TECHNOLOGY TRANSFER FOR CHINESE AGRICULTURE - THEORY AND IMPLICATIONS FOR STRATEGY*

by

Robert D. Stevens
Department of Agricultural Economics
Michigan State University

"The. . .technology backlog. . .creates the possibility for late-developing countries to bypass the vast investment of time and resources that the accumulation of this knowledge involved. This opens the way for more rapid rates of economic growth. . ." (Johnston and Kilby, p. 76)

I. INTRODUCTION

China is in the midst of an immense many-decades-long transformation of her traditional agricultural technology to a modern, much more productive science-based agricultural technology. The kinds of investments made and science policies followed in obtaining more productive technology for Chinese agriculture can greatly affect the rate of this transformation. China, as is the case in all nations, has limited resources available for investment to obtain more productive agricultural technologies, whether from overseas or through domestic effort.

This paper examines the guidance provided by the induced innovation model of agricultural development and the phases of technology transfer for strategies to increase the productivity of Chinese agriculture. The paper carries out this objective by first identifying the three phases of technology transfer. It then explores the mechanism of induced innovation and its implications for obtaining more productive technologies for Chinese agriculture. Finally, conclusions are summarized from this economic theory for Chinese agricultural science and technology policy.

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*Agricultural Economics Staff Paper No. 87-67. Prepared for the Joint Meeting of the Chinese Association of Agricultural Sciences Societies, the Chinese Association of Agricultural Economists and the International Association of Agricultural Economists at Beijing, October 25-29, 1987.

Two central hypotheses underlie this paper. The first is that China during the next two decades has a unique opportunity to greatly increase the productivity of her agriculture if effective science and technology policies are pursued. Such policies would allocate considerable resources to the material and design phases of technology transfer. This opportunity is present because until the late 1970s high barriers discouraged the transfer from overseas of many more productive agricultural technologies into Chinese agriculture. Some of the new technologies can at least double crop yields.

The second hypothesis is that the positive agricultural productivity impact of the recent significant institutional change to the family-based production responsibility system in China now needs to be complemented with much greater effort to accelerate the rate of technological change in agriculture. This investment is needed to sustain further rapid increases in agricultural production in China and to meet government targets for the year 2000 (see World Bank, p. 94). Increased productivity in Chinese agriculture would also aid a shift of labor for more rapid expansion of industry in rural areas.

A. The Transformation of Traditional Agriculture and the Role of Technology Transfer

China is transforming her traditional agriculture to a much more productive science-based agriculture. This long process requires establishing a large number of immense new streams of more productive agricultural technologies that originate in domestic mines and factories and other nations and flow all the way to millions of farming households in all parts of China. Increasing technical and economic specialization is a fundamental part of this process. To establish and feed these streams of more and more productive agricultural inputs requires national investment in both obtaining the new technologies from abroad and in creating and producing these technologies domestically. A fundamental agricultural science policy question concerns the time pattern of investments to achieve more productive agricultural technologies through (1) transfer from overseas and (2) domestic creation to enable the greatest possible progress in agriculture. A general answer to this question is provided by economic theory. Investment in these two activities should be allocated in such a way that the rate of return from investments to obtain new agricultural technology from overseas is equal to the rate of return from investments to create and produce new technologies domestically.

World economic history demonstrates that very large levels of agricultural technology transfer have occurred among all nations, leading to large increases in agricultural production. The United States, early in its history, obtained much of its agricultural and other technology from Europe. In the 1930s and 1950s, Japan obtained much new agricultural and other technology from Europe and the United States. Some new agricultural technologies have already been transferred to China. I understand, for example, that the duck breed currently used for Peking duck offered in restaurants in China had its origin on Long Island, New York.

Two extremes of national science policy to create and produce new agricultural technology are (1) to focus most investments domestically or (2) to make investments primarily to import more productive agricultural technologies from overseas. Each of these extreme choices would slow the rate of growth of Chinese agriculture.

B. Phases of Technology Transfer - Material, Design, and Capacity

The material, design, and capacity phases of technology transfer were outlined by Hayami and Ruttan (pp. 260-62). They provide a useful classification of technology transfer activities that aid identifying appropriate transfer strategies at particular times.

Material transfer. This phase of technology transfer involves such agricultural inputs as seeds, plants, machinery, pesticides, and fertilizers. New agricultural inputs usually have to demonstrate a fairly high return above cost, perhaps 20 to 30 percent, before farmers are likely to become interested in them. For farmers have to bear the costs of change and the risks and uncertainties associated with incorporating the new production materials and practices into farming. Because imports of new agricultural inputs have been restrained formerly, there are likely to be many more new high productivity agricultural inputs (seeds, animals, chemicals, and machinery) that could now be imported into China which would provide high returns to farming households and to the nation.

In this phase, specialists in the many agricultural disciplines, through orderly testing of new and old agricultural technologies, the multiplication of seeds, and particularly, careful tests on farmers' fields, can identify the most productive agricultural technologies obtained from other nations.

Material transfer activities will also provide greatly increased knowledge of the range of agricultural technologies available in the world that might be of use in Chinese agriculture. Knowledge of these technologies lays the groundwork for more productive investments in the design transfer phase of technology transfer. Scarce design resources can be wasted if they are used to reinvent agricultural technology already available in another country (see also Khan).

Design transfer. In this phase of technology transfer, designs, blueprints, formulas, and books used by scientists and other technologists are transferred to the target agricultural areas. This activity can involve book translations and English language training so that researchers may read scientific journals and books in English and other languages. Short-term training abroad up to the Master's level can accelerate design transfer activities.

Many modifications of agricultural technologies obtained from abroad can be made in the phase to increase the profitability of the new technologies. These more productive inputs will provide new higher-return investment opportunities for farmers in the different agricultural regions. This phase of technology transfer includes expanded local production of machinery and parts and other inputs and the strengthening of experiment stations. We hypothesize that an immense number of opportunities to produce more productive agricultural technologies through design transfer activities are present in China today.

Capacity transfer is the longest-term, most costly investment activity in technology transfer. In addition to all the activities in the previous phases, it requires the production of significant numbers of agricultural and social science Ph.D.s, or their equivalent, who can provide scientific and technical leadership in each of the agricultural disciplines. A task of many decades. Professional working environments have to be created in many parts of China that include large libraries, laboratories, computers, and other equipment to enable highly qualified professionals to be productive in their research. Salaries and perquisites sufficiently high to draw and retain top talent from within the nation are needed. Sufficiently free working environments are also necessary so the professionals can concentrate on scientific matters and communicate with peers around the world. When this level of technology transfer has been reached, China will contribute at the scientific frontier by creating more productive agricultural technologies that are unknown in other nations.[1]

The question of relative allocation of resources to each of the three phases of technology transfer at a particular time, in a specific country or region, for whatever identified crop, livestock, fish, or forestry enterprises, depends upon the amount of activity which has already been undertaken in each of these three phases, the costs of each phase, and the probable success in obtaining new technology from investment in each phase. The costs to a government for material transfer can often be low. Relatively few scientists and technologists traveling in the most appropriate foreign agricultural regions can often obtain new, more productive agricultural technologies at relatively little cost. Joint ventures with agricultural input suppliers from other nations can greatly facilitate transfers of material technologies at little cost to government.

In the design transfer phase, more government resources are required than in the material transfer phase for the training of agricultural scientists and the provision of libraries, laboratories, and computers. The investment required to achieve the capacity level of technology transfer in any field of agriculture will require large investments and will take a long time. We hypothesize, therefore, that during the next decade in China, the highest returns to the nation are likely to be obtained by placing primary emphasis on material and design transfer activities.

Many studies have been made of the returns to agricultural research in many nations. Most have demonstrated very high internal rates of return, from 25 to 90, or more, percent (Hayami and Ruttan, pp. 63-64). It is likely that China now has many opportunities to obtain such high returns from research that obtains more productive agricultural technologies through international transfer and domestic development.

II. ECONOMICS OF INDUCED TECHNICAL CHANGE AND INVESTMENTS IN TECHNOLOGY TRANSFER

A brief review of the economic model of induced innovation in technology enables clearer identification of agricultural regions from which material transfer is likely to be most successful.

A. Interrelations Between the Four Elements of the Induced Innovation Model of Agricultural Development

In the induced innovation model of agricultural development, four groups of factors affect the performance of agriculture: (1) resource endowments of land, labor, and capital; (2) the agricultural technology employed; (3) the institutional arrangements in each society that affect agriculture, such as land tenure arrangements, marketing arrangements, and national agricultural price and other policies; and (4) the cultural endowments of the society that determine its tastes, social values, and governing system (Figure 1). Resource availability and cultural endowments cannot usually be changed very rapidly, but technology and institutions often can. The institutional change to the family-based production responsibility system in 1978 in China had a large impact on agricultural production. This change was examined in the Hayami-Ruttan induced development framework by Lin. Greater changes in technology will be required to sustain agricultural growth in China. This can be achieved by devoting more resources to the three phases of technology transfer that comprise agricultural and social science research.

In any nation, a certain amount of increased production can be obtained by better allocation of the current resources used in agriculture (often achieved through changes in relative prices), and through the addition of more of the resources currently used in agriculture. However, using more of the same resources generally results in declining returns on the current national agricultural production function (Figure 2, Production Function I). Significant increases in national production and agricultural productivity can usually be obtained only through the use of new, more productive technologies in agriculture, illustrated by Production Function II. With these more productive technologies either greater agricultural production is obtained with the same resources, a move from k to b in Figure 2, or fewer resources are required to obtain the same level of agricultural production as at point m. To achieve greater productivity in any agriculture requires the allocation of resources to move to more productive systems of agriculture.

B. The Very Different Economic, Technical, and Social Environments of National Agricultures

The productivity of investments to transfer agricultural technologies to China are greatly affected by the wide differences in economic, technical, and institutional conditions in Chinese agriculture, particularly as compared to conditions in more developed nations. These differences influence which agricultural technologies will be most productive in China. For example, in more densely populated nations, land costs are usually much higher relative to labor costs, as compared, for instance, with the United States. Three other very important general differences impinging on technology transfer to China are: (1) the small size of the farm household fields; (2) the limited number of domestic factories and firms which currently have the ability to develop and produce new, more productive mechanical or chemical technologies for agriculture; and (3) the very limited supply of individuals who have the technical and scientific knowledge to create and produce new, more productive agricultural technologies.

The differences in the physical and biological environments in the different parts of China and between nations are generally well understood, such as the tropical, subtropical, and temperate climates. Also, the quite different pest and weed conditions that exist in different areas are generally well recognized.

The widely different institutions and social agreements in different nations and in different regions that affect agricultural production place varied constraints on introductions of new, more productive technology. Thus, the fundamental institutional change to the family-based production responsibility system created a new and different incentive environment for family members to work in agriculture, as did the additional reform in 1985 that replaced the command-oriented grain marketing system with a contract system and a shift to taxes paid in cash rather than kind (Niu and Calkins). These institutional changes have greatly affected the productivity of different technologies in Chinese agriculture. For example, the productivity of large and small agricultural machinery was greatly affected by these changes.

Recognition that the vastly different technical, economic, and social environments can greatly influence the productivity of new agricultural technologies leads to understanding the importance of gathering better information about these realities in the different regions of Chinese agriculture. Such knowledge will aid more effective technology transfer. Thus, farming systems research (see conference paper by Nagy and Sanders), and similar detailed studies of the economic, technological, institutional, and cultural factors which directly affect agricultural production, will contribute to this needed knowledge.

C. The Mechanism of Induced Technical Change

The Hayami and Ruttan model of induced technical change demonstrates how economic factors also determine whether new agricultural technologies, transferred from other nations, will be productive. Many new agricultural technologies transferred from more advanced nations to less developed nations may not increase agricultural productivity. The essence of the argument is that in many developing nations the availability of low-cost labor and the high cost of capital cause many of the capital-intensive agricultural technologies of more-developed nations to be unproductive in less-developed nations (see also Evenson and Binswanger).

Thus, the varied ratios of the costs of the resources used in agricultural production in different parts of the world cause a limited number of technologies to be the most productive in each location. Different relative prices in the various economic environments also induce different technologies to be developed. Specifically, in the large number of low-income nations, labor-intensive technologies are usually more productive than capital-intensive technologies. These realities are demonstrated using production isoquants (Figure 3). A traditional, or low productivity currently used technology, is shown as isoquant t, with an equilibrium point a on the isocost line L, that indicates a certain ratio of the cost of labor to capital. Labor cost is assumed to be $0.33 per unit (hour, day). In this economic environment, more productive technologies l, m, and n would be induced to be imported or developed domestically. The figure shows that these technologies would provide the same output with a lower resource cost indicated by isocost line K. These technologies are on a higher production function (or surface) such as indicated by Production Function II in Figure 2. Thus, with the same product price, these technologies would provide a greater net return to farmers (same output with lower input costs). The administrators, researchers, and businessmen involved in finding such new, more productive technologies would obtain increased prestige and probably larger budgets. Hence, such individuals have an incentive, or are induced, to search for these new technologies. To be successful in technology transfer, however, they will usually need a certain amount of government support, both financial and in other ways.

An empirical example of relative prices of agricultural inputs and their change over time has been developed for the United States and Japan since 1880. The cost of labor relative to capital, as represented by agricultural machinery, has increased about three times (Table 1). So in recent years in the United States, Japan, and other more-developed nations, technologies have been induced to be developed that enable the substitution of relatively lower-cost capital for labor. The high cost of labor relative to capital in these two nations is indicated by the much steeper isocost line J in Figure 3. This isocost line was drawn by increasing the cost of labor nine times relative to capital. Thus, only one-ninth the amount of labor can be obtained in the more-developed nation illustrated here for a given amount of capital, as compared to the labor-capital price ratio illustrated by isocost line L.

D. High Investment Returns Obtainable From Carefully Chosen Material Transfer of Agricultural Technologies

The analytic framework set forth in Figure 3 indicates that much agricultural technology in more-developed nations that has been induced to be developed is likely to be capital-intensive. Hence, many of today's technologies in more-developed nations are likely to be represented by isoquants w and v. These isoquants are, however, above isocost line L, which indicates the unit cost of currently used technology in a less-developed nation with low labor costs. Thus, agricultural technology v, that is currently the most productive in the more-developed country, would provide a lower net return (would be more costly) for farmers to use in the less-developed nation than the current technology (isoquant t). However, the more productive agricultural technologies l, m, and n may be available from other nations with low labor costs.

A point of particular interest related to material transfer arises if technology u is available from a more-developed nation. Note that its adoption would reduce resource costs (it is on a lower isocost curve than L in the less-developed nation) and thus it would increase income in the less-developed nation. This is an example of material technology transfer, which has been occurring in a fairly widespread manner for many decades among many nations. Technology u, however, is likely to have serious drawbacks for a developing nation. It can greatly increase unemployment as compared to technology t, and it is not as productive as the more desirable technologies l, m, and n, if they could be obtained.

Pursuing the analysis further, investments in material technology transfer that attempt to reach isoquants l, m, and n (Figure 3) are likely to have high returns in China because the costs of finding these new technologies in other low-labor-cost nations with progressive agricultures may be quite low. (For discussion of these costs, see Evenson and Binswanger, pp. 167-169.) The highest probability for finding such agricultural technologies is from regions in countries that have <u>both</u> similar physical <u>and</u> similar economic environments, and that have made considerable strides in increasing agricultural productivity.

It should also be recognized that in the case of some technologies for use in agriculture, the productivity of the technologies in capital-intensive more-developed nations may be much closer to the origin than isocost line K in Figure 3. Such technologies might provide high returns even in low-labor-cost nations. Two examples of such technologies are certain pesticides and veterinary medicines, and computers.

E. Increasing Investment in Design Transfer for Greater Agricultural Productivity

When productivity increases are not obtainable through material transfer of more productive agricultural technologies, increases in the productivity of agriculture in each region will depend upon designing new agricultural technologies. In the design phase of technology transfer, agricultural research institutes, experiment stations, and factories producing agricultural inputs make significant modifications of currently available agricultural technologies. Examples of design transfer work include many improved plant varieties, improved chemical fertilizer and pesticide placement, and timing practices tailored to the needs of different crops, and more productive hand-powered technologies as well as motor-powered stationary and self-propelled equipment for agriculture. China has already made great progress in producing much higher yielding rice and wheat varieties. Much additional progress in increasing the productivity of agriculture can be achieved through more design phase work. In the social sciences, agricultural economists in this phase of technology transfer have recently made large contributions to national policy (Niu and Calkins, p. 448). High national returns from investment in these activities can usually be obtained with additional investment of government resources in human capital, research institutes, and experiment station facilities and equipment beyond that required for effective evaluation of agricultural technologies obtained in the material phase of technology transfer.

F. Building Agricultural Science Leadership

All large nations desire to move as quickly as possible to the capacity phase of technology transfer in all fields. But the costs and time needed to achieve this level of performance in the many areas of the physical, biological, chemical, and social sciences are sometimes not recognized. In this phase, agricultural and social scientists trained at least at the Ph.D. level are able to contribute at the frontier of world science in agriculture. Premature attempts to put large resources into long, costly training programs and large investments in specialized equipment and facilities can be associated with high risks leading to low returns from this investment. Considerable waste from agricultural research for long periods of time due to poor management and low scientist productivity can occur.

Thus, the relative allocation of national resources to the three phases of technology transfer should vary over time. Usually the most productive pattern will include much greater emphasis on material transfer in early periods, gradually shifting to emphasis on design and then to capacity transfer as the returns to resources invested in material and design technology transfer activities decline.

The achievement of the capacity level of technology innovation, in-country, can be accelerated through cooperative arrangements with other countries, or through collaborative arrangements with the international agricultural research institutes, such as the International Rice Research Institute in the Philippines. Capacity-level research enables a nation to gradually obtain more productive technologies even closer to the origin than technologies l, m, and n in Figure 3.

G. Alternative National Paths of Efficent Agricultural Technology Development

Evidence of the very different paths of technology development in agriculture that have been induced to be followed by nations with different economic conditions was provided by Hayami and Ruttan when they examined labor and land productivity changes between 1960 and 1980 in different nations (Figure 4). Relatively labor-short, land-rich nations, such as the United States, adopted agricultural technology that greatly increased labor productivity while only slightly increasing land productivity. In contrast, land-short agricultures, such as the region of Taiwan and Egypt, have used technologies that increased land productivity without increasing labor productivity very much. For example, in 1960, the United States is estimated to have produced about 90 wheat units per male worker in agriculture (a wheat unit is the equivalent of one ton of wheat). At this time, the United States achieved a land productivity of only about 1 wheat unit per hectare. In contrast, at the same time, Japan is estimated to have produced an annual agricultural output of 10 wheat units per male worker and 9 wheat units per hectare of land. Thus, in 1960, labor productivity in agriculture in the United States was more than 10 times as great as in Japan, while in Japan land productivity was almost 9 times as great as in the United States. By 1980, the United States had increased its labor productivity to 285 wheat units per male worker in agriculture, while land productivity had only increased a little over the period to 1.2 wheat units per hectare. During the same period, Japan increased its labor productivity to about 28 wheat units and its land productivity increased to 12 wheat units per hectare.

Changes in land and labor productivities of other selected nations are also seen in Figure 4. The intermediate positions in the figure are represented by a wide range of nations, including most European countries which have employed agricultural technologies that have increased both land and labor productivity considerably. In the coming decades, we can expect China to achieve large increases in agricultural productivity, along technology paths induced by the relative cost of capital to labor in its economy. This will occur as technology transfer moves through the material, design, and capacity phases in each region of the nation. Note, finally, that Figure 4 suggests more-developed nations which have followed intermediate paths in technology change are likely to have agricultural technologies that would be more profitable in labor surplus, land-short developing nations than, for example, U.S. agricultural technologies.

III. IMPLICATIONS FOR CHINESE AGRICULTURAL SCIENCE AND TECHNOLOGY POLICY

A. Continued Strong Growth in Agriculture Requires Large Investments in Technology Transfer

To assure continued strong growth in agriculture requires continuing shifts to more productive technology in each agricultural region. The new, more productive technologies for agriculture are obtained through continuing long-term investment in the material, design, and capacity phases of technology transfer and development. Providing farming households with better technologies will complement and assure continued strong growth in Chinese agriculture that was begun by the significant shift to the family-based production responsibility system. Over time augmenting the productivity of agricultural technology on Chinese farms will become increasingly critical for national economic progress.

B. The Importance of Effective Sequencing of Investments in the Phases of Technology Transfer

Material Transfer. As import and communication barriers have until relatively recently been high in China, large amounts of material transfer of agricultural technologies are likely to provide high returns from investment of society's resources.

During this phase, it is essential to develop the capacity to test a wide range of agricultural technologies on experiment stations and on farmers' fields through farming systems, or similar kinds of research. Effective work at all three levels of technology transfer requires detailed knowledge of representative farming systems in the many regions of the nation. Such information is gathered through surveys and comparative on-farm testing. Research objectives on the fields of farming households include at least: (1) measurement of the technical and economic characteristics of the agricultural technologies in current use; (2) identification of the most pressing technology needs; (3) estimation of the costs and supply elasticities of resources (inputs) used by farmers, including costs of using capital and labor, particularly at peak labor demand periods; and (4) identification of significant price distortions, so that useful information may be provided to officials who can influence price policies.

Comparative tests of the performance of agricultural technology transferred from the agricultures of other nations are also essential for decisions about what design transfer activities to undertake. Although tests on experiment stations are useful for some purposes, the performance and cost estimates obtained using different technologies under usual farm household operating conditions are a core requirement for effective agricultural technology transfer (Figure 5). Any new agricultural technology will need to provide a higher net return than current technology, perhaps a 15 to 25 percent increase in return to the farm household, to compensate for the costs of learning about and undertaking the change to the new technology. Technologies which are less costly for a farmer to adopt will require a smaller increase in returns to induce use. Important policy information that can be obtained from comparative tests on farms include estimates of the shifts in the amounts of resources required by the new, as compared to currently used, agricultural technology. In this way, knowledge can be obtained of changes in capital requirements and labor use, and how labor use patterns may shift in relation to current peak labor demand periods with the adoption of new technologies.

<u>Design Transfer</u>. Effective design transfer usually requires cooperative agreements and working arrangements between national and regional research units and experiment stations. Although one government unit may now have a sole, or monopoly, responsibility in providing new agricultural technologies to an agricultural area, in the future some forms of competition between different units that seek to provide the most productive new technologies to farmers are likely to accelerate the performance of these units and hence benefit both farm families and the nation. For example, a number of operating units, whether government or individual, could be given the responsibility of supplying new, more productive inputs, such as new seed varieties, new types of fertilizer, and better pesticides in a given

agricultural area. The more aggressive, successful unit would, in the next cycle, be given the opportunity to produce and distribute more of the new inputs.

Capacity Transfer. The capacity transfer level is a long-term high pay-off objective in technology transfer. To be cost-effective, this objective has to be carried out in relation both to the evolving international network of agricultural institutions that do capacity-level research and international agricultural firms that are creating the most productive new agricultural technologies. (A list of the international institutes was provided by Hayami and Ruttan, pp. 268-9.) Because of economics of scale in much capacity-level research and technology development, large research investments for unimportant crops and livestock will generally be a poor use of scarce research resources. New technologies for many of these enterprises can sometimes be obtained from overseas.

Thus, planning and investing in the further expansion of capacity-level agricultural research needs to be considered carefully. As the long-run pay-off of this research can be high, some investment should be commenced as soon as possible. Useful focus for capacity-level activities in the early period is two-fold: (1) training Ph.D.s, or their equivalents, and (2) building physical and administrative research environments where scientific frontiers could be reached. Such an environment includes libraries and laboratories, but more important, the support of substantial numbers of trained scientists at attractive salaries. It also requires the development of an administrative structure able to provide effective direction and incentives for useful research that will have an impact on agriculture. The incorporation of graduate training at the advanced level usually aids the development of frontier breakthroughs in agricultural science and technology. Government policies and financial support for success at the capacity level of technology transfer need to be large, long-run, and stable in the many technical and social science fields of agriculture.

C. General Policies to Support Accelerated Technological Progress in Chinese Agriculture

Effective science policy for technology transfer also requires addressing wider issues which directly affect the incorporation of more productive technologies in agriculture. Three of the more important wider issues relate to (1) licensing and patents, (2) institutional flexibility, and (3) the need for knowledge of potential impacts of new technologies on agricultural areas.

Different laws about licensing and patents will affect the rates of transfer, development, and adoption of new agricultural technologies. If individuals or private and government organizations have the right to copy and produce any technologies they obtain, there will be less incentive for individuals and units of government to seek and distribute more productive technologies to farming households. For the investment costs spent by the individuals, or government units, in obtaining the new technologies would not be able to be replaced through large enough sales of the new technology. To pay for the investment costs, some form of licensing and patents that give the holder rights for a certain period of time to produce, license, and sell the more productive technology will generally lead to greater effort to obtain and produce greater numbers of new, more productive technologies for Chinese agriculture. In joint ventures with international agricultural firms, appropriate licensing can encourage the international firms to bear most of the costs of technology transfer, development, and distribution. This reduces the investment costs of government. Thus, workable licensing and patent arrangements in most nations make very significant contributions to increasing the productivity of agriculture.

The successful introduction of new agricultural technologies will often induce institutional changes to enable additional increases in agricultural productivity. In the Hayami-Ruttan induced development model, the interrelations between technological change and institutional change (Figure 1) show that if institutions are not able to change, they will slow agricultural development. For example, there are many questions about the most productive institutional arrangements for the supply of new, more productive inputs for farmers. How can pesticides, animal breeding services, machine repair services, and the wide range of product marketing services be best supplied to farming households? Flexible institutional responses to these new needs will enable the new technologies to be adopted and more productive and so accelerate development.

Because more productive agricultural technologies sometimes can have large negative impacts on farming households in different agricultural areas, it is important for government to be able to foresee them. To do so requires the training of more agricultural economists and other scientists who can do this research. In this way, government can be ready to take any actions needed to ameliorate problems as they arise. Such actions were considered by Schultz. They include offers of alternative employment opportunities to farm households displaced by technological progress, providing additional government resources to these households for different kinds of technical training, or education, or aid to transfer to other economic sectors in rural areas that would offer more productive employment.

D. The Critical Role in Science and Technology Policy of High Performance Input Supply, Repair Services, and Technical Advice

The rate of adoption of modern, more productive agricultural technologies by Chinese farming households will depend upon science and technology policies that affect the supply of these technologies, associated needed technical advice, repair services, and credit for their purchase. Agricultural input supply systems for modern technologies are rudimentary in many developing nations. How can the increasing variety of more productive specialized farm inputs be provided at least cost to farming households? As development proceeds, increased specialization in production and marketing very often occurs, leading to the establishment of many different input supply channels to farmers for the varied technologies. To what extent should government units attempt to supply most of the new inputs directly to the farm household? What role for individual salesmen at what levels, the village only, or in a region?

Many nations have found it very difficult for government units to supply farm households with inputs. For example, after the government of Pakistan decided to stop attempting to supply fertilizer to farmers directly, it contracted with wholesale merchants at the district level who worked with local retail shops to supply farmers. Much increased use of fertilizer followed due to these more effective input supply arrangements. (For additional material on the Pakistan experiences, see Eckert and Stevens, Alavi and Bertocci.) Another illustration of the importance of input supply is provided by machinery services. Many countries, both socialist and free-market, have found that large government machinery stations are less effective in providing machine services than smaller units controlled by individuals or small groups, especially in providing machine repair services. Thus, each nation at each stage in development needs science and technology policies that will facilitate production and distribution of the new technologies developed by science, to assure that they reach farmers. When, for example, agricultural machine repair services are not available in a timely fashion, low utilization levels of equipment increase unit costs so they become greater than the less productive technologies they were supposed to replace. Then a new, potentially more productive technology such as m in Figure 3 would, due to poor repair arrangements, become a high-cost technology such as z. Under these circumstances, farmers get discouraged and return to using the older technologies with less productive potential. They also become more conservative about accepting any new technologies proposed to them.

The supply of credit to aid the purchase of new, more productive technologies raises similar questions. A variety of agricultural credit channels is likely to increase the use of new technologies in agriculture. For example, in purchasing agricultural machines, units selling the machines in many nations are able to offer loans to the purchaser. This credit arrangement has two advantages. The machine supplier has an incentive to provide sufficient instruction to the farmer so he can operate it effectively. For if the operator does not use it properly, he may not increase his income and hence would be less likely to be able to repay the machine supplier for the loan. Secondly, the same incentive is present for the machine supplier to have available a sufficient number of repair parts and to assure that repair services are available.

Hence, to insure that the new, more productive agricultural technologies transferred from other nations, or produced domestically, become incorporated into national agricultural production, science and technology policy needs to be concerned with the performance of the new input supply system. Some new agricultural technologies, such as artificial insemination, will require highly specialized delivery systems. Thus, new technologies will often induce the development of new institutional arrangements for their supply to farmers. Flexibility on the part of government in the face of these new institutional needs will aid more rapid growth in agriculture.

NOTES

1. The literature on augmenting agricultural research at the design and capacity transfer stages includes additional discussion of skill levels at different phases in the transfer of technology by Evenson. See also Boyce and Evenson, pp. 78-100.

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TABLE 1

Change in the Cost of Labor Relative to Capital as Represented by Agricultural Machinery in Japan and the United States, 1880 to 1960

	Labor Cost (Farm Wage)	Machine Cost	Ratio of Labor Cost to Machine Cost	
			Ratio	Index
Japan	Yen Per Day	Yen	(1000)	
1880	.22	66	3.3	100
1920	1.39	160	8.7	263
1960	440.00	37000	11.9	361
United States	$ Per Day	$		
1880	.90	146	6.2	100
(1925)[a/]	2.35	152	15.5	250
1960	6.60	356	18.5	298

[a/] The year 1925 is more representative of long-run changes in prices than the year 1920 for the United States.

Source: Adapted from Yujiro Hayami and Vernon W. Ruttan, Agricultural Development: An International Perspective (Baltimore: The Johns Hopkins University Press, 1971), Table C-2, p. 338.

Figure 1. Relationships Between Accelerators of Agricultural Development and Elements of the Hayami-Ruttan Model of Induced Innovation.

Source: Stevens and Jabara, Figure 11.1, modified from Hayami and Ruttan, Figure 4-3.

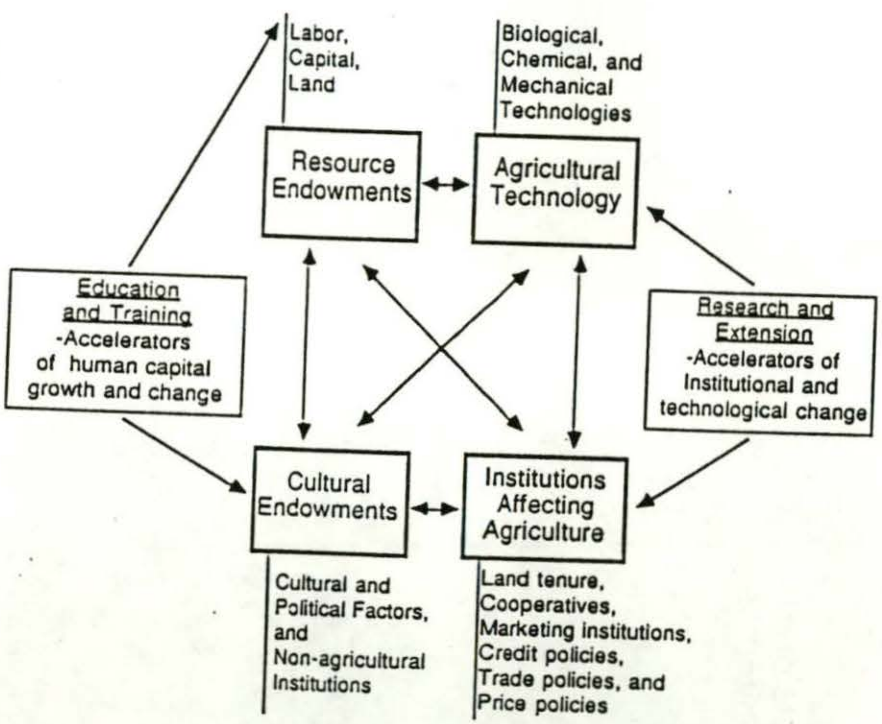

Figure 2. A Production Function Illustration of How More Productive Technology Increases Agricultural Output, or Reduces Input Costs.

Source: Stevens and Jabara, Figure 6.2.

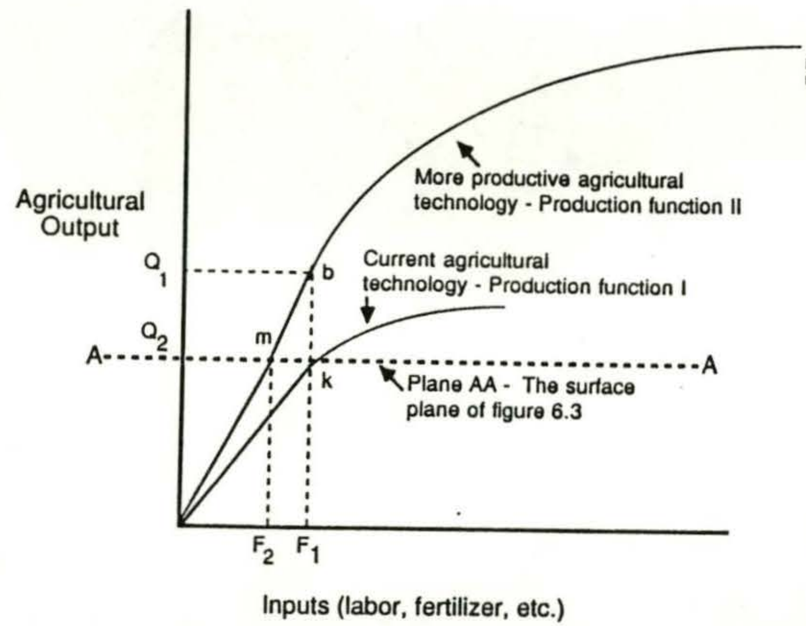

Figure 3. Identifying More Productive Agricultural Technologies With Two Different Ratios of the Cost of Capital to Labor.

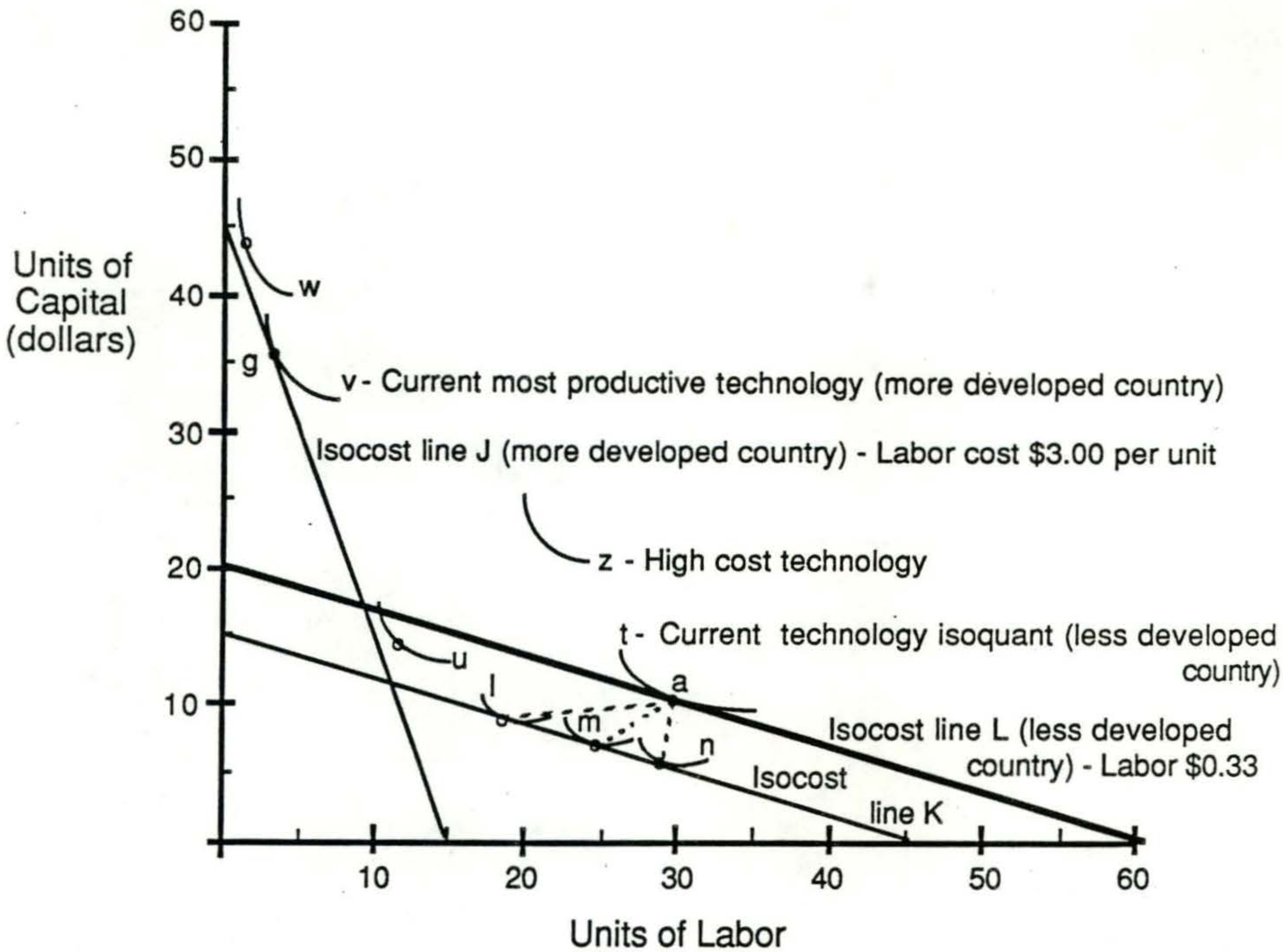

Figure 4. Paths of Labor and Land Productivity Increases in Agriculture for Selected Nations, 1960 to 1980.

Source: Data from Hayami and Ruttan, Table 5.1.

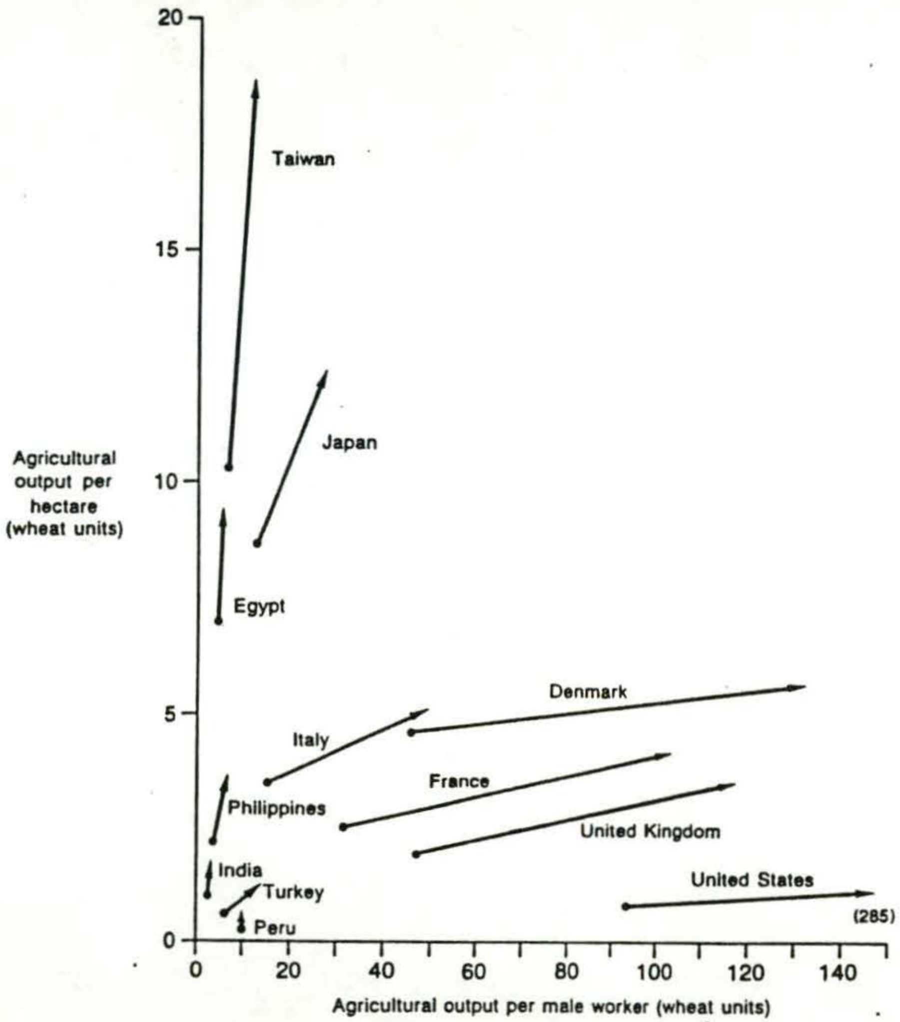

Figure 5. Interrelations Between Agricultural Research at the Farm Level and the Experiment Station Level.

Source: Adopted from Collinson, 1982, p. 5.