in: C. Richard Shumway, Models and Methods Used to Allocate Resources in Agricultural Research: A Critical Review and Per Pinstrup-Andersen and David Franklin, A Systems Approach to Agricultural Research Resource Allocation in Developing Countries. Both are published in: Thomas M. Arndt et al, Resource Allocation and Productivity in National and International Agricultural Research. University of Minnesota Press, Minneapolis, 1977.

[4] Agricultural research organization is treated in: I. Arnon, Organization and Administration of Agricultural Research. Elsevier Publishing Company, Ltd., Amsterdam, 1968.

This section will focus on a discussion of the factors influencing the content of the research effort and, thus, the type of technology attempted to be achieved. While the decision-making process as well as research organization and management are important in that respect, no attempt will be made to make an in-depth analysis of these matters.

Factors influencing the content of the R&D effort may be divided into two highly related groups: research supply and research demand factors. The interaction of these factors and the decision-making, organizational, and management structures may be expected to lead to the establishment of a research strategy including a set of intermediate and final goals, although neither strategy nor goals may be explicitly stated in the individual case (Figure 2).

Research Supply Factors

Five research supply factors have been identified for this discussion. First, the professional interests of the researchers and research managers are likely to exercise great influence on the R&D content. Secondly, the research capacity, i.e., available financial, physical and human resources, provides the framework within which R&D must be carried out. Thirdly, the existing body of knowledge, the "state of the art", and recent directions in R&D will influence the type of R&D to be carried out. These factors may be closely related to professional interests of researchers. A fourth factor influencing R&D at any point in time is the inertia in research planning and execution. Continuation of on-going R&D activities, tasks and programs with very little or no changes or adjustments taking place is very typical for a number of public agricultural research institutions. Immediate research goals are vaguely specified and effective mechanisms for terminating or drastically changing individual research tasks and programs including periodic reviews of progress are frequently absent. Changes in overall resource availability, e.g., budget cuts or increases, are frequently distributed across existing activities more or less in proportion to current resource use, e.g., an x percent cut in all program or task budgets. Where such inertia is strong it may effectively prohibit other supply and demand factors from having their proper influence. The inertia problem is most pronounced in well established institutions with a small staff turnover and only marginal resource changes over time. New research programs and tasks and major changes in existing ones, will come about primarily through the granting of additional, earmarked resources into existing institutions or the creation of new ones. Replacement of existing research institutions (frequently a department of the ministry of agriculture) with new semi-autonomous institutes has been done in a number of developing countries during recent years. While the overall purpose of such organizational change has been to obtain a more flexible and effective research environment it has presented the opportunity for major revisions in research goals, strategies and activities which might have been prohibited by inertia in the old structure. Whether the new institutes, ones established, will suffer less from inertia remains to be seen.

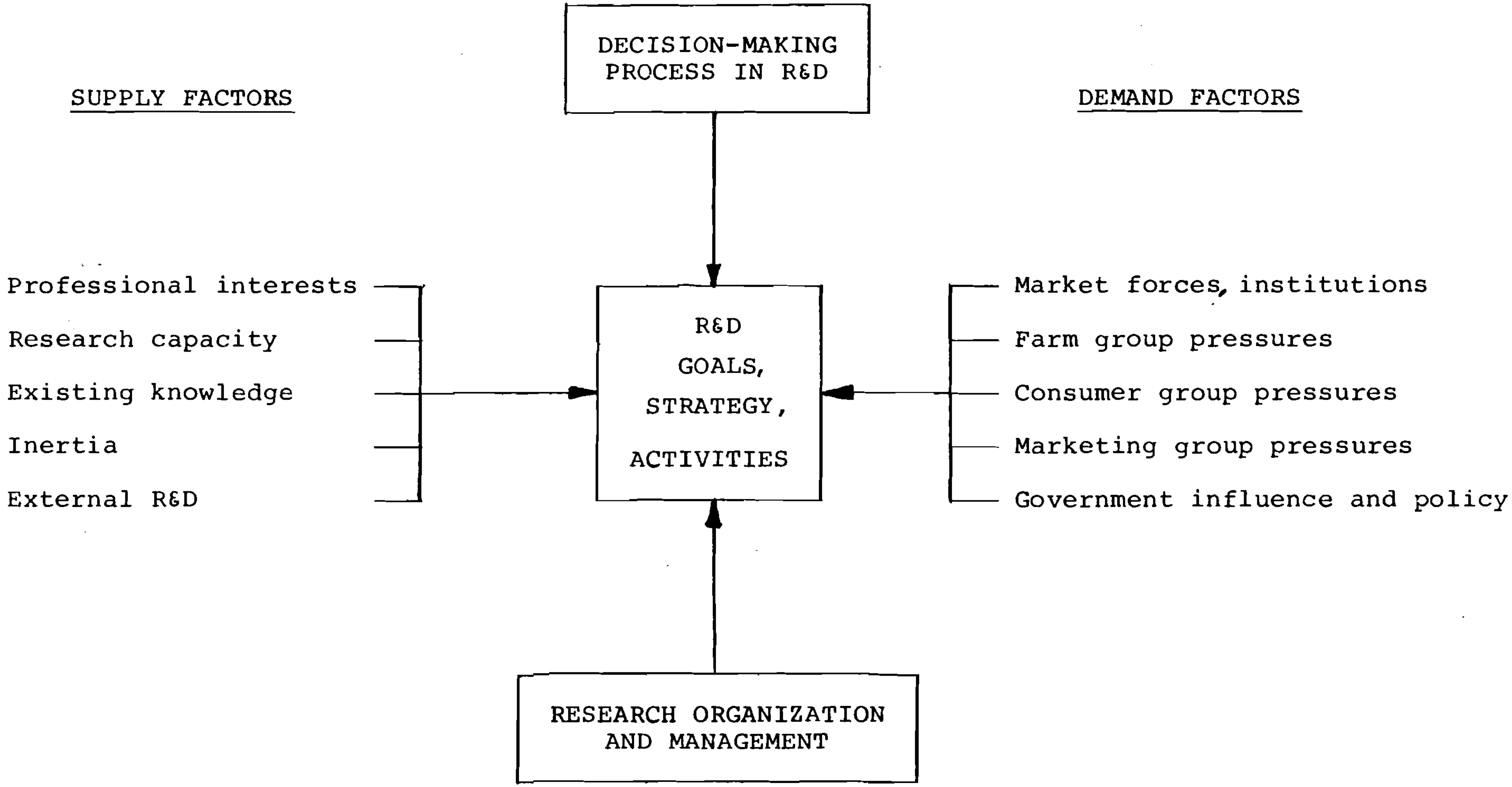

Figure 2. Factors influencing goals, strategy and activities in Agricultural R&D.

The fifth supply factor influencing R&D is the ongoing research outside the individual institution and the availability of research results and technology from other institutions expected to be useful either for further research or for testing and diffusion. One important aspect here is the influence of the international agricultural research institute network on national R&D. A considerable amount of the research results of these institutes may be viewed as "intermediate products" requiring further research at the national and local level before becoming useful to agriculture. The continuing development of such intermediate products together with an excellent communication network between international and national institutions including seminars, training programs, etc., plays an increasing role in the formulation of national R&D. Demonstrated success in international research supported by the appropriate national activities for wheat and rice, the so-called "Green Revolution", has increased the power of international institutes to influence national research activities in developing countries.

Research Demand Factors

As earlier mentioned, relative resource and output prices may have considerable impact on the direction of technological change through their influence on R&D. The theory of induced innovation advances the hypothesis that the direction of technological change and the supporting R&D tend to be heavily influenced by relative resource endowment and prices.[5] Thus, in societies with relatively ample supply of labor but severe land scarcity, R&D will focus on the development of labor-using, land-saving technology. Similarly, changes in relative resource prices, e.g., increasing energy prices relative to the price of other resources, would tend to adjust R&D accordingly. The proponents of the induced innovation theory do not claim that relative resource and output prices are the sole determining factor in the direction of agricultural R and D, only that they play an important role. The limitations of the ability of market forces to guide the technological change path were mentioned earlier and will not be repeated. The important issue here is that, to the extent that relative resource endowment and prices as well as output prices are affected by technological change and in turn affect future R and D, they are to be considered endogenous to the process. Furthermore, relative input and output prices are often manipulated by governments. The effects of such manipulations on future R and D as well as the opportunities they offer to obtain the desired long run technological change should not be overlooked in analyses of agricultural technological change.

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[5] See Hans P. Binswanger and Vernon Ruttan, Induced Innovation: Technology, Institutions, and Development. Johns Hopkins University Press, Baltimore 1978 and Yujiro Hayami and Vernon Ruttan, Agricultural Development: An International Perspective. Johns Hopkins University Press, Baltimore 1972, for a comprehensive treatment of induced innovation in agriculture.

As mentioned earlier, the majority of agricultural research is financed by public funds. The primary reason why the private sector does not enter into these research activities to a greater extent is that the research executing firm may be unable to capture a sufficiently large proportion of the economic gains associated with the research results to make a research undertaking profitable. This, of course, is a well known problem in cases where the use of research results cannot be protected or controlled by the research agency. However, such research may be highly profitable for society as a whole. Thus, public investment may be justified. The distribution of economic benefits from publicly funded agricultural research among groups in society will depend on the particular R&D goals, strategies and activities. Thus, various groups in society will attempt to influence the R&D efforts in order to obtain as large a share as possible of these benefits. Such influence may come about in different ways depending on the organizational structure of the R&D decision-making body and the various pressure or interest groups. Interest groups from the producer, consumer and marketing sectors are likely to be actively trying to influence agricultural R&D (Figure 2). Considerable conflict of interest may exist among the three sectors and even among pressure groups within a given sector, e.g., small and large farmers, farmers in one region vs. another, and among organizations representing producers of different commodities.

In some countries, notably the United States, it appears that the food processing firms have had a very large impact on agricultural R&D. In other countries, particularly some market oriented developing countries, larger farmers seem to have had considerable access to the decision-making on R&D while farmers with smaller land holdings have not. In some countries, agricultural R&D is heavily influenced by the desires of farmers, e.g., Denmark, while in others, the communication from the farm sector to agricultural research institutions is virtually non-existent. In general, consumers seem to have had very little direct impact on agricultural R&D although in most cases they have been the major beneficiaries. Of course, consumers exercise a considerable influence through their demand behavior. Finally, it should be mentioned that, while suppliers of capital inputs, e.g., fertilizers, pesticides, etc., exercise some influence on publicly funded R&D, the rural labor force seems to have had absolutely no direct impact in spite of the fact that alternative technological change may have very different effects on employment and wages.

The above mentioned group pressures may be brought to bear on R&D either directly or through some government policy measures. A series of other policy measures may influence agricultural R&D. Some of these may be directly focused on R&D while others may focus on different matters but with a strong effect on R&D. The means available to government to influence agricultural R&D directly or indirectly are many and varied and cannot be thoroughly discussed here. It should be pointed out, however, that failure to take into account the relevant policy measures - whether existing or likely future measures - in analyses of technological change in agriculture may greatly reduce the validity of the results.

TECHNOLOGY ADOPTION

The term adoption, as used in this note, refers to the act of incorporating something into the production process. Adoption of a new technology or a technology not previously used in the production process implies "technological change". The technological state of any given production process is a description of the qualitative (not quantitative) composition and combination of inputs and technologies that exist at a given time. Thus, technological change describes a movement from one technological state to another. Adoption of technology must be preceded by technology diffusion where the latter term refers to the act of making technology available to potential adopters. Diffusion, then, is the link between R&D and adoption. Thus, effective diffusion is an essential but not sufficient condition for adoption. Decision-makers on technology adoption must be made aware of available technology and they must believe that adoption will be in their best interest. On the basis of the consequences of adopting a certain technology, the expected benefits from continuing, modifying or discontinuing its use will be assessed. Furthermore, the consequences of adopting a certain technology among some farmers may create awareness of its existence and potential benefits among others. This somewhat simplistic overview of the adoption process is illustrated in Figure 3.

Figure 4 presents a more detailed schematic illustration of the farm level decision process related to adoption and use of new technology. Each of the elements in Figure 4 will be briefly discussed in the following. When appropriate, a short summary of empirical findings related to the individual element will be provided. Issues related to a possible modeling and quantification of the relationships will also be discussed.

The point of departure is an externally induced diffusion of information and materials which together form technology T_1. The diffusion effort will make a certain proportion of the farmers aware of the technology and facilitate access to it. Ideally, farmers becoming aware of a new technology will also have access to it. This is not always the case. A large number of cases could be cited in which farmers were made aware of fertilizers, pesticides, improved seeds, etc., but without having access to these technologies at the time and place needed.

Having become aware of the existence and accessibility of a certain technology, the farmer's adoption decision will depend on considerations regarding at least four questions: (1) Is the technology perceived to be suitable for the particular physical environment and climatical conditions within which the farmer operates? (2) Is adoption perceived to add to the farmer's net economic returns? (3) Is adoption perceived to contribute to the achievement of other goals maintained by the farmer and will adoption have negative effects on some of these goals? and (4) Are there any factors that prohibit or makes it difficult to adopt or obtain the perceived benefits from adoption? Let us take a closer look at each of these four questions.

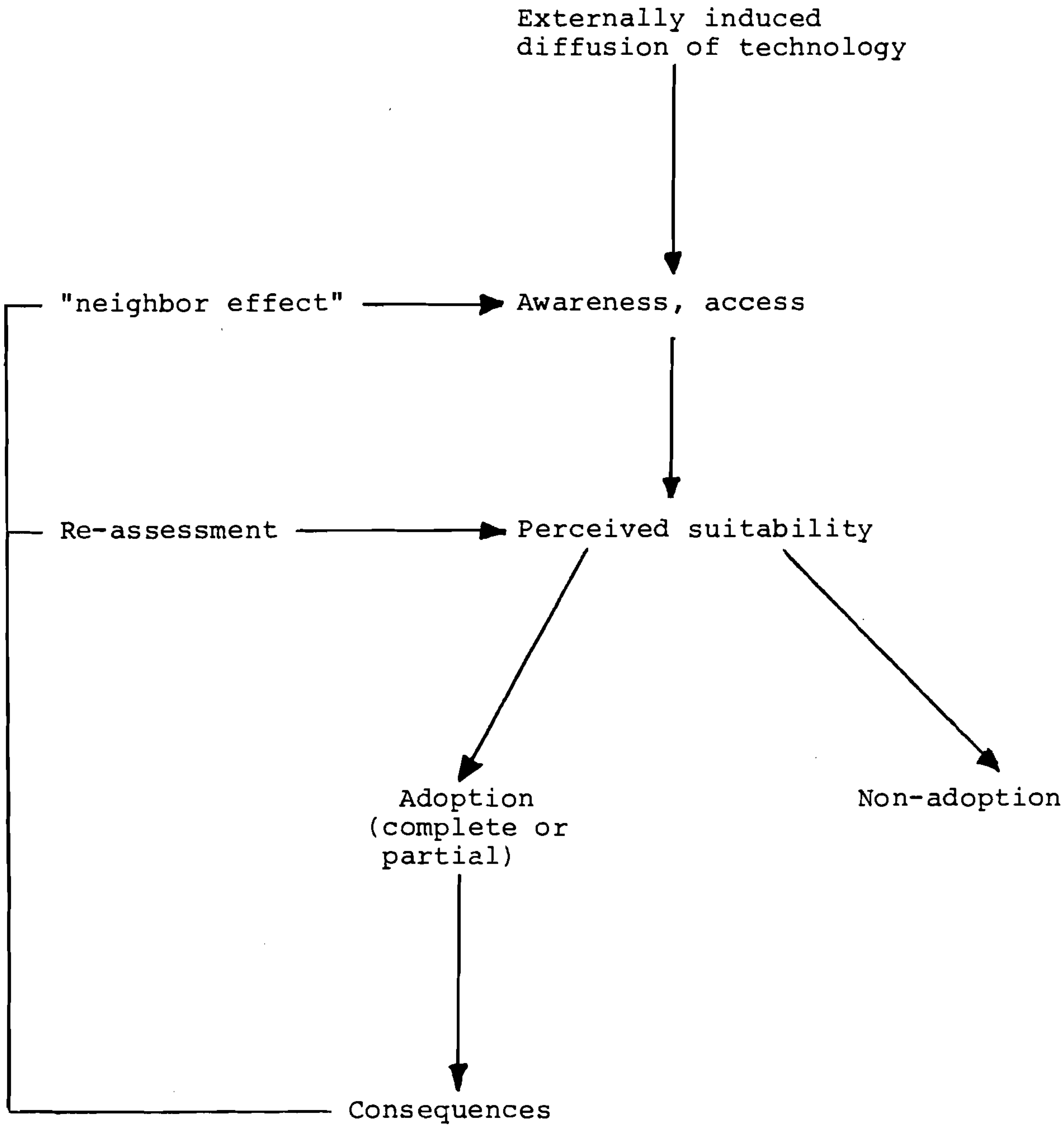

Figure 3. Schematic overview of adoption process in agriculture.

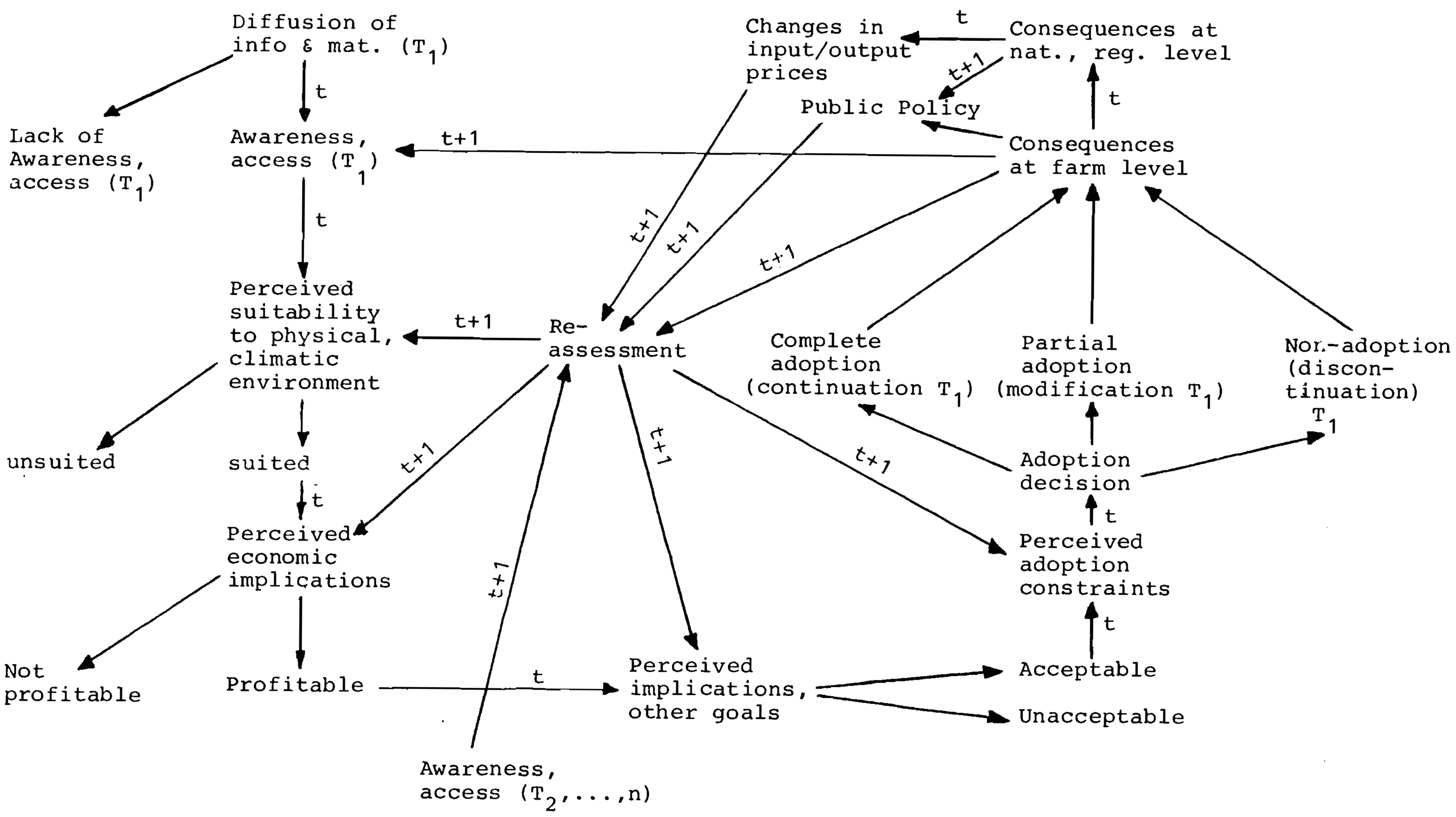

Figure 4. Schematic and simplified illustration of farm level decision process for adoption and use of new technology.

A considerable proportion of agricultural technology is commodity specific. Examples are improved crop varieties and animal breeding stock. Such technology would, of course, only be relevant for producers of the particular commodity. Furthermore, the potential benefits from agricultural technology may be obtained only within certain physical environments and/or under certain climatic conditions. There has been a tendency to develop agricultural technology primarily for situations of optimal physical and climatic conditions. Such technology may be poorly suited or completely unsuited for farmers not controlling such conditions. A large majority of the world's agricultural research and experiment stations are located on very good soil. If climatic conditions are not optimal at these sites, considerable efforts are made to approach optimality, particularly with regard to water availability. Soil fertility is maintained at close to optimal levels (unless, of course, soil fertility factors are being studied) and adverse crop or animal conditions such as diseases, pests, weeds, etc., are being eliminated or controlled by means of chemical and other measures. These are the places where a considerable proportion of new or modified agricultural technology is being developed and tested. In all fairness, it should be noted that there are exceptions to the above. Some agricultural research is now being carried out under more realistic farming conditions and local testing under actual farming conditions is becoming more common. The principal point to be made here, however, is that a large part of available modern agricultural technology is suited for only narrow ecological environments.

If a farmer perceives that a given technology is suited for the environment he controls, his next question is whether and to what extent its adoption would be profitable. In estimating the profitability, the farmer will take into account not only the change in costs and returns regarding the particular technology to be considered but also the effect on costs and returns from corresponding adjustments in other farm activities. The thoroughness of the economic analysis would vary among types and sizes of farms and, at least among smaller farmers, experience-based guesses are probably more common (and they may give more realistic results!) than more structured estimates. The profitability is closely linked to the above suitability of technology for the particular environment. Because agricultural technology may not have been tested under conditions relevant for a given farmer, any indications of profitability implied in the recommendations from the diffusion agency may be grossly misleading for the individual farmer. Reliance on such recommendations have resulted in great losses to adopters. One single set of fertilizer recommendations for a region with great variation in soil type and fertility is but one of a large number of examples of this type of thing.

While perceived increase in net returns may be necessary for the adoption of new technology, it may not be sufficient.[6] The

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[6] Perceived increase in net returns is not always necessary for technology adoption. Some farmers may adopt technology which is perceived to contribute to other goals, e.g., income stability, even though net incomes are not expected to increase.

anticipated impact (positive or negative) on the achievement of other goals may be of great importance. Particularly among low income farmers, goals such as income stability (reduced risk and uncertainty), assurance of a desired mix and sufficient quantity of commodities for home consumption and reasonable family work loads are common and may greatly affect adoption decisions. Thus, failure to consider farm level goals other than profitability in ex ante analyses of technology adoption may result in erroneous estimates of the expected adoption rates. The interaction between technology characteristics and farm level goals should be considered in any such analyses.

The influence of risk and uncertainty on technology adoption has been studied to a great extent and various models have been developed for farmers' risk behavior. Much less has been done on the other goals.

The issues treated here are integral parts of the total farm-household decision process regarding production, consumption, time allocation, and other farm-family matters. While traditional economic analysis tends to look at production, consumption and time allocation as separate sets of activities, recent methodological and empirical work on the so-called "household economics" have been successful in providing additional insights into the interrelationships among these and other sets of activities and goals. Ignoring this approach in analyses of the adoption decisions, particularly among low-income farmers, would be to forego an excellent opportunity for gaining a better understanding of the decision process and a related improvement in the power of the analyses to project adoption rates of various technology alternatives. On the other hand, household economics models may become very complex. Hence, care must be taken to select only those relationships of greatest importance for the technology adoption and use decisions to avoid excessive complexity of the overall models. This point will be further discussed in a subsequent section of this paper.

A number of factors may make adoption difficult or impossible or they may prohibit the farmer from obtaining the benefits associated with adoption and, thus, make adoption undesirable. Such constraints would tend to be location specific and may only be identified through a thorough knowledge and understanding of the production environment (including physical, climatic, cultural, social, and economic factors) in which the farmer operates. Some constraints may be internal to the actual farm household activities, e.g., lack of sufficient family labor during peak labor demand periods and unwillingness to use hired labor, while others would be external, e.g., lack of access to the necessary inputs. It would be inappropriate to attempt a clear distinction between internal and external constraints because they are highly interdependent. Labor constraints may be considered an internal constraint if we ignore the possibility of hiring labor but an external constraint if we only look at the supply of hired labor ignoring the possibility of expanded family labor. Similar examples could be given for capital constraints. Social and cultural constraints may be imposed from the community in which the farmer lives or they may be deeply rooted within the individual farm family. In any case, some of these constraints may play a very important role in the adoption decision. Some may be removed, while others must be accounted for in the design and choice of technology. Those that are not expected to be removed either (1) because it is too difficult or impossible or would have unacceptable side effects or (2) because the appropriate policy measures or institutional changes are not likely to come about, must be explicitly incorporated into analyses of the adoption process if they are expected to have serious effects on the adoption behavior. Alternative model runs with and without each of these factors would also provide some estimate of the pay-off from policy measures or institutional changes aimed at their removal.

But which are those constraints? As mentioned above, the presence and importance of any given constraint tend to be specific to the particular case, e.g., region, farm size, even in some cases to the individual farm. This is why any effective ex ante analysis aimed at the estimation of expected adoption rates and technology use efficiency for a given technology must be based on a thorough knowledge and understanding of the production environment within which the farmers of interest are operating. Such understanding can only be obtained by interaction with the farmers. Thus, the specific constraints to be incorporated into the analysis will vary from one case (region, farm size group, or some other disaggregation) to another.

A large number of studies have been done on constraints to technology adoption in agriculture.[7] These studies clearly illustrate the great diversity of constraints and the interdependence between the farm group studied and the factors of importance in the adoption decision. Certain patterns within this interdependence are emerging. These patterns may be useful to establish hypotheses about which constraints are of most significance given certain characteristics of the production environment. Such hypotheses may then be used to decide on the specific constraints to be included in an analysis of a given case.

It should be clear from the above, that attempts to generalize the relative importance of individual constraints across farm groups, regions and countries, are unlikely to be very useful for ex ante analyses. However, a few constraints frequently found to be important among low-income farmers may be mentioned. Lack of access to credit and purchased input such as fertilizers and pesticides at the time and place needed, seems to play a major role. Uncertainty about the performance of a given technology under actual farming conditions is another constraint frequently encountered. Such uncertainty stems primarily from lack of technology testing under the relevant conditions which result in highly unreliable recommendations provided by the diffusion agencies. This situation tends to induce farmers to initially adopt a new technology only on a small plot of land, in essence to do his own testing, before

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[7]An excellent review of such studies related to economic constraints in developing countries is presented in: Wayne A. Schutjer and Marlin G. Van Der Veen, Economic Constraints on Agricultural Technology Adoption in Developing Nations. AID, Occasional Paper No. 5, Washington, D.C. 1977.

proceeding to rejection or full adoption. It also causes farmers who are unwilling to take great risks, because crop failures imply unacceptable consequences for the family's well-being, i.e., low-income farmers, to postpone adoption until they have observed the technology performance on neighboring farms. This is one reason why small farmers lag larger ones in adoption of new technology.

A number of other constraints have been identified under specific circumstances. These include: adverse institutional arrangements and public policies, certain cultural and sociological factors, limited output markets, complexity of the technology and land tenure. The important point to be made here is that any modeling of the interaction among technology, agricultural production, resource use, and environment must take into account the most important adoption constraints and these constraints must be identified on the basis of existing production environments, including physical, climatic, cultural, social and economic factors.

The Adoption Decision

Taking into account the above mentioned issues and probably a few more, the farmer makes his decision whether to adopt or not adopt a given technology. Adoption may be complete, i.e., for the total relevant production activity (e.g., adopting a new rice variety for his total rice area for which he thinks it is appropriate[8] or it may be partial, i.e., on a small plot of land for the purpose of seeing the results. In addition, the farmer decides whether to make any other adjustments in the farm activities, i.e., reducing or increasing the area sown with the various crops, purchasing more or less of certain complementary inputs, etc.

Adoption of new technology will have certain consequences for the adopting farmers, e.g., changing net incomes. These consequences will, in turn, motivate the farmer to re-assess his decisions on adoption and related adjustments within the farm. The additional experience obtained will influence his perception of the suitability, profitability and other aspects of the technology which, in turn, will influence his decision-making in the subsequent time period (t + 1). He may decide to continue "complete use", he may discontinue or he may make certain modifications in the use of technology and other production activities (see Figure 4). Awareness of other technology ($T_2,\ldots,n$) may also enter the re-assessment. The farm level consequences among adopters may create awareness and desires to adopt among other farmers. In fact, in a number of cases, this demonstration effect has been found to be extremely important to accelerate technology adoption.

Widespread adoption will imply significant consequences outside the individual adopting farm. Changes in input and output prices might result. Such changes would enter into the re-assessment.

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[8] The farmer may perceive (rightly or wrongly) that a given commodity specific technology is only advantageous on some of the area grown with the particular crop. Such a case would be considered complete adoption as opposed to partial adoption explained above.

Furthermore, the consequences may cause policy changes on a number of issues such as prices, institutional structures, credit, extension service, crop insurance, etc. The perceived effects of such policy changes would also enter into the farmer's re-assessment. It should be emphasized that the individual farmer will include in his re-assessment only those issues which he perceives will affect him directly. Broader socio-economic effects such as environmental, employment, resource and foreign exchange effects will only enter into his decision-making to the extent they are reflected in input/output prices, costs, resource availability to him, or in some other way that directly affects him. If the relative resource endowment at the national or regional level is not reflected in relative input prices or absolute availability it will not be taken into account in his decisions. Energy scarcity is of little concern to him unless it is reflected in the prices he pays (or expects to pay) or the access he has (or expects to have) to energy. Extensive unemployment will not affect his production decisions on labor use if minimum wage laws or labor unions maintain relatively high wages. Effects on the local community, such as pollution of local streams, may be exceptions to this general rule because of community pressures.

Obviously not all the factors and relationships mentioned in this section can or should be explicitly included in the IIASA models on agricultural technology. However, awareness of the overall decision process, together with a good knowledge and understanding of the farm groups, which the models are supposed to deal with, is important for the correct choice of factors and relationships to be incorporated. While the overall framework may possibly be suited to any group of farmers, the specific variables to be included would vary. The dynamics of the adoption process including the gradual change of the use of technology following the period of adoption, the lag effect in adoption among farmers, and the arrival of other technological opportunities should be explicitly included. Profit maximizing subject to a series of constraints for each time period may be an appropriate approach. Goals other than profit maximization may be considered as constraints. Available information would probably not justify the incorporation of complicated risk models.

So far the discussion has been taken to the point of the consequences at some aggregate level. Among these consequences, those of greatest interest here are those affecting food production, resource use and environment. Each of these will be discussed subsequently.

EFFECT ON FOOD PRODUCTION

The effect of technological change on the quantity of food produced is given by the magnitude of adoption, e.g., the area where new technology is applied, the impact on the production per unit of land, and the effect on the production of foods for which the technology is not applied, i.e., the substitution effect. In addition, new technology may change commodity characteristics, e.g., changes in the amino acid composition of maize or making tomatoes more apt for mechanical harvesting, and create new products, e.g., triticale. However, in this paper emphasis will be placed on technology aimed at the increase of technical efficiency of a given product. Such technology may increase production for a given quantity of resources, maintain the same production with smaller quantities of resources, or a combination of the two. In fact, application of new technology usually results in a combination of output expansion, expanded use of at least some resources, and resource substitution. I shall return to the resource issues in the subsequent section.

In principle, the impact of adoption and use of new technology on food production should be estimated by means of some quantitative functional relationship in which total farm production of food is a function of all the inputs used including the particular technology of interest. Such a whole-farm approach would capture not only the change in the production of commodities for which new technology was introduced (the direct impact), but also the resulting changes in the production of other commodities (the indirect impact). However, most empirical analyses of the impact of technology on food production do not apply such an approach. Instead, a partial analysis is done in which only the direct impact is considered. Of course, in the case of farms producing only one commodity, there is no difference between the two approaches.

Technological change may be incorporated into such functional relationships in various ways. Binswanger outlines three ways of introducing what he calls the "research processes" into production functions.[9] Empirical studies have focused on either an index number or a production function approach.[10] The index number approach is based on an estimation of the average yield impact followed by an estimation of the area where the particular technology is adopted. The average yield impact may be estimated in a number of ways. Some have used data obtained from technology testing, in some cases applying a discounting factor to allow for differences between the testing environment and the actual farm level production environment.[11] Others have estimated the average yield impact by means of production function analyses of various kinds. In

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[9] Hans P. Binswanger and Vernon W. Ruttan. Induced Innovation Johns Hopkins University Press, Baltimore 1978, pp.129-130.

[10] Willis L. Peterson. Return to Poultry Research in the United States. Journal of Farm Economics, August 1967, pp.653-669.

[11] The classical example of this approach is: Z. Griliches, Research Costs and Social Returns: Hybrid Corn and Related Innovations. Journal of Political Economy, Vol. 66, 1958, pp.419-431.

studies where production functions have been used, whether to estimate yield or production impact, technological change has frequently been represented by a proxy variable to avoid serious data problems.[12]

Technological change has been dealt with in various programming frameworks but usually in a somewhat superficial or aggregate manner. Furthermore, agricultural sector models, irrespective of type, generally incorporate the output effect of technological change in some--usually very aggregate--manner.[13]

A large body of empirical evidence on the output effect of technological change in agriculture has been accumulated during the last twenty years. T.W. Schultz and his graduate students and colleagues (Griliches, Peterson, Evenson, Ardito-Barletta and Hertford to mention a few) have been the prime forces behind a series of ex post studies on the output effect of agricultural research and technology in the United States, Mexico, Colombia, and other countries.[14] Furthermore, the aggregate output effects of fertilizer use have been estimated in recent studies.[15]

On the ex ante side, recent studies have been aimed at the identification of yield and production limiting factors in specific regions and crops and the estimation of the likely production impact of removing each of these factors.[16] The primary purpose of such studies is to provide guidelines for future R&D by estimating the expected output effect and pay-off associated with the development of alternative technologies. The methodologies used in these studies are usually some combination of regression analysis and accounting procedures where primary data are obtained through farm level interviews, longitutional observations and agricultural experiments.

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[12] Examples of studies using a production function approach are: R. Evenson, The Contribution of Agricultural Research and Extension to Agricultural Production. Ph.D. Thesis, University of Chicago, 1969 and S. Sidhu, Economics of Technical Change in Wheat Production in the Indian Punjab. American Journal of Agricultural Economics, Vol. 56, No. 2, May 1974, pp. 217-226.

[13] For a brief review of this issue, see: M. Neunteufel, The State of the Art in Modeling of Food and Agriculture Systems. IIASA, RM-77-42, Laxenburg, Austria, 1977.

[14] See: Thomas M. Arndt, et al, (cited previously) for references to these and similar studies.

[15] The estimated contribution of fertilizers to cereal production in market oriented developing countries using both an index number and a production function approach is reported in: Per Pinstrup-Andersen, Preliminary Estimates of the Contribution of Fertilizers to Cereal Production in Developing Market Economies. The Journal of Economics, Vol. 2, 1976.

[16] R. Barker, Production Constraints and Priorities for Research. International Rice Research Institute, Los Banos, Philippines, 1977 and Per Pinstrup-Andersen, et al, A Suggested Procedure for Estimating Yield and Production Losses in Crops. PANS, Vol. 22, No. 3, 1976, pp. 359-365.

As mentioned earlier, virtually all of the above mentioned approaches and empirical findings focus on estimating only the direct output effect thus ignoring the output effects caused by changes in the quantity produced of commodities for which the technology was not applied. But the change of relative productivity of one commodity is expected to cause commodity substitution at the farm level. This would be of particular importance in cases where a number of commodities compete for fixed amounts of a given resource, e.g., land or family labor. The incorporation of the commodity substitution effect on food production would greatly improve the predictive power of the model, not only for output effects but also for the resource implications, provided the necessary data can be obtained. Conceptually, such a whole-farm approach should not cause major difficulties. The principal problems will be to obtain sufficiently reliable data for ex ante assessments.

EFFECT ON RESOURCE USE

Technological change may greatly affect the resource use pattern in agriculture. Different technologies may have different impact on the quantities of resources used and the optimal resource composition for a particular production process. A given technology may be "resource x saving" and resource y using". Introduction of a resource x saving technology does not necessarily imply that less of resource x will be used. It merely implies that current output quantities can be maintained with a smaller quantity of resource x provided, of course, that the necessary resource substitution takes place. But since more is produced per unit of x, i.e., the technical efficiency of x increases, it will be profitable to expand production and thus expand the use of x unless product demand or resource supply makes such expansion unattractive.

Resources used in agriculture may be grouped into labor, land, fuel, energy, water, biological and chemical materials and other capital inputs. On the other hand, agricultural technology may be grouped into biological, chemical and mechanical technology. The issue of interest here is to develop and test methods (models) capable of assessing the impact of specific technologies and technological change paths on the demand for each of the resource groups. As stated elsewhere, relative resource prices tend to exercise considerable influence on the type of technology to be developed and made available to farmers. The relationship between relative resource prices and adoption, i.e., farmers' choice among available technologies, is even more clear. However, as mentioned earlier there is reason to believe that current relative resource prices may not be effective in assuring the socially optimal, long run technological development path. Facilitative and corrective public policy may be needed. One of the reasons why relative resource prices may not provide an effective guideline for the long run technology path is the presence of price distorting policies and institutions. Thus, part of the job of facilitative and corrective policies is to undo adverse effects of other policy measures.

Conceptually, the estimation of resource demand is closely limited with the estimation methods and models discussed in the previous section. Functional relationships between output and resources provide the basis for estimating resource demand functions, i.e., functions representing quantity demanded of a given resource as a function of its own price and prices of output and other resources used in the production process. The derivation of such resource demand functions from production functions before and after a given technological change is illustrated by Sidhu.[17]

Resource supply functions must also be estimated. While the individual farmer may be faced with a fixed supply of certain resources, e.g., land, and an infinitly elastic supply of other resources, e.g., fertilizers, at any given point in time, the agricultural sector will face an upward sloping supply curve for most resources. Thus, shifts in the sector resource demand curves will imply price changes. These price changes must be taken into account in a dynamic model. In some cases, well founded assumptions may replace efforts to actually estimate resource supply functions.

The direction of resource bias ("saving" or "using") may be intuitively obvious for some technologies but not for others. The magnitudes of such biases and the net impact on resource demand are not usually known without formal analysis. On the basis of common sense and results from empirical work the following brief overview of the resource biases related to the various types of agricultural technology is offered.

Most biological technology, e.g., high yielding varieties, has been "labor, land and fuel energy saving" and "water, chemical resource and other capital input using". Chemical resources, particularly fertilizers, capital inputs and, in some cases, irrigation water have been substituted for labor, land and, in some cases, energy fuel. But expanded output and higher productivity of labor and land have expanded the demand for these resources. Thus, where the supply of agricultural land has been fixed, prices of land suitable for the particular biological technology have increased significantly. Such price increases have been particularly pronounced in areas where most or all suited land was grown with the crop for which biological technology was introduced, e.g., many rice areas in Asia. In other areas, where suited land was used for a number of crops, a considerable crop substitution has occurred. A case in point is the extensive substitution of rice for other crops in certain regions of Colombia following the introduction of high yielding rice varieties.[18]

Regarding labor, it is now documented beyond reasonable doubt that the increase in labor demand due to output expansions have been considerably larger than the labor saving effect of biological

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[17] S. Sidhu, op cit.

[18] Grant M. Scobie and Rafael Posada, The Impact of High Yielding Rice Varieties in Latin America, with Special Emphasis on Colombia. CIAT, Cali, Colombia, Series JE-01, April 1977.

technology. Thus, the net result has been an increase in labor demand. In areas with large unemployment and highly elastic labor supply this has resulted in considerable increases in employment. In cases of little unemployment and an inelastic labor supply, whether existing prior to the introduction of technology or brought about by the technology, considerable wage increases have occurred, e.g., in the Punjab region of India. However, availability of labor saving mechanical technology tends to establish upper limits for such wage increases.

A considerable amount of new biological technology depends on fertilizers and--in some cases--on irrigation and pesticides to express its full yield increasing capacity. Thus, the introduction of the type of biological technology behind the Green Revolution and earlier yield increases in Europe and North America has greatly increased the demand for and use of fertilizers and other chemical input. Continuing technological improvements in the fertilizer industry and low raw material prices (rock phosphate, natural gas and potash, primarily) assured a sufficient fertilizer supply at stable prices. Cyclical investment patterns in the fertilizer industry, increasing prices of rock phosphate and energy, and rapid increases in fertilizer demands disrupted the trend of sufficient supplies at stable prices (during the 1960s fertilizer prices actually fell) in 1973-74. However, fertilizer prices are again stable although at a somewhat higher level than prior to 1973 and current as well as expected future supply capacity exceeds expected demands.

Some biological technology is chemical resource saving both in a relative and an absolute sense. Examples of such technology are biological N-fixation from the atmosphere and biological insect control. If reduced usage of chemical technology or reduced rates of increase in such usage is a long run goal of society, emphasis might be placed on such technology. One reason for such a goal might be to reduce foreign exchange requirements for import of fertilizers, fertilizer raw materials, or fuel energy. Environmental considerations might be another reason. However, as long as fertilizer supplies are plentiful for the individual farmer at reasonable prices he may have little interest in adopting fertilizer saving technology. Public policy aimed at the above should consider the output effect as well as the resource and environment effects.

As shown above, the introduction of much modern biological technology is closely linked with simultaneous introduction of chemical technology. Introduction of chemical technology by itself would tend to have the same resource biases as biological technology. There is one important exception, however. Labor saving chemical technology with little or no output effect will reduce net labor demand. Chemical weed control is an example of such technology.

The impact of the introduction of mechanical technology on the demand for fuel energy and capital is obvious and need not be elaborated. Its impact on land and labor demand would depend on whether there is an output effect or not. Introduction of mechanical technology with a considerable output effect, e.g., irrigation equipment, may cause considerable increases in the demand for labor and land, although it is land and labor saving. Thus, the case is identical to that of biological technology in so far as land and labor are concerned. However, a large portion of mechanical technology has little or no output effect while the labor saving effect may be very large. Tractors, farm machinery of various types and installations in animal production have greatly reduced the demand for labor in Europe, North America and certain regions of developing countries. While many of these technologies have significant output effects through better land preparation, more timely planting and application of pesticides, reduced harvesting losses as well as facilitating multiple cropping under certain circumstances, the majority of these output effects are not reflected in the labor demand because the activities are already mechanized. Of course, mechanical technology results in higher labor productivity and, thus, permits increasing wages for those remaining in agriculture. The impact of mechanical technology with little or no output effect on the demand for land is closely related to the scale economies associated with the particular technology. Introduction of technology with extensive scale economies tends to push for larger farm sizes. This has been observed both in developed and developing countries.

ENVIRONMENTAL EFFECTS

Concerns about adverse and in some cases irreversible effects of agricultural production practices on the natural environment are becoming more widespread as the use of chemical inputs increases and larger crops are removed from the land. A number of other trends in the intensification of agriculture such as increasing concentration of animal production contribute to these concerns. These increasing concerns are closely related to the general increase in the awareness of environmental deterioration such as air and water pollution and depletion of non-renewable resources.

Since agricultural production practices are heavily influenced by technological change, the path of the latter over time will greatly affect the future environmental impact of agriculture.

Adverse environmental effects are usually a long run phenomenon. The long run consequences may not be obvious when decisions for short run production activities are made. Thus, the accumulation of seemingly unimportant short run effects may lead to unacceptable and sometimes irreversible consequences. Furthermore, the social cost of environmental deterioration may not influence private costs faced by the individual firm (farm) in a free market economy. Thus the long run environmental interests of society as a whole or certain groups within society may be protected only through public policy measures including policies to guide the path of technological change.

No attempt will be made here to list all the possible adverse environmental effects which might be brought about by agricultural technology. Soil erosion and the replacement of rain forests by food crops without the appropriate soil conservation practices, pollution of streams and rivers due to excessive fertilizer application and misuse of chemical pest control measures are but a few examples. Development and introduction of improved crop varieties resulting in the reduction of genetic diversity in mono crop regions increases the risk of large and simultaneous crop failures due to diseases and pest for which the particular variety has no resistance. Furthermore, extensive use of pesticides may result in the development of new resistance among insects and other pests. Pesticide use on crops may have adverse effects on humans and animals and, in cases where pesticides end up in streams and rivers, on fish.

The above are only some of the environmental risks associated with new agricultural technology which have been mentioned in recent literature.[19]

While air and water pollution effects of industrial activities related to agricultural inputs and outputs may be severe, e.g., air and water pollution associated with fertilizer manufacturing, available empirical evidence does not support the hypothesis that significant air and water pollution problems are created by the application of new technology in agricultural production.

It has been suggested that application of increasing quantities of fertilizer might contribute significantly to the pollution of streams and rivers. However, on the basis of a recent survey,[20] it may be concluded that in the few cases where fertilizer application has in fact contributed significantly to water pollution, it has been due to wrong (wrong from the point of view of the economic goals of the individual farmer) timing of application or excessive quantitites. Furthermore, cases have been found where the initiation of irrigation has resulted in water pollution caused by nutrients already in the soil. In general, however, increasing use of fertilizers within the limits provided by the farmer's profit motives does not seem to offer any threat to the quality of water in streams and rivers. It has been argued that application of increasing quantities of nitrogen fertilizers, resulting in increasing nitrogen losses to the air may have a significant adverse effect on the ozone layer. However, current knowledge is insufficient to draw firm conclusions on this aspect.

The environmental risk associated with the reduction of genetic diversity in a given region is real and should be taken into account in the planning of plant breeding. Furthermore, substitution of annual or semi-annual crops for rain forests without proper soil management offers serious environmental threats. Even with proper soil management, adverse effects on environment may be serious. New technology which makes food production more profitable may contribute to such substitution. On the other hand, guiding a sufficient amount of agricultural R&D towards avoiding these adverse effects may have high social value.

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[19] See: Erik P. Eckholm, Losing Grounds. W.W. Norton, New York 1976, for a more extensive treatment of the topic.

[20] Per Pinstrup-Andersen. Plantenaeringsstoftilfoerslens betydning for foedevareforsyningen. Nordic Agricultural Researchers' Association, Oslo 1979.

Incorporation of the environmental effects into an agricultural technology assessment model may be difficult for a number of reasons. First of all, there is very little concrete relevant and generalizable information on the topic. Thus a realistic quantification of the relationships may be difficult. Secondly, environmental effects may only be measurable over a relatively long time period. As a consequence, the impact relevant to any given decision period may be difficult to estimate. These and other difficulties are not necessarily specific to agriculture.

Two additional points to finalize this section. First, it is important to separate real environmental effects from fictitious ones before environmental effects are introduced into the model. In my (obviously biased) opinion, much of the recent debate over adverse environmental effects of agriculture has been more emotional than factual and based on very little hard empirical evidence. Secondly, where adverse environmental effects of new agricultural technology do occur, the trade-off between removing such effects and the consequences for food production and resource use must be explicitly treated. Some environmental effects may be removed or avoided at little or no adverse effects on food production. Others might not.