DEVELOPING SCIENCE AND TECHNOLOGY SYSTEMS -- EXPERIENCE AND LESSONS FROM AGRICULTURE

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DEVELOPING SCIENCE AND TECHNOLOGY SYSTEMS -- EXPERIENCE AND LESSONS FROM AGRICULTURE

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Introduction

The science and technology system in agriculture is a potentially important source of lessons and institutional forms for adaptation to the needs of other sectors. Science and technology development is crucial to the economic growth of the agricultural sector. It must, in most countries, service a production sector which is large, widely dispersed and comprised of small scale units of operation. Even in countries in which the private enterprise system is dominant, cultural science and technology system is largely in the public sector. Thus agriculture can illustrate the importance of a science and technology system and demonstrate its mode of operation in circumstances which are now of increasing importance in low income countries.

Many low income countries may now prefer a largely public sector system of science and technology for industry or parts of industry as well as for agriculture and hence may turn to agriculture for system prototypes. Similarly, development objectives may give substantial weight to public attention to health, education and environmental conditions with consequent early and large need for publicly controlled research systems directed to these problems. Most immediately relevant, the current emphasis in low income countries on employment oriented strategies of growth is likely to increase the importance of the small scale industrial sector.1/ That sector has many of the characteristics of agriculture and may require a similar supporting science and technology system.

Agriculture may also be a source of important development **lessons** because of the well documented history of first, inattention and then misdirected attention to science and technology. Many of the views now discredited for agriculture are still cogently argued for industry. The usual argument about the agriculture of low income countries in the 1950's was that the appropriate technology for rapid growth was known -- it only needed transfer from the rich countries to the poor and then to the ignorant farmer. In part because of this view many low income countries,

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1/ For elaboration of this view in a broader context see, Uma J. Lele and John W. Mellor, "Jobs, Poverty and the 'Green Revolution'," International Affairs, Vol. 48, No. 1, January, 1972, pp. 20-32.

as compared to high income nations, spent disproportionately on systems for transfering knowledge compared to systems for creating appropriate knowledge.1/ The production response to that allocation was small.

By the 1960's the need for adaptation of research to the specific conditions of low income countries was widely recognized. However even at that stage the emphasis was on highly applied research and the argument was often primarily on the side of test demonstrations which were only a small step toward creative research from pure transfer activities.2/ It has become increasingly apparent that research suitable to a low income country's agriculture requires a full set of research resources and capabilities, not simply adaptive efforts.3/

Despite the frequently erroneous definition of the problem there is now developing a substantial international research system tuned to the needs of agriculture in low income countries. The growth of this system, from which so much general knowledge can be derived, is in no small part due to the persistence of a few individuals in low income countries and of a few international organizations. As acceptance of the more complex science and technology needs in agriculture becomes more widespread it is striking to note the similarity of the current arguments with respect

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1/ For a tracing of the evolution of Indian policy in this context see, John W. Mellor, Thomas F. Weaver, Uma J. Lele and Sheldon R. Simon, Developing Rural India, Cornell University Press, Ithaca, N. Y., 1968; for detailed evidence on the relative weight to extension and research see, Robert E. Evenson and Yoav Kislev, "Investment in Agricultural Research and Extension: A Survey of International Data," Center Discussion Paper No. 124, Economic Growth Center, Yale University, August, 1971; for an early case study of the science based differences between the agriculture of a low income country and a high income country see, Robert W. Herdt and John W. Mellor, "The Contrasting Response of Rice to Nitrogen: India and the United States" Journal of Farm Economics, Vol. XLVI, No. 1, February 1964; for a comparison of indigenous research output with user practice, see W. David Hopper, "The Mainsprings of Agricultural Growth," paper presented at the 18th Annual Conference of the Indian Society of Agricultural Statistics, January 28-30, 1965.

2/ See, for example, Government of India, Ministry of Food and Agriculture and Ministry of Community Development and Cooperation, Report on India's Food Crisis and Steps to Meet It, New Delhi, 1959.

3/ See the complexity of the work performed and the range of disciplines, theory and methodology used at the International Rice Research Institute, Los Banos, Philippines, Annual Reports.

to the industrial sector to the old position for agriculture -- an emphasis on technology transfer and a minimal level of adaptive research.1/ Low income countries can benefit from past basic science developments in high income countries, but the optimal proportioning of research resources may be different to that of high income nations. However, the example of agriculture suggests that the optimal organization may also be complex and require thoughtful and rigorous attention. The problem is not simply institutional transfer, but rather the complexity of institutional innovation.

The purpose of this paper is to describe the science and technology conditions of the agricultural sector and the means by which those conditions have been serviced, as a basis for drawing lessons for the development of similar systems for the industrial and other sectors. The underlying emphasis of the paper is on the special role research may play in a more employment oriented strategy of growth and the similarity of the industrial research needs in such a strategy to the needs of agricultural research. A high employment strategy requires good rapid growth in agricultural production through technological change, a structuring of the industrial sector towards relatively labor intensive modern industry and expanded trade, with export of efficiently produced labor intensive commodities in exchange for capital intensive intermediate products and capital goods.2/ Each of these three elements of a high employment growth strategy requires science and technology support to facilitate increased incomes in accompaniment with rising employment.

The Key Role of Science and Technology in Agricultural Development

There are two aspects of the agricultural sector which give a key role to science and technology. First, in low income countries a program for broad participation of the poor in growth requires rapid expansion of food supplies. As the poor obtain employment and receive higher incomes they spend a high proportion of that added income on food grains and other agricultural commodities. Thus in India, for the bottom three deciles in the income distribution, about 60 percent of increments to income are spent on

1/ For the need for research in agriculture and its low state see, Hopper, op. cit; John W. Mellor, Chapter 15, "Improved Production Possibilities-Research," The Economics of Agricultural Development, Cornell University Press, Ithaca, N. Y. 1966, pp. 268-288; and Herdt and Mellor, op. cit.

2/ See, Lele and Mellor, op. cit.

food grains and 95 percent on agricultural commodities in general.1/ If the supply of these commodities is not increased then prices will rise, on the one hand depressing the incomes of the poor and causing an economic setback to efforts to raise incomes of the poor, and on the other hand, depressing real incomes of the urban middle classes and setting into motion political forces destructive of policies for continued employment growth.2/

Second, under traditional technologies agriculture is subject to rapidly diminishing returns and rising costs. Put simply, limited land areas cause the returns to more labor and even fertilizer to fall rapidly when they are combined with traditional production practices and seed varieties. Such behavior is damaging to an employment oriented strategy of growth as it necessitates an increase in relative agricultural prices in order to provide the incentives for increased production. The very fact of the rising prices then brings about political and economic forces which slow the growth of employment and the increases in demand.3/ In this context technological advance breaks the bottleneck of diminishing returns by providing plants with the capacity to productively use vastly greater quantities of inputs such as labor and fertilizer. It is the interaction of diminishing returns and rising demand that give such a key role to science and technology for agriculture.

The Characteristics of Agriculture and Their Relevance to Science and Technology Systems

Agriculture has three key characteristics which substantially influence the nature of an optimal science and technology system.

First, agriculture is comprised of a myriad of small scale units. As a result the individual firm lacks the financial resources to command or economically justify a large scale science and technology system. An effective system thus requires recourse to a large scale private sector, which often either does not exist or lacks mechanisms for obtaining payment for its science and technology services or the system requires recourse to a public sector system.

1/ B. M. Desai, "Analysis of Consumption Expenditure Patterns in India," Occasional Paper No. 54, Department of Agricultural Economics, Cornell University, USAID-Employment and Income Distribution Project, August, 1972.

2/ See, Lele and Mellor, *op. cit.*

3/ For discussion of the complex role of agricultural price policy in its interaction with technological change see, John W. Mellor, "The Functions of Agricultural Prices in Economic Development," *Indian Journal of Agricultural Economics*, Vol. XXIII, No. 1 January-March, 1968; and, John W. Mellor, "The Basis for Agricultural Price Policy," *War on Hunger*, Vol. IV No. 10, October, 1970.

Most countries including the United States, have developed large public sector systems of research for servicing agriculture. Without such systems, the importance of research in reducing costs of production may force agriculture to organize in otherwise uneconomically large units to the detriment of employment.1/ This lesson is an important one in the context of current interest in achieving growth in employment in small scale industry. Such industry may be placed in an uncompetitive position by lack of the science and technology support that it cannot provide for itself. Thus, in both agriculture and industry current social objectives demand attention to means of making science and technology output available to small scale labor intensive firms.

Second, agriculture is highly varied in the conditions under which production occurs. This not only greatly limits the transferability of research results from high income countries to low income countries but also requires an intricate system of research stations within the low income countries if the wide range of conditions are to be serviced. It is likely that the sharp contrast between success of the green revolution in wheat and in rice arises from the markedly greater heterogeneity of production conditions in the rice production areas of Asia and the relative inadequacy of the rice research system to fill this much larger and more complex requirement.2/

Meeting the varied regional needs of technological change in agriculture is important from a production point of view and crucial from an income distribution point of view. The close interaction between programs of rural development and income distribution tends to insure that areas not experiencing vigorous science and technology based rural development are likely to become the future areas of

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1/ The persistence of plantation agriculture which is often otherwise less efficient than smallholder agriculture may be explained partly on grounds of access to research as well as to marketing and financing facilities. See, David H. Penney, "The Transition from Subsistence to Commercial Family Farming in North Sumatra," Unpublished Ph.D. thesis, Cornell University, June, 1964.

2/ See the extensive treatment of the rice problem in this context in, Gunvant M. Desai, "Some Observations on Economics of Cultivating High Yielding Varieties of Rice in India," paper presented at Rice Policy Conference organized by the International Rice Research Institute, Los Banos, Philippines, May 9-13, 1971, reprinted as "Viewpoints on Rice Policy," Artha Vikas, July, 1971.

intense and entrenched poverty.1/ To the extent that other sectors of the economy process commodities of a heterogeneous nature or are otherwise influenced by varied conditions, they too will require a diffused research system. Agriculture illustrates the tendency to understate the complexity of these needs.

Third, because of its size, its initial dominance as an employer and its potentials for intensification through technological change, agriculture itself must provide a major portion of future increases in employment in low income countries. Thus, technological change must be tailored to this employment need. Also, because of the quite different factor proportions facing high income nations, the research effort may need to be somewhat differently directed, staffed and organized to meet the employment needs of low income countries. Again this point appears to have considerable relevance in the non-agricultural sectors as well.

The Role of Small Scale Industries in Low Income Countries

The small scale industries sector is the part of the industrial sector most obviously analogous to agriculture. It is comprised of large numbers of small scale units, often geographically dispersed, unable to provide their own science and technology needs and yet operating under diverse physical conditions and serving complex markets. These latter two forces may both require careful adaptation of science and technology input. Current strategic concern with employment and income distribution focuses attention on the small scale sector and places increased demands on it. The small scale sector typically produces commodities which lend themselves to labor intensive production which, in turn, fosters a highly labor intensive approach within the given structure of production.2/

Labor intensive small scale industries pose three substantial problems likely to require indigenous science and technology input.

First, their comparative advantage in labor intensive approaches, and national need to pursue that advantage, provides different factor proportions and hence, a different production context to that

1/ See Lele and Mellor, op. cit.; and, T. W. Schultz, The Economic Organization of Agriculture, McGraw Hill, New York, 1953.

2/ For a comprehensive analysis of labor intensity in small scale industries, see, Jan H. van der Veen, "Small Industries in India: The Case of Gujarat State," unpublished Ph.D. thesis, Cornell University, 1972.

of high income nations. Processing methods, machinery design, output mix and choice and utilization of raw materials are all variables which may be modified to accomodate greater labor intensity. It is important to recognize that the crucial issue for employment is to decrease costs of production and hence increase competitiveness for production which is basically labor intensive. Through that process employment expands as the industry expands. Thus the research need is much broader than developing less capital intensive machinery and equipment. Similarly the choice of products and sectors is complex, involving considerations of demand structure and the nature of competing products as well as present and potential labor intensity.

Second, labor intensive industries are normally materials intensive. That is, they use low price labor to process large quantities of raw materials.1/ As a result there is a particular concern to utilize materials more efficiently and to do so under conditions of small scale units operating under highly varying conditions. It could be argued that the support needed for such firms is simple extension or testing research. However, that supposition has proved wrong for agriculture and at the least needs testing for small scale industry. Reinforcing this point, small scale industries in low income countries are often based on agricultural raw materials thereby compounding the problem of variability and the need for indigenous research resources.

Third, the effort to broaden the distribution of income through reduced capital intensity encourages increased imports of capital intensive intermediate products such as metals, fibres and chemicals which are then processed through labor intensive techniques. Exports of labor intensive products must be increased to pay for these imports. Export markets are likely to require standardization of product and quality which are difficult to achieve given variability of production conditions and raw materials common to small scale labor intensive industries. Science and technology systems need to be adapted to facilitate increasing productivity under these circumstances.

1/ Ibid.

Science and Technology to Service a Widely Dispersed Small Scale Sector

Science and technology systems for agriculture must meet particularly severe problems of communication between user and scientist, variability in conditions, and interaction of social policy with growth policy.

Production in small scale units has the immense advantage of tapping sources of entrepreneurship not appropriate to large units or government bureaucracies.1/ Such entrepreneurs are likely to have substantial business acumen, but only modest formal education. The result may be a difficulty of communication between research establishment and productive user.2/ Such communication is crucial to success of both agricultural and industrial research. Most important is a channel to take problem definition from the user to the researcher, including feedback with respect to the initial research efforts. In agricultural research the feedback of knowledge occurs by close contact between research institutions and extension organizations. In Japan and Taiwan farmer's organizations have been heavily used for this purpose.3/

Agriculture can teach much about failure as well as succes in communication between research producer and user. The common complaint in low income countries about agricultural research is that of irrelevance--foreign trained researchers working on problems irrelevant to the local conditions within which they work. The problem, however, is basically one of communication and clientele. The foreign trained researcher often has a clientele in foreign journals and participants in international conferences and an incentive system which encourages cultivation of that clientele. The need is for incentives that steer the research worker to service a domestic productivity oriented clientele. The nature of the institutional structure is the key to this problem. That structure must tie the researcher to the users of his product and compensate him as he benefits those users.

1/ See the discussion of different forms of entrepreneurship in, van der Veen, op. cit.

2/ The problem is probably more one of cultural and social connections of different classes than simple physical difficulties associated with illiteracy and complete lack of formal education and thus is likely to be as great between research workers and small businessmen as between research worker and farmer.

3/ Supreme Commander for the Allied Powers, Natural Resources Section, The Agricultural Experiment Stations of Japan, Report No. 59, Tokyo,1946.

The variability in conditions in agriculture creates a need for a widely dispersed system of research to meet varying regional conditions. Concurrently, individual research stations serving specific adaptive needs must be tied directly to sources of more basic research. The problem is one of conflict between the need for a broadly dispersed system on the one hand, and for interplay of applied and basic research on the other. The one calls for many small stations, the latter for large integrated units. The necessarily complex solution is coordination between central stations and field stations. This is a complex institution building problem.1/ The appropriate research support for small-scale industries based on natural or agricultural raw materials, such as gems, forest products, fibres, vegetables and fruits are most probably quite similar. The inaccessability to the small scale firms of such research support would lessen their ability to compete with large scale firms and in foreign markets. Such failure is apt to be crucial in the effort to shift to higher employment strategies of growth.

The impact on social policy of what is done in science and technology is particularly great in the agricultural sector, primarily because of the large absolute number of people and the very large proportion of the total population. A technology which changes the distribution of income between the laboring classes in rural areas and the peasant farming classes, or between small farms and large farms, has major impact on the social objectives of the society. Hence, society must be very much concerned with the nature of the technologies which are being created and the impact which they will have. This has a major impact on the choice of technology and the way it is applied. It should also have a major impact on the institutional organization of science and technology institutions - for that to a substantial extent determines the technology options. The choice between working on yield increasing, biologically oriented innovations as opposed to labor saving and mechanically oriented innovations is a simplistic example because some mechanical innovations may break seasonal labor bottlenecks which, in turn, may allow major yield increases in technology.2/

1/ For a fuller discussion of related issues see, John W. Mellor, Chapter 15, "Improved Production Possibilities - Research," The Economics of Agricultural Development, Cornell University Press, Ithaca, N. Y., 1966, pp. 268-288.

2/ For a substantial discussion on this issue, see, Yujiro Hayami and Vernon W. Ruttan, Agricultural Development: An International Perspective, The Johns Hopkins Press, Baltimore, Md. 1971.

The problem becomes much more complicated when we deal with regional allocation of science and technology resources. For example, to what extent should one take a particularly high risk with respect to rate of return from research resources by allocating them to backward areas which seem to have rather poor prospects for technological development but within which the social problems are particularly serious. These types of problems are likely to occur in the development of a research structure to service the small-scale industry sector. Decisions must be made about products to be emphasized, regional location of stations and labor intensity of areas of enquiry. Again, agriculture illustrates the complexity of the problem. Where social and economic conditions have been determinants of research thrust, in isolation from technical scientific considerations, the result has often been a problem definition which was insoluble.1/ There needs to be interaction between the social objectives and physical realities -- an exercise in the art of the possible.

Institutional Organization of Research

The agriculture experience has particular relevance to four research policy issues: (1) public sector emphasis; (2) integrated interdisciplinary approach; (3) integration of basic and applied research; and, (4) development of interregional and international research grids.

Public Sector Organization

Organization of a science and technology system largely in the public sector raises difficult problems of setting and enforcing priorities. Public sector objectives are not only likely to be diverse, but the political process may inhibit explicit statement of objectives while public sector bureaucratic procedures may make it difficult to allocate resources consistent with unstated objectives. This raises complex questions as to the extent to which research structures should be organized in institutions substantially autonomous from political processes so that within the organization objectives may be dealt with more explicitly, but at the risk of less contact with and responsiveness to societal needs.

In science and technology systems the key allocative decisions have to do with personnel allocations and incentives. These

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1/ See, as an example, the case of emphasis on plant breeding for low fertility conditions in India prior to the late 1950's in, Mellor, et. al., Developing Rural India, p. 108.

allocations are important to the total size and effectiveness of the research effort among various objectives and programs.

Particularly in ex-colonial low income countries, the priority systems and salary structures for the public sector have probably reflected priorities which emphasize a stable administration and the generalist administrator. Change may thus be needed to give emphasis to technically trained persons for research. A shift in relative salaries and prestige may be necessary. Such change against the interests of existing bureaucrats is difficult to achieve. The problem is exacerbated in the context of mixed economies, in which the private sector is likely to adjust more rapidly by drawing the best technical manpower to the detriment of those types of work most appropriately done in the public sector. Such situations have been particularly detrimental to agriculture, small industries and public welfare programs. The need is explicit recognition of the role of salary schedules and administrative structure in achieving research objectives and explicit structuring of priorities.

Integrated Interdisciplinary Approach

The solution of applied problems in the agricultural sector illustrates the need and the institutional means for integrated research that cuts across disciplinary lines. Academic disciplines are defined to maintain homogeneity of basic theory and empirical methods of research within a discipline. The research answer to an applied problem may draw from any one or a combination of such disciplines. Thus, crop yields reduced by apparent disease or insect pests may prove in reality to be a trace element deficiency dealt with through the discipline of agronomy, rather than entomology, plant pathology or plant breeding. Unless the problem is examined by persons from several fields the optimal solution may not be found. The problem of coordinating across several fields may be more difficult in public sector research institutions because of close relations with academic institutions and their strong tie to disciplinary organization. The problem is one of maintaining a strong tie with the efficiency increasing logic and methodology of the academic discipline while developing a capacity to constantly regroup along problem oriented lines in the face of constantly changing problems. Again, the closer the tie with the clientele the greater the pressure to find productive patterns of institutional organization.

Integration of Basic and Applied Research

Short-run research results which increase net incomes require a problem solving approach. Within that context, however, first-rate minds are needed and efficiency can be increased by selective applications of basic theory and sophisticated methodology. Much of the criticism of basic research is, in fact, based on examples of poorly defined applied research. Research results have, in general, been sparse where research has been largely carried out on highly applied stations with little integration with a larger system and staffed entirely by persons with only applied training. However, it is not clear how and at what level basic research needs to be integrated to applied research. Nor is it clear the extent to which the return to such integration occurs by increasing the efficiency of research through the direct utilization of basic research, or by providing greater upward mobility of research staff to potential national and international institutions. It would appear, however, that research systems have all too often erred on the side of adequate basic science support.

Poor definition of problem or choice of irrelevant problems should not be confused with excessive emphasis on basic research. Proper definition of problems is a function of institutional structure and its relation to the research clientele.

Interregional and International Research Grids

The need for complex mixes of disciplines and of basic and applied science poses problems of scale for small countries which, in turn, necessitate integration into a larger research system. Even for a large country, economies are available from large scale operations and from interchange of knowledge within a given structure. The public nature of agricultural research has facilitated the building of international systems of research and provides a prototype for other research systems.

The international institutes of agricultural research provide: (a) major centers for interdisciplinary interaction to which less fully staffed stations may integrate; (b) the basis of communication and institutional structure for developing a core of relatively basic research; (c) a quality level which facilitates setting a desirable standard of problem definition; (d) an apex to which country research stations may integrate. That pattern could usefully be duplicated for other commodities outside agriculture.

Complex problems remain in the international research system for agriculture. Initially finance came largely from American private foundations. More recently, international and bilateral aid agencies have played a growing role. But the policy is not yet clear as to how they are to be financed. That question interacts with the complex problem of the role of the international institutes as separate operations to provide complete solutions compared to their role as part of a total complex of research fully integrated with national systems.

Conclusions

The experience of agriculture illustrates the key role which research-technology systems can play in economic development. The experience has particular relevance to other geographically dispersed small-scale sectors, such as small-scale industries and family welfare programs. It has less relevance to the large-scale heavy industry sector. Current trends in thinking about development, with their emphasis on employment and broad distribution of income and welfare, give added emphasis to a structure of growth to which the agricultural experience is most relevant. Particularly useful lessons can be learned from agriculture about development of large integrated systems of research, means of developing close relations and exchange between research institutions, client and problems, and means of setting research priorities. Most important, the experience in agriculture should help guard against an overly simplistic view of the scope of research needs and the complexity of the institutions for meeting those needs.