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Science and Technology Policy: Lessons from the Agricultural Sector in the South and Southeast Asia

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Table of Contents

1. Introduction 3

2. Technology Policies 4
   2.1 Public R&D and Extension: Expenditure and Institutional Development 4
   2.2 Policies to Encourage Private R&D 8
   2.3 Public Input Production and Supply. 10
   2.3.1 Fertilizer 10
   2.3.2 Seed 13
   2.3.3 Other Inputs 16

3. Impact of Past Technology Policies on Agricultural Innovation 17
   3.1 Public sector R&D and Extension 17
   3.2 Impact of Policy on Private R&D and Technology Transfer . . . 20

4. Future Challenges to Technology Policy: Sustaining the Green Revolution 24
   4.1 The Need for Increased Food Production and Improved Environment 24
   4.2 Technological Opportunities 26

5. Lessons from Past and Future Technology Policies for Agriculture . . 28
   5.1 Strengthening Public Agricultural Research 29
   5.2 Strengthening Legal and Institutional Infrastructure for Private Innovation and Diffusion 32
   5.3 Reduce the Size of Public Input Supply. 33

6. Lessons for Industrial Technology Policy 34

1. Introduction

One of the major successes of development since 1960 was the dramatic increase in wheat and rice production in Asia. There were also less publicized but equally dramatic increases in production of commercial poultry, milk oilpalm and in some important crops other than wheat and rice. Technology policies pursued by the governments of Asia have played a major role in these developments.

Technology policy is defined as a set of policies which are designed specifically to influence the process of technological innovation. Technology policy for agricultural development can be categorized into two types: policies aimed at increasing innovation[1] and policies aimed at increasing the diffusion of innovations.

The most productive technology policy for increasing innovation in the agricultural sector has been probably public investments in agricultural research. The development of agricultural universities is another important policy that has produced new technology but more important trained scientist, extension agents, policy makers and bureaucrats. Policies that increase technology transfer and research by the private sector are also important. They include tax policies, property rights, antitrust policies, import policies, government procurement of new technology, regulations on R&D and regulations on the use of new technology.

Governments also spend large amounts of trying to encourage the spread of new technology. Governments provide public extension services and supply new agricultural inputs. They subsidize the adoption of new technology by farmers in an effort to speed the diffusion of new technology. They subsidize producers and importers of inputs which embody

[1]. Innovation is defined as the first commercial use of a new technology in a country.

new technology. Governments provide general education to farmers and their children so that they can use technology more efficiently and adopt profitable technology more rapidly.

This paper will review the evidence on the effectiveness of technology policies in the past in Asia. Then we will look at the challenges to agricultural in the future and suggest technology policies that might help Asian governments meet these challenges. Finally, we will try to draw out technology policy lessons for other sectors of LDC economies.

2. Technology Policies

2.1 Public R&D and Extension: Expenditure and Institutional Development

2.1.1 Expenditure

The trends in agricultural research expenditure by the public sector vary considerably in Asia. In general the 1960's and 1970's were periods of rapid growth in Asian research. All Asian countries increased real research expenditure in the 1960's. In the 1970's some countries like Bangladesh and Indonesia made huge increases in expenditure while most of the others grew quite rapidly (see Table 1). Agricultural R&D expenditure declined in only one country - Sri Lanka. The right side of Table 1 shows R&D trends in five countries for which 1980's data is available. Real expenditure in the Philippines declined. Local expenditure in Indonesia declined, but this decline was offset by increased donor expenditure. Research expenditure in India, Thailand and Bangladesh increased.

Research expenditure as a percentage of the value of agricultural production increased in all regions of Asia in the 1960s and in all regions except China in the 1970s (Table 2). The research expenditure pattern of East Asia, which is primarily Japan but also includes South Korea and Taiwan, is similar to Australia and New Zealand and higher than Europe or the U.S. South and Southeast Asia start at less than 0.2 percent of agricultural product and grow to about one half of one percent during the

1970s. This represents a very large increase in research expenditure because agricultural output was growing very rapidly during that decade.

The pattern of extension expenditure is also shown in Table 2. The low income countries of Asia started out spending more on extension than on research. In contrast East Asia was spending more than three times as much on research as extension. In South and Southeast Asia extension expenditure grew during the 1960s and 1970s but not as rapidly as agricultural production during the 1970s.

Research and extension in Asia are also conducted private companies, and international institutions conduct research in Asia. Table 3 provides an overview of the relative importance of government research, International Agricultural Research Centers of the CG and research by private companies in seven Asian countries in 1985. We have not been able to locate any data on private extension. Public sector clearly dominates expenditures on agricultural research. In some countries, however, the private sector invests more in R&D on certain crops and inputs than the public sector. Table 4 shows some rough estimates of the allocation of private breeding, pesticides, plantation and livestock R&D in the Philippines. Private R&D in rice is greater than public R&D (excluding the International Rice Research Institute) because several multinational corporations have regional pesticide research stations in the Philippines. Private corn R&D is larger primarily because of Pioneer HiBred International's large breeding program, and high levels of private fruit and vegetables R&D is due to large investments by private plantations and exporters.

2.1.2 Institutional Development

In the 1950's most public agricultural research institutions were part of the ministry of agriculture or were single crop institutions, usually on export crops, financed by groups of commercial farmers. Linkages to agricultural science in the rest of the world were to scientists in former colonial powers through organizations like the British Commonwealth. Ministry of agriculture research institutes were linked to farmers through

government extension services which were quite weak. Commodity institutes were linked more closely to farmers through the members of their board which usually included farmers and through extension services that worked closely with farmers.

The 1950's was the extension and rural development decade in Asia. Asian officials and donors believed that improved agricultural technology was available from the U.S., Europe and colonial research in Asia. They thought that the weak extension systems were the primary constrain to wider adoption of improved technology and faster agricultural growth. As a result, most countries in Asia invested heavily in extension services.

A major institutional innovation was the establishment of research in agricultural universities. Research at agricultural universities started in the Philippines and India in the 1950's. New agricultural universities were built which included research, teaching and some extension. They were modelled after U.S. land grant universities in contrast to the colonial agricultural colleges which concentrated almost all of their effort on undergraduate teaching. Agricultural universities of this type were established in almost all of the Asian countries in the 1960's and 1970's.

Governments of most Asian countries centralized their research systems during the 1960's and 1970's. This usually took the institutional form of a national agricultural research council which took control of regional research and research by commodity group. Centralization of R&D was part of a general trend toward centralization of government power in Asia.

Attempts to decentralize research are probably the major institutional change in the public sector since the 1980. India is building experiment stations in all 121 agro-ecological zones. Indonesia is building regional agricultural universities and experiment stations. Bangladesh has built a number of regional experiment stations. Most Asian research stations are doing more on-farm research, usually called farming systems research. India has the "lab-to-land" program. Despite these efforts most of the control over budgets and the allocation of research resources remains centralized.

There extension became part of the agricultural university structure. A major change in extension institutions in the late 1970s was the introduction of the Training and Visit system of extension. This system differs from traditional Asian extension systems by increasing the number of extension agents and having them focus exclusively on agricultural extension. Extension agents have a rigid schedule of contacts with farmers and contacts with subject matter specialists. The system has a hierarchical structure with subject matter specialists and managers to ensure the quality of information and efficiency of its delivery (Benor and Baxter). The World Bank has successfully encouraged this structure in all South Asian countries.

A major institutional innovation of the 1960's and 1970's was the establishment of the International Agricultural Research Centers (IARCs). The International Rice Research Institute (IRRI) was established in 1960 and it grew rapidly in the 1960s and 1970s. The International Maize and Wheat Improvement Center (CIMMYT) was established in Mexico in 1966, but it was already working with India and Pakistan while it was formally part of the Mexican research system before 1966. International Crops Research Institute for the SemiArid Tropics (ICRISAT) was founded in India in 1972. The International Food Policy Research Institute (IFPRI) in Washington DC. and International Potato Centre (CIP) in Peru also began to play a role in Asia in the 1970s. Thirteen IARCs are now organized under the umbrella institution of the Consultative Group for International Agricultural Research (CGIAR).

The first non-CGIAR international center in Asia was the Asian Vegetable Research and Development Center in Taiwan which started in 1972. It was followed by the International Center for Living Aquatic Resources Management in 1973. In the 1980's two other centers which were oriented to resource management were established - the International Irrigation Management Institute in Sri Lanka and the International Board for Soils Research and Management.

2.2 Policies to Encourage Private R&D

Research by private companies has grown rapidly in recent years in Asia. They have broken the public sector's monopoly on research in certain crops and substantially changed the total allocation of research resources in some countries (Table 3). Local companies and foreign multinationals play roughly an equal role in Asian R&D. Research by multinational corporations not only adapts technology developed elsewhere and builds research capacity. It also provides new linkages to scientists in other countries. Pioneer Hi-Bred seed company, for example, tests corn hybrids in more than 90 countries. This network is almost as widespread as CIMMYT's.

Government investments have established the infrastructure upon which private R&D developed. Public agricultural research provided the opportunity for profitable private R&D especially in plant breeding. The hybrid corn breeding programs in Thailand and the Philippines are based on downy mildew resistance lines identified by the Kasetsart U./Rockefeller Foundation/CIMMYT research program. The private pearl millet and sorghum breeding programs in India are based on inbred lines developed in the Indian government research program and ICRISAT (Pray et.al.1989). Pesticide R&D on rice by multinational companies in Southeast Asia is centered in the Philippines largely because IRRI is located there.

Investments in agricultural universities and public research have reduced the private sector's cost of scientists. In a recent survey of private research programs in Asia (Pray 1987) nearly all of the scientists were educated in agricultural universities and most of them first worked in government research institutions and then were hired away by the private sector. Private companies hired some of their scientists from the IARCs. In the absence of local research institutions and universities firms would have to import foreign scientists or finance degree training for their staffs in foreign universities.

Government restrictions on private R&D and regulations on the use of new technology are probably the most important policies affecting levels of

private R&D after government investments in research. Pakistan did not allow private companies to do plant breeding until the 1980s. The Philippines did not allow foreign companies to do research on rice and corn from the early 1960s until the mid 1970s. India did not allow large Indian companies or companies controlled by multinationals to do plant breeding until 1987. Regulations on importing plant and animal germplasm, importing foreign scientific equipment and on foreign scientists have reduced incentives for research in some countries. In others regulations on the commercialization of new inputs have been a constraint. Seed companies have faced difficulties getting new varieties approved by government certification agencies. New pesticides must go through a regulatory process that delays commercial innovation[2].

Asian countries have followed contrasting policies on importing technology. India and Indonesia have restricted the import of certain types of technology in order to encourage local research. For example, they have restricted imports of grandparent stock of commercial poultry to encourage local breeding and production of chicks. This does not appear to have encouraged much local research. The Philippines took the opposite position of trying to encourage technology transfer by private companies with tax incentives on R&D inputs and technology transfer activities.

Most Asian countries do not have strong property rights on agricultural innovations. Table 5 shows that patent coverage of agricultural inputs is limited. In many countries that have patent coverage, they are not effectively enforced. In a few countries petty patents have been an effective way of providing extra incentives for innovation in the machinery industry. In the Philippines utility patents are quite inexpensive and if you have one the taxes on the income from sales of that product are greatly reduced.

The demand for commercial inputs will influence firms' decisions to

[2]. In some countries there are almost no restrictions on pesticide use in which case the absence of regulations acts as an incentive to R&D and importing new products.

invest in R&D and extension. Government macroeconomic policies, exchange rate policies and agricultural price policies affect agricultural prices which will affect the demand for agricultural inputs. Government interventions in the input sector which are described below also affects the demand for privately produced inputs. Government production and price controls can reduce the size and profitability of markets for innovations by private firms, and thus reduced their ability to capture the benefits from R&D. Reductions in the expected profits from R&D will reduce private investments in R&D.

2.3 Public Input Production and Supply.

Government intervention in input markets is frequently justified as a way to encourage the spread new technology. There are four common types of intervention: subsidies to users of improved inputs which embody new technology; government importation or production of the inputs; government distribution of the inputs through government corporations, cooperatives or the extension system; and restrictions on private imports of inputs.

2.3.1 Fertilizer

Since the early 1960s every major agricultural country in Asia has established substantial fertilizer production capacity. Fertilizer consumption has expanded dramatically as the result of the introduction of fertilizer responsive crop varieties and subsidized fertilizer prices designed to encourage both rapid adoption of the new crop varieties and high levels of fertilizer use. In most countries the new fertilizer capacity was established with substantial financial assistance from the US/AID and/or the World Bank. Subsidies to the industry and to farmers have imposed heavy burdens on the development budgets of most countries. In some cases countries were saddled with inefficient or obsolete technology. During the last decade and a half major efforts have been made to modernize the technology and rationalize prices. The contrast between Korea and Pakistan in this effort is quite instructive.

The Fertilizer Industry in Korea[3]

From 1945 into the 1960s, U.S. assistance was the major funding source for the import of current inputs used in farming such as pesticides, fertilizers, and new seed varieties. Throughout the 1950s and into the early 1960s the US/AID financed between two-thirds and three-fourths of all nitrogen fertilizer imports and an even higher percentage of phosphorus and potassium components--and almost all of the fertilizer used by Korean farmers during this period was imported.

Beginning in the late 1960s, five large fertilizer plants were constructed. Three were operated by the public sector (Korean Government Chemical Company) and two by the private sector. The public sector plants were constructed with US/AID loans as a joint venture with U.S. firms. The two private plants received loan guarantees in order to attract private investment. Initially the industry was criticized as relatively inefficient. However, operating ratios improved rapidly. Even more importantly, the new fertilizer industry became a source of trained personnel who later played an important role in the development of the Korean petrochemical industry. By the late 1960's Korea became a net exporter of nitrogen fertilizer. US/AID assistance for fertilizer imports terminated after 1969.

Efforts to develop the fertilizer production and distribution system was not without problems. During the 1950s and well into the 1960s, the government priced fertilizer well below the open market price, which made distribution through the free market impossible. During this time, fertilizer was rationed and black market prices often were two to three times the official price level. Efforts by the US/AID during the 1960s to encourage the privatization of fertilizer distribution met with little response. Marketing reforms during the 1970s brought prices closer to market levels. The efficiency of the distribution system increased and the

[3]. The material in this section draws primarily on Ban, Moon, and Perkins (1980); Ruttan and Krueger (1986); Krueger, Michalopoulos and Ruttan.

black market was largely eliminated.

The Fertilizer Industry in Pakistan[4]

The World Bank has played a major role in the development of the fertilizer industry in Pakistan. Beginning in 1969 the Bank/IDA has helped finance four of the eight fertilizer producers in Pakistan. These producers, two public and two private, account for about two-thirds of the output of nitrogen fertilizer and one-fourth of the output of phosphatic fertilizer. Three of the other four producers, including the only large unit, are also public.

In the mid 1960s, discussion between the Bank and the Government of Pakistan led to agreement that the private sector would play the lead role in fertilizer production. The first project selected was a joint venture between the local Dawood Industrial Group and Hercules Chemical (U.S.). Subsequent political and economic crises led to a change in policy. The second fertilizer loan was to the Pakarab facility at Multan which was jointly owned by the Pakistan Government and the Abu Dhabi National Oil Company. The third fertilizer loan went to the Fauji Foundation, a charitable trust for military personnel and the forth, in 1982, was for expansion and improvements in the Multan and several other facilities. The Bank also helped fund a technical training center to educate skilled operating staff. By the mid-1980s, the fertilizer sector was operating at near full capacity and supplied all of Pakistan's needs for nitrogenous fertilizer.

Fertilizer price policy has, however, represented a continuous concern to the Bank. The problem has been described as follows:

> "The prices of both the inputs and the outputs of the fertilizer industry are regulated. On the output side, the price received by each factory is different and is adjusted through a system of taxes and

[4]. The material in this section draws on Diwan and Hamid (1985), Burki (1986) and World Bank (1986).

subsidies. The prices for the products of each factory are fixed to provide a 15 or 20 percent after tax return on equity, calculated at a negotiated level of capacity utilization. This whole procedure is extremely cumbersome and deters both foreign and local private investment from going into the fertilizer industry. . . . It is clear that the present system discourages new investment." (Diwan and Hamid)

The system of pricing fertilizer has the effect of taxing the efficient facilities in order to subsidize the inefficient facilities. The prices paid by farmers are heavily subsidized. During much of the 1970s and early 1980s nitrogen fertilizer prices averaged around 30 percent below border prices and phosphate fertilizers averaged 50 percent below border prices. In the mid-1980s, as a result of depressed world prices, border prices of nitrogen fell to near domestic prices. Prices of phosphate fertilizers remained well below border prices. During the Fifth Plan Period (1978-83), the fertilizer subsidy amounted to 58 percent of the development budget for the agricultural sector.

The Bank and other donors have been encouraging the GOP to rationalize fertilizer pricing at least since the 1970s. Much of the dialogue has centered on the rather archaic issue of how to calculate subsidies. There has been some reduction in subsidies and a general agreement that fertilizer should be priced at or near border prices. But while there is increasing agreement with the principle of getting prices "right" the concern on the Pakistan side has been how to set them right. Almost no Pakistan economist believes that the market will establish the "right" prices.

2.3.2 Seed

Asian governments have been deeply involved in the development of the commercial seed industries. The R&D which developed fertilizer responsive rice and wheat created a large shift in demand for improved seed in South and Southeast Asia. This pushed up prices of improved seed to which the private sector responded but not before high seed prices and sales of low quality seed by some firms induced a political response.

In South Asia that response took the form of a government seed supply corporations or input supply corporations. Before the Green Revolution India and Pakistan produced a limited amount of seed on farms of state departments of agriculture. The Government of India encouraged private seed firms by providing them with foundation seed, technical assistance on seed production and processing, subsidized processing equipment and high prices for quality seed. The government also established a seed certification program to ensure that both government and private seed met certain standards of performance. When the demand for HYV wheat and rice expanded rapidly in the late 1960s and early 1970s India and Pakistan established government owned seed supply corporations.

Government intervention was different in the Southeast Asia, with the exception of Indonesia which produced and distributed seed through the BIMAS input supply organization. In the Philippines and Thailand the Departments of Agriculture provided improved seeds of HYV rice. The governments also assisted small private companies in both countries. During the Marcos regime the Philippine government also promoted a private corporation which had many government connections which provided many agricultural inputs including seed. However, neither Thailand nor the Philippines established large government corporations to produce and distribute seeds like the Indian National Seed Corporations.

To understand what has happened to these government efforts recently, it is necessary to discuss briefly some technical determinants of demand for improved seeds over time. Demand for commercial seed of HYVs of self pollinated crops like wheat and rice followed the path shown in Figure 1a. Demand for commercial seed grew rapidly as farmers learned about the yield gains from HYVs. Farmers soon start to produce and store HYV seed and so farmer's demand for commercial seed drops unless better HYVs are introduced.

Figure 1a Demand for Commercial HYV Rice and Wheat Seed

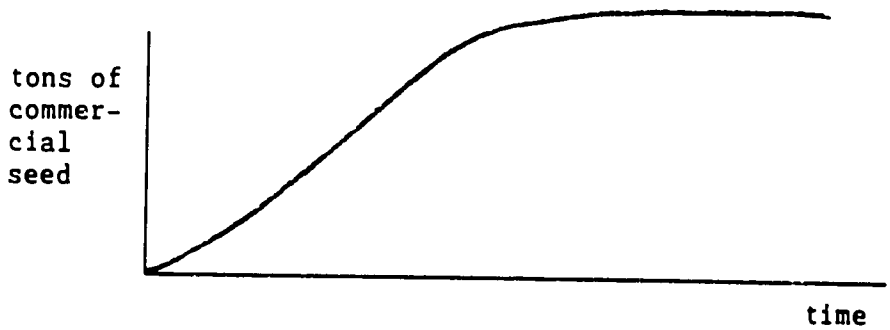

Figure 1b. HYVs of Hybrid Corn, Sorghum and Pearl Millet

The demand for hybrid HYVs of corn, sorghum and pearl millet has a similar pattern of rapidly increasing demand in the initial period. However, farmers can not use the grain they produced as seed in the following year and get yields as high as new hybrids. Therefore to obtain high yields farmers must buy new seed each year. HYVs of a crop like soybeans which is not a hybrid but is difficult for farmers to preserve would have the same initial adoption path as the other HYVs, but demand would level somewhere in between the other two patterns.

In the 1970s when Asian research was no longer able to produce new rice and wheat HYVs which were greatly superior to the previous varieties, the demand for commercial seeds went down because farmers could produce their own. In India corporations found themselves with excess seed processing capacity, excess stocks of seed and falling in debt.

Recently much of the new crop technology has been in crops like corn, sorghum, pearl millet and sunflowers which are naturally cross pollinated.

As commercial F1 hybrids of these crops were developed for the tropics, both government corporations and large private corporations started producing improved seed of these crops. Prices of hybrids are higher and the quantity demanded does not fall off because the farmer has to buy new seed each year if he wishes to produce the maximum yields. Government corporations are attracted by the prices and quantities demanded and they frequently have excess capacity and subsidies.

The private sector also is attracted by the prices and quantities. Firms can sometimes buy excess government capacity, particularly human capital, as it expands. Firms are able to compete with the government through better quality control, lower prices and superior varieties. If the economic "playing field" is fairly even, the private sector usually seems to push the public sector out of hybrid seed production. The government gets tired of subsidizing the public corporation. The private sector proves that it can do the job and starts lobbying to reduce government competition. Unfortunately, during the transition period governments can waste a lot of money keeping redundant government seed production programs going.

2.3.3 Other Inputs

The pattern of government intervention in pesticides is a variation of the fertilizer story. At first they were imported by governments with the assistance of foreign aid and distributed by the government at highly subsidized prices. Governments then tried to encourage local formulation of the pesticides and large countries like India and Indonesia tried to force companies to produce the active ingredients locally by restricting inports. Unlike fertilizers Asian governments are not heavily into the business of pesticide production, although the Indian and Indonesia governments produce some pesticides. Since 1980 government supply corporations have generally withdrawn from pesticide distribution. At the same time government environmental and safety regulation of the industry is growing.

3. Impact of Past Technology Policies on Agricultural Innovation

3.1 Public sector R&D and Extension

Local agricultural research has been an important source of new technology because agricultural technology can rarely be transferred directly from one region to another. It almost always has to be adapted to local climatic, soil and market conditions by local research.

Table 6 lists rates of return from past studies of Asian R&D and extension. Rates of return to agricultural research have been very high. Studies using the consumer surplus approach estimate rates of return to national research of about 20 to 40 percent. They are subject to the problem of selectivity bias because the studies are usually conducted on successful crops. More recent studies using the metaproduction function or profit function approach are less subject to selectivity bias because these usually cover the R&D costs and benefits from the entire crops sector or agricultural sector. The rates of return from these studies are even higher than those calculated from the consumer surplus approach.

Recent studies by Evenson have estimated returns to different levels of public research. Using a data set of 10 crops[5] in 24 developing countries[6] for the period from 1972 to 1979 to estimate the impact of national research systems and the international centers. He found that CG research has a significant positive impact on the production of all the crops except sweet potatoes. National research investment was highly productive in all commodity groups in Asia. He found rates of return to research by Asian NARS of 50 percent for rice and wheat research and over 80 percent for maize, millet and sorghum research. He also calculated separate returns to CG research in Asia and found returns of over 80 percent for wheat and rice

[5] Maize, millet, sorghum, rice, wheat, beans, cassava, groundnut, potatoes and sweet potatoes.

[6] Sri Lanka, Indian Taiwan, Pakistan, Indonesia, Thailand, Philippines, Korea, Malaysia, Turkey.

and 68 percent for staples like potatoes and cassava.

Evenson's studies of India (Evenson 1988) and Philippines find that national research systems are productive even after controlling for HYVs that were produced jointly with the IARCs. In the Philippines where there is data on both regional and national research the returns from national and regional research in provinces were both over 70 percent (Evenson 1986).

The CGIAR Impact Study (Anderson,et.al.1987) examined the impact of the international centers of the CGIAR on crop production and agricultural productivity. The final report emphasized the collaborative nature of the CG and national agricultural research systems and calculated the impact of this joint effort on food production in developing countries. Table 7 shows the percentage of total wheat and rice area under center-related varieties[7] in Asia and North Africa. These varieties resulted in an additional 50 million tons of food world-wide (World Bank 1985) of which 25 to 30 million tons were produced in the Asia. Table 7 also contains data on improved open pollinated varieties (OPVs) and hybrids of maize. Many of the OPVs are related to International Maize and Wheat Improvement Center (CIMMYT) or earlier Rockefeller Foundation material as are the hybrids in the Philippines, Thailand and Indonesia. About half the hybrids in India were developed by public R & D working with the Rockefeller Foundation in the 1950's and 1960's and half are hybrids developed more recently by the private sector. Only one study (Boyce and Evenson 1975) has attempted to measure the relative impact of applied vs. more basic R&D in LDCs. It found that "science-related" research generated economic returns that were four times larger than the "technology-oriented" research.

Many Asian policy makers continue to ask the question: Are these high returns simply a product of the Green Revolution in wheat and rice or is there really a high return to current research by public sector R&D?

[7]. Center-related means varieties that were developed at the centers and varieties developed in the NABS that germplasm or lines from the centers in their ancestry.

Evenson (1988) shows that the impact of the CG and the national research systems was not confined to wheat and rice. A study still underway at Yale suggests that public R&D has been productive since the Green Revolution in wheat and rice. The preliminary results are that productivity grew more rapidly in the period 1974 to 1983 than it did during the Green Revolution period 1964 to 1974.

The few studies that include extension indicate that it also has a positive returns. These returns are generally about 15 percent or above. The selectivity problem is greater for returns to extension studies than for research studies. A number of studies found insignificant or negative impacts and so rates of return were not calculated. More recent studies, which are methodologically stronger, have found that extension does have a positive and significant impact on profits (Birkhaeuser, Evenson and Feder 1988).

Public research on the basic grains has had a generally favorable impact on income distribution. Consumers have gained most of the benefits from modern varieties through lower prices of food. Since purchases of basic grains make up a large share of the income of the poor, they benefit much more than the rich who spend little on grain. The only places where local research may not have reduced prices are the North African countries that import much of their food grain. Increases in local production would have little impact on prices which are determined in the world market.

Agricultural laborers are affected through changes in their wages and in the prices of staple foods. The consensus of economists that have looked at the question is that the effect of high yielding varieties has been to increase the demand for labor (Lipton & Longhurst 1986). This has not shown up as higher wages in most areas because the supply of labor has grown more rapidly than demand for labor.

The impact of HYVs and local public R&D on the demand for labor have been estimated directly in several studies using cost functions or profit functions. In north India HYVs shifted demand for labor to the left while

local research had a negative effect (Evenson 1988). In Thailand the impact local public R&D was positive but insignificant (Evenson and Setboonsarng). In the Philippines the impact of HYVs on labor demand was positive but regional research and national research both had negative impacts (Evenson 1986).

The people who are probably most negatively affected are the farmers in regions which are not suited to new technology. Increased productivity of food grains in favored areas reduces the demand for the food grains grown in unfavored conditions and pushes the price of food grains down. They do not have any new technology to reduce their costs of production and so their net income and profits are reduced. These problems are mitigated somewhat by new technology, as the examples of hybrid pearl millet and sorghum illustrate. Agricultural laborers will go to areas which can adopt new technology, and they will not be affected as adversely as owners of land. This has happened in the Punjab which has absorbed much labor from U.P. and Bihar.

3.2 Impact of Policy on Private R&D and Technology Transfer

Breakthroughs by public research and recent policy changes have had a stimulated private research in Asia. Thailand and the Philippines provide examples of the way public R&D can stimulate private R&D. In the Philippines firms started trying to grow hybrid corn seed in the 1950s but were unsuccessful because the hybrids were susceptible to downy mildew. In Thailand the public sector worked on hybrids without much success because of downy mildew. The discovery of downy mildew resistant lines in Mindanao and their identification by the Kasetsart U./Rockefeller Foundation/CIMMYT program in the mid 1970s opened the way for private corn breeding. In the Philippines four companies established large corn breeding programs in the late 1970s. In Thailand five companies started corn breeding research between 1978 and 1981 and seven more companies established breeding programs in 1984 and 1985[8].

[8]. Personal interviews with Thai seed companies in 1985.

The pearl millet and sorghum breeding programs of Indian seed companies are also dependent on public sector research. A recent survey of 24 private companies in India revealed that all of the private pearl millet hybrids that were being sold commercially in 1987 were based on germplasm or inbred lines that the companies had acquired from ICRISAT (Pray et.al.). All of the public and private sector sorghum hybrids use one popular male sterile line which was developed by the Indian government research system.

The other policies that clearly have had some impact on private research are restrictions on private research. Since the Pakistan lifted its restrictions on private sector plant breeding, at least two local companies and three foreign companies have established plant breeding programs there. Since 1987 when India dropped its restrictions on seed production by large companies and foreign owned companies, many companies have entered the industry. In a 1987 survey of seed companies large companies such as Hindustan Lever (subsidiary of Unilever), E.I.D.Parry, Coromandal Indag, NOCIL and Sakthi Sugars had research programs and were producing seed. Since then it is reported that Sandoz, Cargill, Indian Tobacco Company (with Pacific Seeds which is owned by Continental Grains), and two smaller US companies have established joint ventures with Indian companies (Chengappa).

Policies that influence the level of private research also influence productivity of agriculture. Several recent studies on private sector research in LDCs have established the link between private research and productivity. Research by seed companies in India produced pearl millet hybrids which yield 25 to 30 percent more than earlier hybrids and are resistant to downy mildew. These hybrids have been adopted on almost 900,000 hectares(Pray et al). There is also evidence of the impact of MNC R&D on productivity. Using data for major maize growing LDCs Echeverria finds a positive statistical relationship between multinational seed company's R&D and maize yield per acre (Echeverria 1988). The Philippines, Thailand, India, and Pakistan were included in his sample.

The revolution in poultry production throughout the Asia has been based on imported technology. Growth in poultry production in Asian LDCs excluding China was 6.2 percent annually between 1961 and 1985. During that same period poultry production grew by 8.4 percent annually in the Near East/North Africa. This compares with 2.5 percent growth in beef production in both regions (FAO). The technology behind this revolution was US and European breeds of poultry, pharmaceutical, feeds and confinement management. The feeds, management practices and buildings have been modified to fit the available raw materials and climate. The other inputs have not been adapted with the exceptions of the breeds used in India which were developed in R&D by joint ventures.

Commercial swine production is taking off in Southeast Asia. Like poultry, it also is largely based on imported technology which has been adapted to local conditions by private companies.

The key technology in the expansion of cassava in Thailand was the pelletization process which cut transportation costs and made cassava acceptable to the European market. This technology was introduced by Cargill. The rapid expansion of banana production in the Philippines is based on production technology which was developed in Central America by United Fruit and adapted to conditions in the Philippines. Other examples of private companies importing and adapting foreign technology are commercial tomato production in the Philippines, pineapple production in the Philippines and Thailand, and rubber and oil palm technology the Philippines, Thailand and Indonesia.

No quantitative studies exist of the impact of private research and technology transfer on income distribution in Asia. To the extent that private technology lowers the price of basic foods, it improves the position of the poor. Private plant breeding which produces higher yielding hybrids of pearl millet, sorghum and maize would lower prices unless the research only improves the crops as livestock feed.

Private research and extension does have one distinct income

distribution difference from public R&D and extension. The people who benefit from private R&D usually have to pay for it through higher prices of the inputs in which improved technology is embedded. In contrast if public research is financed from general tax revenue, the people who adopt the technology are paying only part of the cost of R&D the rest is being paid by all tax payers.

The impact of private R&D on the relative position of landowners and agricultural labor depends on the technology. Herbicides, improved tractors, and threshers are generally labor-displacing while hybrid seeds and fertilizer are usually labor-using. If input markets are not too distorted, the adoption of labor saving technologies would take place when wages are going up, and so there would not be major welfare losses to laborers.

3.3 Impact of Public Input Production, Distribution and Input Subsidies on Diffusion of Technology

The original justification for government intervention in agricultural input markets in most LDCs was to speed the spread of modern, more productive agriculture. Subsidies to farmers were supposed to speed diffusion by increasing the profitability of adoption by farmers. Government production was also supposed reduce input prices by shifting the supply curve of critical agricultural inputs downward.

Economic theory of the adoption of new agricultural technology shows that subsidies on the price of inputs which embody new technology can influence the speed at which farmers adopt new technology (Feder and Slade 1984 and Stoneman 1987). Unfortunately, there are few studies on the effect of lower prices on the diffusion of new technology. Empirical studies of adoption of agricultural technology have not included input prices as variables. There are no studies to our knowledge that really constructed the counterfactual diffusion path of new technology with minimal government intervention and compared its costs and benefits with the actual diffusion path. In the absence of such studies we only have

anecdotal evidence on the impact of these policies.

The seed industry seems to have benefitted from government interventions in the early years. Public seed production programs were the training grounds of future employees of the private sector. Technical training in keeping inbred lines pure and efficiently producing hybrids were also important. However, it appears from the experience of the Philippines that a large public seed corporation is not necessary to achieve rapid rates of adoption of new varieties of rice. Thus, our hypothesis is that some government training and investment may contribute during the early stages of development but large public sector seed corporation are not necessary.

Fertilizers present a different situation because of the size of investments required to build an efficient plant and the thinness of the international market for fertilizer. Thus, it may have been more important for governments to make the early investments in fertilizer production. Government production and subsidies may also have led to more rapid adoption of fertilizer. However, it seems equally clear that many governments expanded far beyond what was needed and this reduced private sector investment in fertilizer production.

4. Future Challenges to Technology Policy: Sustaining the Green Revolution

4.1 The Need for Increased Food Production and Improved Environment

Research on major food grains is still essential to LDC development despite the fact that many countries have reached self-sufficiency. FAO predicts that most Asian countries will stay above the self-sufficiency level in food grains through the 1990's (FAO 1987). Almost all of Asia's cultivable land is now in use and so increased food production must come from increased yield/ha. But yields of wheat and rice are not growing as fast as they were in the 1970s and there is concern that they their yield potential has reached a plateau (Herdt 1988). The only solution for the levelling out of yield of major grain crops is a breakthrough in biotechnology and such a breakthrough will require a large investment in

government research. Even if the danger of a yield plateau is exaggerated there is a need for research on major crops to ensure that their productivity keeps growing so that more of the poor can reach the minimum consumption levels. Research is also needed to find ways to make these crops less vulnerable to drought and other fluctuations in the weather and policies.

There is also a need for maintenance research to preserve the gains of the Green Revolution in the face of continually evolving pests and pathogens. The speed with which pathogens evolve is most dramatically illustrated by pearl millet in India (Jansen, 1988). Since public sector research on hybrid pearl millet started in the late 1950's, it has produced three series of hybrids. ICRISAT and the private sector have produced a fourth series. The first series was based on a male sterile line from Tifton, Georgia, called Tift 23 and released over the period 1965 to 1972. They covered over 20 percent of the pearl millet area in 1972-73 because of their high yield potential of 2500 kg/ha (compared to the 500 kg/ha average yield in farmers' fields). These cultivars became susceptible to downy mildew in the early 1970's. A second series of public hybrids were released in 1975. They were popular, but their resistance to downy mildew broke down within a few years. They were replaced by public hybrids BJ-104 and BK-560. Their resistance broke down in 1983-84, and they were replaced by the fourth generation of hybrids: the private and public hybrids based on ICRISAT lines and ICRISAT variety WC-C75.

In the absence of the maintenance research which produced the new downy mildew resistant hybrids and varieties, pearl millet production might well be back at the 3.86 million ton level of 1961-65 rather than the current (1983-87) level of 5.4 million tons (India 1988).

Concerns about the impact of deforestation, erosion, and salinity in irrigated areas have already become sufficiently serious problems to attract some NARS and international research resources. These problems will become more serious in the 1990's and the need for research on these topics will undoubtedly grow. Agricultural and non-agricultural pollution is not a big issue now but more tragedies like Bhopal, poisoning from pesticides

on vegetables and US and European barges dumping hazardous wastes in LDCs will increase demand for research on these issues in the 1990's.

4.2 Technological Opportunities

The NARS and IARC research that produced the original HYVs also created opportunities for high pay-off local research to adapt HYVs to replace traditional varieties. Dalrymple(1986) estimates that about 79 percent of the wheat and 45 percent of the rice in Asia are planted to HYVs. Table 3 shows that there is considerable variation between countries. There is much more scope for improved maize (lower panel Table 3). In most countries the area planted to high yielding sorghum, millets, pulses or oilseeds is very small.

Robert Herdt (1988) has recently evaluated the potential for further spread of HYVs of wheat, rice and maize. He felt there was little opportunity for further spread of wheat and rice, but that there were some opportunities in maize - particularly in Africa. Others argue that there are still opportunities to adapt rice HYVs to new areas[9]. Sorghum, pearl millet and sunflower probably offer good opportunities for the spread of HYVs, since HYVs are starting to spread in some countries as noted above.

In regions which are already covered by modern varieties there are still possibilities for improving yields through R&D. Modern varieties now cover about 90 percent of wheat acreage in Asia. In Pakistan and Mexico since the Green Revolution, plant breeders have been able to maintain yield gains in new varieties of one percent a year in irrigated areas (Byerlee, 1987). CIMMYT staff feel that opportunities are even greater from research to improve management:

> There are, however, considerable opportunities to increase yields and productivity in irrigated areas through changes in other cultural practices such as reduced and zero tillage, better stand establishment , more efficiency in fertilizer use, identification of soil micronutrient

[9]. Robert Evenson at the HIID/USAID meeting in Washington, September, 1988, argued that Herdt was too pessimistic about rice.

deficiencies, control of weeds and pests, crop rotation to manage soils and reduce conflicts with wheat planting, and more efficient management of irrigation water. Likewise, in dryland areas, improvements in productivity usually rest on better tillage to conserve moisture, weed control, and efficient use of fertilizer...To realize these gains, a strong crop management research program, linked with effective extension and input supply systems and combined with skilled farmers and a conducive price policy environment is often required. (Byerlee 1987).

Developments in biotechnology have opened up opportunities for developing new technology through more basic research combined with traditional plant breeding. Advances through biotechnology require knowledge about the genetic characteristics of the crop. Rice is the only tropical crop in which there is a major program to generate this knowledge. Research programs in the US and Europe study the genetics of crops like maize that are important in temperate climates. Thus, it is possible that research in the Asia could build on basic knowledge of rice and maize. In other important crops much basic research still needs to be done.

Even in rice, which is probably the most advanced in terms of genetic engineering, there will be little impact of biotechnology on agricultural production in LDCs in the next five to ten years (Herdt 1988). The impact will be primarily on stability of rice yield. It will be achieved by reducing the susceptibility of rice varieties to disease and insects. Advances that actually raise the yield potential of rice will not come until the next century (Herdt 1988). Possibilities exist for improving some other staple foods like cassava and oilseeds before rice???

Despite these somewhat pessimistic predictions about the impact of biotechnology on major field crops, it appears that research on improving stability and eventually increasing yield potential will have high economic rates of return. In addition, biotechnology research may have a more rapid impact on tree and bush crops like oil palm, rubber, and tea. It may also reduce some of the environmental problems like deforestation through rapid propagation of improved trees and reduce environmental problems like pesticides by improving the pest resistant characteristics of plants.

The trends in private sources of technology in the U.S. and Europe which could the basis of applied and adaptive research in Asia vary from industry to industry. The growth of aggregate private R&D on agriculture by the input industry in the US is slowing down (Pray, Neumeyer and Upadhyaya,1988). This is particularly dramatic in farm machinery where expenditure has declined since 1980. Agricultural chemicals R&D growth has just kept up with inflation, but the number of new chemicals produced from a dollar of research has declined. Biotechnology is one area where there is an increase: probably at the expense of traditional agricultural chemicals research. There is no recent industry level data available for the seed industry but two of the leading research firms, Pioneer and DeKalb, increased their research by 9 percent between 1986 and 1987 ("R&D Scoreboard",1988).

These trends imply that there will be less R&D opportunities available in agricultural machinery and agricultural chemicals but more in seeds and biotechnology products (veterinary pharmaceutical, biological pesticides, improved plant and animal varieties).

There are conflicting trends in technological opportunities in the plantation industry. Advances in tissue culture can greatly increase the efficiency of breeding tree crops - especially oil palm. However, the productivity of the Malaysian Rubber Research Institute, which was an important source of technology for all of Southeast Asia, continues to deteriorate. In addition the Malaysians are attempting, so far unsuccessfully, to prevent the export of planting material of plantation crops. The future of banana technology is also uncertain. United Fruit turned their banana research facility in Honduras over to a research foundation of unproven capacity. Public sector research on banana has been strengthened by the develop of an international network for bananas called INIBAP.

5. Lessons from Past and Future Technology Policies for Agriculture

The lessons are quite clear. Public R&D and extension in Asia has been a

very productive investment. Private R&D has probably produced high financial and social rates of return. The one study the measure the distribution of benefits from private research suggests that most of them go to farmers rather than input supply firms. Finally, governments can play an important role in the early years of modern input production. Unfortunately, they usually build capacity beyond what is needed and continue to intervene in markets through subsidies long after the justification in terms of efficiency for these subsidies was gone.

This final section proposes three technology policies which would help LDCs meet their food and cash crop production goals: (1) Strengthen public sector R&D through better articulation of researchers with farmer and agribusiness and by more resources for strategic and basic research; (2) Improve the legal and institutional infrastructure for private research and technology transfer; and (3) Reduce public intervention in the supply of high technology inputs.

5.1 Strengthening Public Agricultural Research

Private sector R&D will not provide sufficient technology to meet the challenges in section 4.1 The private sector is too small, and in most Asian countries there are still insufficient incentives to induce optimal levels of R&D in the future.

It is not clear that public sector R&D will receive sufficient support from Asian governments to meet future challenges. There will be increasing need for applied maintenance research, for more basic research and better adaptive research. International agricultural research centers in new areas may be needed. There is evidence of underinvestment in both national and international research. However, few Asian countries are increasing their expenditures on public research. Therefore it appears that support from USAID, the World Bank and other donors is still needed.

We have listed below two areas where national research programs can be strengthened.

5.1.1 Improving Articulation between R&D and Users

National Agricultural Research Systems have developed effective applied research programs. "Most Asian countries now have reasonably well-established plant breeding programs for major food crops capable of sustaining a continuing flow of improved varieties" (Byerlee, 1987). In contrast, adaptive research is quite weak. According to a recent World Bank review adaptive research is generally "the weakest, most neglected and most confused aspect of national research systems" (The World Bank, 1985).

The most effective government research programs have well developed systems of articulation between scientists and users of technology. Punjab Agricultural University in India, the Academy for Rural Development in Comilla, Bangladesh and the Philippine Tobacco Research and Training Center are (or were) public sector institutions with very effective research programs. In the Punjab, farmers control the state legislature which provides most of the money for research in the state. This makes the Punjab Agricultural University very responsive to farmers' needs. The Comilla Academy and the Philippine Tobacco Center have close ties with organized farmers groups which makes them responsive to farmers' needs.

An important weakness of many government research systems is a weak public extension system which is supposed to be an important means of articulation between farmers and scientists. The training and visit system has strengthened some extension systems but others remain quite weak.

The most important element in strengthening adaptive research is greater participation in R&D decision making by farmers and private companies. Farmers and agribusinesses can provide scientists with information on farmers' needs, provide incentives for effective research and provide financial and political support to public research. Governments can encourage the development of institutions for articulation by giving existing farmers' organizations control over research resources, encouraging the organization of farmers' groups interested in technology,

and strengthening the private sector.

5.1.2 Strategic and Basic Research in Biotechnology and the Environment

To raise the yield potential of major food crops of Asia during the next two decades Asia will have to invest in new biotechnology. Countries can either develop new technology themselves or buy it, but in either case they will need scientists who are well trained in biotechnology. The more advanced research systems of Asia such as India, Thailand, Egypt, the Philippines and Pakistan, are already doing some new biotechnology research. They should continue to expand their research capacity in this area. This will require investments in least three areas: training scientists; buildings and equipment; and networking and scientific communication. A fourth area which might have a high payoff is joint research between DC and Asian institutions.

PhD level training in the sciences needs to be strengthened in some of the universities in Asia. Even where strong programs exist there is a need for money to finance a continuing stream of students who go abroad for a Ph.D or scientists who go for post-doctoral research and training. Buildings and equipment for institutes on the environment or biotechnology in agriculture can be productive investments in some countries where such facilities do not exist.

Communication is the key to encouraging scientists to be productive. Communications with other scientists is particularly important as countries move into strategic and basic research. The problem is that conferences and good libraries are expensive and require foreign exchange. To many bureaucrats they seem like luxuries. When there is a budget cut or foreign exchange shortage, they are among the first things governments cut. Therefore, funding libraries and conferences is a role that AID could usefully play.

Joint research between scientists in DCs and LDCs on topics of common interest is another way of stimulating better research. Truly joint

research is a very personal thing that arises out of contacts developed at graduate school, post-doctoral study, conferences and correspondence based on publications. As Asian research institutions develop research programs at the cutting edge of their disciplines and communication with other scientists grows, the possibility of productive joint research grows.

One possible model for organizing networks on strategic research like biotechnology, resource management and the environment is a CGIAR for basic biological research (Ruttan, 1987). The danger of a basic CG and the danger in the new UNIDO biotechnology centers is that it would isolate the more basic scientists from the applied scientists. Basic scientists might then work on questions which are not important to applied science or to farmers. A related model is to upgrade the strategic research of the expanded CGIAR. This model would keep the applied and strategic scientists from being separated.

Another possible model is the Rockefeller Foundation agricultural program or Agricultural Development Council in which a network of developed country scientists conduct research and teach in Asian universities and research institutions for a period of three or more years. They are colleagues of local scientists. They identify promising students for study abroad and provide resources for small research projects, journals and books.

5.2 Strengthening Legal and Institutional Infrastructure for Private Innovation and Diffusion

The second most important technology policy after strengthening public research is to strengthen the legal and institutional infrastructure for private sector research. The major problem with trying to encourage private research is that there is no certain formula for strengthening private research.

Privatization of input production and distribution and the removal of legal and administrative barriers to private R&D can be very useful.

Restrictions on private research by the seed industry in Pakistan and India were an important constraints to private R&D until they were removed a few years ago. Similar constraints may exist elsewhere.

Government and CGIAR research can be a very effective policy instrument to influence private research. Public research influences private research through increasing technological opportunity as the examples of maize in Southeast Asia and pearl millet in India show.

Some other policies to encourage research have been tried in Asia but there is little evidence that they have been effective. Government subsidies for research in Asia have been very limited so far and appear to have little impact. The efficacy of patents in encouraging technology transfer is very much in doubt, but it does appear that patents can be designed to stimulate more private research. Other factors like firm size are positively associated with R&D and R&D intensity, but it seems unlikely that AID can do much more than indicate the problems of industrial policies that greatly restrict the size of firms.

More research of the policies that influence firms' decisions to invest in R&D and information dissemination is needed. There are very few empirical studies of the impact of any of the major policy instruments. A number of policies are being tried in Asia. The impact of these policies on R&D and productivity needs to be measured so that future policy can be more effective.

5.3 Reduce the Size of Public Input Supply.

There are surprising few empirical studies on the efficiency and income distribution consequences of reducing public sector involvement in input supply. It is a topic that needs much more study.

Anecdotal evidence and case studies suggest that particularly in South Asia the government share of fertilizer and seed supply is much larger than it needs to be and as a consequence taxpayers are subsidizing inefficient

production. This not only places a severe strain on government budgets but also reduces the incentive of private firms to do research and spread technology.

6. Lessons for Industrial Technology Policy

Public sector research can be a high payoff investment. It has produced useful technology for farmers. It has also produced useful pre-technology that seed companies and other input supply companies have able to develop into profitable technologies.

The most efficient public research systems are linked closely with users of technology. Government research programs like those of the Punjab Agricultural University in India are linked closely to farmers through the political system which gives medium sized farmers most of the power in the state. Farmers expect practical results and force researchers to search for answers to their problems. Agricultural researchers at government institutions in countries where farmers have little political power tend to be more concerned with academic questions which may have little relevance to farmers.

International centers for topics other than agriculture may be an effective way to increase the level of international scientific and financial resources focused on Asian development problems and increase the productivity of local research. Some of the most productive public sector research has been adapting technology from international agricultural research centers. The green revolution in wheat and rice, growth in production of sorghum and pearl millet in India and growth maize production in Southeast Asia have been partially the result of collaborative research between national research systems and international centers.

Private sector research can be encouraged by pre-technology R&D by the government and strong universities that produce local scientists and engineers. It is also important to ensure that there are no barriers to

private research.

TABLE 1. TRENDS IN R&D EXPENDITURES

		1959	1971	1980	1980	1984
		(000 1980 US$s)			(millions constant local currency)	
Indonesia	GOI	564	8688	33200	41	29
	External				16	33
	Total				57	62
Philippines		2781	5499	9533	82950	47608
Thailand		1552	11740	21600	1004	1654
India	State				4605	10398
	Federal				9594	12783
	Total	24825	66108	120167	14199	23181
Bangladesh		-	2348	27613	229	334
Sri Lanka		3104	6340	5057		
Nepal		906	2163	2634		
Pakistan		2256	4696	29899		
S.Korea		2538	23381	29012		
Taiwan		1975	5400	14000		

Sources: 1959-1980; Judd et al (1988)
1980-84; Indonesia; Nestel (1985)
Philippines; Gomez (1986)
Thailand; Rungruang (1986)
India; India (1984)
Bangladesh; ISNAR.

Table 2 Public Sector Research and Extension in Asia as a Percent of Value of Agricultural Product

	Ag. Research Expenditures			Ag. Extension Expenditures		
	1959	1970	1980	1959	1970	1980
South Asia	.12	.19	.43	.20	.23	.20
Southeast Asia	.10	.28	.52	.24	.37	.36
East Asia	.69	2.01	2.44	.19	.67	.85
China	.09	.68	.56	na	na	na

Source: Judd, Evenson, Boyce 1988.

TABLE 3. RESEARCH EXPENDITURE BY TYPE OF INSTITUTION, 1985.
(Millions of U.S.$s)

	India	Philippines	Thailand	Indonesia	Malaysia	Pakistan	Bangladesh
Private Research	16.7	4.4	4.4	2.0	10.5	.8	.1
Government Ag.[a] R&D	248.0	7.0	78.6	62.0	44.4	56.2	8.0
International[b] Centers	22.1	22.6	-	-	-	-	-

[a] These numbers are not consistent on their inclusion or exclusion of capital expenditures. The Philippines does not include capital expenditures, Pakistan does, and some of the others are unclear.
[b] Only part of this research is specifically on Indian or Philippine problems.

Sources: Private Sector; Survey.
Public Sector; India, 1983; India (1984)
Philippines, 1984; Sardido.
Thailand, 1984; Rungruang Isarangkura (1986)
Indonesia, 1984; Nestel (1985)
Malaysia, 1980; Oram.
Pakistan, 1984; Pakistan (1986)
Bangladesh, 1985; ISNAR.

Table 4. Private and Public R&D by Commodity in the Philippines. (millions of pesos)

	Private (1985)	Public (1984)
Rice	20	15
Corn	30	6
Sugarcane	3	29
Coconut	2	11
Tobacco	2	19
Fruits and Veg	19	3
Other Crops	3	27*
Livestock	5	17

Source: Pray, 1987.
* Half of this is root crop research.

TABLE 5

Availability of Patent/Variety Protection for "AABC" Inventions in Selected Developing Countries

	Mechanical/ Electrical		Chemical				Biogenic						Other	
Country	Plough I Major	Plough II Minor	Fertilizer	Insecticide	Herbicide	Chemical Vaccine	Soybean	Corn Hybrid	Rose	Beef Cattle	Nitrogen-Fixing Bacteria	Live Virus Vaccine	Computer Program	Accounting System
U.S.A.	yes	no	yes	yes	yes	yes	yes	no	yes	no	yes	yes	no	no
Asia														
Bangladesh 1,2	no	no	no	no	no	no	no*	no*	no*	no*	?	?	no*	no*
India	no*	no	no**	no**	no**	no**	no*	no*	no*	no*	no*	no*	no	no
Indonesia 2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Korea (South)	yes	yes	no**	no**	no**	no*	no*	no*	yes	no*	yes	no*	no	no
Malaysia 1,2	yes	no	yes	yes	yes	yes	no*	no*	no*	no*	no	no	no*	no*
Nepal 4	yes	no	yes	yes	yes	yes	see footnote						no	no
Pakistan 3	yes	no	yes	yes	yes	yes	no*	no*	no*	no*	yes	yes	yes	no**
Philippines 5	yes	yes	yes?	yes?	yes?	no	no	no	no	no	yes	yes	no	no
Singapore 1,3	yes	no	yes	yes	yes	yes	no*	no*	no*	no*	no	no	no**	no**
Sri Lanka 3	yes	no	yes	yes	yes	yes	no*	no*	no*	no*	no	no	no	no**
Taiwan	yes	yes	no**	no**	no**	no**	no*	no*	no	no*	no	no*	no	no
Thailand	no*	no	yes	yes	yes	no**	no*	no*	no*	no*	no*	no*	no*	no

*This invention is specifically excluded from patent protection by national law.

**Although this chemical substance is specifically excluded from patent protection by national law, the process used to produce the substance is not excluded.

NOTES: This table summarizes the data that record the principal constituents of each country's patent laws.

1. British patent law is assumed to hold in this country, owing to the provisions in its laws. British patent applications (whether or not by British citizens) have priority. In practice, a prior British patent is routinely granted approval in this country at the applicant's request. We refer the reader to chapter 37 of the Patents Act of 1977 of Great Britain. The U.K. prohibits the patenting of microbial processes or products for use on humans or animals. Ghana independently prohibits patents on pharmaceutical and medical substances.
2. This country has no patent act of its own.
3. "Microbiological processes and the products of such processes" are patentable. Whether this protection extends to microorganisms *per se* is not known and will depend on the interpretations of the domestic courts. In the absence of specific indications to the contrary, we have assumed that the nitrogen-fixing bacteria and the live virus vaccine are not patentable under these circumstances.
4. A patent is granted to a foreign inventor if he has obtained a patent in his own country and any three other countries. Presumably, patentability standards in these countries apply.
5. Other than meeting public standards of health and morality, no other criteria for patentability are cited. In general, we take mechanical, chemical, and electrical inventions to be patentable, and others to be unpatentable. In the Philippines, U.S. law is assumed.

Source: Evenson, Evenson and Putnam 1987.

TABLE 6. RATES OF RETURN TO RESEARCH IN ASIA

Study	Country	Public Program	Period	Commodities	IRR
Consumer Producer Surplus Approach					
Pray 1978	Punjab	R&D+Ext	1906-56	Crops	34-44
	Punjab (Pakistan)	R&D+Ext	1948-73	Crops	23-37
Pee 1977	Malaysia	R&D	1932-73	Rubber	24
Pray 1980	Bangladesh	R&D	1961-77	Wheat,Rice	30-35
Nagy 1987	Pakistan	R&D	1967-81	Wheat	58
		R&D	1967-81	Maize	19
Pray and Ahmed 1987	Bangladesh	R&D	1948-81	Crops	35
Metaproduction Function					
Kahlon,Bal, Saxena&Jha 1977	India	R&D	1961-71?	Crops?	63
Evenson & Kislev 1975	India	Extension	Crops		15
Evenson??	Philippines	R&D	1966-75	Rice	75
Salmon 1987	Indonesia	R&D	1972-77	Rice	100+
Pray and Ahmed 1987	Bangladesh	R&D	1948-81	Crops	100+
Feder, Lau & Slade (1987)	Northwest India	Extension	1983	Wheat	(100+)[1]
Decomposition Studies					
Evenson & Jha 1973	India	R&D	1953-71	Crops	40
		Extension	1953-71	Crops	14
Evenson & Flores 1978	Asia-National	R&D	1950-65	Rice	32-39
	Asia-National	R&D	1966-75	Rice	73-78
	Asia-IARC	R&D	1966-75	Rice	74-108
Flores,Evenson & Hayami 1978	Tropics	R&D	1966-75	Rice	46-71
Nagy 1987	Pakistan	R&D	1959-79	Crops and	64.5

				Livestock	
Evenson 1987	10 Asian LDCs	IARC R&D	1972-79	Crops	80+
		National R&D	1972-79	Crops	50
		Extension	1972-79	Crops	80+
Profit Function Studies					
Evenson 1988	North India	R&D	1956-83	Crops	72
Evenson 1986	Philippines	National R&D	1948-84	Crops	70
		Regional R&D	1948-84	Crops	70
		Extension R&D	1948-84	Crops	

IRR = Internal Rate of Return

1. In their article they report that there was a 90% probability that the rate of return was over 15%. Birkhaeuser, Evenson and Feder report that if they had used conventional methods to calculate rates of return it would have been over 100%.

TABLE 7. HYV WHEAT, RICE AND MAIZE IN ASIA
(as % of total area of each crop)

	HYV WHEAT					
	1970	1975	1980	1982	1983	mid80s
Bangladesh	11	59	97	96	--	100
India	39	75	73	81	79	85
Nepal	49	84	89	85	90	87
Pakistan	50	69	83	91	--	85

	HYV RICE				
	1970	1975	1980	1982	1983
Bangladesh	5	15	21	25	--
Burma	4	8	43	51	49
India	15	32	45	48	54
Indonesia	13	43	63	65	72
Nepal	6	17	26	36	36
Pakistan	5	39	43	46	--
Philippines	51	66	75	79	--
Sri Lanka	12	54	74	91	--
Thailand	0	7	12	(1981)13	--

	MAIZE	
	IMPROVED 1985	HYBRID 1985
Burma	34	0
India	36	13
Indonesia	25	1
Pakistan	28	2
Philippines	26	1
Thailand	70	8

Sources: Wheat and Rice 1970-83; Dalrymple (1986).
Wheat mid-80s; unpublished estimates from CIMMYT.
Maize; CIMMYT (1987)

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