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Private Investment in Agricultural Research and International Technology Transfer in Asia

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Abstract

This study addresses the questions of future sources of technology for increasing food and agricultural production by considering the situation in Asia. This region of the world is particularly appropriate for studying these questions because of the dynamic changes in population and incomes. How much private research is there and what is it producing? Will the private sector compensate for declining public agricultural research investments in Asia? What can governments do to stimulate private research and protect farmers from harmful or defective technology? Agribusiness firm's R&D investments were evaluated in selected developing countries during 1996 and 1998 and compared with data from a similar study conducted in the mid-1980s. The largest amount of private research was in India where investment was about $55 million per year in the mid-1990s, followed by Thailand, Malaysia, and China. China's private R&D spending represents less than one one-hundredth of 1 percent of agricultural gross domestic product. In contrast, in Thailand and Malaysia, firms spent about 0.1 percent. From the mid-1980s to the mid-1990s, private sector R&D grew in real terms in the countries in our sample. However, at this rate, private research will not fill the gap needed to support rapid growth in demand for agricultural products. Foreign firms made an important contribution to private research in all of these countries. The most important policy that helped induce this growth was liberalization of industrial policy that allowed private and foreign firms to operate and expand in agricultural input industries. A second important policy was investments in public research. Patents and tax incentives seem to have had little effect so far, but could be important in the future.

Keywords: Agricultural research and development (R&D), private sector R&D, technology transfer, Asian R&D.

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About the Authors

Much of this work was done while Keith Fuglie was employed by the Economic Research Service and while Carl Pray was on sabbatical leave with the Economic Research Service.

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Executive Summary

Research Problem

A consensus has developed that technology will be required to provide the major source of growth in Asian agriculture in the 21st century. Public financing of agricultural research seems to be declining in developing countries. The question is whether private research and technology transfer will fill that gap. The answer to that question is important to U.S. farmers because Asia is now the most important market for U.S. agricultural exports and is likely to be much more important in the future.

This report presents an overview of trends in private research investment and a summary of findings from country case studies.

Research Methods and Sources of Data

The countries we studied are India, Pakistan, Thailand, Indonesia, Malaysia, the Philippines, and China. The first six were chosen because they had been the subject of an earlier study by Pray in the mid-1980s. China was added because of its size and importance.

We collected the data on research and development (R&D) through personal interviews at key firms and from government statistics. The authors visited each country and participated in the surveys, except in Pakistan where we commissioned Nagy and Ahmad to conduct the survey.

Stylized Facts about Private Agricultural Research in Asia

The largest amount of private research was in India where investment totaled about $55 million per year in the mid-1990s. The next largest amounts of private research expenditure were in Thailand, Malaysia, and China.

Relative to the size of its agricultural economy, investment in private research in China was particularly small—less than 0.01 percent of agricultural gross domestic product (GDP). In contrast, in Thailand and Malaysia, firms spent about 0.1 percent.

Between 1985-87 and 1995-98, private sector R&D grew in real terms in all countries in our sample. In India, Pakistan, Indonesia, and China, research funding more than doubled in 10 years. Even at this rate, however, private research will not fill the gap needed to support rapid growth in demand for agricultural products.

The agricultural chemical industry conducted the most private research, followed by the agricultural processing and plantation industries.

Foreign firms made an important contribution to private research in all of these countries. At one extreme is China in which almost all private research was by joint ventures between foreign and local firms. Malaysia is at the other extreme with little research by foreign firms. In Pakistan and India, foreign-owned firms conducted about a third of the research.

Causes of Patterns of Research Expenditure

Growth in Demand

There is a positive relationship between growth of private agricultural research and growth in demand for agriculture as measured by agricultural GDP. Research and production were growing at roughly the same rate from the mid-1980s to the mid-1990s in Thailand, Malaysia, and the Philippines. In India, Pakistan, Indonesia, and China, private research grew even more rapidly than agricultural production.

Impact of Growth in the International Supply of Technology

The slowdown in growth in demand for agricultural inputs in the United States, Europe, and Japan made Asian markets very attractive relative to U.S. firms. Foreign firms accounted for much of the growth in private research in Asia. They accounted for about half of all private research in these countries and were concentrated in the industries where private agricultural R&D has been growing most rapidly—chemicals, livestock, and seed.

Market Liberalization and Competition Policy

The major policy changes that stimulated more private research in Asia were eliminating public sector monopolies, reducing subsidies for public sector input firms, and allowing foreign firms to play a larger role in input industries. The most liberal market economies in the mid-1980s—Thailand, Malaysia, and the Philippines—had the highest private research intensities. The countries with the most controlled economies—China, Indonesia, Pakistan, and India—had the lowest private research intensities. The countries in which private research intensity grew most rapidly—China, India, Pakistan, and Indonesia—had major liberalization programs during this period. China and India still have important barriers to the importation of agricultural inputs, and China severely restricts foreign investment.

Public Research

There is evidence of strong complementarities between public and private agricultural research in Asia. Public investment in agricultural science was one of the principal sources of new technological opportunities for applied R&D. Public research provided basic technology such as downy mildew-resistant corn in Southeast Asia and downy mildew-resistant pearl millet. Public research has also been very important as a source of scientists for private research.

Intellectual Property Rights

Although legal protection of intellectual property has been strengthened in several countries, its enforcement remains weak. Thus, intellectual property rights have played a limited role in stimulating the growth of research. Input firms primarily used technical means of protecting their intellectual property. Seed companies protected new plant varieties by producing hybrids. Chemical companies protected new pesticides or pharmaceuticals by keeping the process of production secret and by making chemicals that are difficult to reproduce. Plantations captured benefits of research by developing technology that can be used only on their own plantations.

Encouraging Private Research in Asian Countries

To encourage private investment in research, Asian governments might consider the following strategies:

1. Continuing liberalization of economies, particularly agricultural input industries.
2. Strengthening intellectual property rights.
3. Continuing to support public research to complement private research—national, provincial, and international.
4. Developing transparent regulations that are based on local concerns and science.

Policy Implications for the United States

Agricultural development in Asian developing countries has benefited U.S. farmers by creating more demand for their goods and for U.S. food and input firms that invest and export to Asia. Thus, the United States can benefit from rapid economic development through the private sector. Policies that encourage economic development consist of:

1. In the World Trade Organization and in bilateral trade discussions, the U.S. Government could benefit by emphasizing reduced barriers on agricultural input trade and foreign investment in agricultural input industries, because this could have particularly high payoffs in Asian agriculture.
2. Continued U.S. support to the International Agricultural Research Centers is valuable because the centers have provided much of the science and many of the scientists, which are the basis of private research in Asia.
3. Enhancing public research in Asia with additional funds and resources could help draw the attention of private biotechnology firms to developing-country opportunities in food and agriculture.
4. Research opportunities can be expanded through collaborative efforts between USDA's Agricultural Research Service, land-grant universities, and the international agricultural research centers.

Introduction to Private Sector Agricultural Research in Asia

Carl E. Pray and Keith Fuglie

This chapter provides data on the amount of private research, trends in funding, and sources of private research funds and discusses some of the effects of that research.

Methodology for the Country Case Studies

To better understand the significance of the private sector in international agricultural research and technology transfer, we conducted a survey of agribusiness firms in selected developing countries during 1996 and 1998. In addition, we conducted interviews with several multinational agricultural input companies based in the United States and Europe. The goals of the surveys were to:

- determine how much and what kind of agricultural research is conducted by the private sector,
- identify policy constraints and incentives to private research and technology transfer, and
- assess major impacts of these private investments on agricultural productivity.

For the survey, we selected seven countries in Asia: China, India, Indonesia, Malaysia, Pakistan, the Philippines, and Thailand. These countries were selected for several reasons. First, together they represent a broad range of developing countries: two are large developing economies (China and India), two are middle-income, mid-size economies (Malaysia and Thailand), and three are low-income, mid-size economies (Indonesia, Pakistan, and the Philippines). Second, an earlier study conducted a survey on the same set of issues in these countries in 1985 (Pray, 1985 and 1987; and Pray and Echeverria, 1991). As the survey design parallels this earlier work, the present survey enables us to compare results across time. Finally, there has been little recent work on private agricultural research in Asia. Recent studies by Falconi (1992 and 1993) and Echeverria, Trigo, and Byerlee (1996) provide estimates of private agricultural research for several Latin American countries. Little private research is thought to take place in Africa (Thirtle and Echeverria, 1994), with the exception of South Africa and possibly Egypt. Thus, this study helps to fill an important gap in private agricultural research in developing countries.

For each country case study, we conducted personal interviews with managers from the principal seed, livestock, agricultural chemical, farm machinery, biotechnology, and plantation companies in those countries. A mail questionnaire was used when an interview could not be scheduled due to time conflicts. In India and Pakistan, mail questionnaires were used more extensively than in the other countries to reach a large number of companies. In addition, interviews were conducted with government officials from agricultural and science ministries and knowledgeable individuals from universities, research institutes, and foreign aid agencies. However, the personal interviews were conducted in a semi-structured interview format and the list of questions served only as a general guide. This allowed specific issues to be explored in greater depth according to the knowledge and interest of the respondent. The individual country case studies contain more details on the survey design for that country.

Overview of Asian Economies and Agriculture Since 1980

The period from 1980 to 1997 was a prosperous one for most countries in Asia. Per capita incomes and some characteristics of agriculture of the countries in this study are shown in table A-1. Per capita income grew very rapidly in East and Southeast Asia (last column in table A-1) with the exception of the Philippines. Income grew, but less rapidly than in Southeast

Table A-1—Economic and agricultural indicators in selected Asian countries, 1980-95

Country	Agriculture value added	Growth of agriculture value added		Value of agricultural exports	Per capita income	Growth of per capita income
	1995	1980-90	1990-95	1995	1995	1985-95
	Million U.S. dollars	*---Percent---*		*Million U.S. dollars*	*U.S. dollars*	*Percent*
Large, low-income:						
China	146,506	5.9	4.3	14,363	620	8.3
India	93,984	3.1	3.1	5,494	340	3.2
Middle-income:						
Malaysia	11,090	3.8	2.6	8,228	3,890	5.7
Thailand	18,376	4.0	3.1	9,022	2,740	8.4
Mid-size, low-income:						
Indonesia	33,673	3.4	2.9	5,493	980	6.0
Philippines	16,320	1.0	1.6	1,881	1,050	1.5
Pakistan	15,769	4.3	3.4	1,018	460	1.2

Sources: All data from World Bank *World Development Report*, 1997, using PPP exchange rates, except ag export data from the Food and Agriculture Organization of the United Nations' statistical databases.

Asia, in India and Pakistan. The Asian crisis that started in 1997 and was particularly disastrous in Southeast Asia is excluded from this study because we had completed our case studies of Thailand, the Philippines, Indonesia, and Malaysia before the crisis struck.

Agriculture did quite well during this period. All countries except the Philippines had annual growth rates of about 3 percent or more. China, which was going through a massive restructuring of its economy, grew most rapidly. This rapid growth was faster than increases in population and allowed most countries to keep up with increased demand for agricultural products. Most of the growth in these countries can be attributed to increases in yield per unit of land. The increase in crop yields was a function of new plant varieties, developed primarily by public plant-breeding institutes, and increased use of fertilizer and irrigation. Growth in animal productivity was attributable to the combination of new breeds of poultry and swine, developed primarily by the private sector and new feed, health, and commercial management practices, also developed by private firms.

Private Agricultural Research in Asia

The largest amount of private research was in India, where investment was about $55 million per year in the mid-1990s (table A-2). The next largest amounts of private research expenditure were Thailand, Malaysia, and China. The private sector in each of these countries spent $15 to $20 million per year for agricultural research. They were followed by the Philippines, with about $10 million, and Indonesia and Pakistan, with about $6 million. The last column of the table shows the research investment relative to the size of the country's agricultural economy. China's investment in private research was particularly small, spending less than 0.01 percent of agricultural GDP on private research. In contrast, Thailand and Malaysia spent about 0.1 percent. The other countries fall somewhere in between.[1]

Between 1985-87 and 1995-98, private R&D grew in real terms in all of the countries in our sample (table A-2). In India, Pakistan, Indonesia, and China, research funding more than doubled within 10 years. In the Philippines and Thailand, research funding grew between 60 and 70 percent. Malaysia, which had the highest research intensity in both periods, had the smallest increase in growth. Table A-2 shows a clear inverse relationship between research intensity in the 1980s and growth in research expenditure since then.

[1]Some of the differences in levels of research between countries are due to the differences in how state-owned enterprises (SOEs) are handled. SOEs conduct a substantial amount of research in China, India, and Malaysia. This research is included in the private research data in India and Malaysia but China's data were unavailable. In India, SOEs account for 18 percent of the private research— mainly in fertilizers. In Malaysia, government-owned plantations accounted for about 23 percent of private research.

Table A-2—Private agricultural R&D expenditures, growth, and research intensity, Asia, 1985 and 1995

Country	Private R&D expenditures		Increase in private R&D,	Private research intensity (private R&D as percent of agriculture value added)	
	1985-87	1995-98	1988-89	1985-87	1995-98
	Million 1995 ---U.S. dollars[1]---		*---Percent---*		
Large, low-income:					
China	0.0	11-16.0	Infinite	0.000	0.009
India	25.7	55.5	116	0.026	0.059
Middle-income:					
Malaysia	14.1	16.6	19	0.173	0.150
Thailand	10.6	17.4	64	0.124	0.095
Mid-size, low-income:					
Indonesia	2.8	6.1	118	0.010	0.018
Philippines	6.2	10.5	69	0.059	0.064
Pakistan	2.4	5.7	138	0.019	0.036
Total	61.8	122.8-127.8	99-107		

[1]Inflated to 1995 prices, using U.S. implicit Gross Domestic Product deflator.

Sources: Expenditures from 1985 Asian countries from Pray and Echeverria, 1991, and 1995-97 author's survey. Research intensity was calculated using agricultural GDP data from World Bank, World Development Report, Washington, DC,. 1987 and 1997.

Table A-3 indicates the importance of private agricultural research relative to all agricultural research in 1995. China again stands out for having only 3 percent of its research conducted by the private sector. The private sector had the highest share in both Malaysia and the Philippines—each over 20 percent. The other countries had between 10 and 20 percent in the private sector.

The agricultural chemical industry conducted the most private research followed by processing and plantation industries. We lumped together processing and plantation industries, because many plantations also conduct research on processing and many processors finance research on agriculture (e.g., breweries support barley variety selection and breeding). Research by the agricultural chemical industry—primarily for plant protection chemicals but also for fertilizer use and biotechnology—experienced the most rapid growth, tripling in real terms between 1985 and 1995 (table A-4). Private livestock research grew almost as rapidly. Private research doubled in other input industries and in the plantation and processing sector.

Foreign firms made an important contribution to private research in all of these countries in 1995 (table A-5). At one extreme was China in which almost all private research was by joint ventures between foreign and local firms. Malaysia was at the other extreme, with little research by foreign firms. In Pakistan and India, foreign-owned firms conducted about a third of the research. In Southeast Asia, seed and pesticide research was done primarily by foreign multinational corporations. The foreign share of the plantation research was determined by government rules on foreign investment. In the Philippines and Thailand, foreign firms were allowed to operate plantations. In Malaysia and Indonesia, foreign plantations owners were gradually bought out (Malaysia) or nationalized (Indonesia). As a result, Malaysia and Indonesia did not have much research by foreign firms related to plantations. For all seven countries, the pesticide industry had the largest share of research. About 40 percent of the research of the seed and livestock industries was conducted by foreign firms. The other industries had a very small percentage of their research funded by foreign firms.

Declining barriers to trade are opening the way for more regional research as multinational companies research for a particular agro-climatic region in the country in which research is the least expensive to do and best protected from copying. The companies then export the technology to other countries in the region. For example, seed companies were moving most of their Southeast Asian corn research to Thailand and had planned to export their varieties from Thailand to other countries. Charoen Pokphand (a Thai agribusi-

Table A-3—Private and public research and research intensity, Asia,1995

Country	Private R&D	Public R&D	Private R&D intensity[2]	Public R&D intensity[2]
	Million 1995 ------U.S. dollars[1]------		*------Percent------*	
Large, low-income:				
China	16.0 (3)[3]	479.5	0.009	0.327
India	55.5 (14)	347.9	0.059	0.370
Middle-income:				
Malaysia	16.6 (21)	64.0	0.150	0.577
Thailand	17.4 (12)	127.0	0.095	0.691
Mid-size, low-income:				
Indonesia	6.1 (12)	81.0	0.018	0.241
Pakistan	5.7 (19)	25.0	0.036	0.159
Philippines	10.5 (22)	37.5	0.064	0.230
Total	127.8 (11)	1,125.3		

[1]Calculated using official exchange rates.
[2]R&D intensity = R&D as percent of agricultural value added.
[3]Numbers in parentheses show private R&D as a percent of total agricultural R&D.
Sources: See country case studies.

Table A-4–Growth of private R&D, by industry, Asia, 1985 and 1995

Item	1985	1995[1]	Growth
	Million 1995 -------U.S. Dollars------		*Percent*
Agricultural machinery	3.9	7.5	92
Agricultural chemicals	14.5	47.0	223
Livestock/animal health	5.4	15.9	193
Plant breeding	8.2	16.4	100
Plantations and processing	21.2	40.8	93
Total	53.2	127.5	140

[1]For 1985 data, see sections for country case studies.

Sources: 1985 surveys by Pray (1985) and Pray (1987).

Table A-5—Research expenditures and share of foreign firms, Asia, 1995

Country	Private R&D	Foreign firms' R&D	Foreign as percent of total private R&D
	Million 1995 ---U.S. dollars[1]---		*Percent*
Large, low-income:			
China	16.0	16.0	100
India	55.5	16.8	30
Middle-income:			
Malaysia	16.6	1.6	10
Thailand	17.4	11.0	63
Mid-size, low-income:			
Indonesia	6.1	3.5	58
Pakistan	5.7	1.8	31
Philippines	10.5	7.3	69
Total	127.8	58.0	45

[1]Calculated using official exchange rates.
Source: Country case studies.

ness conglomerate) is doing poultry research in China and exporting improved breeds to Thailand.

Another measure of the importance of foreign versus local research in providing technology is patent data. Table A-6 shows the total number of patents in industries that produced agricultural inputs and the percentage of patents owned by local individuals or organizations rather than foreign individuals and organizations in 1987-95. All of these countries are importers of technology, but the largest countries—India and China—by the early 1990s were producing between one-third to one-half of their own inventions as measured by share of patents going to domestic inventors. In contrast, the middle-income countries represented by Malaysia (latest available data is for 1987) and smaller, low-income countries produce few patentable inventions domestically and rely primarily on imported foreign technology. The percentage of local patents is inversely related to the percentage of research by foreign firms in table A-5—except in the case of China where foreigners do almost all of the private research, yet Chinese inventors have more than half of the patents.

These tables show three distinct patterns. The first pattern is represented by China, a country with a mixed socialist and market economy. It has low private research expenditure and very low private research intensity; private research was a small share of total public and private research. But private research is growing very rapidly. A second pattern is observable in the middle-income countries, such as Malaysia and Thailand. They are major exporters of agricultural products in raw or processed form. They spent a relatively high share of agricultural GDP on both public and private research. However, private research expenditure was growing more slowly than in some other countries in the sample, with private research intensity declining: that is, private research has not kept up with the rapid growth in agricultural output. The third pattern is found in the low-income countries other than China—India, Pakistan, the Philippines, and Indonesia. In these countries, private research intensity is lower than in the middle-income countries, but their private research expenditure grew more rapidly than that of the middle-income countries and more rapidly than agricultural GDP, raising research intensity.

Effect of Private Research and Technology Transfer

Companies invest in research to expand markets for their products and to enhance company profits. In addition, private research can contribute significantly to raising agricultural productivity and output. This, in turn, can increase farm income and lower the cost of food for consumers. Below, we identify some areas where private research has had significant economic effects on agriculture in Asia, and briefly review the evidence on the distribution of spillover benefits to farmers and consumers.

Table A-6—Patenting by industries that develop technology for agriculture and other Industries, Asia, 1987-95

Country/year	Unit	Agriculture	Chemicals	Pharmaceuticals	Other machinery	Food	All industries
India, 1992	Number	0	507	81	510	22	1,908
	Percent	0	33	41	29	30	31
China, 1995	Number	6	2,386	1,177	4,460	395	20,585
	Percent	63	37	53	59	65	56
Philippines	Number	0	486	265	114	25	1,091
1990	Percent	0	8	8	22	13	11
Malaysia	Number	0	314	92	153	15	942
1987	Percent	0	0	0	3	0	2
South Korea	Number	3	2,519	446	2,640	132	15,210
1995	Percent	67	36	37	51	77	54

Source: Calculated from Johnson-Evenson Patent Set at *http:\\www.wellesley.edu\Economics\johnson.htm*

Production and Productivity

The major effects of private research on field crop production in Asia have been to increase yields of corn, sunflower, pearl millet, sorghum, and cotton in India; corn and horticultural crop yields in Thailand; corn in the Philippines; and corn and tobacco in Pakistan. Corn yields grew more rapidly than other major crops in Thailand and the Philippines. In India, regression analysis of yields in the semi-arid regions of the country shows that private hybrids of corn, pearl millet, sorghum, and cotton increased yields (Ramaswami and Pray, 1998). The effects on plantation crops of public and private research have been to increase latex yields of rubber and oil palm in Malaysia. In the Philippines, private research increased sugarcane yields and reduced the cost of producing bananas by tailoring fertilizer applications to the soils, reducing fungicide applications, and developing control techniques for pests that are unique to the Philippines. In China, the only effects of private research we have identified were an increase in cotton yields, reduced pesticide use on less than 100,000 hectares, and increased yields in a few areas where private sorghum, maize, and sunflower were planted.

Private animal research and technology transfer has had a significant effect on increasing output and reducing the real prices of animal commodities. The production of poultry, pork, and eggs tripled or quadrupled from the early 1970s to the early 1990s in the countries in this study. Milk production also increased significantly. Much of the growth in animal production was due to increases in inputs. But modern technology allowed the increase in inputs to be used efficiently and increased productivity of animal production. These changes in technology— improved breeds of poultry, swine and cattle; improved feed; veterinary medicine, and confinement management technology—were the result of imported technology combined with the local adaptive research discussed earlier in this paper. In the United States, these improvements cut the real cost (in 1994 dollars) of producing a kilogram of poultry from over $5 in 1955 to about $2.60 in 1965 and then down to about $1.60 in 1994 (Henry and Rothwell, 1995). The private sector played a major role in transferring and adapting this technology to Asia. In Thailand, the feed conversion ratio of broilers improved by 10 to 20 percent, the time to produce a finished bird declined by 10 to 15 days, and the size of the finished bird went from 1 to 1.5 kilogram for each bird. The only study that attempted to measure the effect of technology outside the United States is a recent study by Narrod, Pray, and Peterson (1999). They found that, after controlling for the changes in the ratio of poultry prices to feed prices, modern breeds of poultry and compound feeds were major contributors to the growth in production. These productivity changes are reflected in the declining price of broilers, which has gone steadily downward since the early 1960s (Henry and Rothwell, 1995).

The few studies that measure the effect of private agricultural R&D in developing countries concentrated on crop research, and only a few were conducted in the countries under study here. These studies indicate that private research can increase agricultural productivity and generate positive spillover benefits to farmers and consumers. Ribeiro (1989) estimated the social rate of return to private plant-breeding research in India to be 38 percent or more, depending on the crop. Evenson, Pray, and Rosegrant (1999) measured the effect of private research on total factor productivity (TFP) in India. They found that private sector research, advances in agricultural research outside India, and public research all made major positive contributions to TFP growth in the Indian crop sector. Echeverria (1991) found that private research in tropical countries, including the countries in our study other than China and Malaysia, had an important positive effect on corn yields. He also found that in temperate developing countries, direct imports of corn technology had an important positive influence on yields, but private research did not have a statistically significant effect on yields.

Income Distribution

Studies have shown that a large share of the economic benefits from improvements in food crop production have gone to small-scale farmers and low-income consumers. The effect on income distribution of high-yield varieties of rice and wheat, which was developed by the International Centers and national research systems in these countries, was generally positive in developing countries. Low-income consumers and farmers and landless laborers had larger income gains from the technology than large-scale farmers and wealthy consumers. Some regions without irrigation were left behind, but the negative effects were mitigated to a degree by the movement of laborers to the regions with irrigation (David and Otsuka, 1994).

The income distribution effect of private research on crop hybrids has taken two paths. In some regions of

Thailand, the Philippines, and India, large commercial farmers rapidly turned to production of private hybrid corn and used much of it for animal feed. Thus, the benefits from increased productivity went to larger commercial farmers and to producers and consumers of animal products. Small-scale farmers benefited from producing hybrid corn in many areas of India and the Philippines. Small-scale farmers have also benefited from private hybrid sorghum, hybrid pearl millet (Pray et al., 1991), and hybrid sunflower in India. In areas where small-scale farmers adopted hybrids, the income distribution effect was similar to that of modern high-yield varieties of rice and wheat. Sorghum and pearl millet are primarily eaten as food staples by the poor in the semi-arid regions of India. Thus, poor consumers are important beneficiaries of improved productivity.

The income distribution effect of productivity growth in poultry and pork production has been different from the effect of the major grain crops. The adoption of modern poultry and swine technology has been a phenomenon serving urban markets. In most developing countries, a few large, private integrators have organized poultry production. These large integrators process and market the meat, own the hatcheries that provide baby chicks, own feedmills that provide commercial feed, and organize contract farmers who actually produce the broilers and swine. These integrators undoubtedly capture a considerable amount of the gains from the commercial poultry and pork production, with some benefits reaching the contract farmers who tend to be large-scale farmers. Egg production is less integrated than broiler production. Adoption of commercial technology for eggs was slower than for broilers, but egg production is now largely commercial and concentrated in and around urban areas.

There has been sufficient competition in most countries to dramatically reduce the price of poultry meat and eggs (see Gisselquist and Pray, 1999, for the example of Turkey). The main beneficiaries of the price reductions are mid- and high-income consumers who can afford to eat meat.

Environmental Effect

Private hybrids have the same benefits and costs to the environment as hybrids and improved varieties developed by the public sector. The main environmental advantage is that high yields reduce the pressure to turn more forests, hillsides, and savannas into cropland. The disadvantage is that high-yielding varieties tend to induce farmers to use more fertilizers, pesticides, and irrigation, which may have negative environmental effects. One exception is that plantation research in the Philippines has reduced use of fungicides and chemical fertilizers in banana plantations.

In animal production, modern confinement poultry and swine operations are now major contributors to air and water pollution in many developing countries. These systems create waste that can be useful as fertilizer, but confinement operations that are concentrated around major cities add large amounts of nitrogen and phosphorus to water supplies (Narrod and Pray, 1995). These nutrients cause algal blooms, which lower light penetration and the amount of oxygen in the water, reducing fish production. Economists studying Laguna Bay, a lake near Manila in the Philippines, showed statistically that poultry manure production around the lake reduced fish production in the lake (Pingali, Hossain, and Gerpacio, 1997).

Conceptual Framework for the Country Studies

Economic Determinants of Private Research

Most private agricultural research is directed at developing and supplying improved inputs to farmers. These inputs can be in the form of higher yielding crop varieties or animal breeds, more effective agricultural chemicals or farm machinery, or entirely new kinds of inputs that are more efficient than existing inputs. Private research can also improve the manufacturing of these inputs so that they can be provided at less cost to farmers. All of these types of technical improvements raise farm productivity by lowering the average cost of producing farm products.

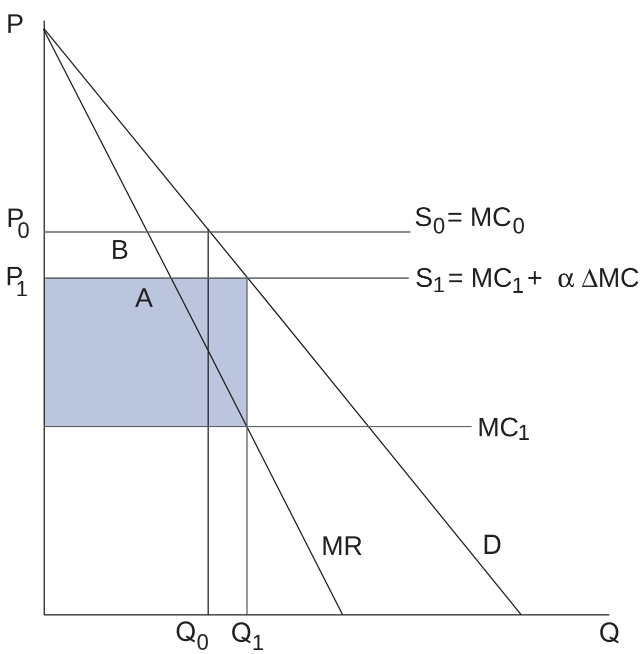
To understand how economic and policy factors affect the incentives for private agricultural research, we need to consider the demand and supply characteristics of farm input markets. Neoclassical theory shows that the demand for a production input is positively related to the price of the final product and negatively related to the input's own price. It is positively related to the prices of other inputs that are substitutes in production, and negatively related to the price of other inputs that are complements in production. The supply function for agricultural inputs can in many cases be considered to be perfectly elastic. For the chemical and machinery industries, for example, the quantity of products supplied to the agricultural sector is usually a small share of the total market for these industries, so shifts in demand from the agricultural sector have little or no effect on the prices of these products. Other inputs, such as animal feed and crop seed, are produced by the farm sector. The supply of these inputs may be less than perfectly elastic.[2]

Figure A-1 presents a conceptual model of the economics of private research for a farm input supplier in which the aggregate farm demand for the input is downward sloping and the industrial supply of the input is competitive and perfectly elastic. In the figure, the initial supply of an agricultural input is given by S_0, which is the marginal cost of producing input Q and is constant for all Q. The market equilibrium price and quantity demanded by farmers for input Q is given by P_0 and Q_0, the intersection of S_0 and D.

For simplicity, assume that private research aims to reduce the cost of producing input Q. This would also apply to research that reduces the costs of manufacturing the input and research that develops a new kind of input to substitute at less cost for an existing input, such as labor-saving machinery or a chemical fertilizer that substitutes for organic fertilizer. Assume that a firm faces a research production function in which a vector of research inputs X is expected to result in a reduction in the marginal cost of producing Q from MC_0 to MC_1, given by $\Delta MC(X)$. We assume that the parameters of the research production function $\Delta MC(X)$ are determined by the present state of scientific knowledge, and that $\Delta MC(X)$ increases with X at a declining rate. In other words, $DMC_x > 0$ and $\Delta MC_{xx} < 0$, where ΔMC_x and ΔMC_{xx} are the first and second derivatives of $\Delta MC(X)$, respectively. Research inputs X are priced at W, so that the private investment in research is X•W. Once made, investment in research is a sunk cost.

[2]See Dasgupta and Stiglitz (1980) for a model examining the relationship between noncompetitive market structure and industrial R&D. Levin and Reiss (1984) present an empirical test of the model.

Figure A-1
Economic benefits from private agricultural research



This research production process mirrors that conceptualized by Evenson and Kislev (1975). They described applied research as a random draw from a distribution of potential experiments, some of which may result in a technology that is better than the current technology. Increasing the number of draws (i.e., increasing the investment in research) increases the probability that a superior technology is drawn. It also increases the expected reduction in marginal cost, compared with the current technology. However, the probability distribution function for the random draws is fixed, and increasing the number of draws produces higher expected gains at a declining rate. Basic research changes the parameters of the probability distribution function for applied research, and thereby increases the expected gains from a given level of applied research. We assume that only the private sector makes investments in applied research and that only the public sector makes investments in basic research.

The new technology developed through private research is provided to farmers in the form of a production input that embodies the new technology developed through research. In a competitive market for farm inputs, the input would be offered to farmers at its marginal cost of production MC_1. Assuming also that the demand for farm output is perfectly elastic (so that the adoption of improved technology does not alter farm output prices), then the full gains of technical change would be passed on to farmers. Since research is a sunk cost, it is not included in the marginal cost of manufacturing the input; therefore, the input manufacturer is unable to recoup the costs of research. In order to capture some benefits of the research, the input supplier must charge farmers a price for the input that is higher than its marginal cost of manufacture. In figure A-1, a firm is assumed a charge a premium for the improved input so that the offer curve for the input is given by S_1 and farmers pay P_1 for the input. The difference between S_1 and MC_1 is the premium charged by the developer of the improved input. This is the profit the input manufacturer earns as a return on its previous investment in research.

The size of the premium is a function of the appropriability of the new technology and other factors. Appropriability is influenced by market structure and how well the new technology can be protected through patents, trade secrets, or other forms of intellectual property protection. If an input manufacturing industry is characterized by one or a few large firms, then a firm may exert market power and set the input price above its marginal cost. A firm may also exercise market power through a patent that gives it an exclusive right to use the new technology. Another possibility is that a firm may keep the technology out of its competitors' hands by keeping key elements of the new technology secret. The production of agricultural chemicals, for example, can sometimes be protected by keeping the manufacturing and formulation process secret even if a patent on the chemical compound itself is not available or has expired. Intellectual property in hybrid varieties can also be protected by restricting access to the parent inbred lines. In this way, a firm can be the sole provider of a technology, at least for a while.

If a firm acted as a pure monopolist, it would maximize profits by supplying the quantity of the input when marginal cost equaled marginal revenue, taking into account the effects of the quantity of input supplied on market price. A monopolist's marginal revenue curve for input Q is shown by MR in figure A-1. The quantity and price that maximize profit are therefore Q_1 and P_1. Monopoly profits are shown by region A, which is the return to private research. Nevertheless, the new input is still offered at a lower price than the old technology, so farmers also realize benefits from the new technology (region B in the figure).

In figure A-1, the monopoly price for the new input P_1 is shown to be less than the price of the old technology P_0. In other situations, P_1 may exceed P_0. However, so long as the old technology remains available in the market at its marginal cost, it provides an upper bound to what a firm could charge with monopoly control over a new technology. A firm could at most charge a farmer P_0, the price of the available technology, otherwise farmers would have no incentive to adopt the new technology. In fact, the firm would likely charge significantly less than P_0 in order to achieve rapid and widespread adoption. Griliches (1957) showed that there is a direct relationship between the size of the economic benefit provided by a new agricultural technology and its speed of diffusion. If a firm charged a price for the new technology that was only a fraction less than P_0, diffusion could be expected to be very slow. Thus, the premium charged by a firm for a new technology is determined not only by the level of appropriability (or market power) in an input market, but also by dynamic considerations of technology diffusion. The firm will balance the price premium earned per unit of input sold with the total quantity of input it can sell. One strategy may be to offer a lower price for the new technology until it is well established, and then raise the price in order to recover the costs of research and market development.

In figure A-1, we abstract away from the dynamics of diffusion and simply assume that a is the share of the reduction in marginal costs a firm charges for a new technology. Then $S_1 = MC_1 + \alpha^*\Delta MC$. Thus, for an input manufacturer considering an investment in research, the expected profit from the research investment X is given by:

$$\pi = P\, Q_1\, \alpha\, \Delta MC(X) - W\, X. \qquad (1)$$

The profit-maximizing level of research is given by the first-order necessary condition that equates $\partial\pi/\partial X = 0$, or

$$P\, Q_1\, \alpha\, \Delta MC_x = W. \qquad (2)$$

The left side of equation 2 is the marginal private benefit of research to a firm. It is a function of appropriability a, market size ($P\,Q_1$), and the technology opportunities described by the research production function $\Delta MC(X)$. The right side of equation 2 is the marginal cost of research given by the prices of research inputs W. Equating private marginal benefits with marginal costs describes the profit-maximizing level of research X for a firm.

Equation 2 can be used to explore how changes in appropriability, market size, technology opportunity, and cost of research inputs influence the optimal level of private research (see table A-7). This is done by taking the total differential of equation 2 with respect to the parameter of interest, and letting X adjust so that the first order of the necessary condition for profit-maximization is maintained.

Consider market size. Taking the total differential of equation 2 with respect to Q_1 (differentiating with respect to P gives a similar result) and solving for $\partial Q_1/\partial X$ gives:

$$\partial X/\partial Q_1 = - \Delta MC_x / (P\ Q_1\ \Delta MC_{xx}) > 0. \qquad (3)$$

Since the marginal returns to research are positive ($\Delta MC_x > 0$) but declining ($\Delta MC_{xx} < 0$), $\partial X/\partial Q_1$ is greater than zero. Thus, an increase in market size increases the optimal level of private research. Similarly, an increase in appropriability a increases the optimal level of private research:

$$\partial X/\partial \alpha = - \Delta MC_x / (\alpha\ \Delta MC_{xx}) > 0. \qquad (4)$$

A decline in the cost of research inputs W would also lead to an increase in the optimal rate of private research:

$$\partial X/\partial W = 1 / (\alpha\ P\ Q_1\ \Delta MC_{xx}) < 0. \qquad (5)$$

Finally, if we define an improvement in technological opportunity to mean that each level of X produces a larger expected reduction in marginal cost, i.e., ΔMC_x is larger for each level of X, then an increase in technological opportunity would also increase the optimal level of private research. Holding other parameters constant, it would require a larger amount of X to equate the expected marginal benefit of private research to its marginal cost according to equation 2. Recall that technological opportunities in the model expand through investments in basic research, which is assumed to be exclusively a public activity.

In addition to providing comparative static results, the model outlined above provides insights into the distribution of benefits from private agricultural research. In figure A-1, the shaded region A is the share of benefits captured by the input developer. Region B is the share of benefits that goes to farmers. So long as the old technology remains available to farmers at its competitive price P_0, private research will never reduce the economic welfare of farmers.

The model could be expanded to consider possible effects of new technology on agricultural commodity price. If final demand is less than perfectly elastic, then private agricultural research could increase total agricultural production sufficiently to reduce output prices. In figure A-1, this would have the effect of shifting the derived input demand function D downward, reducing farm demand for inputs. Lower commodity prices would serve to shift some of the benefits of private research from farmers and the input firm to consumers. In some special circumstances, it is possible for farmers as a group to be left worse off by new technology. But this possibility is not a feature of private research *per se*, but rather is characteristic of any agricultural research, public or private, that occurs under specific market conditions (see Alston, Norton, and Pardey, 1995).[3]

Another modification to the model would be to examine other types of technology improvements provided by private research in addition to those that lower the cost of inputs to farmers. For example, a technology

[3]The downward shift in the input supply function shown in figure A-1 would result in a downward shift in the supply function for the final output, since the marginal cost of commodity production is reduced by lower input costs. A circumstance in which agricultural producers can be left worse off by technical change is when new technology results in a pivotal downward shift of the commodity supply function and when demand for the commodity is inelastic (Alston, Norton, and Pardey, 1995).

Table A-7—Factors affecting private incentives for agricultural research

Parameter	Effect of the parameter in private research
Size of input market	Larger market size increases private research
Appropriability	Greater appropriability increases private research
Technological opportunity	Expanded technological opportunity increases private research
Cost of research inputs	Lower cost of research inputs increases private research

that increases crop or animal yield would have the effect of creating a new derived demand curve that would lie above the old input demand curve D in figure A-1. A firm would recoup costs of research by charging a premium for the new technology above the price of the current technology. The input price premium would need to be less than the economic benefits of higher output yield in order to induce farmers to switch to the new technology.

A further modification could be to consider the effects of risk and uncertainty in research and in future market demand and prices on private research. These modifications to the basic model, while adding to its complexity, are not likely to alter the comparative static results shown in table A-7.

Public Policies and Incentives for Private Agricultural Research

The conceptual model described earlier provides a framework for assessing the likely effect of public policies on incentives for private agricultural research. The model showed that investments in agricultural research by profit-maximizing firms is a function of four main determinants: market size, appropriability, technology opportunity, and the cost of research inputs. Factors 3 and 4 are often grouped together because both are primarily functions of public investments in research and higher education. Public investment in research in basic agricultural sciences and precommercial technology expands the opportunities available for applied research and development by the private sector. Public investment in agricultural postsecondary and graduate education increases the availability of agricultural scientists and technicians. This reduces the cost of conducting research, since human capital is often the largest single component of research costs.

Table A-8 describes how different policies may affect these determinants. First, there is the general economic environment. Macroeconomic stability, good transportation and communication infrastructure, functioning capital and insurance markets, and a reasonable level of general education and training, especially agricultural training, are factors that positively affect all the determinants. These factors reduce the costs of transacting business in an economy, including agricultural research and the delivery of improved inputs to farmers (Evenson and Westphal, 1995).

In addition to these general conditions, the size of input markets is affected by several specific policies. In some countries, state-owned enterprises maintain a monopoly on the production and/or distribution of cer-

Table A-8—Policies and incentives for private agricultural research, Asia, 1998

Private research determinants	Policies affecting determinants
General state of the economy	Macroeconomic stability Public infrastructure General education and training Development of capital and insurance markets
Size of input markets	Market share of state-owned enterprises Restrictions of foreign participation in input markets Trade restrictions on inputs Price interventions in input or product markets
Appropriability	Intellectual property laws (patents, plant breeders' rights, trademarks, trade secret protection) and enforcement
	Technology-licensing requirements and regulations affecting technology imports
	Competitiveness and antitrust policies
Technological opportunity and cost of research inputs	Public investment in agricultural research and education Trade restrictions on inputs and restrictions on foreign direct invest ment
	Registration and testing requirements on new seed and agricultural chemicals
	Biosafety requirements for biotechnology field trials
	Public subsidies for private research, including tax holidays, tax credits, research grants, and technology parks

tain agricultural inputs. Limiting the access of the private sector to input markets acts as a disincentive to private research. Similarly, some countries may pursue protectionist policies to help national industries and limit the degree to which foreign companies can participate in local markets. These restrictions may be outright bans of foreign input firms, regulations that require majority control by a local partner in a foreign subsidiary, restrictions on the foreign remuneration of profits, or regulations on foreign direct investment. These restrictions can reduce the incentives for private research in a country by multinational firms. Moreover, empirical research shows that protectionist policies retard the technological development of national industries by blocking access to critical elements of foreign technology (Evenson and Westphal, 1995).

Government intervention in agricultural input or output markets may also take other forms. Subsidies that increase farm prices increase farm demand for inputs, and likewise explicit or implicit taxes on agriculture reduce farm demand for inputs. Prices of inputs themselves may be subsidized or taxed, similarly affecting input demand and, therefore, the size of the market for improved inputs.

Appropriability is affected by policies toward intellectual property rights (IPRs), trade secret protection, and market competitiveness (e.g., antitrust policy). Several countries have until recently excluded agricultural inventions from patent protection. And even in countries with legal protection for patents and trademarks, enforcement may be lax or cumbersome. However, under the Uruguay Round of the GATT (General Agreement on Tariffs and Trade, which is now the World Trade Organization), member countries are required to provide IPRs for agricultural and other inventions, including new plant varieties. Otherwise they may face retaliatory trade measures.

National laws influence a firm's ability to protect technology through trade secrets. Some countries require foreign companies to import and license their technology locally in order to participate in local markets. For example, agricultural chemical companies may be required to manufacture active ingredients locally, or seed companies may be required to import advanced breeding material and produce hybrid seed locally for sale. While technology importation and licensing requirements are often designed to increase technology transfer, they can also cause companies to stay out of a market completely. Since maintaining control over proprietary technology is critical for appropriating gains from research, multinational companies may be reluctant to participate in markets that put their patented technology and trade secrets at risk.

A recent survey of U.S. manufacturing companies suggests that the strength of IPRs and a government's willingness to enforce them influence firms' willingness to license technology, transfer it through their subsidiaries, and conduct research in a country (Mansfield, 1994). In the survey, Mansfield asked companies whether strong IPRs or the lack of them influenced the companies' willingness to transfer technology to a country. Companies were also asked to rate the strength of IPR protections in 16 countries. Eighty percent of the companies said that IPRs had a strong effect on their decision to invest in research and development (R&D) facilities. Only 20 percent of them, however, said that the strength or weakness of IPRs had a strong effect on their decision to establish sales and distribution outlets. Of the 16 countries named in the survey, Brazil, India, Nigeria, and Thailand were seen as having weak laws, while Hong Kong, Japan, Singapore, and Spain were perceived as having relatively strong laws. In Asia, only 8 percent of the companies surveyed indicated that they thought Japanese IPRs were too weak to permit licensing of their newest and most effective technology. But 38 percent thought Thailand's IPRs were too weak, and 44 percent thought Indian IPR laws would not protect their newest and best technologies.

Antitrust or competitiveness laws also affect the appropriability of private research. Schumpeter (1950) hypothesized that industries with a concentrated market structure have higher rates of technical change, because it is generally easier for a company to appropriate the gains from research when it has sufficient market power to influence prices. Such market power is usually enhanced when a company gains a large share of a market with significant barriers to entry of potential rival firms. However, too little competition can reduce incentives for private research. A firm facing little or no competition may see little need to devote resources to research and innovation, and be content to charge monopoly prices for old technology. Scherer (1980, page 438) summarizes the findings of subsequent research on Schumpeter's early theory:

> *A bit of monopoly power in the form of structural concentration is conducive to invention and innovation, particularly when the advances in the relevant*

knowledge base occur slowly. But very high concentration has a favorable effect only in rare cases, and more often it is apt to retard progress by restricting the number of independent sources of initiative and by dampening firms' incentive to gain market position through accelerated research and development (page 438).

The main policies affecting technology opportunity and the cost of research inputs are public investments in agricultural research and higher education. A strong public agricultural research and university system can significantly reduce the cost of private research by expanding the supply of highly skilled scientific and technical personnel available for private agricultural research. Public research can also provide key enabling technologies that increase the likelihood that private research endeavors will be successful. For example, in the 1960s, public research helped identify sources of varietal resistance to downy mildew, a major corn disease in southeast Asia. This provided an impetus to private seed companies to expand their research in corn breeding in the region. In the United States, public research developed many basic scientific tools for genetic engineering and helped launch the biotechnology industry.

Restrictions on imports of technology and foreign direct investment can also reduce technological opportunity. If these restrictions keep out new foreign technology and research by foreign firms, there will be less spillover of technology and knowledge to local firms. If farmers are using the foreign technology, local firms can improve and adapt it to local conditions. If foreign firms conduct research in the country, the scientists they hire can eventually leave and start their own firms to compete against the foreign firm.

Regulatory policy also influences technology opportunities and the cost of conducting research in a country. Countries differ in their requirements for efficacy and safety testing for registering new pesticides, which affects the time and cost of introducing new products into a market. Countries also differ in their regulations governing the introduction of new seed varieties. Some countries allow only varieties that have been demonstrated to be superior to existing varieties to be released and sold to farmers. Other countries allow companies to market any new variety they develop, relying on market competition to provide an incentive to seed companies not to introduce low-quality varieties. With respect to biotechnology, some countries have moved quickly to establish protocols for conducting field trials with genetically modified plants in order to encourage applications to agriculture. Other countries have not yet developed protocols or used very strict ones to discourage biotechnology.

Finally, governments may provide direct subsidies to private research in the form of research grants, research tax credits or tax holidays, or more indirect subsidies such as public investments in technology parks. Through technology parks, governments may provide research infrastructure to private firms at a subsidy. Technology parks may help create a critical mass of private entrepreneurs in order to establish a new industry or to commercialize the results of research from public research institutes and universities.

Global Forces Affecting Private Agricultural Research in Asia

Growth in Consumer Demand for Food

The model discussed earlier indicates that large markets induce more private research. Thus, the largest agricultural sectors should attract the most private agricultural research, and those growing most rapidly should have the most rapid growth of private research. Figure A-1 shows a weak positive relationship between private research expenditures and agricultural gross domestic product (GDP). Table A-2 also shows a weak relationship between private research intensity and agricultural GDP. Note that if research and agricultural GDP were perfectly correlated, then all countries would have the same research intensity. Instead, China and Indonesia have very low research intensities relative to other countries in our sample, while Malaysia and Indonesia have high research intensities.

A major factor that led to the increase in private agricultural R&D in Asia was increased demand for agricultural production at a time when investments in traditional sources of growth—land expansion, irrigation, additional agricultural labor, and public research—were slowing down or declining. In addition, demand for higher value agricultural commodities—meat, fruits, and vegetables—was growing particularly fast. Demand for more agricultural goods leads to demand for more modern inputs. As sales of modern inputs grow, private input firms and plantations revise upward their expectations about the future returns to research.

Also, these firms have more money to spend on research from input sales. These factors lead to higher expenditures on research by these firms.

There seems to be a closer relationship between growth of private agricultural research and growth in agricultural GDP. Research intensity remained roughly constant from the mid-1980s to the mid-1990s in Thailand, Malaysia, and the Philippines (table A-2). Thus, research and production were growing at roughly the same rate, which suggests that the growth in value of agricultural production accounts for most of the growth in private research in these countries. However, in India, Pakistan, and Indonesia, private research intensity nearly doubled. Thus, only part of the growth in research intensity can be accounted for by agricultural GDP growth. In China, the starting point for private research was zero, so growth was even more rapid. In these countries, we have other explanations for the sources of growth in private agricultural research.

Growth in the International Supply of Agricultural Technology

The period since 1985 has seen agricultural biotechnology functioning in the United States and elsewhere. There has also been a tremendous growth in large multinational firms in the agricultural input industries and the food trade and processing industries. These two trends are closely related. One of the most significant areas of consolidation in market structure has been the development of life-science biotechnology firms out of what had been chemical and pharmaceutical firms. These trends fit into our model of private research by providing new technological opportunities and increasing the efficiency of research by Asian firms and Asian affiliates of the multinationals.

Two types of evidence show the importance of these trends for Asia. First, about half of the research conducted in the seven countries included in this study is being done by foreign firms (table A-5). They perform the majority of the private research in all countries except India, Pakistan, and Malaysia. Second, foreign firms are concentrated in the industries where private agricultural R&D has been growing most rapidly—chemicals, livestock, and seed—and play a small role in private plantation and machinery research, where R&D growth has been slower.

Most foreign firms conducting agricultural research in Asia have their headquarters in industrialized countries where they conduct a substantial proportion of their firm's research. Private agricultural research in industrialized countries accounts for half of total agricultural research in these countries and is growing about 5 percent annually, more rapidly than public agricultural research (Alston, Pardey, and Roseboom, 1998). This growth was driven by breakthroughs in biotechnology and information technology, stronger intellectual property rights, and expectations of relatively high prices for agricultural commodities (Fuglie et al., 1996). Firms have made these investments in agricultural research to develop new crop varieties, veterinary pharmaceuticals, agricultural chemicals, and machinery. They are now looking for ways to market these new products worldwide to pay for their research. Asia is one of the targets for these marketing efforts.

Changes in the demand for agricultural inputs in the United States, Europe, and Asia have made the markets of countries of Asia look very attractive relative to U.S. firms' traditional markets. Three major U.S. agricultural input firms—Monsanto, DuPont, and John Deere—reported to us that since 1985 they have made major policy decisions to expand into Asia and other developing countries. From World War II to the late 1970s were boom years for agricultural input firms in the United States, Europe, and to a lesser extent Latin America. The 1980s were a period of stagnant or declining growth. Starting in the mid-1980s, many U.S. companies reacted to stagnant market size by reducing costs. By the early 1990s, opportunities for further cost reductions were limited. At this point, many of them started to look to new potential markets in developing countries, Central Europe, and countries of the former Soviet Union for further growth. Asia, in particular, looked attractive because of the rapid growth in demand for modern inputs, especially for labor-saving inputs such as herbicides and tractors. John Deere, DuPont, and Monsanto specialize in these kinds of inputs, so their decision to expand into Asia in the 1990s is not surprising.

Mergers and acquisitions by the United States and European life-science companies appear to be increasing the flow of new technology to Asia. Mergers and acquisitions in the agricultural input industries and food industries in the United States and Europe have been fueled by developments in these countries such as biotechnology, the expansion of the stock market, and a drive to achieve economies of scale and scope. Much of the consolidation centers on the chemical and pharmaceutical multinational corporations (MNCs). Firms sold their chemical manufacturing and marketing components in order to raise money for increased investments in high-technology and high-profit products in pharmaceuticals, veterinary medicine, pesticides, and biotechnology. One of the earliest of these decisions was by ICI (the British chemical firm), which split into ICI for the traditional bulk chemicals and Zeneca to concentrate on drugs, pesticides, seeds, and agricultural biotechnology. In 1997, the U.S. firm, Monsanto, announced it would sell its bulk chemicals business to concentrate on the high-technology life sciences. Later, DuPont sold its gasoline business and invested heavily in a joint venture with Pioneer Hi-Bred, a large U.S. seed company.

A second trend is the merger of large chemical and pharmaceutical firms (see the first column in table A-9). The German firms Hoechst and Schering formed a joint venture for their agricultural and environmental products called AgrEvo. The Swiss firms Ciba-Geigy and Sandoz merged in 1997 to become Novartis. Merck of the United States and Rhone-Poulenc of France formed a new joint venture for their animal products (veterinary medicines and poultry genetics) called Merial Animal Health. As recently as 1999, Hoechst and Rhone-Poulenc merged to form Aventis.

These large chemical firms used the money raised from selling their chemical businesses to fund research and development and to buy small biotechnology firms and seed companies or, in some cases to negotiate strategic alliances with them. Table A-9 shows some key purchases of biotechnology and seed firms. AgrEvo purchased Plant Genetic Systems, the largest European plant biotechnology firm, in 1996. More recently, it purchased Cargill's U.S. seed business. DuPont purchased 20 percent of Pioneer Hi-Bred. Monsanto has been the most active of all. It bought into three important biotechnology firms, purchasing 100 percent of Agracetus and Calgene and all of the technology assets of Ecogen. Monsanto also purchased the corn and soybean seed businesses of Asgrow (the second largest soybean seed producer), Holdens Foundation Seeds (the largest foundation seed firm in the United States), DeKalb (the second largest hybrid corn firm), and Cargill's international seed business. Monsanto tried to acquire Delta and Pineland, the largest cottonseed producer in the United States, but subsequently dropped that pursuit.

These purchases brought these large life-science companies into the seed business of many developing countries in 1998. In addition, they purchased firms or entered into joint ventures with local seed companies in these countries. This gave them a market for the plant biotechnology products that they have developed through their own research and the research of the firms they purchased. Table A-10 documents the purchase and joint ventures of the major U.S. and European life-science companies with local seed firms in India, China, Southeast Asia, and Latin America.

A small but growing trend in industry structure is the purchase of technology-based companies in industrialized countries by emerging MNCs from developing countries. A pioneer in this area was the Thai firm Charoen Pokphand, which has extensive business interests in Southeast Asia, China, and the United States. It has a long history of joint ventures in Asian countries, with DeKalb for seed and Arbor Acres for poultry genetics. However, recently it decided to purchase the U.S. broiler-breeding company Avian Farms to give it another source of poultry genetics. More recently, the Mexican firm Empresas La Moderna purchased the U.S. biotechnology company DNA Plant Technology and vegetable seed companies Seminis, Peto Seeds, and Asgrow Seeds. It then sold Asgrow's corn and soybean business to Monsanto and kept the vegetable part of Asgrow.

The emergence of biotechnology and changes in the structure of the international agricultural input industries helped to stimulate more private agricultural research in Asia. Monsanto's investments in biotechnology, chemical, and seed research have been important sources of new opportunities and funds for research in India, China, and Thailand. AgrEvo is investing in biotechnology research and seed industries in India and China. DuPont is expanding its research in China and India.

Although the breakthroughs in biotechnology may be pushing the structural changes in the international agricultural input industries, so far biotechnology has had limited direct effect on food production or private R&D in Asia. The technological opportunities created by the new tools of biotechnology first stimulated private research in the early 1980s in Malaysia. Plantation companies thought that tissue culture would allow them to develop high-yielding oil palm clones. Despite considerable amounts of money and time, this research has yet to prove profitable. The second wave of biotechnology research has been in the seed industry. Major seed firms are testing transgenic corn, cotton, rapeseed, and soybeans in greenhouses or confined plots. In China, India, and Thailand, seed companies

Table A-9—Mergers and acquisitions in agricultural chemicals, biotechnology, seeds, and food/feed, Asia, 1994-98

Parent company	Agricultural chemicals	Biotech	Seeds	Food/feed
Monsanto		Calgene Agracetus Ecogen (13 percent) Millenium Pharmaceutical (JV for crops genes)	DeKalb, Asgrow corn and soybeans, Holden's Foundation Seed, Delta & Pineland (not yet approved), Cargill International Seeds, Plant Breeding International Cambridge.	Cargill JV feed and food (Monsanto already has brands like Nutrasweet).
AgrEvo	1994, merger of Hoechst and Schering plant agriculture business.	Plant Genetic Systems PlantTec.	1997, Nunhems Plant Genetic Systems, Pioneer Vegetable Genetics, Sunseeds; 1998, Cargill U.S. Seeds.	
Novartis	1996, merger of Ciba-Geigy and Sandoz; 1997 buys Merck's crop protection business for $910 million.		1996, merger brings together Northrup-King, S&G Seeds, Hilleshog, Ciba Seeds, Rogers Seed Co.	
Dow Chemicals	1997, Dow purchases Eli Lilly's 40% share of Dow Elanco for $900 million; 1997, buys Sentrachem Ltd. of South Africa $495 million.	Mycogen 1996 Ribozyme Pharmaceuticals Inc.	1996, United AgriSeeds becomes part of Mycogen; 1992, Mycogen bought Agrigenetics.	
Zeneca	1997, Ishihara Sangyo Kaisha.	1997, Mogen International N.V.	Advanta (merger of Zeneca seed and Vanderhave).	
DuPont			1997, Pioneer (20%) Hybrinova (France).	Quality Grain (JV with Pioneer), Protein Technologies (food), Cereal Innovation Centre (United Kingdom).
Empresas La Moderna/ Seminis		DNA Plant Technology.	Asgrow vegetables, Petoseed, Royal Sluis, Seminis (ELM owns 62%, George Ball, Jr., the rest).	Bionova.
Rhone-Poulenc	December 1998, discussing merger with Hoechst.	Limagrain (alliance) owns Nickersons, Vilmorin, Ferry Morse, and others.		
Merck	Merial Animal Health a JV with Rhone-Poulenc.			

Table A-10—Effect of mergers and acquisitions on U.S., Indian, Chinese, and Latin American seed industries, 1998

Parent company (main business)	U.S./European seed companies	Indian seed companies	Chinese seed companies	S.E. Asia	Brazil and Argentina
Monsanto (U.S. agricultural chemicals, pharmaceuticals, food additives)	Holden's DeKalb Asgrow (soybeans and corn) Stoneville Delta & Pineland, Cargill International Seed Business	MAHYCO (50-50 cotton Monsanto; 26% of MAHYCO) E.I.D. Parry (corn, sorghum and sunflower with DeKalb), and Cargill	CASIG (corn with DeKalb), Xingjiang, and Shaanxi Provincial Seed Companies Hebei Provincial Seed Co. (cotton Delta & Pineland), Cargill (Liaoning)	DeKalb (JV with Charoen Pakpoen) Cargill	Agroceres (Brazil) Asgrow DeKalb Monsoy (Brazil), and Cargill
DuPont (U.S. chemicals, oil, fiber & food)	Pioneer	Southern Petrochemicals (Pioneer)	Pioneer Research Subsidiary	Pioneer	Pioneer
Aventis (German French agricultural chemical, pharmaceuticals)	AgrEvo PGS Nunhems	Proagro Sunseeds	Sunseeds JV	Sunseeds	Sunseeds JV in Chile Granja 4 Irmaos S.A. (Brazilian rice breeder)
Novartis (Swiss agricultural chemicals and pharmaceuticals, and food)	Northrup King	Novartis (was Sandoz)		Novartis (was Ciba Seeds)	Northrup King
Astra/Zeneca (Swedish/U.K. agriculture chemicals and human health)	Advanta	ITC/Zeneca	Advanta	Advanta (was Pacific Seeds)	None
Dow (U.S. chemicals)	Mycogen	None	None	None	Morgan SA (Argentine), Dinamilho (Brazil)
Empresas La Moderna (Mexican agribusiness)	Seminis Peto Asgrow (vegetables) George Ball	MAHYCO (Asgrow), Nath Slius, Indo-American Seeds	Petoseeds has JV with CASIG and subsdiary in Shanghai	Petoseeds	Petoseeds

are conducting government-approved field trials of transgenic plants. China is the only country of this group that has approved the commercial use of transgenic plants developed by a private firm; Monsanto is selling its transgenic cottonseed in China.

Effect of Country Policies on Private Agricultural Research in Asia

In addition to the global forces described earlier, policies undertaken in individual Asian countries have also influenced incentives for private agricultural research and technology transfer in those countries. Probably the most important policy change has been market liberalization and greater participation by foreign firms in domestic markets.

Market Liberalization and Competition Policy

The major policy changes that stimulated more private research in Asia were eliminating public monopolies, reducing subsidies for public sector input firms, and allowing foreign firms to play a larger role in input industries. The most liberal market economies in the mid-1980s—Thailand, Malaysia, and the Philippines—had the highest private research intensities at that time. The countries with the most controlled economies—China, Indonesia, Pakistan, and India—had the lowest private research intensities.

The countries in which private research intensity grew most rapidly—China, India, Pakistan, and Indonesia—had major liberalization programs during the mid-1980s (table A-11). China allowed foreign firms into the seed, pesticide, feed, and agricultural machinery as joint-venture partners starting in the late 1980s, although there were still restrictions. Before the late 1980s, only a few poultry genetics firms had been allowed to sell technology in China. In India, the government gradually reduced restrictions on the foreign input firms—particularly in the seed industry but also in pesticides and agricultural machinery where foreign firms had been restricted to being minority partners in joint ventures. In the 1980s, Pakistan and Indonesia reduced the role of the public sector in supplying subsidized inputs to farmers. In addition, Pakistan had a strong policy of privatization and liberalization after 1988. None of these countries eliminated or even substantially reduced the size of the government corporations in the agricultural input industries, but they did level the playing field by reducing subsidies and eliminating monopoly powers of state-owned enterprises.

Malaysia, Thailand, and the Philippines already had private input industries before 1985. Furthermore, the plantation sector, where much of the private agricultural research in these countries is concentrated, was held by private firms. The Philippines was the only country that made important changes after 1985, when it reduced subsidies and political favors to one large input firm, Planters Products, which was run by associates of then-President Marcos.

Intellectual Property Rights

Firms do not conduct research unless there is some way to capture some of the benefits from research and turn them into profits—which is called appropriability in our model. In Asia, input firms have primarily used technical means (i.e., product formulations that are difficult to copy) of protecting their intellectual property. Seed companies protect new plant varieties by producing only hybrids. Chemical companies protect new pesticides or pharmaceuticals by keeping the process of production secret and by making chemicals that are difficult to reproduce. Plantation owners capture benefits of research by developing technology for use on their own plantations.

Patents and other forms of intellectual property rights (IPRs) have not played a very significant role in stimulating private research in these countries. In fact, the empirical relationship between the strength of the patent system and private research in these countries is weak—perhaps because none of the countries had strong intellectual property rights systems in the 1980s and 1990s (table A-12). China and Indonesia, with no patent system for agricultural inventions at the beginning of the period, had the lowest research intensity in the mid-1980s, and Malaysia, with the strongest laws, had the highest research intensity. However, Pakistan, which had stronger IPR laws than India (although both had very weak enforcement), had much lower research intensity than India which had IPRs with less coverage.

Nor is the strengthening of IPRs strongly associated with growth in private research. There were some substantial changes in policies during this period (table A-12), but they are not consistently related to changes in research intensity. For example, Malaysia and Thailand made improvements to their patent laws but had declining research intensity. India and Pakistan, which

Table A-11—Industrial policy changes, impact, and future policy options

Countries	Industrial policy changes since mid-1980s	Effect: increase in private R&D	Further policy options
China	Allows foreign firms 20% of pesticide, JVs in seed and poultry hatcheries.	More than $16 million	Reduce subsidies to parastatals, allow foreign and local private larger share of market; and allow foreign firms to be majority share-holders in joint ventures in seed and agricultural chemicals.
India	Allows foreign firms & large Indian firms into seed and biotech industry. Government corn seed sales from 4,842 metric tons in 1981 to 3,984 metric ton in 1991. After 1991, wholly owned subsidiaries of foreign firms allowed in most industries. Barriers to imports of active ingredients of pesticides reduced.	More than $3.6-million seed industry More than $8 million in pesticide R&D	Allow imports of agricultural inputs.
Malaysia	Promoted privatization and foreign investment.	Small effect	Restrictions on foreign investment in tree and crop production.
Thailand	Promoted privatization and foreign investment before 1985. Government corn seed sales from 2,000 metric tons in 1980s to 5 metric tons in 1995.	Small effect	
Indonesia	Pesticide subsidies reduced, and private companies allowed to market pesticides to farmers.	More than $1.6 million in pesticide R&D	Restrictions on private investments in plantations.
Philippines	Role of planter products in distributing subsidized inputs eliminated. Import barriers on inputs reduced.	More than $0.8 million in pesticide R&D	
Pakistan	Early 1980s, pesticide distribution privatized. Since 1988, privatization of processing industries.		Punjab and Sind Seed Corporations still major seed suppliers.

Table A-12—Intellectual property rights, Asia, 1979-98

Countries	IPRs in 1980	IPR changes since mid-1980s	Current exclusions	Further policy options
China	No patent law.	Invention patent system and petty patent system in 1985; coverage extended to agriculture chemicals in 1993; successful lawsuit by American Cyanamid against copying 1997; and plant breeders' rights passed 1997.	Only plants and biotech products excluded.	Administration to enforce plant breeders' rights for stronger enforcement of patents.
India	Patent law excludes product patents on chemicals, plants, and food	No major changes, and revised patent law and plant breeders' rights proposed to parliament but not passed.	Agriculture chemicals, pharmaceuticals, foods, plants, and biotech excluded.	Change legislation to include excluded products and better enforcement.
Malaysia	Patent law only excludes plants.	Stronger patent law passed 1986.		
Thailand	1979 patent law included pesticides, excluded agriculture machines and plants.	1992 patent law extended coverage to farm machinery, biotechnology processes, and genetic sequences. Plant breeders' rights before parliament.	Plant and animal life forms excluded.	
Indonesia	No patent law.	1991 patent law.	Plants, animals, biotech	
Philippines	Patent law only excluded plants; weak patents allowed.	No major changes. Plant breeders' rights proposed to parliament but not passed. New patent regulations were passed in 1997.	Plants, animals, biotech	
Pakistan	Patent law only excluded plants.	No major changes. Plant breeders' rights proposed to parliament but not passed.	Plants, animals, biotech	

had very limited changes in IPRs during this period, had the most rapid growth in research intensity.

Investments in Public Agricultural Research

The relationship between public and private research can be one of either substitutes or complements. If public research institutions develop and disseminate technologies similar to those developed by private companies, then public research could discourage the private sector from investing in new technology. However, public research can provide important "upstream" science and technology for private firms to adapt into applied product innovations. Public research institutions and universities also reduce the cost of research inputs for private companies, especially by expanding the available pool of scientific and technical personnel.

In most instances, we find evidence of strong complementarities between public and private agricultural research in Asia. Public research provided basic technology such as downy mildew-resistant corn in southeast Asia and downy mildew-resistant pearl millet in India. These breakthroughs allowed the development of the hybrid seed industries in south and southeast Asia. A survey of Indian private plant breeders found that the Indian public research system has been a major source of breeding material for cotton and sorghum, while the International Center for Research in the Semi-Arid Tropics (ICRISAT) has been a major source of germplasm for pearl millet (Pray, Kelley, and Ramaswami, 1998). In China, two emerging local private research firms are evolving out of provincial hybrid rice and hybrid corn research programs (see the China case study section).

In addition, public research is providing technology to improve seed firms' appropriability. Hybrid rice is the focus of much private research in India and some private research in the Philippines, Pakistan, and Thailand due to the work of the International Rice Research Institute (IRRI) and national government programs that developed hybrid rice technology for the Tropics. In addition, hybrid mustard, developed by Indian universities and European firms, and techniques like genetic fingerprinting, developed in part by public institutions in industrialized countries, are providing technical means of capturing more of the gains of private research.

Public research has also been very important as a source of scientists for private research. Almost all Asian private-sector plant breeders first worked in government research institutes and/or international agricultural research centers. This is not surprising because there is virtually no place else to hire trained scientists. The important point is that firms are likely to invest more in research in countries with many well-trained agricultural scientists.

Between 1971 and 1991, public research grew much more rapidly in developing countries than in industrialized countries. In low-income Asian countries, research expenditures grew by 8.9 percent in 1971-80 and 6.0 percent in 1981-93. In middle-income countries, research expenditures grew by 6.8 and 6.4 percent in the same periods (Alston, Pardey, and Roseboom, 1998). From 1971 to the early 1990s, public research intensity grew in all countries in our sample except China.

Public and private research expenditures and research intensities are positively related in the Asian countries in our sample. In 1985 and 1995, public and private research intensities were highest in Malaysia and Thailand and lowest in Indonesia (table A-13). There is no obvious connection between growth in private research and high research intensity or high rates of public sector growth (table A-13). China's and Indonesia's public research grew slowly but had the highest private research growth. Thailand had the second highest growth of public research in 1981-93, but private research there grew relatively slowly.

Public sector flows of agricultural technology between industrial and developing countries through international agricultural research increased markedly after 1960 but recently began to ebb. The most notable development was the establishment of the Consultative Group for International Agricultural Research (CGIAR) system of international agricultural research centers (IARCs). This evolved into an effective system for breeding and transferring new crop varieties and germplasm to national agricultural research programs in developing countries. Advanced germplasm provided by IARCs has also benefited industrialized countries.

Funding for the international agricultural research centers declined in real terms since the early 1990s. The decline in real funding at the four original centers—IRRI (for rice, located in the Philippines), ICRISAT (pearl millet and sorghum, located in India), International Maize and Wheat Improvement Center (CIMMYT) (maize and wheat, located in Mexico),

Table A-13—Agricultural research expenditures, Asia, 1985 and 1995

Country	Public			Private		
	1985	1995	Growth	1985	1995	Growth
	Millions of 1995 U.S. dollars		*Percent*	*Millions of 1995 U.S. dollars*		*Percent*
India	206	348	69	26	56	116
China	403	485	20	0	16	Infinite
Indonesia	62	81	31	3	6	118
Malaysia	44	64	44	14	17	18
Philippines	17	38	113	6	11	69
Thailand	67	127	89	11	17	64
Pakistan				2	6	138
Total	800	1,142	43	62	128	99

Source: Country case studies.

and International Center for Tropical Agriculture (CIAT) (rice, cassava, and beans, located in Colombia)—started in the late 1980s (Alston, Pardey, and Roseboom, 1998). Of these centers, IRRI, ICRISAT, and CIMMYT have had major effects in Asia, including helping to stimulate more private seed research by providing a better pool of crop germplasm. As of 1998, there was no evidence that the decline in research by international centers had reduced the private sector's technological opportunities. This may be because the small decline in international center research is offset by the large increase in technological opportunity due to the increased interest in Asia by large private multinationals.

Most government research programs in Asia are now implementing or at least considering ways to strengthen linkages between public and private agricultural research. This is taking more concrete form in several countries. One approach is to establish government programs to fund joint public-private research projects. Indonesia, Thailand, and India have developed programs of this type. Another approach is to require public research institutions to raise a certain proportion of their research budgets from the private sector, such as through product sales. Public research can stimulate private research by selling research inputs such as plant germplasm to the private firms. So far, most systems are selling finished technology or other nonscience assets such as land. China is the furthest in the privatization process. About 40 percent of the revenue of China's public research system comes from commercial enterprises, but most of that is from nonscience assets and does little to stimulate private research (Pray, 1999). The aim of privatization of public research in Malaysia is that eventually 60 percent of the money will be from private sources. The Indian Council for Agricultural Research is setting 20 percent as its goal.

Research Subsidies and Tax Incentives

In recent years, Asian governments have started to offer special subsidies and tax benefits to encourage private research. For several years, Malaysia has had an R&D tax credit program that allows firms to write off 200 percent of their research expenditures from their corporate income taxes. In 1997, India introduced a 120-percent R&D tax credit. The Philippines, Malaysia, Thailand, and some Indian states have invested public resources to establish research parks, some of them specifically for biotechnology-related food and agriculture. Research parks are designed to encourage private research by improving access to research facilities and public research institutions

From our interviews with private companies, we found little evidence that the tax policies or the research parks have had an important effect on private research. Most of these policies had just been established. Thailand has had an R&D tax credit for a number of years, but none of the firms we interviewed were aware of the tax credit or took it into account in their research investment decisions. However, in the 1980s, the Thailand Board of Investments introduced incentives for the seed industry, including a 10-year tax holiday for new seed companies, a waiver of import duties on research equipment and materials, and permission for foreign companies to own agricultural land for research purposes. Some firms acknowledged that this was an important incentive for them to invest in seed processing and research in Thailand.

Regulations for Public Health, Environmental Protection, and Product Efficacy

To protect farmers and consumers from health and environmental hazards, fraud and product mislabeling, and potentially harmful plant and animal diseases, governments have developed an extensive set of regulations on new plant varieties, seed and animal imports, pesticides, agricultural machinery, and food. Some new regulations have received additional support from industries that wish to use them as nontariff barriers against foreign competition. Multinational corporations often encourage the development of environmental and safety regulations because they will raise the cost of production of local firms. Regulations in foreign countries that import agricultural products from Asia also influence local regulations.

Some of these regulations can have an important effect on R&D. Establishing a clear and consistent regulatory regime for agricultural inputs can encourage private companies to undertake research. For example, few international companies are willing to do research on transgenic plants unless a country has some system for government regulation of testing because the negative publicity of such activity in the absence of an approved regulatory framework would be too great. Thus, while private research on transgenic plants is being conducted in Thailand, China, and India, none is being conducted in the Philippines because the Philippines has not approved testing of transgenic plants in the field. However, excessive regulation reduces the amount of private research. Mandatory government testing and registration of new crop varieties developed by private companies can add years and tens of thousands of dollars of research costs. This reduces the rate of return to investments in research and thus acts as a disincentive for private breeders.

Table A-14 lists the regulations that are in place on seeds, pesticides, and biotechnology for several Asian countries in 1997-98. In general, China and Thailand have placed the least emphasis on environmental and safety regulations and the most emphasis on obtaining technology quickly in all industries. India, Malaysia, and the Philippines have been at the other end of the spectrum, with more emphasis on environmental and safety regulations. This often leads to a longer lag between the time when research is conducted and the time the new technology reaches farmers. International chemical firms reported that in the past regulations did lead companies to test and market chemicals more rapidly in Thailand than in India. However, recent changes in the way the Indian regulatory system works seem to have increased their interest in doing research in India. As mentioned earlier, the lack of regulations for testing genetically engineered plants in the field has meant that private agricultural biotechnology research is being conducted in Thailand, China, and India but not in the Philippines.

The seed industry is the one industry that is an exception to the statement that China has the least regulation and India the most. India (along with Thailand and the Philippines) has voluntary testing and registration of varieties, while China has mandatory testing and registration. This has been one of the reasons Thailand and India have most of the private plant breeding research in Asia. Mandatory testing and registration of new varieties has also discouraged private seed research in Indonesia.

Policy Options for Developing Countries

The country case studies provide several lessons for policies and policy options for developing countries that wish to encourage the private sector to invest in agricultural research and technology transfer in their countries. Some of the major lessons are described in this section.

Sequencing of Policies

The country case studies provide clear evidence that certain policies will have little effect on private research unless a country meets certain prior conditions, has passed through some minimum stages of development, and has some key policies in place. For example, passing plant breeders' rights legislation or strengthening the patent system when there is no demand for modern seed or when the seed industry is a government monopoly will not stimulate private research. Likewise, tax incentives and research parks will not stimulate small biotechnology firms if intellectual property rights are weak or there is no possibility of field-testing and commercializing genetically modified organisms.

The first requirement for private research is a large and growing demand for agricultural products so that farm-

Table A-14—Regulations on use of pesticides, seeds, and genetically engineered plants, Asia, 1997-98

Country	Pesticides	Seeds	Genetically engineered plants
China	Relatively quick ecological tests, health/safety tests based on foreign data, time reduced in recent years, and data not secret.	Mandatory variety testing and seed registration.	1997 testing protocol established, although use of genetically engineered crops has been growing since the early 1990s.
India	Field testing takes several years and have to duplicate tests done elsewhere, and data not secret. Years required recently declined.	Voluntary variety testing and seed registration.	Field testing since 1996.
Malaysia	Strictly follows WHO/Food and Agriculture Organization guidelines. Banned dirty dozen and pushing integrated pest management (IPM).	Mandatory variety testing and seed registration.	Field testing protocol, but no field tests yet.
Thailand	Quick registration based mainly on foreign data.	Voluntary variety testing and seed registration.	Field tests since 1994.
Indonesia	Banned dirty dozen, pushing IPM for rice.	Mandatory variety testing and seed registration.	No field testing protocol.
Philippines	Relatively quick ecological tests, health/safety tests based on foreign data, data is kept secret, and banning dirty dozen.	Mandatory variety testing and seed registration.	Field testing protocol in 1998. First tests scheduled for 1999.
Pakistan		Mandatory variety testing and seed registration.	

ers demand modern and improved inputs. Traditional agriculture or agriculture which does not have effective demand for modern inputs because infrastructure is inadequate or because policies discriminate against the agricultural sector will not attract private research. Public investments in research and a means of supplying inputs to farmers will be required in countries where land rather than labor is the key constraint to production and locally appropriate modern technology is not readily available. In small countries or niche markets, private research may not develop or supply the needed technology, and public research will continue to be needed to provide technology.

The second requirement is that private firms be allowed to supply agricultural inputs and operate plantations in a competitive market. Obviously, if there is a state monopoly on input supply or if governments run the plantations and food business, private investment will not grow. If public monopolies of input supply are turned into private monopolies, welfare losses are likely to increase. Allowing foreign investment and trade in the input industry is an important way of increasing competition and increasing a country's access to technology that has been developed and commercialized elsewhere in the world. Other needed policies are competition policies that ensure that no local or foreign firm has too much market power.

When these conditions are in place, intellectual property rights and regulatory frameworks can be an important stimulus to private research. With IPR protection, firms will have the ability to capture some of the benefits from research even in competitive markets. Firms will then choose to invest in developing improved inputs or management practices for which there is potential demand and technology opportunities based on local public and private research or research conducted elsewhere.

Finally, with intellectual property rights in place, tax subsidies for research or research parks may be important inducements to further research. R&D tax credits are being tried in a number of places in Asia, although the evidence on their records is mixed. The success of some of the science parks in Taiwan and in industrialized countries demonstrates their potential. But these science parks are typically most successful when they are near major research universities or research institutes that supply ideas for new firms as well as scientists and technicians for the firms. The synergistic relationship between the private science parks and public institutions re-emphasizes the importance of public research, especially on generic problems of industries rather than applied research that provides competing technology.

Competition in Input Industries

Continued policy reform to increase competition in the input industries in Asian countries is an important step.

China still greatly restricts the role of the local private sector and would likely benefit by moving its state-owned enterprises closer to being private firms. That observation is especially true for the seed industry, as the government still has a monopoly on hybrid seed sales.

Reductions in nontariff and tariff barriers by India and China against foreign competition in the input industries would aid the transfer of technology. China not only restricts finished inputs but also restricts foreign firms to 20 percent of the pesticide industry and has official regulations that do not allow foreign firms to own a majority of shares in seed firms. India recently allowed foreign firms to produce pesticides, seeds, and machines for local sale but does not allow imports of any finished agricultural inputs, whether of seed, pesticide, tractors, or irrigation pumps. China is under some pressure to liberalize agricultural input markets as a condition for joining the World Trade Organization (WTO). India is also under pressure from the WTO because it is already a member and has actions pending against it for its nontariff barriers.

Antimonopoly or competitive policies may be important in most advanced developing countries such as Thailand, where the public sector plays a minor role in supplying inputs. In some countries, antimonopoly policy may become important if mergers and acquisitions in the input industries give too much market share to one company. For example, if Cargill combines with DeKalb/Charoen Pokphand, the merger will control up to two-thirds of the hybrid corn seed market in Thailand.

Intellectual Property Rights for Agricultural Inventions

India's and Pakistan's intellectual property laws are not consistent with the Trade Related aspects of Intellectual Property Rights (TRIPS) agreement of the WTO, and all countries in this study except Malaysia (which already has well-respected IPR laws), could use stronger and more effective enforcement. In countries where sufficient IPR laws are already established, the industries will often need to push for better enforcement.

Public Research To Complement Private Research

Enhanced public research support can advance each stage in the research and development process: In traditional agricultural systems, public research can jump-start the agricultural development process and create new markets for modern inputs. Further, public research extends the set of technological opportunities available for private R&D. Public research is also important for conducting the public goods research on environmental and health issues, and working on orphan crops and neglected regions.

Excessive privatization of funding of public research may have the unintended effect of reducing funding for the public sector and the incentive to do public goods research.

Rational Regulatory Regimes

1. Consistent protocols for field testing and commercialization of genetically modified plants and animals among countries would enable better exchange of information between countries for monitoring and enforcement. Public-sector costs for biotechnology regulation can be charged to input companies, as in the case of pesticide regulation.
2. Shared new crop variety testing protocols among countries could help eliminate requirements for mandatory testing and registration of new crop varieties that exist with China and Indonesia and could,

hence, increase the rate of delivery of new private varieties to farmers.

3. To assure that quality inputs are delivered to farmers, countries could strengthen enforcement of truth-in-labeling laws.

Emphasis on Technology Transfer for Small Countries

Openness of borders to international supplies of agricultural inputs can be supplemented by activities, such as providing a network of locations for testing new technology that would reduce firms' costs of bringing in new technology.

Implications of International Technology Transfer for U.S. Policies

The increased rate of international technology transfer has important implications for U.S. farmers, agricultural input industries, and consumers. In this section, we examine some of the implications for U.S. policies toward trade, development, and public agricultural research. But first, we discuss the general question of how agricultural productivity growth in developing countries affects U.S. farmers, industries, and consumers.

Effects of Technology Transfer on U.S. Farmers, Industries, and Consumers

Growth in agricultural productivity is becoming increasingly important for countries to maintain or enhance their competitiveness in the global economy. New technology that lowers unit costs of production makes it easier for producers to export their commodities or compete against imports from other countries. However, there are compelling reasons for maintaining a relatively open environment for international technology flows. In addition to enhancing markets for agricultural input industries and providing consumers with cheaper and more varied products, promoting the international exchange of agricultural technology can yield significant benefits to U.S. agricultural producers.

The first point to recognize is that international technology transfer increases U.S. agricultural productivity. Although the United States is a net exporter of agricultural technology, foreign technology has made major contributions to the productivity of U.S. agriculture and is becoming an increasingly important source of new technology for U.S. producers (Pray and Fuglie, 1999). For example, the ability of the U.S. agricultural research system to provide new and improved crop varieties and livestock breeds relies to a significant degree on access to foreign crop and livestock germplasm. Pardey et al. (1996) estimated that wheat and rice germplasm obtained from the International Agricultural Research Centers added between $3.4 billion and $14.7 billion to the value of U.S. agricultural production between 1970 and 1993, compared with a U.S. contribution of only $134 million to these centers since 1960. Private international technology transfer has also made significant contributions to U.S. agriculture. For example, PIC, based in the United Kingdom and now the market leader in swine genetics in the United States, supplies hybrid swine breeds that incorporate the exceptionally high fecundity of Chinese parent lines and the leanness of European parent lines.

At the same time, international technology transfer does increase the productivity of agricultural producers in other countries. Foreign producers can make new farming methods and improved inputs to raise their productivity and reduce production costs. For U.S. agricultural seed, chemical, and machinery industries, this means new and expanded market opportunities. For U.S. consumers, this implies reduced costs of imported food and food products. For U.S. farmers, some commodity groups may be adversely affected by increased foreign competition or reduced demand for imports, at least in the short run.

The net effect of foreign productivity growth on the U.S. economy is usually measured by how it affects the international terms of trade. The terms of trade is simply the ratio of export prices to import prices. If foreign productivity growth reduces the price of goods imported by the United States (i.e., causes the terms of trade to rise), then the United States could purchase more from abroad with the same level of exports. Thus, foreign productivity growth that caused the terms of trade to increase would provide a net gain in U.S. economic welfare. Productivity growth in imported tropical fruits and beverages that lowered the prices of these commodities, for example, would enhance U.S. terms of trade because fewer U.S. exports would be required to pay for them. On the other hand, productivity growth in commodities that compete with U.S. farm export commodities, such as corn, wheat, and soybeans, could adversely affect U.S. terms of trade by reducing world prices for these goods.

Some studies have suggested that agricultural productivity growth in developing countries, even if it may have shortrun negative effects on U.S. terms of trade, can have positive effects in the long run (see Pinstrup-Anderson, Lundberg, and Garret, 1995 and the collection of studies in Vocke, 1990). This is due to: (1) the importance of the agricultural sector in these countries, so that the rate of growth in the agricultural sector required for growth in the overall economy, and (2) the large share of household incomes spent on food in poor countries, so that an increase in the rate of economic growth translates into a rapid rise in the demand for food. As incomes rise and food consumption turns away from food staples to include more high-valued meat and other products, these countries often increase their imports of agricultural commodities such as meats and feed grains. According to this view, efforts to increase the rate of agricultural technology transfer should not harm U.S. farmers, but can instead enhance markets for U.S. agricultural exports. Agricultural productivity growth in industrialized countries, however, would not have a potentially positive longrun effect on the demand for U.S. agricultural products. In industrialized countries, the size of the agricultural sector is relatively small, and food is a small share of household expenditures. Thus, agricultural productivity growth in these countries will have only a small effect on the economy as a whole and only a small share of increased per capita income will be spent on food.

The empirical evidence on the relationship between agricultural productivity growth and demand for agricultural imports in developing countries is mixed and may have weakened over time (Paarlberg, 1986). One reason is that economic growth and the demand for food imports by developing countries is more strongly influenced by macroeconomic variables, such as interest rates and exchange rates, than by the performance of individual sectors. Another reason is that the emergence over the past decades of international private capital markets to finance economic development has weakened the necessity for agricultural growth to generate overall economic growth in developing countries.

Implications for U.S. Trade and Development Policies

The trade policies endorsed by the United States generally have supported technology transfers to developing countries and greater U.S. food exports. The U.S. Government has supported reductions in agricultural trade barriers through multilateral trade negotiations under the auspices of the World Trade Organization (formerly GATT). Reduced restrictions on trade and foreign direct investment increase the profitability of international technology transfer by multinational agribusiness firms. Further, the United States has sought and obtained commitments to stronger legal protection for intellectual property in these multilateral trading agreements. Stronger intellectual property rights (IPRs) will encourage more private agricultural research and technology transfer, especially in countries that have established the right prerequisites, such as competition in input industries (see the earlier discussion on "Sequencing of Policies"). Most of the effect of these changes will be on developing countries because they have the most trade and investment restrictions and weakest IPRs, especially the developing countries in transition from communism.

> *Reducing barriers to agricultural input trade and foreign investment in agricultural input industries could have particularly high payoffs in Asian agriculture.*

U.S. development policy has provided support for international and national agricultural research systems in developing countries since the 1950s. While the primary aim of these investments has been to increase food production in poor countries, international agricultural research has also provided significant spillover benefits to U.S. agricultural producers. The U.S. Agency for International Development (USAID) has also had a small program to enhance private-sector technology transfer from U.S. agricultural input firms to private companies in developing countries, particularly in biotechnology. However, overall USAID support for technical assistance for agriculture has fallen considerably in real dollars in the past several years.

> *Continued support of the International Agricultural Research Centers (IARCs) is a key element for maintaining research and economic growth. Funding IARC also helps direct the attention of private biotechnology firms to developing-country opportunities in food and agriculture.*

Implications for U.S. Agricultural Research Policy

The main implication of increased speed of international technology transfer is that there are far-reaching benefits from U.S. involvement in collaborative research with other countries and collaborative funding of international agricultural research. Because the benefits of agricultural research, especially research in basic agricultural science, spread to many countries so quickly, research policy needs to find ways to encourage other countries that benefit to pay some of the research costs. Otherwise, a free-rider problem may develop in which no country wants to pay the costs of research, relying instead on technology developed and paid for elsewhere. Spillover benefits from U.S. public research may go to foreign farmers who adopt the technology early, food processors, and consumers of agricultural products.

There are at least three ways to increase cost sharing of this research. The first option is to encourage joint government funding of basic agricultural research. Funding could be shared according to the likely share of benefits received by each country. The actual research could be done collaboratively between institutes in the funding countries, at international agricultural research centers, or by individual national institutes selected on the basis of a competitive grants program. A second option is to develop a public-private international research consortium in which multinational firms fund agricultural research at public universities or national research institutes on generic research that is important to firms but they cannot afford to do by themselves. A third option is to charge multinational firms higher royalties or higher fees for contract research when that research will primarily benefit foreign farmers or consumers. This requires public universities and national research institutes to invest more resources in enforcing their intellectual property rights (which some are already beginning to do) and assessing the foreign markets for their technology.

Increased international collaboration in public agricultural research is already taking place in genome mapping of major food crops. In addition to sharing the costs of basic research, collaboration with agricultural research institutes in developing countries can improve the efficiency of research spending. The costs of research can be reduced by allocating research activities to countries with a comparative advantage in that activity. For example, collaboration can be built on U.S. strengths in basic biological research and the comparative advantage of developing countries in labor-intensive research activities. For example, activities such as plant or poultry breeding that hire large numbers of well-trained workers could be carried out in countries in which labor is relatively inexpensive.

Collaboration could also combine the elite germplasm developed in industrialized countries with unimproved germplasm from developing countries to produce hybrids adapted to each area. Collaboration between U.S. public research institutes and the international agricultural research centers has already proven to be extremely useful to U.S. farmers, and continued success can be anticipated.

Future Research Topics on Private Agricultural Research

A number of questions need to be answered before policymakers in the developed or developing countries can be assured that they have developed an appropriate science and technology policy for agriculture. These questions include the following:

> *What is the relative importance of the developing countries' policies and institutions on firms' investments in private research and the distribution of benefits from that research?*

Quantitative studies are needed to determine the effect of policies in industrialized countries on private research in those countries. When studies of private research in Latin America are completed by the International Food Policy Research Institute and International Service for National Agricultural Research, it may be possible to combine their data with results from this effort for some quantitative studies. In addition, it may be possible to obtain indicators of research and technology transfer in specific industries such as biotechnology, which could be used in quantitative studies.

> *What is the effect of private research and technology transfer on farmers and consumers?*

The only quantitative studies on the effect of private agricultural research in developing countries are in India. More studies are necessary for a more reasoned debate on the role of the private sector in agricultural research and its contribution to economic growth.

> *Can the Consultative Group on International Agricultural Research (CGIAR) institutes play a larger role in stimulating private research and the transfer of technology developed by the private sector?*

Much biotechnology is being developed by the private sector in developed countries. The CGIAR is exploring ways of working with the private sector, but even tentative moves in that direction are criticized vigorously by nongovernmental organizations. But whether the CGIAR can help to ensure competition in the international seed and biotech industry has yet to be demonstrated.

Have the donors and development banks developed some successful investments and policies to stimulate private research?

The developed countries have been talking about the importance of private research for some time. But they have yet to demonstrate any successful projects that have stimulated private research to oppose the argument that private research develops naturally when markets are liberalized.

References

Alston, Julian M., George W. Norton, and Philip G. Pardey. *Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*. Ithaca, NY: Cornell University Press. 1995.

Alston, Julian M., Philip G. Pardey, and Johanes Roseboom. "Financing Agricultural Research: International Investment Patterns and Policy Perspective," *World Development*. Vol. 26. 1998. pp.1,057-1,071.

David, C.C., and K. Otsuka (eds.). *Modern Rice Technology and Income Distribution in Asia.* Boulder, CO: Lynne Rienner Publishers. 1994.

Echeverria, Ruben G.. "Impact of Research and Seed Trade on Research Productivity," *Agricultural Research Policy: International Quantitative Perspectives*. Philip Pardey, Johannes Roseboom, and Jock R. Anderson (eds.). Cambridge: Cambridge University Press. 1991. pp. 365-395.

Echeverria, Ruben G., E.J. Trigo, and Derek Byerlee. "Institutional Change and Effective Financing of Agricultural Research in Latin America," World Bank Technical Paper No. 330. World Bank: Washington, DC. 1996.

Evenson, Robert E., Carl E. Pray, and Mark Rosegrant. *Agricultural Research and Productivity Growth in India*. Washington, DC: International Food Policy Research Institute.1999.

Evenson, Robert E., and Larry E. Westphal. "Technological Change and Technology Strategy," *Handbook of Development Economics, Volume III.* J. Behrman and T.N. Srinivasan (eds.). Elsevier Science. 1995. pp. 2,209-2,299.

Evenson, Robert E., and Yoav Kislev. *Agricultural Research and Productivity*. New Haven, CT: Yale University Press. 1975.

Falconi, Cesar. *Public and Private Sector Interactions in Agricultural Research in Less-Developed Countries: The Case of Ecuador*. Discussion Paper 92-13. The Hague, Netherlands: International Service for National Agricultural Research. 1992.

___________. *Public and Private Sector Interactions in Agricultural Research in Less-Developed Countries: The Case of Colombia*. Discussion Paper 93-14. The Hague, Netherlands: International Service for National Agricultural Research. 1993.

Food and Agriculture Organization of the United Nations. Statistical databases. http://apps.fao.org/cgi-bin/nph-db.pl

Fuglie, Keith O., N. Ballenger, K. Day, C. Klotz, M. Ollinger, J. Reilly, U. Vasavada, and J. Yee. *Agricultural Research and Development: Public and Private Investments Under Alternative Markets and Institutions*. AER-735. U.S. Department of Agriculture, Economic Research Service. May 1996.

Gisselquist, David, and Carl E. Pray. *Deregulating Technology Transfer in Agriculture: Reform's Impact on Turkey in the 1980s.* Policy Research Working Paper 2086. World Bank: Washington, DC. March 1999.

Griliches, Zvi. "Hybrid Corn: An Exploration in the Economics of Technological Change," *Econometrics*. Vol. 25. October 1957. pp. 501-522.

Henry, R., and G. Rothwell. "The World Poultry Industry," *International Finance Corporation Global Agribusiness Series*. Washington, DC: World Bank. 1995.

Mansfield, Edwin. "Intellectual Property Protection, Foreign Direct Investment, and Technology Transfer." Discussion Paper 19, International Finance Corporation. World Bank: Washington, DC. 1994.

Narrod, Clare, and Carl E. Pray. "Technology Transfer in the Poultry Industry: Factors and Externalities Associated with Increased Production," *Animal Wastes and the Land-Water Interface.* Kenneth Steele (ed.). Boca Raton, Florida: CRC Press. 1995. pp. 523-532.

Narrod, Clare, Carl E. Pray, and Willis Peterson. "Technology, Policies, and the Global Poultry Revolution." Unpublished paper. 1999.

Paarlberg, Robert L. "Farm Development in Poor Countries: The Disputed Consequences for U.S. Farm Trade," *American Journal of Agricultural Economics.* Vol. 68. December 1986. pp. 1,353-1,357.

Pardey, Philip G., Julian M. Alston, J.E. Christian, and Shenggen Fan. *Hidden Harvest: U.S. Benefits From International Research Aid.* Food Policy Report, International Food Policy Research Institute, Washington, DC. 1996.

Pingali, Prabhu, M. Hossain, and R.V. Gerpacio. *Asian Rice Bowls: The Returning Crisis?* Wallingford, United Kingdom: CAB International. 1997.

Pinstrup-Andersen, Per, M. Lundberg, and J.L. Garrett. *Foreign Assistance to Agriculture: A Win-Win Proposition*. Food Policy Report, International Food Policy Research Institute, Washington, DC. June 1995.

Pray, Carl E. *Private Sector Research and Technology Transfer in Asian Agriculture: Report on Phase I AID Grant OTR-0091-G-SS-4194-00.* Bulletin 85-5. Economic Development Center, University of Minnesota. December 1985.

Pray, Carl E. *Private Sector Research and Technology Transfer in LDCs: Report on Phase II.* Bulletin 87-1. Economic Development Center, University of Minnesota. March 1987.

Pray, Carl E., Bharat Ramaswami, and Tim Kelley. "Liberalization, Private Plant Breeding and Farmers' Yields in the Semi-Arid Tropics of India." Unpublished paper. World Bank: Washington, DC. April 1998.

Pray, Carl E., and Keith O. Fuglie. "The Private Sector and International Transfer of Agricultural Technology," *Public-Private Collaboration in Agricultural Research.* K. Fugli and D. Schimmelpfennig (eds.). Ames: Iowa State University Press. 2000. pp. 269-299.

Pray, Carl E., and Ruben G. Echeverria. "Determinants and Scope of Private Sector Agricultural Research in Developing Countries," *Agricultural Research Policy: International Quantitative Perspectives.* Philip Pardey, Johannes Roseboom, and Jock R. Anderson (eds.). Cambridge: Cambridge University Press. 1991. pp. 343-364.

Pray, Carl E., Scott Rozelle, and Jikun Huang. "Incomplete Commercialization of the Chinese Seed Industry: The Need For Further Reform." Paper presented at the Global Agricultural Science Policy For the Twenty-First Century conference. Melbourne, Australia. August 29, 1996.

Pray, Carl E., Sharmila Ribeiro, Rolf A.E. Mueller, and P. Parthasarathy Rao. "Private Research and Public Benefit: The Private Seed Industry for Sorghum and Pearl Millet in India," *Research Policy*. Vol. 20. 1991. pp. 315-324.

Ribeiro, Sharmila. "Private Research, Social Benefits and Public Policy: The Case of Hybrid Sorghum and Pearl Millet in the Indian Seed Industry." M.S. thesis. Department of Agricultural Economics, Rutgers University, New Brunswick, NJ. 1998.

Scherer, F.M. *Industrial Market Structure and Economic Performance*. Boston: Houghton Mifflin Company. 1980.

Schumpeter, Joseph A. *Capitalism, Socialism, and Democracy*. Third edition. New York: Harper and Row. 1950.

Thirtle, Colin, and Ruben G. Echeverria. "Privatization and the Roles of Public and Private Institutions in Agricultural Research in Sub-Saharan Africa," *Food Policy.* Vol. 19, No. 1. 1994. pp. 31-44.

Vocke, G. (ed.). *Trade and Development: Impact of Foreign Aid on U.S. Agriculture.* AGES 9004, U.S. Department of Agriculture, Economic Research Service. June 1990.

World Bank. *World Development Report.* New York: Oxford University Press. 1987 and 1997.

List of Tables and Figures

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Issues in Private Agricultural Research

The demand for new agricultural technology is growing in India. The population continues to rapidly grow, and per capita income growth has grown even more rapidly, pushing up the demand for food. In India, the land frontier is closed, irrigation is becoming more expensive, and urban growth is pulling people out of agriculture, which leaves research as the remaining major source of growth. Wealthier consumers want higher quality food and less environmental pollution, which also increases the demands on research.

Since 1985, public sector investment in agricultural research in India has continued to grow, but at a slower rate. In many of the Indian Council of Agricultural Research (ICAR) institutes, an acute shortage of operating funds has reduced scientists' productivity. In some of the state agricultural universities, the funding crunch has been even more acute. For example, the state government of Maharashtra has been gradually reducing funding every year to the state universities. In addition, the international agricultural research centers that contributed to India's growth in earlier years have had their budgets reduced considerably.[1] (Desai, 1997; and Pal, Singh, and Jha, 1997)

The result of the shortages of funds in some states and ICAR institutes and the weakness of public institutions for distributing public technology is that new public technology has spread very slowly to farmers. Consequently, farmers have begun planting older varieties. For example, wheat varieties in India have an average age of 9 years, versus 3 years in the United Kingdom (Witcombe, Virk, and Farrington, 1998).

The private sector has held the promise of alleviating some of these problems. Private firms began funding more agricultural research in Asia and the rest of the world. In addition, private firms have been conducting certain activities, such as commercializing and marketing new varieties more efficiently than the public sector. Thus, private research has presented an opportunity for more growth for Asian agriculture. It may have been encouraged through policy changes and public research that are more responsive to private firms' needs.

Since 1985, major international trends have reshaped world agricultural input and food industries to provide more technology for developing countries through the private sector. Barriers to international trade and foreign direct investment fell. Breakthroughs in biological sciences and favorable business conditions led to a major consolidation of biotech, seed, pesticide, veterinary, and human pharmaceutical firms into a few major life-science companies. These same firms began linking with the food industry through alliances, mergers, and acquisitions. These companies have made the latest biotechnology available to developing countries with large markets and an attractive business climate.

The increasing prominence of these life-science companies is, however, raising some questions: Will the technology they provide really be appropriate for India's small farmers? Will they force Indian farmers to use seeds with terminator genes, which would prevent farmers from keeping their own seed? Will they force farmers to use certain herbicides, which fit genetically engineered crops? Will they force the price

[1] According to some estimates, the agriculture-related R&D and education expenditures (in real terms) funded by ICAR and state governments grew at the rate of about 5.7 percent during 1974-83. This rate of growth declined to 4.9 percent during 1984-93 (see, Pal, Singh, and Jha, 1997). Presumably, if agriculture education-related expenditure is excluded, the decline would have been sharper.

of seed, pesticides, or machines to increase because of their market power? Will they patent products that farmers have been using for decades and restrict their use to farmers who pay high prices? Will Indian scientists be unable to access new genes and constructs developed in Organization for Economic Co-operation and Development countries that would be useful to Indian farmers?

To fulfill the growing demand for food, fiber, and beverages, India would benefit from the private sector's playing a larger role. The international private sector appears to be ready to play a larger role, and Indian firms are increasing their investment in agricultural research. Local and international firms could fund more research and conduct research and technology transfer activities more efficiently than the public sector. The questions that this chapter answers are: What role is private research playing? What role should the private sector play? What policy instruments are available for policymakers to influence the amount and direction of private research? Finally, what policies would be appropriate for India?

Agricultural Development

The major impetus to Indian agriculture was given during the late 1960s and early 1970s, with the advent of the so-called "green revolution technology." Agricultural production in India has rapidly grown since then.

The index of agricultural production rose from about 86 in 1970-71 to 176 in 1996-97. Since the last major drought in 1987-88, agricultural growth has been good, despite marginal setbacks in 1991-92 and 1995-96. Given the limits to area expansion, the increased production has essentially been the result of rising land productivity. These higher yields in turn were achieved by the use of modern agricultural inputs, including irrigation, chemical fertilizers, as well as improved and high-yielding seeds and pesticides.

About 80 million hectares of cropped area were irrigated in the 1990s. While the area under irrigation consistently increased over the years, only about 38 percent of the gross cropped area had access to irrigation in the 1990s (Government of India, 1998, pp. 92-93). The dependence of Indian agriculture on rainfall continues to be significant. The use of high-yielding varieties (HYVs) rapidly grew during the 1970s and 1980s; the rates of growth of HYV use seem to have declined in the 1990s. Along with the use of HYV seeds, the production and distribution of certified and quality seeds and the consumption of chemical fertilizers has also increased (table B-1). The index of fertilizer consumption rose from about 40 in 1970-71 to 259 in 1996-97. Fertilizer consumption per hectare rose from about 13 kilograms to 77 kilograms (Government of India, 1998, pp. 97-98).

About 56,000 tons of pesticides (technical grade material) was consumed in 1996-97. This is a marked increase from 24,000 tons in 1970-71 (Government of India, 1998, pp. 97-98). As table B-1 shows, the 1990s experienced some deceleration in the quantity of pesticides used; the index declined from 167 in 1990-91 to 125 in 1996-97. These indices are based on official statistics. Estimates provided by industry sources suggest an increase in the consumption of agro-chemicals even during the 1990s (Unni, 1997, table 6, p. 559). The pesticide market in India was dominated by insecticides (76 percent); the share of herbicides (13 percent) and fungicides (11 percent) in the agro-chemical market was rather small (Unni, 1997, p. 560).

Tractor production in India has been rising since the early 1970s. More than 191,300 tractors were manufactured in 1995-96, while the reported production in 1990-91 was only about 138,500. No reliable estimates are available for production of diesel engines and electric motors for irrigation. According to industry sources, approximately 500,000 to 600,000 diesel engines were produced for agriculture, and the demand for such engines rose by 5 percent per year during the 1980s and early 1990s (Basant, 1997).

Recent changes in India's cropping patterns and trends in capital formation also need to be highlighted. Changes in cropping patterns can contribute to increases in agricultural yields per hectare if the area shifts from low-yielding to high-yielding crops. Such changes also have implications for the demand patterns of agricultural inputs as the use intensity of these inputs varies significantly across crops. The rate and nature of capital formation in agriculture also impinges on the rate of agricultural growth.

The share of food grains in gross cropped area declined from about 75 percent in 1971-72 to about 67 percent in 1994-95. Within the food grains category, the percentage of area under coarse cereals (maize, sorghum, and millets) declined from 28 percent to 17 percent. The share of area under pulses also marginally declined. While rice retained its share of 23 percent,

Table B-1—Trends in agricultural growth, India, 1970-97

Item	1970-71	1980-81	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97
Agricultural production (index 1982 = 100)	85.9	102.1	148.4	145.5	151.5	157.3	165.2	160.7	175.7
Area under principal crops (index)	96.3	99.7	105.2	102.6	103.1	103.8	104.2	103.8	106.8
Yield of principal crops (index 1981-82 = 100)	92.6	102.9	133.1	131.1	137.0	140.7	145.5	139.9	149.0
Irrigated area (index 1981-82 = 100)	74.3	96.8	121.5	127.8	129.9	132.8	137.4	140.9	NA
Area under HYV (index 1981-82 = 100)	35.7	100.0	150.1	150.1	151.7	155.4	164.5	167.3	NA
Fertilizer consumption (NPK, index 1980-81 = 100)[1]	39.5	100.0 (31.9)	227.4 (67.5)	230.7 (69.8)	220.4 (65.5)	224.2 (66.7)	245.9 (72.6)	251.6	259.4
Pesticides consumption (NPK, index 1980-81 = 100)	54.0	100.0	166.7	160.2	157.3	141.6	136.4	136.2	124.7
Tractor production (index 1981-82 = 100)	21.1	71.7	131.2	159.7	159.4	146.4	172.9	202.8	NA
Gross capital formation in agriculture, (index 1981-82 = 100)[2]	61.2 (71.4)	103.0 (61.3)	102.0 (74.9)	105.0 (78.8)	119.3 (80.3)	111.7 (77.1)	138.9 (79.0)	154.6 (81.8)	155.4 (83.8)
Production of breeder seeds (1,000 metric tons)		.5	3.4	3.5	3.6	3.7	4.0	4.3	4.5
Production of foundation seeds (1,000 metric tons)			34.0	38.0	39.0	41.0	47.0	48.0	57.0
Distribution of certified/quality seeds (1,000 metric tons)		250.0	571.0	575.0	603.0	622.0	659.0	699.0	700.0

NA = Not available.
[1]Figures in parentheses indicate consumption of fertilizer per hectare of gross cropped area (kilograms per hectare).
[2]Figures in parentheses indicate the share of the private sector in the gross capital formation in agriculture.

Source: Government of India, 1998.

the share of wheat increased from 11 percent to 14 percent. Oilseeds were the major gainers among non-food grains; their share in cropped area increased from 9 percent to about 15 percent. Cotton, which suffered a bit in the 1980s, improved its share in the 1990s (Sawant, 1997, table 2, p. 235; and Government of India, 1998, p. 94). Crop pattern shifts in favor of superior cereals and nonfood grain crops, such as oilseeds, can *ceteris paribus* increase the demand for agricultural inputs as these crops consume relatively more inputs per unit of land. For example, most pesticides are used on cotton.

Despite the decent performance of Indian agriculture, which augurs well for the agriculture-related industry, a few disconcerting aspects need to be emphasized (see Desai, 1997 for details):

- The annual rate of growth of agricultural production (food grains and nonfood grains) was lower in the 1990s, than in the late 1980s; and
- The annual rate of growth of input use (high-yielding varieties, fertilizer, irrigation, and power) was also lower in the 1990s than in the late 1980s.

This downturn is partly due to the relatively slow growth of real plan expenditure on agriculture since the early 1990s (Desai, 1997). Estimates suggest that, after peaking in 1978-79, (52 billion rupees (Re) at 1980-81 prices), gross capital formation in agriculture declined afterwards. India's agricultural economics improved again in the 1990s, with investment going up to Re 70 billion in 1996-97 (1980-81 prices). The stagnation of the 1980s, which continued into the early 1990s, was essentially due to the decline in public sector gross capital formation. Private investment did not rise fast enough to compensate for the relative decline in state-sponsored investment. The 1990s saw a reversal of this trend with private investment rapidly rising (see Government of India, 1998, table 15, p. 8 for some estimates). In 1996-97, as much as 84 percent of the total investment came from the private sector (see table B-1).

One can view these trends in two ways. It can be argued that public investment is gradually being replaced by private investment, and one need not be concerned about the decline in the state's role in agriculture-related investment. The other view could be that given the complementarities between public and private investments (especially in irrigation), private investment would have risen even faster if the public investments had continued to grow rapidly. In fact, the decline in the rate of growth of fertilizer use, irrigation, and high-yielding varieties could have been arrested, given the complementarities of use in these inputs and the importance of state support in expanding the use of high-yielding varieties (extension), irrigation (investment), and fertilizer (subsidy). Limited availability of concessional agricultural credit could have also contributed to this process.[2]

Overall, the picture that emerges is that agriculture's growth since the beginning of the 1990s has been good enough to support the growth of agriculture-related businesses. However, there are some indications that the growth performance (and, therefore, the market for agricultural inputs, etc.) could have been better if public investment in agriculture had not declined in recent years.

Private R&D and Technology Transfer

Research: Levels, Trends, and Goals

Most agricultural research conducted in India is very applied. The types of research conducted by private firms, the amount of expenditure, and some effects of this research are shown in table B-2. Estimates of levels and growth of private research and development (R&D) expenditures by different industries (based primarily on the Department of Science and Technology (DST) data to obtain comparability in 1984-95) are presented in table B-3. These estimates are supplemented by some firm-level estimates for different agricultural subsectors from the Centre for Monitoring Indian Economy (CMIE, 1998). These estimates are reported in tables B-4 and B-5.

In the 1990s, the private sector spent between $39 and $43 million on food and agricultural research in India.[3] The second column of table B-2 shows our estimates of R&D expenditures based on interviews, questionnaires, and individual firm data from DST. In industries where interview data were insufficient, industry-level data for 1994-95 from DST were used. We did not include any expenditure from government-owned firms in constructing this table. The largest research expenditure was by the food industry (about $13 million), followed by pesticides ($7 million to $11 million); the seed industry and agricultural machinery were both $5 million to $6 million. The poultry, fertilizer, and feed industries made smaller investments in R&D.

Private research in India has grown rapidly since 1985. Between 1985 and 1995 (the last year for which official figures are available), private research expenditures at least doubled. This is faster than public agricultural R&D, which grew 69 percent. Table B-3 shows growth in food and agricultural research by private firms and government-owned corporations that are registered Science and Technology Firms by the DST. Table B-3 also provides data from the seed industry from a survey by Pray and Kelley (1998). The DST data underestimates growth—particularly in industries with many new entrants—because it takes a number of years for new firms to get approval. In addition, some firms do not get approval because there is little benefit from this designation—some tax reductions—and a substantial cost in paperwork. In the Pray and Kelley (1998) survey of the Indian seed industry, firms not approved by DST conducted 24 percent of the research of the firms surveyed. Similarly, the DST estimates of private R&D for firms producing chemical fertilizers and tractors (tables B-2 and B-3) are much lower than the estimates derived from CMIE data (tables B-4 and B-5): $2.2 million versus $7.6 million for fertilizers and $5.6 million versus $19.9

[2] See Desai (1997) for the role of credit in the recent experience of agricultural growth in India.

[3] The data compiled by these sources are not strictly comparable. For example, the estimates of R&D expenditures compiled by the DST are based on the data made available by firms having DST-recognized R&D units in different industry groups. Not all recognized firms provide this information every year and not all firms doing R&D are recognized by DST. Consequently, these data usually underestimate the R&D in the sector. The CMIE estimates are based on data compiled from company annual reports. All companies listed in the Mumbai Stock Exchange are covered. Here again, not all firms' annual reports are available to CMIE every year. At times, firms do not report R&D expenditures in their annual reports. By and large, for the organized sector, CMIE estimates are more robust than DST estimates.

Table B-2—Private research objectives, expenditures, and effect by industry, India, 1996-97

Industry	Research objectives	Amount of research	Effect of research
Seed---field crops	Increase yields, pest resistance and quality of maize, sunflower, PM, sorghum, cotton, rice, rape/mustard.	More than $5 million (survey)[1]	Higher yields of maize, sunflower, PM, sorghum, and cotton.
Seed---vegetables	Increase yields, pest resistance and quality of tomato, cabbage, okra, hot pepper.	$1 million (survey)	Higher yields of tomatoes.
Pesticides	Increase yields and quality of crop, reduce farmers' costs of production, improve human and environmental safety. New processes for active ingredients. Combinations of pesticides. Integrated pest management.	$7 million-$11 million (survey)	Reduced costs through herbicides and improved environment through safer products. Indian production of foreign technical materials.
Fertilizers	Better agronomic practices for farmers and lower costs of fertilizer production.	$2.2 million (DST)[2]	
Agricultural machinery	Increase power of tractors keeping cost low. Adjust gears, brakes for hauling on road.	$5.6 million (DST)	
Poultry breeding	Breeds adapted to Indian conditions.	$3.2 million (survey)	Increased FCR and eggs for each bird.
Dairy research	Buffalo & cow breeding and management.	$1.7 million (DST)	
Vaccines, veterinary pharmaceuticals	Produce vaccines for new diseases and testing foreign products.	$2.72 million (DST)	Vaccine for new type of hepatitis, approval of veterinary, pharmaceuticals.
Feed	New ingredients, reduce anti-nutritional factors, and identify useful additives.	$300,000 (survey)	
Food processing sugar and oilseed		$13.0 million (DST)	

[1] "(survey)" indicates data from the authors' survey.
[2] "DST" indicates data from the Department of Science and Technology.

Sources: Survey by authors and Department of Science and Technology. Research and Development Statistics, 1994-95. New Delhi, 1997.

million for tractor firms. The higher estimates from CMIE are largely due to CMIE's including all R&D, chemicals, fertilizers, trucks, and machines of tractor firms.

The most rapid growth took place in food processing, followed by the seed industry, pharmaceuticals, and the sugar industry. Pesticides research almost doubled during 1985-95. Actually, pesticide research probably grew even more rapidly, but several firms that increased their research, such as Monsanto and DuPont, were not registered as research companies with DST. Tractor research also substantially increased: it was 75 percent higher in 1995 than in 1985, then declined the next 2 years. The industry in which R&D declined, according to DST data, was fertilizers. A comparison of tables B-3 and B-4 suggests that the decline was particularly sharp, but given the alternate estimates from CMIE, this decline may be unrealistic. For pesticides, however, the CMIE and our survey estimates are about the same.

Seed Sector

India has a large number of seed firms, but only a few have large operations. About half of seed sales are by public corporations. Since the mid-1980s, large Indian firms and multinationals have entered the Indian seed industry. According to Pray and Kelley (1998), firms with some foreign ownership in 1995 accounted for

Table B-3—Research expenditures by private firms and state-owned enterprises, India, 1984-95

Industry	Research expenditures (1995 dollars) 1984-85	1994-95	SOE in 1994-95	Increase
	----*Millions*----		----*Percent*----	
Seeds	1.33	4.93	0	271
Agricultural machinery	3.70	6.48	13	75
Fertilizers	6.80	6.65	67	-2
Pesticides	9.00	17.02	15	89
Veterinary pharmaceuticals	.90	2.72	5	203
Sugar industry	.90	2.49	1	177
Food processing	1.27	10.33	1	712
Vegetable oil processing	.07	.14	0	99
Total	23.97	50.75	16	112
Public research	206.22	347.90		69

Notes: Pesticides are calculated as 30 percent of chemicals (other than fertilizer) research, based on assessments of each chemical firm's research by Dr. B.P. Srivastava, former head of research at Pesticides India and Union Carbide India. Veterinary pharmaceuticals are calculated as 5 percent of pharmaceutical research. Exchange rate is Re31.4 = $1.00.

Sources: Seed expenditures, Pray and Kelley. 1998 and the Department of Science and Technology.

about one-third of the private half of the seed market, and large Indian firms accounted for 23 percent.

Most seed firms conduct breeding research to develop new hybrids based on inbred lines that have been developed in the public sector, international agricultural research centers, or parent companies. A few large programs conduct research to develop their own inbred lines.

At least three seed companies have major biotechnology labs in India conducting basic biological research. One lab spent about $700,000 in 1997, had 11 Ph.Ds out of a total of 34 scientists, and had collaborative research with some top university biotech labs in the United States. Two of these labs work on hybrid rice issues—understanding hybridization or identifying markers that can screen for grain quality. These labs are also transforming cotton and vegetables with bacillus thuringiensis and other genes. A number of companies test transgenic varieties developed either from their own programs or from foreign programs. The Department of Biotechnology, which must approve any field trials of genetically modified organisms, reports that there have been 28 field trials of transgenic crops since 1996, of which 95 percent were by private firms. These trials have been for cotton, mustard, tomato, eggplant, and cabbage. Soybean trials had been approved but were not yet in the field, and trials for potatoes and tobacco were in progress.

Animal Feed

There are very few corporate players in the animal feed industry; the bulk of animal feed is producted in the small or cooperative sector. Besides, many farmers prepare their own animal feed. The share of the corporate sector in the animal feed industry is near 33 percent and has been rising. This market has about 40 relatively large firms; the others are small. The total estimated market size was Re 23 billion in 1995-96. We have R&D data for only three major firms (table B-4).

Godrej Agrovet and Hindustan Lever emerged as two significant corporate players in this market. Hindustan Lever increased its market share by acquiring some firms and expanding capacities. While the R&D to sales ratio for Hindustan Lever declined somewhat during the 1990s, the R&D intensity increased for the other listed companies (table B-4). Unlike the other two firms, Hindustan Lever is a large diversified firm of which their R&D estimates include expenditures on activities other than animal feed. The research arms of animal feed firms essentially test new ingredients, study ways to reduce anti-nutritional factors, and test new additives provided by other firms.

Table B-4—Market shares and R&D expenditures of major firms: Various product groups, India, 1991-92 and 1996-97

Product	Company	Market share		R&D expenditures in 1996-97 (Re million)			R&D & sales	
		1991-92	1996-97	Capital	1998	Total	1991-92	1996-97
Animal feed	Godrej Agrovet, Ltd.	NA	8.21	0.5	3.4	3.9	Negligible[1] (<0.01)	.18
	Hindustan Lever, Ltd.	1.04	10.29	120.9	227.6	348.5	.66	.45
	Western Hatcheries	.04	2.34	0	1.6	1.6	.08[2]	.10
Flour milling	NEPC Agro Foods	NA	2.32	0	.1	.1	.31[3]	Negligible (<0.01)
	DCW Home Products	NA	.37	0	0	0	.22[2]	0[4]
Flowers	Century Textiles and Industries, Ltd.	NA	12.97	.1	25.9	26.0	.14[3]	.15
	Lakshmi Machine Works, Ltd.	NA	6.25	31.1	32.0	33.1	.23	.61
Pesticides	Bayer (India)	8.39	8.27	.1	14.6	14.7	.52[2]	.33[6]
	Excel Industries, Ltd.	7.97	5.15	1.2	37.4	38.6	.96	1.06[6]
	Hindustan Insecticides	4.57	3.83	.3	7.6	7.9	0	.60
	Hoechst Schering AgroEvo India, Ltd.	NA	6.63	0	9.1	9.1	.55[4]	.40[6]
	Modipon, Ltd.	3.27	3.51	1.0	3.8	4.8	1.11[5]	.15
	PI Industries	3.54	3.41	3.3	1.4	4.7	.52	.32
	Rallis India	9.65	11.29	12.8	94.8	107.6	.77[3]	.92[6]
	Searle (India)	2.57	3.61	25.7	15.4	41.1	.66[3]	2.33
	United Phosphorus	.05	9.15	1.3	12.3	13.6	.52[3]	.35[2]
Marine products	ITC, Ltd.	.77	.67	34.5	40.4	74.9	.08[1]	.24[6]
Poultry	Venkateshwara Hatcheries	82.01	NA	0	10.7	10.7	1.94[1]	.99[4]
	Venkateshwara Research & Breeding Farm	NA	11.56	6.3	33.6	39.9	36.68[2]	39.35
	Western Hatcheries	17.99	51.41	0	1.6	1.6	.08[2]	.10
Tractors	Bajaj Tempo	NA	.01	11.0	93.8	104.8	2.34[3]	1.78
	Eicher, Ltd.	NA	7.55	133.4	42.4	175.8	.19	3.09[6]
	Escorts, Ltd.	21.02	19.41	16.0	83.8	99.8	0	.60
	HMT, Ltd.	9.04	8.25	.3	90.9	91.2	1.86	.99
	Mahindra & Mahindra, Ltd.	17.30	24.54	0	279.2	279.2	.19	.83[6]
	Punjab Tractors	7.43	13.38	2.6	23.6	26.2	.38[1]	.33[6]
	Tractors & Farm Equipment	14.52	18.55	.4	19.7	20.1	.20[3]	.23

NA = Not available.
[1]For the year 1993-94.
[2] For the year 1995-96.
[3] For the year 1992-93.
[4] For the year 1994-95.
[5] For the year 1990-91.
[6] For the year 1997-98.

Sources: Centre for Monitoring Indian Economy, 1998; and CMIE electronic database.

Flowers

This sector attracted a lot of investment in the 1990s, with multinational corporations' (MNC) establishing export-oriented units. There is no estimate of the total sales of flowers. About 15 major firms sell Re 150 million worth of flowers per year. Estimates of R&D expenditures (many of these companies are bio-tech companies) are difficult to obtain; table B-4 suggests that they have increased. The focus of R&D in this area was in testing foreign varieties and developing management techniques to grow flowers efficiently.

Agricultural Chemicals and Crop Protection

Several large firms operate in this segment, and the extent of rivalry is high. Multinational corporations also figure significantly in this sector. Many international mergers and acquisitions have impinged on the market structure of this industry. Hoechst and Schering became Agrevo in 1994. Ciba-Geigy and Sandoz agricultural chemicals merged to become Novartis in 1996. In December 1999, Hoechst and Rhone-Poulenc merged to create Aventis.

In the 1990s, between 70 and 80 firms engaged in producing agricultural chemicals. The top 10 firms had a 63-percent share of a Re 31 billion market. Only a few small firms produce active ingredients of pesticides. However, some small firms formulate the final pesticide composed of the active ingredients and inert chemicals.

Research by the crop protection industry was also almost entirely applied. The two main research activities of these industries are conducting efficacy tests on chemicals new to India and developing new methods of producing commercial chemicals. The first type of research is conducted primarily by the subsidiaries of foreign firms because they are the source of almost all new pesticides. They test the chemicals that have been commercialized elsewhere to find out how effective they are against Indian pests and diseases under Indian climatic conditions, application methods, and market conditions. These tests are required by the companies to ensure that product meets their specifications and the registration requirements of the government. In addition, the chemicals must be tested for their effect on the environment, workers' health, and animals. Foreign and local firms spend some research resources trying to develop the most effective package of practices for the use of these chemicals. Some of these packages probably qualify as integrated pest management.

The main research activity of local firms has been in developing new methods of producing the active ingredient of pesticides discovered elsewhere. This allows the local firm to produce chemicals originally produced by a method kept secret by the inventor or protected by process patents. Local and foreign firms test different formulations for their products and different combinations of their products and other chemicals that might complement them.

A few local firms are starting to develop research programs to develop new active ingredients for pesticides using standard chemical synthesis methods. A larger number of local firms and at least one foreign firm were considering natural products to use as pesticides. Local firms seemed to be concentrating on neem tree extracts, plant growth regulators, and a few other things traditionally used in Indian agriculture. One foreign firm has a program to actively collect plants that might have biological activity. They then screen these plants and send a handful of the most promising ones to Europe each year. In 20 years, this program still has not led to a new commercial product.

Tractors

About 12 firms were manufacturing tractors in the 1990s in India. The major players listed in table B-4 produce 93 percent of all tractors and in 1997 had a share of 92 percent of the estimated tractor sales revenue of Re 47 billion. Mahindra and Mahindra, TAFE, and Punjab Tractors gained in market share, while Eicher, Escorts, and HMT lost. However, all major players, except HMT, increased their R&D intensity in the 1990s. The decline in the R&D expenditures at HMT tractors is understandable since it was for sale.

The tractor industry underwent major restructuring in the 1990s. While the demand for tractors has grown consistently over the years, its rate of growth declined in 1997-98, as compared with 1995-96. It is expected to decline further.

Small tractors (below 20 horsepower) were exempted from excise taxes until 1994. Inputs used to produce these tractors were also excluded from duties. The 1994-95 budget made the final product (small tractor) excise-free, and the companies had to pay duties on raw materials. Subsequent changes in the value-added tax meant that tax advantages of making small tractors declined further. To add to the problems of small tractor manufacturers, in 1995-96 the government also extended subsidies on tractors to the high horsepower versions. This was an extremely important step as tractor demand is significantly influenced by availability of subsidies and soft loans. Larger tractors are not only more efficient in the field but are also more useful for transporting products. Over the years, the inadequacy of transportation infrastructure has resulted in the use of tractors to transport men and produce. Given these policy and market changes, it is expected that firms will try to upgrade the horsepower range of their tractor production.

Tractor firms conduct a substantial amount of research in India. A major thrust has been to develop higher horsepower tractors that are also affordable to Indian farmers. For Indian firms, this means developing tractors with higher horsepower. For example, Eicher, known for its low-horsepower tractors (less than 25-horsepower range), started selling a 38-horsepower model and hopes to produce 42- and 62-horsepower tractors in the future. A large part of R&D by almost all tractor firms is spent to gear up for the production of larger tractors (more than 50 horsepower). In anticipation of a boom in demand, the market players had enlarged their capacities. This expansion, along with the entry of new players, resulted in underused capacities. Exports are seen as a source of improving rates of capacity use. But such a strategy also requires capability to produce large tractors, as the external markets do not prefer small machines. The export markets, especially the United States and Europe, also have certain design and quality specifications that are different from those in the Indian market. Firms are also conducting R&D to conform to these standards to enlarge their export markets.

Most leading players in the market tried to obtain technology for large tractors through multinational participation. In addition, the three new entrants—New Holland, Sami-Greaves, and John Deere-L&T—are entering with more advanced foreign tractor models. For foreign firms, this means modifying large tractor models developed for the United States, Europe, and South America to be less expensive, yet efficient, and safe on the road; one of the main uses of Indian tractors is hauling crops to market.

Diesel Engines

There are about 31 manufacturers of diesel engines in the corporate sector; not all of them, however, make engines for the agricultural sector. Slow, low-horsepower (<10 horsepower) diesel engines are reserved for small firms. As a result, the bulk of the agricultural demand is satisfied by about 800 small manufacturing units spread over the country. The small sector produces about 500,000 small (up to 20 horsepower) diesel engines every year, mainly for irrigation but also for sugarcane crushers and generating power. The corporate sector contributes another 90,000 engines for irrigation. Estimates of R&D are unavailable for this segment.

The diesel engines produced by small firms are based on outdated Petter and Lister models. Concessional credit and government subsidy has been restricted to slow, low-horsepower diesel engines. As such financial support drives demand to a significant extent, policy has contributed to technological obsolescence. Small industry reservation and financial support for slow, low-horsepower engines has meant that producers did not spend on R&D to upgrade the old models (see Basant, 1997 for details).

The diesel engine story is, therefore, somewhat similar to the tractor story in which government-support for small tractors helped their persistence in the Indian market. However, unlike the tractor industry, not many new entrants have started producing new engines with multinational technologies. Field Marshall in Rajkot is one exception, which is trying to introduce HATZ diesel engines through German collaboration.

Marine Products

A significant number of large firms (more than 125) are engaged in the production of marine products. But their share of the estimated 1997 sales of Re 123 billion was only 10 percent. Most of these major players are engaged in exporting marine products. The relatively high R&D expenditure of ITC, Ltd., in this segment (table B-4) is misleading, because ITC is a large conglomerate firm, and separate estimates for R&D in the marine products sector are unavailable. Similar data are unavailable for other firms as well. Our discussions with some large firms in this sector revealed that whatever limited R&D is conducted is to meet the quality standards for exports, especially to the United States and Europe. These efforts have intensified with the European Union's banning some Indian exports. Most Indian firms export unprocessed marine products. Some firms are trying to move up the value chain and are undertaking research for this purpose. Only a few firms are trying to enter the ready-to-cook market, with research to develop such products.

Fertilizers

Tables 5a and 5b suggest that the market for all types of chemical fertilizers grew in the 1990s. It is a relatively concentrated industry, except for phosphate fertilizers. The top 10 companies accounted for more than 73 percent of sales. The industry spent about Re 310 million per year on R&D in the mid-1990s. For most firms, the R&D intensity increased or remained roughly the same during the 1990s. Any increases, however, were marginal. The DST estimates (table B-3) suggest that, compared with the private firms, the government-owned fertilizer firms do much more research. This conclusion does not seem robust given the CMIE data presented in table B-5, but the CMIE data are missing the largest component of public research, Projects & Development, Ltd.

Most of the research is engineering work to reduce costs of fertilizer production and some agronomic tests on how best to apply fertilizer to different crops. Some firms are also actively working on developing bio-fertilizers.

Poultry

India has several poultry-breeding firms—more than any country outside the United States and Europe. These firms use pure lines from the United States or European firms and breed them in Indian conditions. Therefore, the chickens must survive extreme heat and some cold, because few barns have climate controls, and they must tolerate less hygienic conditions. The firms also have to be competitive in the Indian market structure in which the commercial hatcheries are separate firms from the suppliers of grandparent stock. Therefore, the chickens must lay a large number of eggs.

The poultry industry consists largely of small firms. No estimate of the total market size is available. Including Venkateswara, the largest group, there are approximately 10 major corporate firms in the poultry market. The total sales of chickens for these firms was Re 1.6 billion in 1993-94 and 1995-96. R&D data are available for only three firms (table B-4). Since Venkateshwara Research, Venkateshwara Breeding Farm, and Western Hatcheries actually belong to the Venkateshwara group, effectively we have data for only one company. We were informed that other than the Venkateshwara group, only a few other firms undertake any significant R&D in the poultry sector.

While the market share of Venkateshwara in processed chicken (including Venkateshwara Breeding) declined a bit in the 1990s, their R&D expenditures significantly increased. In fact, the data from the firm show an even higher level and increase in R&D expenditures for the group, from Re 52 million in 1993-94 to Re 129 million in 1997-98.

Food Processing

Data on the structure of the food processing industry are difficult to compile as this sector includes a large variety of products. Therefore, only flour milling is included here. Food processing industries do a limited amount of agricultural research to improve their inputs. For example, beer companies try to improve the quality of the grain they use for malting, and tobacco firms try to reduce the cost of the tobacco they buy while retaining a certain quality standard. Pepsi has identified and popularized superior tomato varieties for the Punjab. Most research by the food industry is, however, concentrated on developing new products and manufacturing processes.

Table B-5a—Market size and shares, fertilizer industry, India, 1991-92 and 1996-97

Product	Market size (value)		Growth in market size	Market share of the top 10 companies	
	1991-92	1996-97		1991-92	1996-97
	-----Re billion-----		*-----------Percent-----------*		
Urea	40.9	84.5	106.6	67.6	72.8
Phosphate fertilizers	4.8	8.5	79.5	52.2	62.2
Ammonium nitrate[1]	.2	1.6	688.3	100.0	100.0
Other nitrogenous fertilizers	25.1	5.4	113.7	98.1	99.7
Di-ammonium phosphate (DAP)	21.3	26.8	25.7	82.2	85.0
Mixed & complex fertilizers other than DAP	11.7	27.5	135.0	95.7	98.4

[1]For all seven companies in the product group.

Source: Center for Monitoring Indian Economy, 1998.

Table B-5b—R&D expenditures of major firms, fertilizer industry, India, 1991-92 and 1996-97

Firm	R&D expenses, 1996/97	R&D/sales	
		1991-92	1996-97
	Re millions	*------Percent------*	
Deepak Fertilisers & Petrochemicals Corporation, Ltd.	15.7	.02[1]	.54
Deepak Nitrite, Ltd.	6.5	.31	.52
Dharamsi Morarji Chemical Co., Ltd.	13.8	.33	.64
EID-Parry (India), Ltd.	42.1	NA	.49[6]
Fertilizers & Chemicals, Travancore, Ltd.	5.4	.08[2]	.05
Godavari Fertilizers & Chemicals, Ltd.	0	.06[2]	0
Gujarat Narmada Valley Fertilizers Co., Ltd.	5.4	.02[1]	.04
Gujarat State Fertilizers & Chemicals, Ltd.	54.9	.51[2]	.31
Hind Lever Chemicals, Ltd.	0	028[2]	0
Indian Farmers Fertilizer Co-operative, Ltd.	0	Negative[3]	0
Jay Shree Tea & Industries, Ltd.	1.3	.07[4]	.06
Madras Fertilizers, Ltd.	1.3	0	.02
Mangalore Chemicals & Fertilizers, Ltd.	.5	0	.02
Oswal Chemicals & Fertilizers, Ltd.	0	.11[5]	04
Rama Phosphates, Ltd.	1.2	0	.05
Rashtriya Chemicals & Fertilizers, Ltd.	10.3	.06[1]	.08
Southern Petrochemical Industrial Corporation, Ltd.	78.5	.39[2]	.39[6]
Tata Chemicals, Ltd.	51.8	.07[3]	.35
Tuticorin Alkali Chemicals & Fertilizers, Ltd.	2.6	.24[3]	.23
Vam Organic Chemicals, Ltd.	14.4	.55[2]	.58
All firms	305.7	.15	.19

[1] For the year 1993-94.
[2] For the year 1995-96.
[3] For the year 1992-93.
[4] For the year 1994-95.
[5] For the year 1990-91.
[6] For the year 1997-98.

Source: Centre for Monitoring Indian Economy electronic database.

There are about 30 relatively large firms engaged in the manufacture of flour milling products. Their share in the market was, however, very small, only 10 percent of the Re 58 billion, annual market. Very few of them report R&D expenditures.

The entry of firms in flour milling, especially wheat flour, is a recent phenomenon. By and large, the packed and branded wheat flour could not withstand competition from the small producers. Consequently, the R&D activity initiated in the early 1990s has not increased. Some respondents indicated that increasing the shelf life was the major focus of this research. Apparently, some research is also being conducted to retain the softness of the kneaded wheat flour for relatively long periods.

Technology Transfer

Even in agriculture, where new technology is often embodied in plants and animals that are very sensitive to changes in climatic, soil, and pest conditions, some technology can be transferred with very little adaptive research. Some of this technology comes in as finished or almost finished inputs and the quantities can be indicated by input imports. For other technology, the knowledge is purchased and the product is made in India. Finally, some technology is brought in as a part of direct foreign investment by foreign firms.

Imports of agricultural inputs are very limited for India. For example, seed imports are negligible except in vegetables. Table B-6 shows that sunflower was the only field crop with appreciable imports of commercial seed

Table B-6—Seed imports, India, 1988-95

Year	Cereals (maize, sorghum, millets)	Pulses	Oilseeds (primarily sunflower)	Vegetable seed	Total
			Tons		
1988-89	0.64		0.11	11.34	14.14
1989-90	.13	.02	.14	82.52	82.81
1990-91	.80		5.09	77.59	83.50
1991-92	3.37		373.66	51.33	428.39
1992-93	1.73	.05	22.50	121.31	148.08
1993-94	.76		58.32	170.02	235.06
1994-95	2.19	.01	33.46	414.34	459.91

Source: Ministry of Agriculture, Government of India. Unpublished data. 1997.

for only 1 year, 1991-92. Even that was only 7 percent of the total commercial use. The volume of imports of vegetable seed, for which restrictions on trade were eliminated except for a small tariff, increased much more than field crops but were still small. Imports of many other inputs, such as tractors and diesel engines, were not permitted. Pesticide inputs increased.

Imports of technology through multinational firms can be indicated by proposals approved by the Indian Government. Table B-7 provides details of the proposals approved by the Foreign Investment Promotion Board during 1991-97 for the agriculture-related product groups. Of the 8,795 approved proposals for which we have data, 1,582 (18 percent) were in the agriculture-related sectors. These approved proposals anticipated equity flows of $31 billion, 12 percent of which were to flow into agriculture-related sectors.

The proposed participation of multinational corporations in the agricultural business industry was mainly in the form of equity flows and establishing export-oriented units. Licensing of technology was the third most important MNC linkage (table B-7). Financial and technical participation of MNCs in these industry groups is likely to enhance technology flows as well.

Food processing of various kinds (instant semi-processed foods, meat preparations, and other food products), as well as vegetables, fruits, and flowers are the main sectors attracting MNC participation. Interestingly, input industries, such as fertilizers, pesticides, and agricultural machinery, have not attracted many projects. However, the input industry is not as diversified as the other product groups, and the number of firms in the input industries is also small in relative terms. Consequently, the entry of even a few MNCs may have significantly increased the competitive pressures in the input segments. That may have been the effect of MNC entry on some food processing segments as well.

Effect of Private Research

In the debates about intellectual property rights and biotechnology, critics of the private sector continually argue that private firms will drive up prices of inputs and not provide farmers any benefit from research. In contrast, most economists argue that although the price of improved inputs, such as hybrid maize, may increase, farmers' total costs of production will decrease because they need less of other inputs. The reduction in needed inputs can be measured as partial factor productivity, such as output per hectare or total factor productivity. If output per hectare increases, less land will be needed to produce the same amount of output. Thus, a farmer is saving on his costs of land by using the new technology. If total factor productivity increases, farmers' costs are reduced by using the new technology.

Measuring the effect of private research is beyond the scope of this study. However, three types of evidence indicate that private research has increased productivity and thus reduced farmers' costs of production. First, evidence is available from the companies interviewed about the effect of their R&D effort on partial productivity measures. Second, three studies measured the effect of private research on output per hectare and total factor productivity. Third, studies of industrial research and technology purchase in India show a positive effect of R&D and technology purchase on total factor productivity of industry. This suggests that research on new processes by the food industry and input industries increases productivity, which will eventually benefit farmers and consumers.

The industries interviewed provided several examples of productivity increases due to their research. One example is from Venkateshwara Hatcheries (VH): improved VH breeds increased the productivity of their layers and broilers considerably through breeding. Table B-8 shows that the number of days required to rear broilers to a marketable-size bird was reduced by 20 percent. The amount of required feed declined by 26 percent, and mortality also dropped. Table B-8 shows that the number of eggs from their layers increased by 17 percent, while the feed requirement declined by 7 percent and mortality declined. These

Table B-7—Proposals approved by Foreign Investment Board, India, 1991-97

Product category	Export-oriented units	Holdings	Licensing	Technology	Financial	Equity flows
	Number					*Million rupees*
Animal & animal products	20	0	9	2	38	445
Agricultural products (except flowers)	40	0	40	0	73	838
Flowers	157	0	11	1	111	43,236
Agricultural products (total)	197	0	51	1	184	44,074
Fats, oil, etc.	18	0	9	0	29	1,622
Food products	8	2	27	2	61	21,057
Meat preparations	41	0	14	1	74	661
Dairy products	1	0	1	0	12	5,269
Cocoa	1	0	5	0	14	1,685
Instant semi-processed seeds	47	1	11	0	71	8,316
Vegetables/fruits	108	0	9	0	124	1,327
Beverages	5	1	17	0	48	49,765
Other foods	20	3	11	0	42	10,541
Food industry (total)	249	7	104	3	475	100,243
Food processing machinery	0	0	16	0	19	362
Fertilizers	1	0	6	0	7	2,477
Pesticides	0	0	6	0	8	239
Agricultural machinery	0	0	15	0	11	2,292
Agricultural inputs (total)	1	0	27	0	26	5,008
Total (agriculture industries)	507	7	247	6	815	150,969
			Percent			
Total (agriculture industries)	32.05[1]	4.4	15.6	0.4	51.5	
			Number			
Total (all industries)	1,225	42	2,762	43	4,723	1,226,696
			Percent			
Agriculture-related/total investment	41.4	16.7	8.9	14.0	17.3	12.3

Source: SIA database, Ministry of Industry, Government of India. 1998.

data come from VH poultry operations; data were available from other commercial farms. It seems likely that the productivity increases on other commercial farms would be less.

Another success of the VH group was in producing vaccines that are less expensive than some commercial vaccines and more reliable than government vaccines. They also developed vaccines that provide protection against diseases for which no other vaccine exists. In fact, they developed one vaccine that no other country has developed. This vaccine is for a form of hepatitis that has become a serious problem for poultry in India since 1993. The commercial sale of this vaccine in recent years has greatly reduced deaths from this disease and increased industry productivity.

As mentioned earlier, several recent studies measured the effect of technology developed and introduced by the private sector. A study of maize (Singh and Morris, 1997) used farm-level data from six states in 1994-95 to show that the adoption of hybrid maize led to yield increases of about 1 ton per hectare over improved open-pollinated varieties. In total, this led to an increase

Table B-8—Increases in poultry efficiency due to poultry research, India, 1981 and 1996

Item	Unit	1981	1996
***Broilers*:**			
Days to 1.5 kg body weight	Number	47	38
Feed conversion	Percent	2.5	1.85
Mortality	Percent	3	2
***Layers*:**			
Eggs production to 72 weeks	Number	270	315
Feed efficiency	Percent	145	134
Mortality (72 weeks)	Percent	8	6

Source: Venkasteshwara Hatcheries, Limited.

in maize production of 1.1 million tons. To obtain these increases, farmers had to increase fertilizer, irrigation, and pesticide use in addition to adopting hybrids. Therefore, increased output is not entirely productivity growth.[4] Since most hybrids in 1995 were from private firms, most of this gain was due to private research.

A study by Ramaswami, Pray, and Kelley (1999) looked at the factors that influence the partial productivity index, yield per unit of land. The dependent variables were cotton, maize, sunflower, sorghum, and pearl millet yields. The independent variables included a measure of the spread of high-yielding varieties (HYVs), the spread of private varieties, the proportion of irrigated crop area, fertilizer use, the number of regulated markets, and the length of roads in the district, in addition to profitability of the crop, a trend variable, and variables measuring rainfall. The basic model is augmented by interaction variables of HYVs with private varieties, irrigation, and fertilizer use. Since private varieties have been significant in these crops only recently, their analysis was confined to the period since 1985.

Private hybrids' effects on yields are positive and statistically significant in five of the nine crops and provinces and close to significant in a sixth case. Table B-9 summarizes the results of the regressions. These estimates provide the first econometric evidence that private plant-breeding affects crop yields in developing countries. This is particularly impressive because the region examined is in the semi-arid tropics where private research is not expected to have much effect.

[4]This partial productivity index was used rather than the index of total factor productivity (TFP), because input data are available only for the entire crop sector not for individual crops. Thus, it is impossible to calculate crop-wise determinants of total factor productivity.

The only study that had considered how the benefits of private hybrids were divided was conducted by Pray et al. (1991). It examined the increases in seed prices and increases in farmers' yields of hybrid sorghum and pearl millet in Maharashtra and Gujarat. For hybrid sorghum, at most 18.5 percent of the benefits were captured by the seed companies through higher prices, while 81.5 percent went to farmers as the value of increased production minus the increased cost of seed. For hybrid pearl millet, only about 6 percent of benefits were captured by seed firms. More than 90 percent of the benefits from private pearl millet research went to farmers. Using this same data, Ribeiro (1989) estimated the social rate of return to private plant-breeding research in India to be 38 percent or more.

A study of total factor productivity of crop production, by district in 13 major states of India from the 1950s to the 1980s, also provides evidence of the effect of private research and technology transfer (Evenson, Pray, and Rosegrant, 1998). The study found that private research and technology transfer, advances in agricultural research outside India, and public research all made major positive contributions to total factor productivity growth in the crop sector. The social rate of return from investments in private research was very high—exceeding 100 percent—which suggests that most benefits from private research go to farmers and consumers rather than input companies and that society believes that there is a substantial underinvestment in private research.

Studies of the experience of Indian industry found that technology imports reduced local R&D by a small amount but increased the productivity of Indian firms (Fikkert, 1995; and Basant and Fikkert, 1996). The lost productivity from the small decline in research was more than offset by increased productivity from the imported technology. Indian firms did not need to use their own resources to reinvent technology developed elsewhere and could concentrate their research instead on new products and processes that could not be purchased from abroad.

Effect of Technology in the Pipeline

Perhaps the most important technology in the pipeline is hybrid rice, which the public and private sectors are racing to commercialize. Sixteen private seed firms reported that they are breeding hybrid rice, and several of these breeding programs are quite substantial.

Table B-9—Effect of private and public hybrids on yields, India, 1998

Crop/State	Private	High-yielding variety	Estimation technique
Sorghum, Andhra Pradesh	0.0027[1]	-0.09	Random effects
	(1.92)[2]	(1.54)	
Sorghum, Karnataka	.0083[3]	.44[3]	Random effects
	2.34)	(2.99)	
Sorghum, Maharashtra	.008	.23[1]	Fixed effects
	(1.54)	(1.88)	
Pearl millet, Andhra Pradesh	.0007	-.084	Fixed effects
	(.27)	(1.1)	
Pearl millet, Karnataka	-.0002	.39[3]	Random effects
	(.11)	(3.2)	
Pearl millet, Maharashtra	.01[1]	.02	Fixed effects
	(1.91)	(.32)	
Maize, Andhra Pradesh	.023[3]	-.11	Fixed effects
	(2.27)	(.7)	
Maize, Karnataka	.005	.77[1]	Random effects
	(.48)	(1.7)	
Maize, Maharashtra	.04[3]	.13	Fixed effects
	(3.33)	(.96)	

[1] Estimates significant at the 10-percent level.
[2] T-values are in parentheses.
[3] Estimates significant at the 5-percent level.

Source: Ramaswami, B. C., and Carl E. Pray, and Tim Kelley. 1999.

MAHYCO and SPIC have biotech research programs on hybrid rice. Farmers grew hybrid rice in 1997-98. Most of the 250,000 hectares under hybrids (Indian Council of Agricultural Research, 1998) in 1997-98 was under private hybrids, with Proagro, Pioneer, and MAHYCO leading the way. These private hybrids are based on public lines from the Indian Council of Agricultural Research (ICAR), International Rice Research Institute, and China, but they are private hybrids. Yields are often 1 ton per hectare more than the best conventional varieties, and yields of hybrid seed are high enough to make the 1-ton increase commercially viable. The main problem is the grain quality of hybrid, which is low. Thus, most private firms and many public research institutes are concentrating on improving grain quality.

Another important technology that several private firms and a number of public institutes are researching is single-cross hybrids of maize. Companies reported that singlecross hybrids produce 10 to 30 percent higher yields than double-cross hybrids in trials in India. Seed of single-cross hybrids is still not being marketed in significant quantities because of the high cost of seed production and the ease with which it can be copied by contract farmers and competitors. But this technology will be supplied as intellectual property rights are strengthened.

Among the first biotechnology products likely to be approved are *Bacillus thuringiensis* (Bt) cotton, which allow farmers to reduce the number of insecticide applications from 15 or more to 3 and to achieve higher yields. Another likely early approval of a genetically engineered crop is hybrid rapeseed that yields 10 to 20 percent more than improved local varieties. Other near approvals are pest-resistant tomatoes, cabbage, and eggplant.

A new generation of pesticides were being introduced in 1998 that are effective against some pests that have grown resistant to older pesticides and are much safer for people and the environment. Several new wheat herbicides were approved for control of *Emperata* grass, which is resistant to the herbicides on the market in India. Companies estimate that use of these herbicides, which are much more environmentally friendly, will increase yields by 20 percent.

These new products will be more expensive. An International Maize and Wheat Organization survey found that the ratio of the price of hybrid maize seed to the price of commercial grain in selected developing countries in 1990 ranged from 1.3 in China to 25 in Cameroon, with India at 4.2. Single-cross hybrid seed in the United States and Europe cost more than 30 times the cost of grain (Byerlee and Lopez-Pereira, 1994). Thus, it is probable that as Indian farmers adopt better double-cross and single-cross hybrids, prices will rise. However, as of 1998, prices have been held down by intense competition among private seed companies, public seed firms, and farmers who save seed. There is no evidence that this will change soon. Even if the firms in which Monsanto has some ownership—MAHYCO, Cargill, and E.I.D-Parry—were to merge, they would have less than 14 percent of the commercial seed market, which is a small part of the total seed planted that primarily comes from farmers (Pray and Kelley, 1998).

No one in 1998 knew the price of pest-resistant hybrid cotton with Bt in it. However, the experience of China gives some indication. In China, the price of Bt cottonseed (variety not hybrid) increased from yuan 5 per kilogram to yuan 42 per kilogram.[5] However, because of the higher quality of the seed, the quantity sown could be reduced to one-quarter of the amount of traditional seed. Thus, the seed cost per unit of land doubled, rather than increased five times. In return, farmers saved 10 to 20 pesticide applications, saving money for chemicals plus the cost of labor to apply the chemicals. Bt cotton is very popular in Hebei Province where it was released.

Reasons for Increase of R&D Investments

Liberalization in India and changes in multinational firms' strategies are major causes of the increase in research and technology transfer to India. An analysis of seed industry data indicates that local and foreign companies increased their research in response to liberalization. In 1998, foreign firms, such as Monsanto and DuPont, invested in new agricultural research stations, and John Deere entered the Indian market for the first time with its latest line of tractors. The Foreign Investment Promotion Board data (table B-7) on multinational corporations' proposals for entry into different industry groups also suggest such a trend.

According to neoclassical economic theory, firms seek to maximize expected profits. The expected profits to a firm from investing in research are a function of the expected benefits and costs of research and development of a commercial product discounted by an interest rate. The expected benefits will be based on the expected size of the market, the share of the market the firm hopes to capture, and the expected price of the new product. Firms will calculate the expected market size based on current market size and growth rates for this industry. They will estimate their expected share of the market by looking at their current market share in the industry, the strength of intellectual property rights in the country, and technical means of protecting their product from copying. The expected price will be based on current prices of similar products plus their ability to keep other firms from copying the product and competing against them. Economists use the term "appropriability" to describe a firm's ability to capture economic gains from research.

The expected costs of research depend on the availability of needed technology elsewhere in the world. The environmental specificity of foreign technology will determine whether there are opportunities for adaptive research or direct material transfer. The availability of technology from public institutes, which can be adapted or modified through local research, can reduce research costs. The salaries and benefits of scientists, engineers, and technicians are important components of research costs, as are laboratories, experiment stations, and the supplies to run them.

Market Size and Growth

Increased agricultural research was partially a function of increased demand for agricultural products and modern agricultural inputs. The size of Indian markets for agricultural inputs has grown substantially since 1980, as shown in table B-1. The private sector supplies most of the equipment for minor irrigation, half of the certified and quality seed, half of the fertilizer, most of the pesticides, and most of the tractors. This table and our earlier discussion indicate that production of almost all inputs at least doubled during the 1980s. In the 1990s, rapid growth continued in tractors, power tillers, and minor irrigation. Production of seeds and pesticides, likewise, continued to grow, but that growth was in a different dimension than is captured by the measures used earlier. In the seed industry, more expensive private hybrids replaced subsidized public hybrids and public varieties. This increased the value of the seed market but is not indicated in the quantity measures in table B-1. In the pesticide industry, newer, more expensive pesticides which require only 40 to 50 grams of technical material per hectare replaced older, less expensive pesticides that required 2,000 grams per hectare. The result was more sales measured in value terms.

[5] The exchange rate in 1998 was approximately 8 Yuan = U.S. $1.00. There are 6 metric units per acre.

India is one of the largest national markets for agricultural inputs in the world. It ranks first in the number of tractors produced and sold. It is also one of the largest fertilizer and pesticide producers and consumers. Part of the increase in research in the 1990s was due to foreign input firms' deciding that the Indian market was simply too large to ignore, even if many policies were not conducive to high profits.

Like the input industries, the Indian food industry is one of the largest in the world, and it is rapidly growing. India is expected to become the world's most populated country early in the 21st century. Demand for processed foods, poultry products, dairy, and meat has also rapidly grown, increasing demand for improved livestock technology. Output by the food industry doubled between 1980-81 and 1995-96. Production of poultry products more than doubled in the 1980s and increased another 25 percent from 1990-91 to 1995-96. Milk production increased by 70 percent in the 1980s and 22 percent from 1990-91 to 1995-96 (Tata Services, Ltd., 1997). Production of livestock feed also rapidly grew from 1.2 million cubic meters in 1980-81 to 2.9 million cubic meters in 1995-96 (Compound, 1998). These increases were driven largely by increased demand created by gains in per capita income.

In addition to increased market size, the market share of large private Indian and foreign firms has increased since 1980. Very large Indian firms and firms with foreign ownership of more than 40 percent were excluded from the seed and biotechnology industries until 1986. Half of the active ingredients of pesticides had to be formulated by small firms, and all of the agricultural implements industry was reserved for the small firms until the 1990s. The elimination of those restrictive policies allowed large firms into the seed market and permitted the manufacturers of the active ingredients of pesticides to increase their market. It is also expected to induce tractor manufacturers into the implements industry.

The market shares of government-owned corporations have declined in the seed industry and in tractors as government sales grew more slowly than private sales. In addition, some public companies in this sector, like HMT tractors, have been included in the state's disinvestment program. Both factors increased the market share of private firms.

Changes in the input markets in the United States and Europe have made the markets of countries of Asia, in general, and India, in particular, very attractive, relative to their traditional markets. From World War II to the late 1970s were boom years for agricultural input firms in the United States, Europe, and, to a lesser extent, Latin America. With the stagnant or declining growth of the 1980s, most U.S. companies reacted by reducing costs. By the early 1990s, having squeezed costs as much as they could, many of them started to look to developing countries, Eastern Europe, and the former Soviet Union for further growth. John Deere, DuPont, and Monsanto in the early 1990s expanded into developing countries, including India. In addition, due in part to developments in biotechnology, agricultural chemical and pharmaceutical companies shed their traditional chemical business and bought biotech and seed firms to transform into life-science companies. Table B-10 shows the effect of the mergers and acquisitions in the United States and Europe on the Indian seed industry. These companies invest large sums of money in basic research to develop new drugs, seeds, and agricultural chemicals, which they then try to sell worldwide to pay for their research.

Appropriability

Appropriability—the ability of a firm that owns new technology to capture some benefits that users of the technology obtain—can be due to several causes. First, laws like patent acts can give owners temporary monopolies, enabling them to raise prices and profit from selling the technology. Second, the structure of the industry may allow firms to capture some benefits. Monopoly or oligopoly power in a market can give inventors high enough prices to profit from technology. Third, the technology may allow firms to keep others from copying a technology thus giving inventors market power. Fourth, firms can simply keep inventing and stay ahead of their competition. This also would allow them to charge more.

Since 1985, there have been only a few changes in appropriability in India. The laws and enforcement of intellectual property rights have not changed since 1972, when new chemicals, pharmaceuticals, and food and agricultural products were excluded from product patent protection. However, as earlier mentioned, the markets have become more competitive.

India signed the Uruguay Round of GATT (General Agreement on Tariffs and Trade, now the World Trade Organization) and was committed to a *sui generis*

Table B-10—Effect of mergers and acquisitions on U.S. and Indian seed industries, India, 1998

Parent company (main business)	U.S. seed companies	Indian seed companies
Monsanto (agricultural chemicals, pharmaceuticals, and food additives)	Holden's DeKalb Asgrow (soybeans and corn) Stoneville Delta & Pineland, and Cargill International Seed Business	MAHYCO (50-50 cotton Monsanto; 26 percent of MAHYCO) E.I.D. Parry (corn, sorghum and sunflower with DeKalb), and Cargill
DuPont (chemicals, oil, fiber, and food)	Pioneer	SPIC (Pioneer)
Aventis---Hoechst (Agrevo), and Rhone-Poulenc (agricultural chemicals)	AgrEvo PGS	Proagro (PGS) Sunseeds
Novartis (agricultural chemicals & pharmaceuticals)	Northrup King, and Ciba seeds	Novartis (was Sandoz)
Zeneca (agricultural chemicals & human health)	Advanta	ITC/Zeneca
Empresas La Moderna (Mexican-owned conglomerate)	Seminis DNAP Peto Asgrow (vegetables) George Ball	MAHYCO (Asgrow), Nath Slius (90 percent), Indo-American Seeds

Sources: Various newspapers and trade journals.

plant breeders' rights (PBR) law and strong process patents on biotechnology products by January 1, 2000. The country also plans to issue product patents for new chemicals, pharmaceuticals, and food and agricultural products by 2005. PBR legislation and amendments to the patent act were proposed and debated by several different Indian Administrations but not passed. In addition, India must protect trade secrets and extend liability to third parties that induce breach of a trade secret, and protect test data which is submitted for obtaining marketing approval of a new product. India's signature to the GATT agreement may have raised the hopes of research-based firms for stronger intellectual property rights, but not too much.

In the seed sector, appropriability increased through technical means. Hybrid seed is becoming viable in additional crops. Developments in hybrid rice seed production after 1985 led to the commercial adoption of hybrid rice in 1997. In addition, several systems for producing hybrid rapeseed seem possible. These developments led to private investment in a number of new research programs on rice and rapeseed, increasing total seed research (Pray and Kelley, 1998).

Regulatory changes allowed foreign firms to increase their share of ownership in all sectors. This enables the foreign owner to appropriate a larger share of profits from new technology back to the firm's headquarters where much of the research is conducted. The potential for enhanced profitability will increase the interest of foreign firms to invest in research in India.

The increased entry of foreign firms and some large Indian firms into agricultural input and agricultural processing industries has increased the competitive pressure on all firms in these industries. Firms have to innovate more rapidly to keep their market share. They try to appropriate the gains from their research by staying ahead of the competition.

Cost of Innovation

Firms must weigh the expected benefits, which are based on market size and appropriability, against the cost of innovation and the possibility that the innovation will fail to generate the expected sales. The cost of innovation and probability of success are a function of the state of basic science, quantity and price of scientific inputs such as scientists and labs, and agroclimatic differences between the place for which a new product was designed and India.

Advances in basic science can lead to new possible products from applied research. One major breakthrough since 1980 has been in biotechnology. Profits from plant biotechnology products are no longer a dream, but rather a reality in the United States, Canada, and Argentina. This has drawn a number of seed firms and agricultural chemical firms to invest in biotechnology research in India. In 1985, the first survey found that Hindustan Lever and a few other firms had started to work on plant biotechnology. Now Hindustan Lever, Tata Tea, and at least three seed firms have substantial plant biotech labs in India.

The output of more applied public research can also stimulate private research. During 1985-98, public research institutes in India and international centers provided considerable stimulus to private plant-breeding research. Participants of a study of the Indian seed industry (Pray, Ramaswamy, and Kelley, 1998) reported that the International Center for Research in the Semi-Arid Tropics (ICRISAT) was a very important source of germplasm by 65 and 80 percent of the sorghum and millet breeding firms, respectively. The Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAU) were very important for 66 percent of the cotton breeders. Sunflower was the only major crop for the international centers and ICAR/SAU were reported not to be important sources; joint venture partners are the most important sources of sunflower breeding material. Singh, Pal, and Morris (1995) documented the importance of ICAR and CIMMYT germplasm as the basis of private maize research.

The downsizing of ICRISAT and SAU and weak funding of ICAR meant that many well-trained and experienced scientists were available to private firms to lead and staff their administrative and research positions. The negative side of weak funding is that less public science and technology is available from these institutions in the long run. Some effect of declining funds can be seen at ICRISAT, which has stopped having the sorghum and pearl millet field days, at which ICRISAT scientists displayed and distributed samples of their latest hybrids, varieties, and inbred lines.

Another way to reduce the cost of research is to learn from ideas and innovations elsewhere in the world. Since 1985, several types of innovations have become more accessible to private firms. The reforms of the seed industry in the late 1980s made inbred lines and earlier generation germplasm more easily accessible. The reforms made it easier to import varieties for research and finished varieties for a few years to try them on a commercial basis. The admitting of foreign-owned firms meant that they brought in germplasm and new ideas that spilled over to local firms. Some of our survey respondents expressed the fear that new intellectual property rights (IPRs) might result in less sharing of germplasm and other research materials.

Regulatory reforms that reduced the time for new chemicals to be approved (from 7 or 8 years to 3 or 4) influenced pesticide companies to bring in more products, which stimulates local research on these products. Research by the agricultural chemical industry depends primarily on the number of new chemicals introduced. Each new chemical needs a minimum amount of research to ensure that it works well in India and that it is registered.

Policy

Most key government actions that may have stimulated private research are described in earlier sections and in the sub-sections in this chapter on markets, appropriability, and cost of research in this paper. But the key set of policy changes was the liberalization of the policies and regulations on the input industries. Table B-11 lists some policies before and after liberalization. Reforms allowed foreign firms more control over their Indian operations—as majority owners or wholly owned subsidiaries. Inputs in the production of the finished agricultural inputs—such as the active ingredients of pesticides, grandparent stock of poultry, and germplasm for the seed industry—were easier to import. Requirements for licenses to build new plants or expand old ones were eliminated. In addition, although most of the safety, environmental, and efficacy regulations did not change, their implementation became more efficient. For example, in the past, it took 7 to 8 years, on average, to register a new pesticide, while it now takes 3 to 4 years.

Summary

The two major forces behind the increase in private research are the size and growth in the Indian agricultural input and food market and the liberalization of restrictions on Indian and foreign firms that wish to invest in the food and input industries. Liberalization also resulted in an increase in the competitive pressures faced by the firms in the market. Other important factors, but less important than the first two factors, were developments within the international food and agricultural input industries—declining growth rates in demand in Organization for Economic Co-operation and Development (OECD) countries and mergers and

Table B-11—Key policies before and after reforms, India, 1998

Industry	Before	After
Seed	MRTP & FERA companies not allowed. Vegetable seed restricted. Other seed imports banned.	All firms allowed. Vegetable seeds open general license. Limited imports of commercial seed of coarse grains and oilseeds. Imports of wheat and rice only by government.
Agricultural machinery	No imports. Equipment reserved for small industry Licenses required for production and expansion.	No imports. Anyone can produce equipment. Licenses not required for production and expansion.
Pesticides	Active ingredient (AI) could be imported for limited time with 150 to 180% tariff, then had to be manufactured in India. 50 percent of AI must be formulated by small sector. No imports of formulated products except emergency. Licenses required for production and expansion. New product registration took 5 to 10 years.	AI imports with 35% tariff. No imports of formulated products, except emergency. No reservation of AI for small sector. No licensing requirement for expansion. New product registration takes 3 to 4 years.
Poultry	Grandparent imports restricted, and parent imports banned.	Grandparent stock imports open general license. Parent imports banned.

acquisitions in the food and input industries. Finally, breakthroughs in plant research and biotechnology, as well as an increase in applied research by the Indian Government and international nonprofit institutions, were important for some industries, particularly seed and biotech firms.

Policy Options

The government has a number of policy options that could improve the supply and prices of technology from the private sector. First, if the government is concerned about prices of inputs for farmers, the government could eliminate the bans on the importation of most agricultural inputs. The best way to keep prices down is through competition; protecting local industry behind import bans or quotas is counterproductive. No agricultural input industry is any longer an infant industry. If India is afraid that its local industries, such as the pesticide industry or diesel pumps, might face unfair competition or dumping from subsidized Chinese or other foreign firms, then India's anti-dumping legislation may be more useful than its blanket import bans. Under the World Trade Organization (WTO), India is committed to removing bans and quotas or at least turning the quotas into tariffs, but it is not clear when this will happen. If India wants to produce world class seed, machinery, or pesticide firms, then supporting those industries with public research, loans, and intellectual property rights in their home market might be more beneficial than using current trade barriers. A sensible competition policy must accompany deregulation, trade liberalization, and more stringent intellectual property rights so that monopolistic and unfair trade practices do not adversely affect consumers.

Second, strengthening patents and plant breeders' rights (PBR) is very important. Revised patent legislation to align these laws with the WTO passed Parliament in the spring of 1999. PBR legislation is still in Parliament. Effective enforcement of patents is still lacking. Thus, it seems likely that India will wait until the last moment, 2005, to produce stronger patent laws. In the meantime, Brazilian, Mexican, Turkish, and Chinese inventors and plant breeders have had stronger IPR protection since the mid-1990s.

We asked seed firms to speculate about the effect of potential policy changes on the availability of technology. In our 1997 survey of seed firms, we asked "Would stronger intellectual property rights, changes in the regulatory regime, and trade in agricultural inputs really lead to more technology for farmers?" There was considerable variation in firms' answers. Of the seed firms surveyed by Pray, Ramaswamy, and Kelley (1998), 19 of 33 respondents reported that PBR legislation would encourage them to do more research, while 12 said that it would have no effect on their research, and 2 thought they would do less research. In interviews with the major seed firms, it was clear that they would not start major breeding programs on self-pollinated crops, even with PBRs. It would be impossible to keep farmers and small traders from multiplying and selling protected seed of protected varieties. They did suggest that further research would be done on cross-pollinated crops to protect key inbred lines. A major effect of PBR legislation might be the release of single-cross hybrids of maize. Companies reported that single-cross hybrids produce 10 to 30 percent higher yields than doublecross hybrids in trials in India. No one has released them, however, because they are concerned that they would be immediately copied by their competitors.[6]

The pesticide industry claims that a lot of technology is unavailable to farmers because of weak intellectual property rights, barriers on imports of formulated products, and regulatory hurdles. For example, sulfonylurea herbicides were being introduced in 1985. DuPont's sulfonylurea soybean herbicide "Classic" was first sold in the United States in 1986. It was marketed in Brazil in 1987 but was not to be marketed in India until 1999, at the earliest. Cyanamid's new class of herbicides called IMIs (imidazolinones) were first sold in the United States in the late 1980s. They were first released in India in 1998 as part of the MOA's emergency wheat herbicide program. Several firms reported that they were not bringing in their latest insecticides. A few, however, argued that high competitive pressures and the need to quickly introduce new products for first-mover advantages in such a scenario, may force multinational corporations (MNCs) quickly to bring in new products.

The major questions that remain unanswered are: (1) With stronger IPRs and lower barriers to entry—e.g., allowing the importation of formulated products—would the MNCs come in with new products? and (2) Is the absence of these pesticides really reducing yields? Some pesticides will not be introduced because their superiority over the previous pesticides is not enough for farmers to pay higher prices for the new pesticides. The increase in yield may be small or the main advantage may be the environmental effect or health benefits, for which farmers are not willing to pay. For the first question, only a few major pests seem to have no solutions—the imperata grass problem in wheat and insect pests for cotton are two important ones. The government has a special wheat program that reduced the time for registering a new product from 3 or 4 years to 1 year, allowing them to import more advanced herbicides. Insect pests for cotton are a problem, but it is unclear whether new chemicals would be greatly more effective than the current ones. What India mainly seems to be missing is safer and more environmentally friendly products (see the later discussion of Bt cotton). Stronger IPRs will probably not help much, but allowing formulated products to be imported may. Until farmers or the government are willing to pay a price premium for environmentally friendly products or they can be imported less expensively, they will be unavailable.

In the poultry-breeding, feed, fertilizer, and machinery industries, stronger IPRs will have little, if any, effect on private investments in R&D. However, allowing imports of these inputs would probably reduce the prices farmers pay for some of these products. For example, Chinese diesel engines and power tillers are very inexpensive. We assessed how much prices might be lowered for these commodities. The diesel engine manufacturers in India feel that the Chinese Government provides a lot of hidden subsidies to their producers. Otherwise, exports of engines at the current prices would not be impossible. It is very difficult to check the veracity of these claims.

Third, a change that would increase technology to farmers from the seed industry is less regulation on transgenic plants. At the earliest, genetically engineered crops were expected to be in commercial use in India in 2000, but pressure by environmental groups and bureaucratic inertia easily could cause further delays. In 1998, China produced 200,000 acres of cotton with the *Bacillus thuringiensis* (Bt) gene inserted for bollworm resistance. Monsanto (Achievements: Plant Biotechnology, 1997 *www.monsanto.com*) estimates that in 1997 Mexico was growing 200,000 acres of Bt cotton; Argentina, 10 million hectares of herbicide-resistant soybeans; Canada, 2 million acres of herbicide-resistant canola; and the United States, 25 million acres of herbicide-resistant soybeans, 2.6 million acres of Bt cotton, 10 million acres of Bt corn, and other crops.

Among the first crops likely to be approved are Bt cotton, allowing farmers to reduce the number of insecticide applications from 15 or more to 3 and achieve higher yields. Another likely early approval is hybrid rapeseed, which yields 10 to 20 percent more than improved local varieties. The other crops near approval are tomatoes, cabbage, and eggplant.

[6] With double-cross hybrids, contract seed growers are given seeds from single-cross hybrids, which they cannot reproduce. With single cross hybrids, they are given seeds of two inbred lines, which they can reproduce. Thus, it is easy for them to sell some of the inbreds to a competitor or reproduce the new hybrid themselves.

Fourth, the government passed some tax packages to assist private firms. The new government passed a law allowing R&D firms to write off 120 percent of their total R&D expenditure as costs on their corporate income taxes. These and other R&D-related policies, however, have not been stable. Besides, the implementation of many such schemes requires that the firm register its R&D center with the Department of Science and Technology (DST). The procedures to do this are tedious and time consuming. If this changes from a year-to-year policy into a consistent long-term policy, it might give some firms incentive to do more research.

Fifth, public research has successfully supported private research in the seed industry in the past. However, the reduction in funding of the International Center for Research in the Semi-Arid Tropics (ICRISAT) and other international centers and the poverty of some Indian public agricultural research systems are starting to hurt private research. The public research system is attempting to become more responsive to the needs of private firms, but leading firms are still dissatisfied with public research performance. They reported that part of the problem is that the public sector is perennially short of funds and a scientific culture that rewards basic research more than research that actually solves agricultural problems.

Finally, a number of foreign companies selected infrastructure—particularly roads and communications—as a major constraint to further investment in India.

Conclusions

Private research is rapidly growing—more rapidly than public research—but the total R&D expenditures in the private sector still amounted to only 16 percent of the total funding of Indian research in 1998. According to our estimates, based on our surveys and DST data, about $347.9 million (Re 31.4 = US $1) were spent in 1994-95 on R&D for the development of agriculture, forestry, and fishing, only 14 percent of which was contributed by the private sector. Empirical studies, noted earlier in this chapter, suggest that private research is contributing to agricultural productivity growth and that farmers capture more benefits of research than input firms. There is no immediate threat of Indian or foreign firms' gaining monopoly power over any agricultural input industries in India. There is simply too much competition, not only from other private firms but also from public firms, and, for the seed industry, from farmers. Even if there were a threat, the way to deal with it would be with a competition policy, not a technology policy.

The factors behind this growth in private food and agricultural research fall into four groups. The first factor is the size and growth in the Indian agricultural input and food markets. The second factor is the liberalization of restrictions on Indian and foreign firms that wish to invest in the food and input industries and the associated increase in levels of competition. A third factor is developments within the international food and agricultural input industries—declining growth rates in demand in OECD countries and mergers and acquisitions in the food and input industries. A fourth set of factors important for some industries, particularly the seed industry, is the breakthroughs in plant biotechnology and the applied research by Indian government and international nonprofit institutions such as ICRISAT.

Based on the history of recent growth and the responses of the surveyed firms, we believe that private food and agricultural research can be strengthened and farmers' access to new technology can be improved by further liberalization, continued support for public research, and stronger intellectual property rights:

- Liberalization includes continuing to liberalize rules on foreign investments in the input industries, replacing the bans on imports of inputs with tariffs that will gradually be lowered, and continuing to rationalize regulations on the release of new pesticides and biotech products. Then, farmers and consumers are protected against health and environmental dangers, and the input companies will not be burdened with unnecessary requirements.
- Continued public financing of Indian and international public research will support the growth of competitive modern food and inputs industries. Public research can give private firms opportunities to grow and compete with multinational firms.
- Stronger IPR legislation and enforcement will enable farmers to access the most advanced technology and will give local and foreign firms incentives to conduct research on the problems of farmers.

Most of these policies are not new. India is committed to continued liberalization and stronger IPRs by becoming a member of WTO and is committed to increasing government research. The real question is: How long will it take India to fully realize these commitments?

References

Basant, R. "The Diesel Engine Industry Cluster, Rajkot." Project Report submitted to the Small Industries Development Bank of India. Indian Institute of Management, Ahmedabad. 1997.

Basant, R., and B. Fikkert. "The Effects of R&D, Foreign Technology Purchase, and Domestic and International Spillovers on Productivity in Indian Firms," *Review of Economics and Statistics.* Vol 78. 1996. pp.187-199.

Byerlee, Derek, and Miguel A. Lopez-Pereira. *Technical Change in Maize Production: A Global Perspective.* Centro Internacional para Mejoramiento de Maiz y Trigo Economics Working Paper 94-02. Mexico D.F.:CIMMYT. 1994.

Centre for Monitoring Indian Economy. *Market Size and Market Shares.* Mumbai. July 1998.

Compound Livestock Feed Manufacturers of India. *Annual Report 1996-97.* Mumbai. 1998.

Department of Science and Technology. *Research and Development Statistics, 1994-95*. New Delhi. 1997.

Desai, B.M. "Budget: A Retrograde for Agriculture," *Vikalpa*. Vol. 22, No. 2. April-June 1997. Pp. 23-26.

Evenson, R.E., C.E. Pray, and M.W. Rosegrant. *Agricultural Research and Productivity Growth in India.* International Food Policy Research Institute, Washington, DC. 1998.

Fikkert, B. "An Open or Closed Technology Policy? The Effects of Technology Licenses, Foreign Direct Investment and Domestic and International Spillovers on R&D in Indian Firms." Unpublished paper, Department of Economics, University of Maryland, College Park. 1995.

Government of India, Directorate of Economic and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture. *Agricultural Statistics at a Glance.* New Delhi. 1998.

Government of India, Directorate of Economic and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture. Unpublished data. New Delhi. 1997.

Pal, Suresh, Alka Singh, and Dayanatha Jha. "Levels of Agricultural Research Investment: Lessons for the Future," *Agricultural Development Paradigm for the Ninth Plan Under New Economic Environment*. B.M. Desai (ed.). Oxford and IBH Publishing Co., Pvt . Ltd., New Delhi. 1997.

Pray, Carl E. *Private Sector Research and Technology Transfer in India: Report on September 1985 Survey.* Economic Development Center Report 1, University of Minnesota, St. Paul. 1986. pp. 1-68.

Pray, Carl E., and Tim Kelley. "Impact of Liberalization and Deregulation on Technology Supply by the Indian Seed Industry." Unpublished paper. International Crops Research Institute for the Semi-Arid Tropics. 1998.

Pray, Carl E., Sharmila Ribeiro, Rolf A.E. Mueller, and P. Parthasarathy Rao. "Private Research and Public Benefit: The Private Seed Industry for Sorghum and Pearl Millet in India," *Research Policy.* Vol. 20. 1991. pp. 315-324.

Ramaswami, B., C. Pray, and T. Kelley. "Private Plant Breeding and Farmers' Yields in the Semi-Arid Tropics of India." Unpublished paper. Rutgers University. 1999.

Sawant, S.D. "Foodgrains Output Growth: Emerging Constraints and Perspectives for Technology Development Policies, "*Agricultural Development Paradigm for the Ninth Plan Under New Economic Environment*. B.M. Desai (ed.). Oxford and IBH Publishing Co., Pvt., Ltd., New Delhi. 1997.

Singh, R.P., S. Pal, and M.L. Morris. *Maize Research, Development, and Seed Production in India: Contributions of the Public and Private Sectors.* Centro Internacional para Mejoramiento de Maiz y Trigo Economics Working Paper No. 95-03, Mexico, D.F. 1995.

Singh, R.P., and M.L. Morris. *Adoption, Management, and Impact of Hybrid Maize Seed in India.* Centro Internacional para Mejoramiento de Maiz y Trigo Economics Working Paper No. 97-06. Mexico, D.F. Centro Internacional para Mejoramiento de Maiz y Trigo. 1997.

Tata Services, Ltd. *Statistic Outline of India, 1997-98.* Mumbai. 1997.

Unni, K.K. "Role of Agro-chemical Industry," *Agricultural Development Paradigm for the Ninth Plan Under New Economic Environment*. B.M. Desai (ed.). Oxford and IBH Publishing Co., Pvt., Ltd., New Delhi. 1997.

Venkasteshwara Hatcheries, Limited.

Witcombe, J.R., D.S. Virk, and J. Farrington. *Seeds of Choice: Making the Most of New Varieties for Small Farmers.* Oxford and IBH Publishing Co., Pvt., Ltd., New Delhi. 1998.

List of Tables

Pakistan

Mumtax Ahmad and Joseph G. Nagy

The public sector has provided most of the investment in agricultural research in Pakistan. The country's political and economic climate, coupled with unresolved intellectual property rights and problems with regulation enforcement, has dampened the considerable potential of private agricultural research. Despite these problems, private agricultural research has been increasing. Investment in private agricultural research more than doubled between 1988 and 1998, but remains at about one-fifth of public expenditure in agricultural research, which is at a very low level.

This chapter presents a study of private agricultural research in Pakistan. Its purpose is to: identify the magnitude and scope of private agricultural research, identify current policy and technical constraints that limit the potential of private agricultural research, and suggest policies and programs for increasing private investment to reach its full potential.

Information for the study is based on personal contact with secondary sources and a survey questionnaire. Relevant government agencies, key informants, and private companies were contacted and informally asked questions pertaining to private research. A formal survey was conducted of private companies that provided agricultural inputs and those that process agricultural commodities. The formal survey questionnaire was sent in May 1998 to firms in Pakistan that were conducting private agricultural research, had done this research, or had the potential to undertake private research.

This study follows two previous studies done in 1987 by Ahmad (1987) and by Pray (1987). Some results of this study are compared with the two earlier studies. This study is an update to the Ahmad (1987) study but also includes changes since 1987 in policy toward private research.

This chapter presents an overview of Pakistan's agriculture describing its role in the Pakistani economy, trends in agricultural production and productivity, and food supply and demand projections. It describes the public agricultural research system, the past and present private investment and research environment, and survey results, and identifies trends since the two 1987 surveys. It also discusses the structure and research investment of selected agricultural input industries in Pakistan.

Agriculture Sector

Agriculture is the largest sector of Pakistan's economy—ahead of manufacturing—and accounted for 24.6 percent of the total gross domestic product in 1997-98. The sector in 1998 employed 16.2 million workers, who represented 47.5 percent of Pakistan's total labor force (Government of Pakistan, 1996). Seventy percent of Pakistan's population of over 140 million lived in rural areas; however, there was an alarming upward trend in the growth of urbanization.

Three main sources of demand exist for Pakistan's future agricultural output. The first source is for food and fiber for the population of 140 million (in 1998), growing at a rate of around 3 percent per year. The population doubling time is approximately every 25 years. This means that Pakistan's population could reach over 250 million by 2020 and over 375 million by 2030. The second source of demand is the moderately rising per capita income, which increased at a real rate of 5 percent per year (Government of Pakistan, 1997a). Tastes and preferences change with rising incomes, often leading to a greater demand for edible oils and livestock products, in particular, milk and poultry. The third source is the demand for exports and resulting foreign exchange earnings.

The agriculture sector is an important source of foreign exchange earnings through exports of agricultural commodities and agricultural-based products. However, substantial foreign exchange is required for imports of agricultural commodities and products. The trade balance has been negative for most of Pakistan's history as a nation. Raw cotton has become the largest agricultural export commodity, except in years of depressed cotton production. Raw cotton exports accounted for 7.5 percent of the value of total exports in 1991-92, but exports of raw cotton fell to around 1 percent of the value of total exports in 1993-94 and 1994-95, when the crop was affected by the cotton leaf curl virus and inclement weather conditions (Government of Pakistan, 1997a). Exports of rice, the second major agricultural export commodity, accounted for between 3.6 and 6.7 percent of the total value of all export earnings in 1988-89 to 1994-95. Fish, fruits, and spices follow as the next highest exported commodities in value terms. Total agricultural commodity exports as a percentage of the total value of all exports ranged from a high of 31 percent in 1988-89 to a low of 9 percent in 1993-94, when cotton production substantially declined, indicating the importance of a good cotton crop (Government of Pakistan, 1997a).

Raw agricultural items such as cotton, wool, and leather products provide the material for many value-added industries. Goods such as cotton yarn, cotton cloth, carpets, and leather manufactured from raw agricultural products accounted for between 33 and 38 percent of the value of total export earnings in 1988-89 to 1994-95 (Government of Pakistan, 1997a). Together, raw agricultural products plus semi-manufactured agricultural products (cotton yarn, leather, molasses, animal casings, and tobacco) provided between 45 and 55 percent of the value of Pakistan's foreign exchange earnings in the 1990s.

Agricultural commodity and product imports substantially contributed to total imports and the negative trade balance. The major agricultural import was edible oils, followed by grains, pulses, and flour. By value, edible oil imports were about 80 percent palm oil with the remainder mostly soybean oil. The category of wheat, pulses, and flour consists of over 85 percent wheat imports in any given year. Together, these two import categories represented 30-40 percent of the trade balance deficit in 1988-89 to 1994-95. In all, between 13 and 18 percent of the value of total imports were agricultural food commodities (Government of Pakistan, 1997a).

Agricultural Production, Productivity Growth, and Food Security

More intensive use of land and water resources, in combination with new interventions from research (in particular, new varieties) has yielded increased agricultural production and productivity. The significant potential to increase productivity through increasing the effectiveness of the extension, education, and training systems and investing in rural infrastructure has not been tapped. The agricultural input, product price, and trade policy environment, overall, has had a negative effect on productivity growth (World Bank, 1994). Farm-level prices of several agricultural products have remained below free market prices. These included the price for wheat, which is the staple food, and the two main export crops of cotton and rice. Policies, however, were devised to allow duty-free imports of farm machinery and to subsidize fertilizer and credit. Both subsidies were later withdrawn.

The average annual growth in overall agricultural production since 1959-60 has been an impressive 3.2 percent, which favorably compares with growth rates of similar countries (World Bank, 1994). The overall growth rate in agricultural production for 1988-89 to 1993-94 was 3.6 percent, the same rate of growth as for 1979-80 to 1987-88. The growth rate fell to 2.3 percent during 1969-70 to 1979-80 due to several years of severe weather conditions and a virus that depressed cotton production. The growth rate in agricultural production in these three periods lags far behind the 4.9-percent growth rate experienced between 1959-60 and 1969-70. That period marked the beginning of the green revolution with the use of high-yielding varieties (HYV) and increased external inputs, such as water and fertilizer (World Bank, 1994). Thus, the growth rate in agricultural production slowed and, as indicated by the 1969-70 to 1979-80 data, can be cut in half by weather and disease factors.

Growth in agricultural productivity is also important in assessing the direction of future agricultural production. Partial productivity growth rates in terms of crop yields (kilograms per hectare) are presented in table C-1 for selected crops. The long-term growth rate for wheat yield was very modest at 0.8 percent. The yield growth rate trend of basmati rice, a large foreign exchange earner, was negative. The trend in sugarcane yield was also modest at 0.6 percent. Cotton yield grew steadily at 2.4 percent but suffered a 2.8-percent decline in 1993-94 due to adverse weather and disease. However, the crop rebounded with a record production of over 9 million bales in 1995-96.

Table C-1 suggests that the partial productivity measures of yield per hectare for some major crops have decreased, plateaued, or were increasing more slowly compared with previous periods, in particular, relative to the green revolution period. For example, a study of Punjab wheat yields by Byerlee and Siddiq (1990) indicates that wheat yields between 1966 and 1976 increased by 59 kilograms per hectare, but by only 21 kilograms per hectare in the following 10-year period, suggesting a sustainability problem. Similar compar-

Table C-1—Area, production, and yield growth rates of selected major crops, Pakistan, 1989-90 to 1993-94

Commodity	Area		Production		Yield	
	Weight[1]	Growth rate	Weight[1]	Growth rate	Weight[1]	Growth rate
	Thousand hectares	*Percent*	*Thousand tons*	*Percent*	*Kilograms/ hectare*	*Percent*
Wheat	7,993	0.4	15,187	1.2	1,899	0.8
Cotton	2,748	1.0	1,636	3.4	595	2.4
Basmati rice	1,086	1.2	1,184	.8	1,090	-.4
IRRI rice	863	-.1	1,980	.1	2,285	.2
Sugarcane	896	.1	37,002	.7	42,900	.6
Rapeseed	289	-1.2	215	-.5	748	.7

[1]These are 1989-90 to 1993-94 averages.

Source: Primary data from Agricultural Statistics of Pakistan (Government of Pakistan, 1997b); Growth rates: Log of 1980-81 to 1993-94 annual data for area, production, and yield, regressed on time (1,2,3…14). The growth rate is the first derivative of the estimated equation x 100.

isons indicate that rice yields have plateaued and that cotton yields increased at a decreasing rate in 1993-97, relative to the impressive increase in cotton yields in 1980 to 1990 (see Byerlee, 1994).

Although requiring further verification, this points to a potential problem. Pakistan's future agricultural production and productivity increases may not be able to be sustained at the same growth rates as in the past. Most food supply and demand projections for Pakistan forecast large agricultural commodity imports in the future if investment in the agricultural sector were to remain at its 1998 low levels. International Food Policy Research Institute projections for food supply and demand and net trade for selected agricultural commodities in 2020 are presented in table C-2. The supply projections consider the effect of future public and private agricultural research, agricultural extension and farmers schooling, marketing efficiency, infrastructure, and irrigation. The supply projections in table C-2 are based on a low-investment and slow-growth scenario in these components. The demand projections are based on population growth, per capita income growth, and projected consumer prices.

With the exception of rice, substantial quantities of all remaining commodities must be imported. Wheat imports would be about 8 times higher and edible oil imports 13 times higher than the 1993-94 levels. Wheat imports alone cost about $5 billion per year at 1998 prices. This puts enormous strain on Pakistan's foreign exchange requirements and impedes the future development of the country. Table C-2 also presents the production growth rates that various commodities would have to achieve to satisfy demand in 2020. These growth rates are substantial when compared with those in table C-1 and would require immediate action for a high-investment and high-growth strategy to achieve such rates.

Public Agricultural Research

At the time of the partition of British India in 1947, Pakistan inherited very little of the human and physical capital that made up what then was an internationally recognized research system in British India (Pray, 1978). There remained one agricultural college and one research station in three of the four provinces but with insufficient resources. In the 1950s, two more agricultural colleges were formed. In the late 1950s, research and teaching institutions in the North West Frontier Province and Punjab and Sindh provinces were established with American assistance from three land-grant universities. These institutions laid the groundwork for the current agricultural education and public research system.

In 1998, the publicly funded Pakistan agricultural research system was organized at the Federal and provincial levels. There were 74 research establishments at the Federal level and 106 research institutions at the provincial level in 1990 (Mellor, 1994). Three agricultural universities also conduct research. The Pakistan Agricultural Research Council (PARC) is the main body in agricultural research and conducts, promotes, and coordinates research in the country. The National Agricultural Research Center in Islamabad is PARC's main research facility. Long-term priority research is conducted at the Federal level, along with applied and adaptive research. Research is mostly adaptive at the provincial level.

Table C-2—Food supply and demand projections and net trade, to 2020, Pakistan

Commodity	Production	Demand	Net trade	Required growth rates[1] To meet 2020 production	To meet 2020 demand
	------------*Thousand tons*------------			-------*Percent*--------	
Crops:					
Wheat	27,463	42,913	-15,451	2.3	3.8
Rice	6,207	5,309	898	2.2	1.5
Maize	1,895	2,748	-852	1.5	2.0
Other coarse grains	726	1,233	-507	1.0	2.6
Total cereals	36,291	52,203	-15,912	2.2	3.5
Edible oil	2	1,547	-1,545	NA	24.5
Roots & tubers	1,276	1,776	-499	1.9	2.9
Meat and eggs:					
Beef (buffalo)	764	1,109	-345	3.1	4.2
Sheep meat	1,254	1,507	-253	3.6	4.3
Poultry meat	381	679	-299	2.8	4.6
Total meat	2,399	3,295	-897	3.2	4.2
Eggs	669	775	-106	4.1	4.4

NA = Not available.
[1]Growth rates required to meet 2020 production and demand given 1990 production figures in Rosegrant, (1995, table 13).

Source: Rosegrant et al. (1995).

Pakistan's public agricultural research system has been successful. Several studies have documented the rate of return from past agricultural research in Pakistan (table C-3). Three studies, using slightly different methodologies, research, and extension expenditure calculations and time periods, documented that the overall internal rate of return from agricultural research ranged between 57 and 65 percent. The three major crops of wheat, rice, and cotton also have impressive returns to research. The returns compare favorably with what would be considered a good return from other public and private investments.

The high rates of return presented in table C-3 are largely from the green revolution period. There were substantial productivity gains from strong varietal improvement research programs and cooperation with international research centers. The high rates of return are an indication that Pakistan's public agricultural research system had done reasonably well in the past; however, the research system now faces several major difficulties. There has been a proliferation of research institutes at the Federal and Provincial levels without corresponding increases in trained scientific and management manpower and funding (Pakistan Agricultural Research Council, 1997). Management and control of research resources and information throughout the agricultural research system is weak (World Bank, 1990). Career advancement is largely based on seniority rather than merit.

The proportion of Ph.D's to total scientific staff in Pakistan, roughly 10 percent, would be considered very low relative to the proportion in developed countries. The latest figures show a ratio of agricultural scientists to population in Pakistan in 1988 at 44 per million, down from 60 per million in 1973. For comparison, the United States had 2,360 and the United Kingdom 1,400 agricultural scientists per million population (Mellor, 1994).

Pakistan spent only 0.02 percent of gross national product on public agricultural research in 1993, far below the level of most other countries (Mellor, 1994). The latest budget allocations for public agricultural research was around 1,100 million rupees (PRs) per year ($24 million). The funding environment for agricultural research indicates that it may be difficult to keep future funding levels, in real terms, from decreasing. A more serious problem related to research funding is the proportion of overall funding for actual expenditures on research by scientists (operational expenditures) and capital costs above that for salaries. Operational expenditures for research have declined to 10 to 15 percent, and sometimes lower, of overall research expenditures (Mellor, 1994, Vol. I, p. 202). Yearly expenditures on capital items are near zero unless purchased through a donor-funded project. Many scientists have indicated that soon they will be unable to conduct even maintenance research, and productivity and production will inevitably fall (Nagy and

Table C-3—Returns from agricultural research, Pakistan, selected years

Commodity/study	Period of study	Internal rate of return	Return eventually realized from one rupee invested
	Years	*Percent*	*Rupee*
All agricultural research:			
Azam et al. (1991)--			
All research	1956-85	57	10.9
Applied research	1956-85	82	20.9
General research	1956-85	56	10.2
Evenson & Bloom (1991)	1955-89	65	9.8
Nagy (1991)	1960-79	64	5.0
Wheat:			
Azam et al. (1991)	1956-85	76	16.5
Byerlee (1993) (Punjab)	1978-87	22	NA
Nagy (1991)	1964-81	58	NA
Rice:			
Azam et al. (1991)	1956-85	89	24.9
Iqbal (1991)--			
Punjab	1971-88	57	NA
Sindh	1971-88	50	NA
Cotton:			
Azam et al. (1991)	1956-85	102	43.5
Iqbal (1991)--			
Punjab	1971-88	90	NA
Sindh	1971-88	50	NA
Maize:			
Azam et al. (1991)	1956-85	46	3.8
Nagy (1991)	1967-81	19	NA

NA = Not available.

Source: Nagy and Ali, 1996.

Quddus, 1999; and Pakistan Agricultural Research Council, 1997).

A 1997 Pakistan National Master Agricultural Research Plan (NMARP) has spelled out priority areas of agricultural research and a blueprint and agenda of how the Pakistan agricultural research system can once again become a relevant contributor to increased agricultural productivity (Pakistan Agricultural Research Council, 1997; Nagy and Quddus, 1998). Included in the plan is the upgrading of management, a focus on priority research, and the upgrading of human and capital resources with a budget double the 1998 level. As part of the overall plan, the NMARP also encourages private agricultural research to contribute to increased agricultural productivity. Given the possible decline in long-term agricultural productivity, the projected food deficit problems, and the state of public agricultural research in 1998, private research must be encouraged to reach its full potential.

Private Investment and Research Environment

Agricultural research remained an almost exclusive domain of the public sector until the 1980s. The private sector was dealt a severe blow during 1972 to 1976. Along with large and medium private industries, many agribusiness firms were nationalized and merged under various state-owned corporations that controlled the processing and export of agricultural products. This continued until the early 1980s, when there was a slow beginning to the denationalization and deregulation of agriculture and agricultural industries and parastatals.

Privatization began in earnest in 1988, when the government initiated the privatization of many industries and took a more favorable stance toward private investment. The government, as of 1998, continued with privatization and disbanding of parastatals and introduced programs and policies to stimulate private investment. Steps were taken, for example, to phase out the upper ceiling on landholdings by agricultural companies and facilitate easier access to credit. During 1988 to 1998, most subsidiaries of the Ghee Corporation of Pakistan, the Pakistan Industrial Development Corporation, and the National Fertilizer Corporation were privatized. Other parastatals—-such as the Trading Corporation of Pakistan, the Rice Export Corporation, and the Cotton Export Corporation—-were downsized and merged with the Trading Corporation. The Marketing and Storage Corporation disbanded. Other parastatals, including the Trading Corporation, have been exposed to competition with the private sector.

As previously indicated, Government policies toward agriculture have been unfavorable. Policies have kept farm-level prices of the three major crops—wheat, cotton, and rice—at lower than free-market prices, thereby decreasing farm-level profit margins. This can hurt private agribusiness investment since optimum input levels are lower than they would be under higher prices and wider farm-level profit margins from a free market. Farm-level profit margins were further squeezed with the removal of the subsidies on fertilizer and credit.

The government is still finalizing its regulations on intellectual property rights. Pakistan's Plant Breeders' Rights Act, drafted by the Federal Seed Certification Department in 1996 and vetted by the Geneva-based International Union of Plant Variety Protection has yet to become law. Pakistan, as a member of the World Trade organization and a signatory to the Trade-Related Intellectual Property Rights System, was committed to introduce legislation in the form of plant breeders' rights or a patent by January 1, 2000. In 1998, new open-pollinated varieties of crops developed by the public and private sectors were not patented and continued to be available for multiplication and sale by public and private agribusiness firms without restriction or paying royalties to breeders or public institutions. This has kept the multinationals from introducing many open-pollinated varieties with superior germplasm. Seed firms, however, can register all new varieties with the Federal Seed Certification Department, but many national firms do not use the registry. There is also a 10-year internationally sanctioned exemption of new varieties imported into Pakistan from other countries to 2005. Other agriculture-related innovations are being registered with the Patent Office, which now resides in the Ministry of Industries or the trademarks registry within the Ministry of Commerce.

What may be of more concern in the future for private investment in agricultural research is the enforcement of plant breeders' rights, patent regulations, seed certification, and truth-in-labeling laws. Once plant breeders' rights become law, enforcement becomes an issue. Enforcement of truth-in-labeling laws—labeling and identifying seed as being of a certain quality and pedigree—is a major problem (Alam and Saleemi, 1996). The Federal Seed Certification Department does not have the number of trained staff required to properly monitor seed certification and truth-in-labeling regulations. Seeds can be imported without being tested for their authenticity, and local seed can easily be mixed with good quality or an improved variety seed without much enforcement of the seed certification act. Past experience with enforcing the laws pertaining to weights and measures and the adulteration of agricultural chemicals—particularly fertilizers, pesticides, and herbicides—has been unreliable. This creates an environment of mistrust among farmers who are reluctant to pay high prices for agricultural inputs that may be adulterated or of poor quality.

In 1998, the cotton industry was the largest user of farm-level inputs. Fertilizer, pesticides, and cottonseed were in demand by cotton farmers and were targeted by private research. In particular, good quality and improved cottonseed was in high demand because of the cotton leaf curl virus problem. Seed companies obtain their highest returns from providing new cotton seed varieties but make little money with open-pollinated wheat or maize varieties. Competition is still very strong from the new wheat and maize varieties coming from the public research system and distributed by the Punjab and Sindh Seed Corporations.

The 1998 private investment and research environment was the best it had been since the nationalization policies in the 1970's. Official government policy is one of continued privatization, deregulation, and trade liberalization and the creation of an environment for the expansion of the private sector in agriculture, agribusiness, and research. However, the mood of most private investors in agribusiness is cautious, particularly for research that has a long-term payoff, partly because of the political and financial instability within the country. Despite the political change that brought in a fledgling democracy in late 1988, there were four interim governments consistent with each of the four regularly elected governments. The country's foreign exchange reserves are chronically low as are the government's financial resources to pay for internal and external government debts. Further uncertainty is generated by developments with and in the countries on Pakistan's borders. These uncertainties led to cautious private investment and private research programs that can be characterized as short-term adaptive research taking advantage of technology transfer opportunities. Thus, while the 1998 government policy was amenable to private investment, other developments constrained the private sector and investors still remembered the nationalization period of the 1970's.

Private Research Investment

We conducted a formal survey of firms in the agriculture sector that provide inputs to farmers and to firms processing agricultural products. The survey questionnaire was sent in May 1998 to 362 firms in Pakistan that were identified as conducting private agricultural research, had conducted research in the past, or had the potential to undertake private research. Of the firms surveyed, 244 primarily produced or manufactured agricultural inputs to be used at the farm level and 118 were predominantly processing firms (tobacco companies do both but spend 80 percent of their research on agricultural inputs). The list of firms was based on the Ahmad (1987) survey list updated by information from all 31 Chambers of Commerce and Industries as well as from Agribusiness Trade Associations. Questions were asked about: (1) the area and type of research undertaken, (2) the number of scientists employed by qualification and number of technicians and field staff, (3) research expenditures, (4) support and collaboration with public research institutions, and (5) major constraints to doing research.

Of the 362 firms surveyed, 159 (44 percent) responded to the survey questionnaire. Table C-4 presents the number of questionnaires sent and the number of responses by agribusiness category. The categories are divided into firms that provide or do research on agricultural inputs, and firms that primarily process agricultural products. Each category is further divided by their identity as a multinational or national firm. Most firms that did not initially reply were contacted personally or by telephone. This elicited more responses but also indicated that in the final analysis, the majority of the firms that did not respond to the questionnaire did little or no research. Many firms are registered but not all firms are active. For example, there are over 100 national seed firms registered but only a few are active and fewer still actually do research (Alam and Saleemi, 1996). Thus, the 159 firms that did respond undertake some research and make up at least 95 percent of all firms that undertake private agricultural research.

Private Research Areas

Table C-4 also briefly describes the type of research in each category. The agribusiness categories in table C-5 are similar to the Ahmad (1987) survey categories, except for the addition of herbal medicines and planting material/tissue culture, which are new areas of private research. Research varies from simple adaptive research, done by most national agricultural machinery firms, to technologically advanced research, as in the case of planting and tissue culture research. All respondents indicated that they did adaptive research (adjusting technology to local conditions). All multinational firms indicated that some of their research could also be classified as applied research (new technology creation), but only 5 percent of the national firms said they did applied research. The national firms included the planting material and tissue culture firm and several firms from the seed and sugar categories. Thus, most private research was adaptive and functioned as an adjunct activity to the main business of selling an input or processed product.

Scientists and Staff by Qualification

All 159 respondents answered the question about scientist and staff numbers (table C-5). Of the total 292 scientists reported, 4.5, 31.0, and 64.5 percent are qualified with a Ph.D., M.S., and B.S., respectively. In comparison, the breakdown for the same qualification categories in public agricultural research was 9.5, 63.5 and 27.0 percent, respectively (Pakistan Agricultural Research Council, 1997). The Ahmad (1987) survey reported 3.5, 45, and 51.5 percent for the same categories, respectively, indicating a slight shift toward the use of more B.S.-qualified scientists in place of scientists with an M.S. Multinational firms employ more scientists per firm (7.30 per firm) than do national firms (1.38 per firm). Multinational firms also hire more qualified scientists per firm. For example, multinationals hire more Ph.D.s per firm (0.50 per firm) than do national firms (0.05 per firm). However, comparisons with the Ahmad (1987) survey indicate that tobacco firms had two Ph.D.s in 1987, but none in 1998. Discussions with the tobacco and other firms indicate that they can do most of their adaptive research using well-qualified M.S. and B.S. trained scientists. Also, they say it is more difficult now to employ well-trained Ph.D. scientists, because Ph.D.s

Table C-4—Survey questionnaires sent and received and areas of research, Pakistan, 1998

Agribusiness category	Surveyed	Responses	Description of research
	-------Number-------		
Firms providing agricultural inputs:			
Multinational firms--			
Agricultural machinery	2	1	Manufacturing parts locally
Fertilizer	3	3	Agronomic field trials
Pesticide	5	3	Field trials/intellectual property rights
Seed	4	2	Variety and hybrid evaluation trials
Tobacco	2	2	Agronomic trials
Subtotal	16	11	
National firms--			
Agricultural machinery	98	34	Adapting imported machinery
Fertilizer	2	2	Agronomic field trials
Poultry/livestock feed	21	5	Feed ingredient substitutes
Poultry	8	6	Husbandry, new breeds
Pesticides	21	12	Agronomic trials
Planting material/tissue culture	8	1	Virus-free potatoes, dates, & bananas
Seed	70	26	New variety trials (hybrids)
Subtotal	228	86	
Agricultural product-processing firms:			
Multinational firms--			
Dairy & dairy products	1	1	Developing products to local taste
Tobacco[1]			Processing and curing trials
National firms--			
Dairy & dairy products	5	2	Product & processing development
Food processing	32	22	Product development
Herbal medicines	16	2	Product development
Maize products	2	2	Starch, edible oil, starch-based sugars
Sugarcane	35	17	Byproduct development (molasses, alcohol, biofertilizer), new varieties
Solvent oil extractor	9	5	Processing, new oilseed crops (canola)
Vegetable ghee	18	11	Alternative blending formulas
Subtotal	117	61	
Total	362	159	

[1]The same tobacco companies as above in “Firms providing agricultural inputs.”

have more and better opportunities with pharmaceutical industries and Ph.D.s trained abroad usually try to stay abroad and work rather than return to Pakistan.

There are about two technicians and field staff to support each scientist. This 2:1 ratio holds true for multinational and national firm categories when taken separately. However, the category of firms providing agricultural inputs has about a 2.2:1 ratio, whereas the agricultural product-processing firms category had a 1.6:1 ratio. This compares with only a 0.4:1 support staff per research scientist ratio in the public agricultural research, indicating that the private sector has better support for its scientists (Pakistan Agricultural Research Council, 1997).

Private Investment in Agricultural Research

The survey questionnaire asked firms about their research expenditures. Although some firms responded, few gave complete information. We decided to estimate research expenditures based on the staff costs of technicians, field staff, and scientists, supplemented by the partial information from the survey results and information from personal contact with several the leading firms. Average staff costs were estimated at PRs 60,000 per month for a Ph.D., PRs. 30,000 per month for an M.S., PR. 15,000 per month for a B.S., and PRs. 7,500 per month for technical and field staff. The market for qualified scientists and staff is very competitive, and

Table C-5—Technicians, field staff, and scientists by qualification, Pakistan, 1998

Agribusiness category	Technicians and field staff	Number of Scientists			
		Ph.D.	M.S.	B.S.	Total
			Number		
Firms providing agricultural inputs:					
Multinational firms--					
Agricultural machinery	23	0	1	6	7
Fertilizer	21	2	5	13	20
Pesticide	81	1	8	14	23
Seed	16	3	3	4	10
Tobacco	14	0	6	8	14
Subtotal	155	6	23	45	74
National firms--					
Agricultural machinery	42	0	4	11	15
Fertilizer	21	0	9	4	13
Poultry/livestock feed	18	0	4	14	18
Poultry	86	1	6	12	19
Pesticides	26	1	3	17	21
Planting material/tissue culture	2	1	3	3	7
Seed	48	0	3	11	14
Subtotal	243	3	32	72	107
Agricultural product-processing firms:					
Multinational--					
Dairy & dairy products	18	0	3	7	10
Tobacco	4	0	2	2	4
Subtotal	22	0	5	9	14
National--					
Dairy & dairy products	18	1	5	7	13
Food processing	26	1	7	8	16
Herbal medicines	4	0	6	2	8
Maize products	9	0	2	6	8
Sugarcane	59	2	11	27	40
Solvent oil extractor	11	0	NA	3	3
Vegetable ghee	28	0	NA	9	9
Subtotal	155	4	31	62	97
Total	575	13	91	188	292

NA = Not available.

multinational companies paid the same rates as nationals. From the information provided by the firms, operating costs were estimated to be equal to the sum of total staff costs. Operating costs include management costs, materials and office supplies, laboratory supplies, travel and daily allowances, repair and maintenance, utilities, petrol, oil and lubricants, communications, rent, taxes, and daily paid labor. The firms did not estimate capital costs of research.

Table C-6 presents the estimate of staff and operating costs for private research in Pakistan for 1998. The cost per staff category, as presented earlier, was multiplied by the number of technicians, field staff, and scientists in each staff category from table C-5 and doubled to account for operating costs. Total estimated costs are in the order of PRs 255 million (US$5.7 million). As previously discussed, this estimate would include nearly 95 percent of all staff and operating expenditures in private agricultural research.

In monetary terms, firms that produced or manufactured agricultural inputs accounted for two-thirds of private agricultural research and one-third of agricultural processing firms. Agricultural chemical research (fertilizers and pesticides) accounted for 41 percent of

Table C-6—Private agricultural research expenditure estimates, Pakistan, 1998

Agribusiness category	Research expenditures			Total[2]
	Scientists	Technicians field staff	Total[1]	
	--------------------Million rupees--------------------			*U.S. dollars*
Firms providing agricultural inputs:				
Multinational firms--				
Agricultural machinery	1.44	2.07	7.02	156,000
Fertilizer	5.58	1.89	14.94	332,000
Pesticide	6.12	7.29	26.82	596,000
Seed	3.96	1.44	10.80	240,000
Tobacco	3.60	1.26	9.72	216,000
Subtotal	20.70	13.95	69.30	1,540,000
National firms--				
Agricultural machinery	3.42	3.78	14.40	320,000
Fertilizer	3.96	1.89	11.70	260,000
Poultry/livestock feed	3.96	1.62	11.16	248,000
Poultry	5.04	7.74	25.56	568,000
Pesticides	4.86	2.34	14.40	320,000
Planting material/tissue culture	2.34	.18	5.04	112,000
Seed	3.06	4.32	14.76	328,000
Subtotal	26.64	21.87	97.02	2,156,000
Agricultural product-processing firms:				
Multinational--				
Dairy & dairy products	2.34	1.62	7.92	176,000
Tobacco	1.08	0.36	2.88	64,000
Subtotal	3.42	1.98	10.80	240,000
National firms--				
Dairy & dairy products	3.78	1.62	10.80	240,000
Food processing	4.60	2.34	13.88	308,444
Herbal medicines	2.52	.36	5.76	128,000
Maize products	1.80	.81	5.22	116,000
Sugarcane	10.26	5.31	31.14	692,000
Solvent oil extractor	.54	.99	3.06	68,000
Vegetable ghee	1.62	2.52	8.28	184,000
Subtotal	25.12	13.95	78.14	1,736,444
Total	75.88	51.75	255.26	5,672,444

[1]Estimated expenditure for scientific manpower plus the total estimated expenditure for technicians and field staff multiplied by two to account for operating costs.
[2]One U.S. dollar exchanged for 45 rupees at the time of the survey in May/June 1998.

agricultural input firm research expenditures. The sugar industry accounted for 35 percent of agricultural processing expenditures. Multinational firms accounted for one-third and national firms for two-thirds of research expenditures. Of the multinational firms, pesticide firms spent the most on research and almost twice that of fertilizer, the next highest category of firms in terms of expenditures. Poultry and sugar firms spent the most on research within the national firm category.

Pray (1987) estimated 1987 staff and operating costs to be a minimum of PRs 20 million. The Ahmad (1987) survey estimated 1987 research expenditures for staff and operating costs to be PRs 37 million when the same firm categories were included as in the 1998 survey. The Pray (1987) estimates were from direct personal contact with firms, and thus the expenditure data is very credible for the firms contacted. However, the Ahmad (1987) survey cast a wider net and included more firms in the food-processing and sugar industries.

Using the Pakistani general consumer price index (Government of Pakistan, 1997a) to inflate 1987 rupees to 1998 terms, PRs 37 million (in 1987) are equivalent to about PRs 100 million in 1998 rupees. Thus, the 1998 expenditure estimate of PRs 255 million from table C-6 is about 2.5 times the 1987 estimate. This indicates that the growth in private agricultural research over the last 10 years more than doubled.

A more than doubling of private research activity in 1988 to 1998 is encouraging. However, the amount spent on private agricultural research is small, given the relatively large agricultural sector and its importance to the economy. An expenditure of $5 million to $6 million is very small even if one considers that staff costs are one-half to one-fourth the costs of similar quality staff in developed countries. Private research expenditure is thus about one-fifth of Pakistan's total expenditure of about $25 million per year on public agricultural research.

Collaboration with Public Agricultural Research Institutions

The survey results indicated that there was no contact between 61 percent of all private sector agricultural research firms and Pakistan's public sector research system (table C-7). Only 18 percent of the firms indicated that they had active support and collaboration with public sector researchers, while 21 percent said they had some collaboration. The contact is highest among multinational firms, with over 90 percent of the firms indicating some or active support and collaboration, while the corresponding figure for national firms was only 35 percent. The agricultural machinery firm was the only multinational firm with no contact, and 88 percent of the national firms had no contact. Among the national processing firms, the majority of food-processing firms—sugar and vegetable ghee—had no contact.

Collaboration is in the form of general information flow and information on the latest research methodologies and techniques. Some firms hire public researchers as short-term consultants and collaborative researchers. One dairy firm and two fertilizer firms indicated that they sponsor research projects at public research institutions. Fauji Fertilizer Company and some national fertilizer companies sponsor M.S. degrees at Pakistan's three main agricultural universities in soil science and agronomy.

There was also some collaboration with the Agribusiness Directorate within the Pakistan Agricultural Research Council (PARC) (Nagy and Ali, 1996). PARC's mandate was to actively promote the commercialization of agricultural-related technologies developed in Pakistan at the national and international levels. The Directorate is comprised of two units: (1) the Transfer of Technology and Human Resources Development Unit, and (2) the Agro-Industrial Consultancy Unit. There is also an Agribusiness Cell within the Ministry of Food, Agriculture, and Livestock in Islamabad that promotes agribusiness. The Agribusiness Directorate within PARC and the Agribusiness Cell in the Ministry have a varied history of rising and falling in prominence, depending on the government's focus and the interest of the incumbent Secretary of Agriculture and PARC Chairman.

Incentives and Major Constraints to Research

A survey question asked if government policies and regulations provided incentives for private research. The unanimous answer was "No." No special government policies exist for tax relief to firms that do agricultural research. Most research equipment must be imported and is very expensive. High *ad valorem* duties are imposed on all imported laboratory and field equipment. And there is no differentiation between import duties on research equipment expenditures as opposed to production machinery expenditures.

Another survey question asked about major constraints to research. The questionnaire suggested three possible constraints: inability to find trained personnel, financial constraints, and official regulations and policies. No multinational firms answered this question, whereas 75 percent of all national firms answered (table C-8). Of the national firms, fertilizer, herbal medicines, and maize products did not respond. Followup contact suggested that multinational firms did not want to openly discuss these questions. Since multinational firm financing was linked to head offices abroad, there was a reluctance to discuss finances. Questions about official regulations and government policies are rarely voiced openly by multinational firms.

Of the 119 respondents, only the planting material and tissue culture firms indicated that they had problems finding trained personnel. Being a newer research area may account for this. In 1998, Pakistan produced a high number of good-quality M.S. and B.S. graduates to fill the market for the other areas of research. Ninety-two percent of those who responded indicated that financial constraints hampered their research effort. Most of these companies indicated that they cannot procure credit at reasonable rates for develop-

Table C-7—Public research institution collaboration and support, Pakistan, 1998

Agribusiness category	Private firms		
	No contact	Some collaboration	Active support and collaboration
		Number	
Firms providing agricultural inputs:			
Multinational firms--			
Agricultural machinery	1	NA	NA
Fertilizer	NA	NA	3
Pesticide	NA	1	2
Seed	NA	NA	2
Tobacco	NA	1	1
Subtotal	1	2	8
		Percent	
	9	18	73
		Number	
National firms--			
Agricultural machinery	30	3	1
Fertilizer	NA	1	1
Poultry/livestock feed	1	2	2
Poultry	2	2	2
Pesticides	2	6	4
Planting material/tissue culture	1	NA	NA
Seed	16	7	3
Subtotal	52	21	13
		Percent	
	60	24	15
		Number	
Agricultural product processing firms:			
Multinational firms--			
Dairy & dairy products	NA	NA	1
Tobacco[1]			
National firms--			
Dairy & dairy products	NA	2	NA
Food processing	16	2	4
Herbal medicines	NA	1	1
Maize products	NA	2	NA
Sugarcane	12	3	2
Solvent oil extractor	5	NA	NA
Vegetable ghee	11	NA	NA
Subtotal	44	10	7
		Percent	
	72	16	12
		Number	
Total	97	33	29
		Percent	
	61	21	18

NA = Not available.
[1]The same tobacco companies as above in "Firms providing agricultural inputs."

Table C-8—Private research constraints of national firms, Pakistan, 1998

Agribusiness category	Firms responding to question	Trained manpower	Financial constraints	Official regulations & policies
		Number of firms		
National firms providing agricultural inputs:				
Agricultural machinery	34	NA	31	NA
Fertilizer	0	NA	NA	NA
Poultry/livestock feed	5	NA	5	NA
Poultry	6	NA	6	NA
Pesticides	10	NA	8	8
Planting material/tissue culture	1	1	NA	NA
Seed	23	NA	20	7
Subtotal	79	1	70	15
National agricultural processing firms:				
Dairy & dairy products	2	NA	2	NA
Food processing	22	NA	22	10
Herbal medicines	0	NA	NA	NA
Maize products	0	NA	NA	NA
Sugarcane	0	NA	NA	NA
Solvent oil extractor	5	NA	5	NA
Vegetable ghee	11	NA	11	NA
Subtotal	57	0	40	10
Total	119	1	110	25

NA = Not available.

ing their business or to undertake research. Twenty-one percent indicated that official regulations and policies were a constraint to their research effort. The respondents were pesticide, seed, and food-processing firms. It was not certain if the companies responded to direct constraints that hampered research or to a general complaint about rules and regulations that pertained to their business. Many seed firms did not like the strict regulations about testing and certifying seed, and many pesticide companies may have felt that the Agricultural Pesticide Ordinance Act regulating adulteration standards and generic products was too strict.

Structure and Research Investment in Selected Agricultural Input Industries

Seed Industry

From partition in 1947 into the 1960s, there was no organized effort to establish a formal seed industry. Provincial agricultural departments began producing wheat, rice, and cottonseed on private and public farms during the first part of the green revolution period. The 1998 public seed industry organization owes its origins to the 1976 Pakistan Seed Industry Project, initiated by the Food and Agricultural Outlook/International Bank for Reconstruction and Development (FAO/IBRD). The objectives were to release a new variety, to multiply seed, and to process, certify, store, and market agricultural products (Ahmad and Chaudhri, 1994; and Alam and Saleemi, 1996). Since the Seed Act of 1976, the regulatory, registration, and certification functions have been under the guidance of the Federal Ministry of Food and Agriculture. The new act initially ignored a role for the private sector and developed a public seed industry. The Punjab Seed Corporation (PSC) and Sindh Seed Corporation (SSC) were established for seed procurement and import, production, storage, and distribution in each of those two provinces. Similar corporations in the North West Frontier Province (NWFP) and Balochistan Province were considered economically unviable, and it was thought that the seed demand in these two provinces could be supplied by the PSC and SSC. The NWFP Agricultural Development Authority mandated two seed corporations in Punjab, and the Balochistan Department of Agriculture mandated two in Sindh to identify seed requirements and import the seed.

In the Punjab, for example, prebasic seed is produced at the public research institutes and multiplied at PSC farms to obtain basic seed (Ahmad and Chaudhri, 1994; and Alam and Saleemi, 1996). PSC then contracts the growing of basic seed with registered farmers to obtain certified seed. Seed quality and control is administered by the Federal Seed Certification Department. Seed is then sold and distributed through both public and private organizations. The Punjab Agricultural Development and Supplies Corporation (PAD&SC), a sister parastatal that sells fertilizer and seed, marketed about 60 percent of the PSC seed. PAD&SC has its own sales depots but also sells through private dealers. The remaining 40 percent was sold by PSC through their own outlets and private outlets. At the beginning of each sale season, the agents are asked by PSC to indicate their anticipated demand. Seed pricing by PSC is based on the recovery of the cost to PSC plus a margin for overhead. The PSC and ADA no longer receive direct government subsidies, but SSC still does. However, indirect subsidies in all provinces take the form of government farms for seed replication.

The performance of the seed corporations has been less than was anticipated, although the PSC has had some success. The SSC was designed to operate like the PSC but had problems with organization and management and has not done as well as the PSC. Table C-9 presents the estimated seed requirements and actual seed distribution. Certified seed is made available for the major crops of wheat, cotton, rice, maize, and sometimes for gram (chick pea) and potato. Certified seed for vegetables, spice crops, oilseeds, and other pulses are not available through PSC or SSC. The 1991-92 figures in table C-9 are indicative of previous and more recent years. Although it was never the intent to cover 100 percent of seed distribution requirements for all crops, it was anticipated that high-yielding variety cereal crop requirements would be satisfied at the 75-percent level (Alam and Saleemi, 1996). Table C-9 indicates that they have fallen far short of their earlier intentions, despite the fact that, in the Punjab, PSC seed sales were tied to PAD&SC fertilizer sales. It has also been realized that PSC and SSC cannot fulfill the mandate to supply seed to NWFP and Balochistan. Supplying their own needs takes precedent, and because of different growing and agroecological conditions, the seed supplied by PSC and SSC was sometimes inappropriate.

PSC and SSC had the capacity to procure and distribute more seed. For example, together they could have doubled wheat seed distribution; however, several problems prevented them from doing this (Mellor, 1994, Vol I, p. 252; and Alam and Saleemi, 1996). Problems include a conservative parastatal management style, although it is understandable in light of a policy to take back all unsold seed from their dealers. Other problems include poor coordination, delay in shipments to dealers, wrong seed type shipped, limited storage capacity in certain areas, and poor packaging material. A PSC survey indicated that 51 percent of the farmers sampled in the survey did not use PSC seed because it was unavailable. A survey indicated that 83 percent of farmers sampled in the Punjab said they were satisfied with the quality of wheat seed and cottonseed that were reported to be of very high quality (Alam and Saleemi, 1996).

The Rafhan Maize Products company in the 1960s was one of the earliest private companies to enter the seed business. They developed hybrid maize varieties for contract growers for Rafhan's starch manufacturing business. Cargill Pakistan Seeds (private) Limited entered in 1984, and its activities involved variety trials of maize, wheat, soybean, and safflower hybrids. Among other early entrants were Jaffer Brothers (private) Seed Division, working on seed potato, and the Bukhari Corporation, working on cottonseed (see Alam and Saleemi, 1996; Ahmad, 1987; and Pray, 1987 for a history of the seed industry). The seed industry invested about PRs 25.6 million in 1998 in

Table C-9—Seed requirement and distribution by public seed corporations, Pakistan, 1991-92

Commodity	Estimated total requirement[1]	Annual requirement[2]	Actual quantity distributed	Annual requirement satisfied
	----------------Thousand tons		*---------------*	*Percent*
Wheat	691.3	138.3	51.4	37.2
Cotton	76.8	76.8	15.3	19.9
Rice	36.7	7.3	1.9	26.0
Maize	32.2	10.7	.9	.08
Gram (chickpea)	35.3	7.1	0	0

[1]Estimated total seed requirement for all four provinces, if seed was replaced every year.
[2]Assumes wheat, rice, and gram seed was replaced every 5 years, cotton every year, and maize every 3 years.

Source: Ahmad and Chaudhri, 1994.

research-related activities (table C-6), which is about 1.8 times the PRs 14.4 million (in 1998 rupees) invested in 1987 (Ahmad, 1987). Investment by national seed firms on research is about a third higher than investment by multinational firms.

In 1987, there were 11 registered seed companies (Ahmad, 1987). Alam and Saleemi (1996) listed over 80 registered national seed companies in 1995, but the total rose to 159 in 1998; 150 in the Punjab, 6 in Sindh, 2 in NWFP, and 1 in Balochistan. The Federal Seed Department has 40 more candidate seed companies under scrutiny. The national seed companies organized themselves under two chambers: the Chamber of Private Seed Industry is the larger and is in Multan; the other is organized under the auspices of progressive farmer businessmen in Rahim Yar Khan in southern Punjab. Most companies, however, ceased or never began operation and not all companies certify their seed. Two of the more prominent national seed companies Jalundur Seed Corporation and Zaheerabad Seed Corporation, have established seed-processing facilities and carry out research on scientific lines (Alam and Saleemi, 1996). With the exception of one firm in NWFP, which produced an indigenous sunflower hybrid, all remaining national seed companies were engaged in marketing open-pollinated seed of public-bred varieties of field crops and imported seed vegetable crops. All companies must conform to truth-in-labeling regulations; however, many national companies import seeds and directly sell them to farmers without testing or registering them.

In 1995, there were five main multinational firms registered as seed companies: Cargill, Pioneer, Sandoz, ICI Pakistan, and Lever Brothers (Alam and Saleemi, 1996). Cargill has by far the major share of the market, followed by ICI and Pioneer. Cargill researched maize, sunflower, forage sorghum, wheat, rice and cotton; ICI researched maize and sunflower hybrids; and Pioneer researched maize, sunflower, and forage sorghum. Sandoz did a limited amount of research, and Lever Brothers has terminated its activities. A merger between Sandoz and Ciba Giegy formed a new firm, called "Novartis," but the seed division has yet to become fully operative. Another new company, AgrEvo, the result of a merger between Hoechst and Russul Uclof, was preparing to enter the business. Cargill Pakistan, along with its subsiduaries, was being taken over by Monsanto.

All multinational companies must, by law, register for seed certification. All imported plant material must be tested in Pakistan before large quantities are imported. No control exists over seed pricing, and adherence to the truth-in-labeling standards were left to the determination of the market.

Multinational seed companies mostly develop hybrids of sunflowers, maize, and fodder crops. Some firms market public-bred open-pollinated varieties but are limited by the absence of plant breeders' rights. Public activities dominate the wheat and rice seed market, making it difficult for national and multinational companies to compete. One of the most profitable areas in 1998 was in developing cottonseed varieties because of the leaf curl virus problems and recommendations that farmers change their seed each year.

The effect of the private seed industry on Pakistani agriculture is still relatively small. Many multinational firms have developed superior hybrid maize and sunflower varieties that double or even triple the yield of varieties being used by most Pakistani farmers in 1998. However, the amount of seed for use was still limited. Alam and Saleemi (1996) estimated that in 1995 private national seed companies provided 3 to 4 percent of wheat seed requirements and less than 1 percent of the rice seed requirement of the entire Punjab. Multinational seed companies provided from 1 to 2 percent of the wheat seed, 1 percent of the rice seed, and 3 to 4 percent of the maize seed requirement of the Punjab. No estimates exist for cotton and other seeds, but there is no reason to believe their shares are any higher than those of wheat, rice, and maize. However, the potential is great. Taking into consideration Pakistan's seed requirements and the amount of seed that the public (table C-9) and private sectors distributed, there is considerable scope for private seed companies in the future.

However, several constraints must be overcome before the full potential is realized. Apart from political and economic instability, other factors hamper an increase in private seed research and development. These include policies that favored the public sector over the private in terms of duty-free imports of seed-processing equipment, provision of state land and farms for seed multiplication, and donor agency funding of research and human resources, which to the private sector adds up to a subsidy that they do not get. Private seed companies paid 25-percent customs duty on the import value price of seed and in-bred lines (vegetable seed exempt). There is no tax holiday for the seed industry; they pay duty on the import of processing plants and spare parts and pay local taxes on the movement of seed. There are indiscriminate imports of seed by unregistered seed companies, little enforcement of truth-in-labeling regulations, and a lack of awareness among farmers of the importance of good-quality seed (see Alam and Saleemi, 1996; and Mellor, 1994, Vol. I and II for a further litany of problems and constraints). Of the 23 national seed firms that responded to the survey question on major constraints to research (table C-8), 87 percent said they had financial constraints and 30 percent said that official regulations and policies were a constraint.

Fertilizer Industry

Commercial chemical fertilizer was first used in Pakistan in 1952-53, with a gift of 1,000 tons of nitrogenous fertilizer from the United States. But the existing varieties of wheat and rice were prone to lodging with high fertilizer use. It was not until the green revolution in the 1960s that high-yielding varieties arrived, triggering widespread use of fertilizer. A subsidy on fertilizer also helped to increase fertilizer use. Farmers used 6,600 nutrient tons in 1955-56, which steadily increased to a peak of 2,508,000 nutrient tons in 1995-96 before declining to 2,032,000 nutrient tons in 1997-98 (Government of Pakistan, 1997a). In 1997-98, 446,000 nutrient tons (22 percent) were imported. Pakistan produced most of its nitrogen fertilizer needs but imported phosphatic and potassic fertilizers.

Both public and private sectors were involved in fertilizer production and research. Public sector activities began with the Lyallpur Chemicals and Fertilizer (private) Ltd. plant in 1957 and the Pak-American fertilizer plant in 1958, followed by several joint ventures such as Pak-Arab, Pak-Saudi, and Pak-China fertilizer plants (see Ahmad, 1987, table IV-2). A Pak-Jordan DAP plant near Karachi was the latest and was expected to be completed by the end of 1998. The first private sector plant was built by Exxon in 1968. Two other private fertilizer plants followed: Dawood Hercules Chemicals, Ltd. (in 1971) and Fauji Fertilizers Co. Ltd. (in 1978). All private plants produce only urea.

In the 1970s privatization period, restrictions were put on private company fertilizer sales. In 1973, the government established the National Fertilizer Corporation of Pakistan, Ltd. (NFC) to take over the fertilizer-manufacturing facilities of the then state-owned fertilizer plants. In addition to fertilizer plants, the NFC operates the Fertilizer Research and Development Institute, a technical training institute, and a national fertilizer-marketing subsidiary. Restrictions were taken off private fertilizer sales, the fertilizer subsidy to farmers was abolished, and the NFC operated as an autonomous body that competes with the private sector. About 65 percent of the fertilizer production capacity is held by the private sector. Eight agencies marketed fertilizers in 1998: five public agencies and three private sector agencies represented by each private sector company, each having its own designated areas and dealers at the local level (Mellor, 1994). There is reported widespread adulteration and underweighing of fertilizer at the local dealer level, and black market prices were charged when some fertilizers were in short supply. Imports must be sanctioned by the government through the Directorate of Fertilizer Imports in MINFA, and sometimes the bureaucratic procedures result in delays of fertilizer imports, making them late for the sowing period.

Early research by public and private sectors concentrated on response curve estimation of improved wheat, rice, and maize as well as sugarcane varieties on application methods and demonstration trials (Pray, 1987). NARC and the provinces undertook public research on fertilizers and soils. Private research includes agronomic fertilizer trials on most prominent crops to develop fertilizer application recommendations, fertilizer formulations, and blending recommendations, and soil and water analyses. The effect on increased production of fertilizer use in combination with irrigation and high-yielding varieties of wheat, rice, and maize is well documented and, in part, owes some of this success to fertilizer-related research. Salary and operating research expenditures on private sector fertilizer research in 1987 was about PRs 11.3 million (in 1998 rupees). This compares with an expenditure of PRs 26.64 million in 1998 (table C-6). The private sector continues to actively collaborate with public sector researchers (table C-7) and conduct and support trials with public research institutions and agricultural universities. Multinational and national fertilizer firms declined to answer the question on constraints to research (table C-8).

Plant Protection Industry

Plant protection relates to pesticide use. Herbicides are not widely used; most farmers use weeds as a source of fodder and family labor for weeding, which was inexpensive relative to herbicides. Integrated Pest Management (IPM) is used some for biological control on mango, apple, and sugarcane, but this technology is in the early stages of development and is not widespread.

The pesticide industry is almost exclusively in the private sector. The public sector provides facilities for pest scouting, advisory services, and aerial spraying for locusts. Private firms locally produce, import, and market pesticides. The multinational firms and many national firms have their own field and extension staff. Local production of pesticides was 19,757 tons in 1995-96, matched by imports of 17,447 tons (Government of Pakistan, 1997a). Close to 80 percent of pesticides are used on the cotton crop and the remainder on sugarcane, rice, and fruits and vegetables (Mellor, 1994).

The pesticide industry became active in 1980 when the government deregulated and privatized the industry. The government announced a new agricultural policy that included the withdrawal of the subsidy on pesticides, transferred importing and distribution of pesticides to the private sector, discontinued free aerial spraying, and encouraged the local formulation and manufacturing of pesticides (Ahmad, 1987). The most active multinationals to invest in Pakistan are Hoechst, Ciba-Giegy, Dow Chemicals, Pacific, Chemdyes (Bayers), Sandoz, ICI, FMC, and Burmah Shell.

The pesticide industry is regulated by the Agricultural Pesticide Ordinance and Act of 1973 and prescribes heavy fines and punishment of 1 to 3 years for adulterated pesticide products or generic pesticide products, and for unconformity to strict regulations. These regulations are enforced more aggressively than other government rules and regulations, because most pesticides are used on the cotton crop, the largest single commodity foreign exchange earner for Pakistan.

Research in plant protection is done by both the public and private sectors. Public research at NARC and the provinces include entomology, weed sciences, and IPM research. IPM biological control research was also done by PARC-IIBC, Rawalpindi, and was affiliated with CAB International in England. There were concerns that high and indiscriminate pesticide use had disturbed the natural balance of pests and parasites. In particular, the problem of the cotton leaf curl virus and its white fly vector may stem from this. Plant breeding, new agronomic practices, and IPM's use of biological control methods was a priority research area over 1993-97 to combat the leaf curl virus.

Private sector research on plant protection is mostly in pesticide use and is largely adaptive-type research. In the first instance, research was done to ascertain the suitability of the pesticide, application techniques, and the collection of economic data, which is the requirement under the law for the registering of a brand name and formulation. Many small local companies stop research at this point, but some local and most multinationals maintain a research program gathering additional agronomic and IPM data that feed into product development and demonstration.

The Ahmad (1987) survey estimated research expenditures on private pesticide research in 1987 to be about PRs 26.5 million (in 1998 rupees). This compares with an expenditure of PRs 41.2 million in 1998 (table C-6). Multinational firms spent almost twice as much as national firms. The private sector continued to collaborate actively with public researchers (table C-7). Eighty percent of the respondents to the question on constraints indicated that they had financial and official regulations and policy constraints for undertaking further research (table C-8).

The effect of pesticide use on Pakistan agricultural production is considerable. Production of the hybrid spring maize crop would be impossible without some form of plant protection use. A combination of the hybrid variety and appropriate pesticide use has enabled spring maize yields to increase sixfold over traditional maize varieties and farm practices. Chemical control of pyrilla in sugarcane is credited with having increased raw sugarcane yield by 10 percent and sugar recovery by at least 1 percent. Average per-hectare yield of horticultural crops increased by 72 percent in 1987-97; the cotton crop has doubled production since the 1980s; and the use of plant protection measures, mainly pesticides, is credited for a large portion of this increase. Similarly, the average yield of Virginia tobacco increased from 1,957 kilograms per hectare in 1987-88 to 2,300 kilograms per hectare in 1997-98, largely due to pesticide use (Pakistan Tobacco Board, 1998).

Concluding Comments

Pakistan made great strides in 1982-97 to encourage private investment in the country, in general, and in agricultural input and processing industries in particular. Private investment in agricultural research more than doubled between 1987 and 1997. Although the agribusiness research component is still relatively small, the potential for private investment in the agribusiness input and processing industries and accompanying research and development opportunities appears to be substantial. The seed, plant protection, and poultry sectors alone offer numerous opportunities for investment expansion and research. Opportunities for the food-processing industries could also be substantial, given an effective demand from a growing and increasingly urban and younger population.

However, private investment firms seek political, economic, and financial stability within a country, transparent and appropriate rules and regulations, and the consistent and fair enforcement of those rules and regulations, along with the ability to profit from their investment. None of these conditions were much in evidence in Pakistan in 1982-97. This constrained private investment, which in turn kept private agricultural research at a low level. Private firms accept risk, but where risk is high, firms will do only the short-term adaptive research necessary to keep themselves in the market. Little long-term applied research will be done and basic research will never be undertaken.

Given the possible decline in long-term agricultural productivity, the projected food deficit problems that may occur in the 2000s, and the declining state of public agricultural research investment, encouraging private research to reach its full potential becomes an important option. This can be done only by decreasing the risk and uncertainty within the environment in which private firms operate. This paper has given an overview of private agricultural research and, through the review, has identified some constraints and problems that private research faces. Each agribusiness sector is unique, has its own constraints, and requires its own particular rules and regulations and solutions. Many solutions to the technical problems are documented elsewhere. While it will never be possible to eradicate risk, the government and private sector can work together in those areas where it is possible to make a difference.

The first area in which a difference can be made is by the passing of the intellectual property rights legislation. Such legislation is a prerequisite for any further development in the seed and new plant material research area. The second major area that can make a difference is the enforcement of all rules and regulations pertaining to intellectual property rights, patents, certification procedures, truth-in-labeling regulations, and other regulation areas that make a better agribusiness and research environment. Private investment and research would benefit from a transparent set of enforced rules within which to operate. A third area is ensuring that private sector agricultural research can operate efficiently and on a level playing field relative to public agricultural research and nonagricultural private research. Areas needing redress include local, provincial, and Federal tax policies, research equipment and spare parts import duty policies, custom duties on imported seed and in-bred lines, and regulations regarding research, in general.

As research techniques become more sophisticated and private firms attempt more applied research, developing closer ties with universities and technical schools would ensure that the appropriate number and type of qualified staff and scientists are being trained. Another area for consideration is fostering further and closer cooperation between private research and the public research system. Pakistan's agricultural research agenda benefits when private and public sectors operate efficiently and in collaboration.

While political and financial stability is always a concern, these areas can make a difference and reduce risk and uncertainty, encouraging the private sector to continue and expand its research agenda. Further research on private agricultural research could include more in-depth studies of individual industries. Further independent, in-depth research on research constraint identification and possible solutions to particular problems that can be brought to the attention of the government would be helpful. Agricultural research would also benefit by identifying mechanisms for more formal collaboration between the public and private sectors, and between the research community and government.

References

Ahmad, Mumtaz. *Agricultural Research in Pakistan's Private Sector*. Management of Agricultural Research and Technology Project, The Pakistan Agricultural Research Council and The USAID Mission to Pakistan, Islamabad. 1987.

Ahmad, S.I., and M.Y. Chaudhri. "Seed Research, Production and Availability to Farmers," *Institutional Reforms to Accelerate Irrigated Agriculture*. Mellor Associates. Volumes I and II. Washington, DC. 1994.

Alam, Zahur, and A.R. Saleemi. *Seed Regulatory Frameworks in Pakistan*. Enterprise and Development Consulting (private), Ltd. Economic Development Corporation, Islamabad, Pakistan. 1996.

Azam, Q.T., E.A. Bloom, and R.E. Evenson. *Agricultural Research Productivity in Pakistan*. Pakistan

Agricultural Research Council, Islamabad, Pakistan. 1991.

Byerlee, D. “Agricultural Productivity in Pakistan: Problems and Potential,” *World Bank Agricultural Sector Review*. World Bank, Washington, DC. 1994.

Byerlee, D. “Technical Change and Returns to Wheat Breeding Research in Pakistan’s Punjab,” *In The Post-Green Revolution Period*. The Pakistan Development Review, Pakistan Institute of Development Economics, Islamabad, Pakistan. Vol. 32, No. 1. pp. 69-86. 1993.

Byerlee, D., and A. Siddiq. “Sources of Growth in Wheat Yields in Pakistan’s Punjab, 1965-2000: Is there a sustainability issue?” International Center for Improvement of Maiz and Trigo. Economics Working Paper 90/04. Mexico. 1990.

Evenson, Robert E., and E.A. Bloom. “Research and Productivity in Pakistan Agriculture,” *Agricultural Strategies in the 1990’s: Issues and Policies*. Haider, Hussain, McConnen, and Malik (eds.) Pakistan Association of Agricultural Social Sciences. 1991.

Government of Pakistan, Finance Division, Economic Advisor’s Wing. *Economic Survey of Pakistan*. Islamabad, Pakistan. 1997a.

Government of Pakistan, Ministry of Food, Agriculture and Cooperatives, Food and Agriculture Division, Economic Wing. *Agricultural Statistics of Pakistan*. Islamabad, Pakistan. 1997b.

Iqbal, M. “Rates of Return to Investment in Agricultural Research: The Case of Rice and Cotton in Pakistan.” Ph.D. thesis. Department of Agricultural Economics and Rural Sociology, Ohio State University, Columbus. 1991.

Mellor Associates. *Institutional reforms to accelerate irrigated agriculture*. Volumes I and II. Washington, DC. 1994.

Nagy, J.G., and M.A. Quddus. *The Pakistan Agricultural Research System: Present Status and Future Agenda*. Pakistan Institute of Development Economics, Islamabad, Pakistan. 1999.

Nagy, J.G., and M.A. Quddus. “National Agricultural Commodity Research Priorities for Pakistan.” *Agricultural Economics*. 1998.

Nagy, J.G. “Returns From Agricultural Research and Extension in Wheat and Maize in Pakistan,” “*Research and Productivity in Asian Agriculture*.” Evenson and Pray (eds.), Cornell University Press, Ithaca, NY. 1991.

Nagy, J.G., and M.M. Ali. *PARC Social Science Division Planning Report*. Agricultural Research Project II, Hunting Technical Services, Ltd., and Pakistan Agricultural Research Council, Islamabad, Pakistan. Report No. ARP-II (Federal), 1996-94. 1996.

Pakistan Tobacco Board. *Annual Tobacco Statistics*. Islamabad, Pakistan. 1998.

Ministry for Food and Agriculture, Pakistan Agricultural Research Council. *National Master Agricultural Research Plan*. Islamabad, Pakistan. 1997.

Pray, Carl E. *Private Sector Research and Technology Transfer in Pakistan*. P-02001-1-87. Department of Agricultural Economics, Cook College, Agricultural Experiment Station. Rutgers University, NJ. 1987.

Pray, Carl E. “The Economics of Agricultural Research in the British and Pakistani Punjab, 1905-75.” Ph.D. thesis. University of Pennsylvania, Philadelphia. 1978.

Rosegrant, M.W., M. Agcaoili, and N.D. Perez. *Global Food Projections to 2020: Implications For Investment*. Food, Agriculture, and the Environment Discussion Paper No. 5. International Food Policy Research Institute, Washington, DC. 1995.

World Bank. S*taff Appraisal Report, Pakistan: Agricultural Research II Project*. Agriculture Operations Division, Country Department I, Europe, Middle East, and North Africa Region. Report No. 7614-PAK. 1990.

World Bank. *Pakistan: A Strategy For Sustainable Agriculture Growth*. Agricultural Operations Division, South Asia Region. Report No. 13092-PAK. 1994.

List of Tables

Thailand

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Agricultural Development in Thailand

This study includes a survey of private agricultural research and technology transfer in several Asian countries. The purposes of this survey are to: (1) determine the amount and kind of agricultural research is being conducted by the private sector, (2) identify policy constraints and incentives to private research and technology transfer, and (3) assess major effects of private research investments on agricultural productivity. The survey is similar to one conducted by Carl Pray in 1985, and thus provides an update of that earlier work.

The Thailand survey consisted of interviewing 20 companies in Bangkok and other cities during May 1997. The sample was selected to include companies with research and technology transfer activities in the seed, livestock, agricultural chemical, farm machinery, and plantation sectors. These interviews were supplemented with discussions with officials from the Thai government and local universities, U.S Department of Agriculture's Foreign Agricultural Service, and agribusiness associations in Thailand.

[1]The author thanks Mogens Lemonius, Simon Groot, Kriangsak Suwantaradon, and Carl Pray for their comments on early drafts of the paper.

Agriculture in the Thai Economy

Thailand has experienced exceptional economic growth over the past several decades and is rapidly entering the ranks of the newly industrialized countries. While the agricultural sector continues to experience significant growth as well, its relative importance in the overall economy has declined. Between 1965 and 1995, the share of Thailand's gross domestic product (GDP) derived from primary agriculture fell from 35.0 to 10.9 percent, even though agricultural production tripled in real terms over this period (table D-1). In 1995, the value of agricultural GDP was $18.2 billion.

Agriculture provides many raw materials for Thailand's industrial sector. Rubber for latex, sugarcane for refined sugar, cassava for processed livestock feed, and fruit for canning and juices are examples of manufacturing industries that process agricultural commodities into intermediate products or consumer goods for domestic use and exports. A significant share of Thailand's industrial sector is based on processing agricultural commodities.

Table D-1—Trends in Thailand's economy and labor force, selected years

Item	Unit	1965	1980	1990	1995
Gross domestic product	Billion dollars[1]	17.4	52.2	110.5	166.8
Agricultural GDP	Billion dollars[1]	6.1	12.1	13.9	18.2
Agriculture share of total	Percent	35.0	23.2	12.6	10.9
Labor force	Millions	15.4	27.0	32.3	33.0
Agricultural labor force	Millions[2]	12.5	18.4	19.4	17.1
Agriculture share of total	Percent	82.0	68.3	60.1	52.0
Output per non-agriculture worker	Dollars/worker[1]	3,897	4,639	7,488	9,358
Output per agriculture worker	Dollars/worker[1]	488	658	716	1,064
Non-agriculture to agriculture worker	Productivity ratio	8.0:1	7.1:1	10.5:1	8.8:1

[1]Constant 1995 dollars.
[2]Workers whose principal occupation is agriculture. This overstates agriculture's share of total employment since many farmworkers engage in seasonal nonfarm employment. In 1992, 46 percent of farm-household income originated from nonfarm sources (Thailand Development Research Institute, 1995).

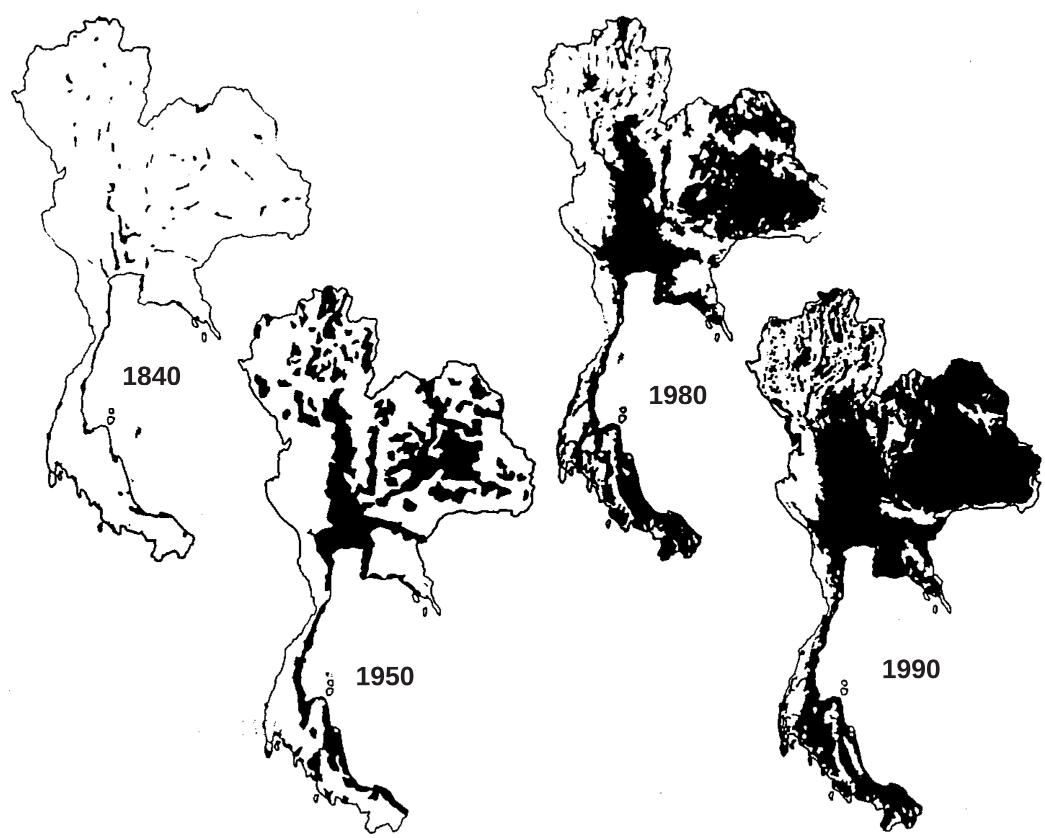
Sources: World Bank; Thailand Development Research Institute, 1997.

In international markets, Thailand continues to possess a strong comparative advantage in producing many agricultural commodities. In 1994, Thailand exported $13.4 billion of agricultural goods and had a positive trade balance in agricultural products of $6.2 billion, despite an overall mercantile trade deficit of $9.3 billion. Major export commodities were shrimp ($1.97 billion), rubber ($1.67 billion), rice ($1.57 billion), tapioca products ($0.75 billion), and sugar ($0.69 billion) (Office of Agricultural Economics, Ministry of Agriculture and Cooperatives, 1996).

Agriculture continues to be the principal source of employment for the majority of the labor force. Even though agriculture in 1998 accounted for only about 10 percent of the nation's GDP, more than 50 percent of the working population resided in agricultural households (table D-1). Availability of new land for settlement and cultivation enabled agriculture to continue to absorb the majority of the rapidly growing labor force up until the 1980s. The absolute size of the agricultural labor force did not begin to decline until the early 1990s, when increasing numbers of farmworkers migrated to urban areas. By 1995, there were 17.1 million workers whose primary occupation was in agriculture, down from 19.4 million in 1990. Furthermore, part-time employment by members of agricultural households in the nonagricultural economy is a significant source of family income. According to one study, nearly half of the income of agricultural households is derived from employment in the industrial and service sectors (Thailand Development Research Institute, 1995). Given the significant wage earnings gap between rural and urban areas, permanent and seasonal rural-to-urban migration is likely to accelerate.

An important implication of rapid economic development for research policy is that the demand for labor-saving technology in agriculture is increasing. Mechanization of agricultural production frees farm labor for the industrial and service sectors. At the same time, mechanization increases the productivity and income of

Figure D-1
Expansion of agricultural cropland, Thailand



Source: Phongpaichit and Baker, 1995

labor that remains in agriculture, thereby helping to close the wage gap between farm and nonfarm employment.

Trends in Commodity Production and Yield

Historically, Thailand's land-abundant economy enabled agricultural growth to be sustained largely through the expansion of cropland. Over the past century, the area planted in rice, rubber, sugarcane, cassava, corn, fruits, and other crops dramatically grew as agriculture expanded into previously forested areas (fig. D-1). By the late 1980s, however, newly settled land was increasingly marginal for agricultural production, and the Thai Government took steps to preserve remaining forestland from further encroachment (Thailand Development Research Institute, 1987; and Fuglie, 1991). Growth in agricultural production will rely increasingly on research and capital investments to increase crop yields and improve production and marketing systems for high-valued commodities.

In 1994, crop production contributed 55 percent of the value of agricultural GDP, followed by fisheries (16.5 percent), livestock (10.1 percent), and other commodities (table D-2). As in other east Asian countries, rice is the dominant crop of Thailand's agriculture. Prior to World War II, rice was the principal export earner for the entire economy (Ingram, 1971). While rice is still the single most important agricultural commodity, occupying more than half of all agricultural land and labor force, its relative importance has declined. Efforts of the Thai Government to promote diversification in the agricultural sector has encouraged the growth of nonrice commodities (Thailand Development Research Institute, 1995). By the early 1990s, rice ranked third in agricultural export value behind shrimp and rubber (table D-3).

Table D-2—Structure of agriculture, Thailand, 1994

Commodity	Value of production	Share of agriculture domestic product
	Million baht	*Percent*
Crops	203,267	55.1
Livestock	37,183	10.1
Fisheries	60,777	16.5
Forestry	4,609	1.2
Other	63,217	17.1
Total agriculture domestic product	369,053	100.0

Source: Ministry of Agriculture and Cooperatives, Center for Agriculture Information, Office of Agricultural Economics, 1996.

Agricultural diversification affected livestock and fisheries as well. Poultry production sustained especially rapid growth in the 1980s and early 1990s (table D-4). Swine, cattle, and dairy production also increased. The number of buffaloes, once the primary source of power in rice production, fell as field cultivation became increasingly mechanized. Aquaculture, especially fresh water shrimp production, has been another growth industry in Thailand's agriculture.

With the closing of Thailand's land frontier, agricultural growth is increasingly dependent on improvements in efficiency and productivity. Between 1978 and 1990, two-thirds of the agricultural growth of 4.01 percent per year was due to increases in labor, capital, and land resources, and one-third was due to improvement in total factor productivity, or the efficiency and quality of input use (table D-5). Agricultural land area grew by only 0.09 percent per year over this period. An important source of productivity growth was diversification of commodity production. By allocating agricultural

Table D-3—Major agricultural exports, Thailand, 1994

Commodity	Production	Exports
	1,000 metric tons	*Million dollars*
Shrimp	NA	1,966
Rubber	1,767	1,663
Rice	21,111	1,558
Sugarcane	37,823	684
Cassava	19,091	664
Poultry	NA	404
Fresh fish	NA	338
Canned pineapple	NA	264

NA = Not available.

Sources: Agrostat database, Food and Agriculture Organization of the United Nations, and Thailand Development Research Institute, 1997.

Table D-4—Number of livestock, Thailand, 1980 and 1995

Commodity	1980	1995	Annual growth rate
	------*1,000 Head*------		*Percent*
Poultry	56,000	80,000	5.01
Swine	3,021	4,507	2.43
Cattle	3,938	7,593	3.67
Dairy	9	120	20.89
Buffalo	5,651	4,807	-2.06

Source: Agrostat database, Food and Agriculture Organization of the United Nations.

resources to commodities with higher value and market potential, Thailand produced more value from a given set of resources and sustained a relatively high rate of growth in its agricultural sector. However, many of the most important agricultural commodities such as rice, cassava, and sugarcane in 1998 had yet to undergo significant technical improvement (Siamwalla, Setboonsarng, and Patamasiriwat, 1991).

Review of Agricultural Policies

Throughout most of the 20th century, Thailand imposed a net tax on agriculture through export taxes levied on its principal export commodities, rice and rubber. Import tariffs on manufactured goods and overvalued exchange rate policies also discriminated against agriculture by increasing the cost of manufactured products to the agricultural sector (Siamwalla and Setboonsarng, 1989). Since about 1980, however, direct and indirect taxation of the agricultural sector has been reduced and direct public support for agriculture increased (Siamwalla, Setboonsarng, and Patamasiriwat, 1991). In 1986, the rice export tax was abolished. In the 1990s, the export levy on rubber was reduced, and the remaining rubber export levy was reinvested in the rubber economy to support research and provide replanting loans to farmers. Increased public support for agriculture has come through price support programs for agricultural commodities, subsidies for irrigation, rural credit, agricultural inputs, and investments in rural infrastructure and agricultural research. Export commodities are generally sold at world prices. Domestic prices of many crops for which Thailand is a net importer are supported through import tariffs or quotas (Siamwalla, Setboonsarng, and Patamasiriwat, 1991).

One form of public subsidy for agriculture is credit for farmers. Public intervention in rural credit markets takes several forms. The Bank for Agriculture and Agricultural Cooperatives is a state-owned financial institution that provides loans to farmers at subsidized rates. In addition, banking regulations require that privately owned banks maintain a minimum lending portfolio to the agricultural and food sectors.

Table D-5—Sources of agricultural growth, Thailand, 1978-90

Source	Annual growth rate
	Percent
Total output	4.01
Total factor input	2.72
Labor	1.91
Capital	.72
Land	.09
Total factor productivity	1.29

Source: Thailand Development Research Institute, 1997.

Since the late 1980s, public investment in irrigation projects has been curtailed due to the declining opportunities for low-cost irrigation schemes and rising social and environmental costs associated with creating large reservoirs. Declining prices for rice on the world market also discouraged new investment in irrigation (Siamwalla, Setboonsarng, and Patamasiriwat, 1991).

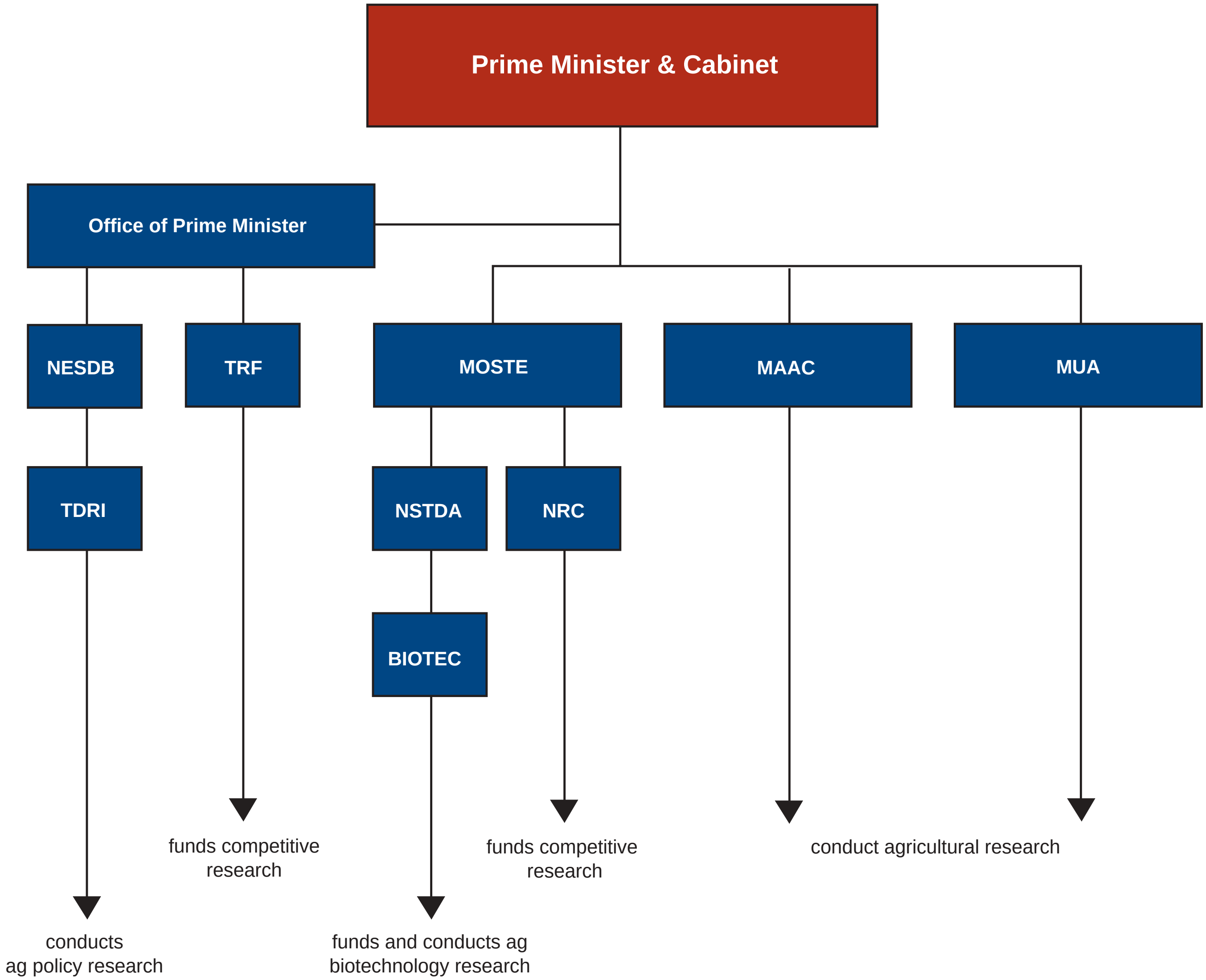
Policies toward land reform and land registration have occasionally generated rural protests. The rapid expansion of farmland into previously forested areas left a large portion of agricultural land untitled. The lack of formal title to agricultural land serves as a disincentive for farmers to invest in long-term capital improvements and limits access to formal credit institutions for many farmers (Feder et al., 1988).

Review of Science Policy

The level of research capacity and scientific manpower in Thailand are low, compared with other dynamic Asian economies such as Korea, Taiwan, and Singapore (National Science Foundation, 1993). However, the Thai Government has recognized since the late 1970s that rapid economic growth could not be sustained without increased investment in science and technology to raise productivity. In 1979, it established the Ministry of Science, Technology, and Energy to coordinate and implement science policy. In 1982-86, the fifth national development plant emphasized investment in science infrastructure and manpower. Subsequent development plans established a goal of increasing the level of science and technology investment from the 1998 level of 0.2 to 0.75 percent of GDP (Ministry of Science, Technology, and Energy, 1997).

Government support for agricultural research precedes recent emphasis given to science and technology investment, and agriculture still accounts for most public expenditures for research. Agricultural research in Thailand dates back to the establishment of the Rangsit Agricultural Experiment Station near Bangkok in 1916. In 1998, agricultural research was supported by a number of government ministries and agencies (fig. D-2). The Ministry of Agriculture and Agricultural Cooperatives is the largest performer of agricultural research, with an annual research budget of $80

Figure D-2
Agencies funding and performing agricultural research, Thailand, 1998

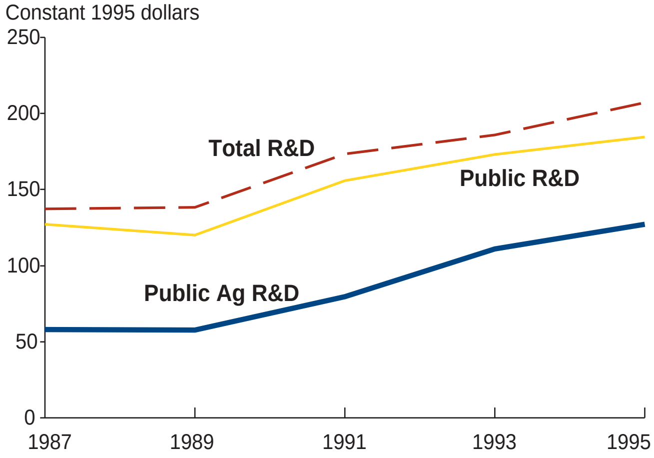


million to $90 million for research on crops, livestock, forestry, and fisheries. Public universities also have significant programs in agricultural research, funded through the Ministry of University Affairs and through grants from the Thailand Research Fund and the National Research Council. A $10-million annual biotechnology research program, most of which is devoted to agriculture, is funded through the National Science and Technology Development Agency, an autonomous public corporation under the Ministry of Science, Technology, and Energy.

The 1998 pattern of public research expenditures indicates the priority given to agriculture. In 1995, of total government research expenditures of $207 million (Ministry of Science, Technology, and Energy, 1997), an estimated $127 million was allocated for agriculture (Poapongsakorn, 1996). Moreover, the share devoted to agriculture appears to have increased over the 1980s, from about 40 percent of the total in 1987 to 60 percent in 1995 (fig. D-3). Within agriculture, the largest share of the research budget is for crop research, with relatively small budgets for livestock, forestry, or fisheries (Poapongsakorn, 1996).

In addition to investing in public research, the Thai Government has also encouraged private investment in research, although these efforts appear to have had only limited success (Thailand Development Research Institute, 1990). Policies to support private research have included tax incentives and subsidized loans, but the overall demand for these subsidies appears to have

Figure D-3
Research expenditures, Thailand, 1987-95



Sources: Total and public agricultural R&D from MOSTE (1997); and public agricultural R&D from Poapongsakorn (1996).

Table D-6—Market for seed, Thailand, 1996

Source of seed	Quantity	Average price	Value
	Metric tons	*Dollars/ kilogram*	*Million dollars*
Private hybrid corn	15,000	3.00	45
Private sector—vegetable	2,000	NA	15 - 20
Public sector— open-pollinated	59,000	.42	25
Farmers' own seed	633,300	NA	NA
Total seed requirement	>710,000		

NA = Not available.

Source: Private seed sales from own survey; public seed sales and total seed requirement from Annual Report 1995, Ministry of Agriculture and Cooperatives, Department of Agricultural Extension, Seed Division, Thailand.

been small. However, public encouragement of the private seed industry does appear to have been an important factor in stimulating private plant breeding in Thailand (see “Private Investment in Agricultural Research” section). Other efforts to promote private research include increasing the availability of science and technology personnel, providing information and consulting services, establishing a science park (opened in 1998), and strengthening protection for intellectual property rights. Under the 1979 patent law, agricultural inventions were explicitly excluded from patent protection. However, a new patent law enacted in 1992 extended coverage to agricultural chemicals, farm machinery, biotechnology processes, and genetic sequences, although the law excluded plant and animal life forms from patent protection. A special patent court to enforce patent laws was established in 1996, and a law enabling *sui generis* plant breeders’ rights is being considered.

Structure of Agricultural Input Industries

A principal way in which new technology reaches farmers is through new and improved agricultural inputs, such as better seed, livestock feed, crop protection chemicals, livestock pharmaceuticals, and farm machinery. The private sector can be expected to invest in research to improve agricultural inputs when: (1) the size of the market is sufficiently large, (2) technological improvements can be made relatively quickly and easily, and (3) individual companies can protect their intellectual property from copiers (Pray and Fuglie, 1999).

Seed

Most agricultural seed in Thailand is from farmers’ own saved seed from their previous crop. Of the more than 700,000 metric tons of seed needed annually, only about 75,000 to 80,000 tons are provided by seed companies or government agencies, with the rest supplied by farmers (table D-6). The private sector produces hybrid seed for corn and vegetable production and some self-pollinated seed under contract with government agencies. In 1996, private companies sold about 15,000 tons of hybrid corn seed estimated at a market value of $45 million. This was sufficient for about 90 percent of farm demand for corn seed. Estimates of vegetable seed sales are unavailable, but are probably about 2,000 tons worth $15 million to $20 million per year. In addition, the Department of Agricultural Extension (DOAE) maintains 23 seed centers located throughout the country to produce seed. In 1995, the DOAE produced 59,200 tons of seed and earned $25 million in seed sales at subsidized prices.

Thailand is also a net exporter of agricultural seed (table D-7). Several private companies use Thailand as a base for seed production for other markets in southeast Asia and elsewhere. The Asia and Pacific Seed Association reports seed exports of $15.2 million and seed imports of $8.5 million in 1995. Japan and the United States are major import and export markets for Thai seed, especially for vegetables. Australia is a major exporter of seed to Thailand, mainly hybrid sorghum, and Vietnam is a major market for hybrid corn seed produced in Thailand.

Table D-7—Seed trade, Thailand, 1995

Crop	Imports		Exports	
	Quantity	Value	Quantity	Value
	Metric tons	*1,000 dollars*	*Metric tons*	*1,000 dollars*
Tomato	2	122	30	4,305
Corn	180	673	1,347	3,103
Watermelon	49	539	122	2,778
Cabbage	22	1,871	3	383
Kang kong	544	627	1,160	1,739
Sorghum	1,650	1,481	0	0
Pepper (hot and sweet)	3	65	10	1,373
Cucumber	1	65	15	788
Chinese cabbage	79	691	5	63
Onion	8	610	0	0
All seed	3,200	8,462	2,915	15,233

Source: Asia Pacific Seed Association.

There are six seed companies in Thailand with breeding programs in hybrid corn that supply at least 90 percent of hybrid corn sold in Thailand. Four of these companies are wholly owned subsidiaries of foreign seed companies. The remainder of the hybrid corn market is supplied by several small local seed companies that reproduce seed from inbred lines developed by Kasetsart University. Hybrid sorghum seed was previously bred and produced in Thailand, but in 1998 was mostly imported from abroad.

Several dozen companies multiply and sell vegetable seed, but only three or four have research programs in Thailand. The dominant company in the vegetable seed market is Chia Tai Seed Company, the oldest seed company in Thailand and part of the Charoen Pokphand conglomerate. Other important suppliers include companies based in Taiwan, Korea, Japan, and the United States with subsidiaries in Thailand, in addition to Thai-owned seed companies.

Table D-8—Agricultural chemical use, Thailand, 1996

Commodity use	Quantity	Value
	Metric tons	*Million dollars*
Herbicides	33,000	145
Insecticides	20,000	100
Fungicides	6,000	35
Others[1]	2,000	10
Total	61,000	280

[1]Others include rodenticides, acaricides, fumigants, and plant growth regulators.

Source: Agricultural Statistics of Thailand and own survey.

Agricultural Chemicals

Annual sales of chemical pesticides and plant growth regulators are estimated at $280 million to $300 million (table D-8). The largest and fastest growing agrichemical market is for herbicides, valued at around $145 million in 1995/96. The rising cost of farm labor for weeding crops is one factor leading to an increase in demand for herbicides as chemical weed control. Field crops (rice, cassava, and corn) and plantation crops (rubber) are the principal users of herbicides. Insecticide sales are estimated at around $100 million annually. Rice and horticultural crops are the largest users of insecticides. More than 90 percent of fungicides are used on horticultural crops.

Companies that produce and distribute agricultural pesticides in Thailand are in two categories. The first group are R&D-based multinational corporations. These companies are based in the United States, Europe, and Japan. They synthesize new chemical compounds, develop chemical manufacturing and formulation procedures, and test their products in markets throughout the world. Many of these companies were in Thailand in 1998, including Agrevo (Germany), American Cyanamid (United States), Bayer AG (Germany), DuPont (United States), Monsanto (United States), Novartis (Switzerland), Rhone-Poulenc (France), and Zeneca (United Kingdom). In Thailand, they probably supplied 70 to 75 percent of the agrochemical market. The second group of companies were manufacturers of generic products, usually of chemicals with expired patents. These companies do not develop new products and, therefore, do not conduct much research, except for the toxicology and other tests necessary to fulfill regulatory requirements for registering products for sale in Thailand or other countries.

In Thailand, most chemical companies import active ingredients and formulate products locally, import formulations for local packaging, or import finished products. Only one company synthesizes active ingredients at its manufacturing plant in Thailand (Zeneca, for the herbicide paraquat). Unlike other countries in southeast Asia, Thailand levies no import duties on agricultural chemical ingredients, formulations, or finished products, so there is no tariff advantage obtained from locally manufacturing products.

Pesticide regulations in Thailand for registration and use follow the standards established in Europe and North America, although they are less rigorously enforced. Thailand did not establish a patent law covering agricultural chemicals until 1992 and does not recognize international patents granted before this date. Thus, any company may produce and distribute chemicals in Thailand, even if that chemical is protected by a patent awarded prior to 1992 in another country.

Farm Machinery

Rising wages in the Thai economy have sharply increased the demand for labor-saving farm machinery. The number of water pumps, power tillers, riding tractors, harvester-threshers, and mechanical sprayers in use by Thai farmers rose from 140 to 300 percent between 1980 and 1993 (table D-9). Farm machines are both imported and manufactured locally by a large number of domestic and multinational firms. The Bank of Agriculture and Agricultural Cooperatives (BAAC) is the principal source of financing farm machinery purchases by farmers. The BAAC is a government-owned bank that provides long-term loans to farmers. Commercial banks are also required to maintain a minimum portfolio of agricultural lending.

Table D-9—Use of farm machinery, Thailand, 1980 and 1993

Machinery	1980	1993	Growth
	---1,000 units---		*Percent*
Water pumps	518	1,577	204
Two-wheel power tillers	281	1,136	304
Sprayer machines	132	318	141
Large riding tractors	37	98	165
Harvester-threshers	18	55	205
Minimum wage (baht/day)	44	102	132

Wages are in nominal terms.
Sources: Farm machinery numbers are from Ministry of Agriculture and Cooperatives, Center for Agricultural Information, Office of Agricultural Economics; minimum wage rates are for poor, rural provinces reported in Thailand Development Research Institute. 1997.

Livestock, Poultry, and Aquaculture

The principal purchased inputs for the animal and aquaculture sectors are compound feed, veterinary pharmaceuticals, and animal housing units. In poultry, purchased feed constitutes more than 60 percent of variable production costs (Narrod and Pray, 1995). Over 80 percent of broiler production is managed by large, integrated operations. These companies provide chicks, feed, and other inputs to contract growers, buy back adult fowl at predetermined prices, then process and market finished poultry products. An estimated 15 to 20 percent of swine production is also conducted by integrators. Poultry layers (eggs), cattle, dairy, and aquaculture farms are owned and managed mostly by independent producers.

Table D-10—Market for manufactured animal feed, Thailand, 1996

Subsector	Annual demand
	Million tons
Chickens (broilers and layers)	5.0
Pigs	3.7
Aquaculture	.6
Ducks	.4
Cattle, dairy, and small ruminants	.4
Total	10.0

Source: Thai Feed Mill Association.

The annual demand for compound livestock feed in Thailand is about 10 million metric tons (table D-10). About 6.5 million tons are produced and marketed by feed millers, and the remaining 3.5 million tons are from producers. About half of the demand for compound feed is for poultry production. The other large market is for swine production (3.7 million tons). Aquaculture, cattle, dairy, ducks, and small ruminants make up the remaining demand for processed livestock feed.

There are a large number of feed millers in Thailand, although the top six companies provide more than half of total feed mill capacity. Charoen Pokphand and Betagro Agro are the two largest feed millers. About half of their feed mill production is provided to their own integrated poultry and swine operations, and half are sold to other producers. Other large millers include Krungthai, Lee Pattana, Ramtong, and Centra-Agro.

Other principal livestock inputs such as breeding stock and pharmaceuticals are provided through imports. Poultry grandparent stock and swine parent stock are imported by several of the large integrated operations and locally multiplied for sale and distribution.

Private Investment in Agricultural Research

Plant Breeding

The private sector has been actively involved in plant breeding in Thailand since the late 1970s. Private research is concentrated on developing hybrid seed for field crops (mainly corn, with some sorghum and sunflower) and vegetables. A relatively small amount of research is devoted to self-pollinated seed, mainly in vegetable seed markets.

Companies with plant breeding programs in Thailand are listed in table D-11. Six companies have breeding programs for field crops and together spend about $3.5 million annually in breeding, nearly all of which is for hybrid corn. An additional $2.1 million is spent on vegetable breeding by three or four other companies. Hybrid and self-pollinated seed varieties have been developed for more than 30 species of vegetables. Pray (1987) estimated private plant breeding expenditures to be about $1.1 million in 1985, or about $1.3 million in 1995 dollars. Thus, it appears that private plant breeding has increased by more than 150 percent in real terms over the past decade.

Private-sector investment in corn breeding began in the late 1970s and early 1980s, following the successful development of corn varieties resistant to downy mildew by Kasetsart University. Kasetsart's effort to develop resistant varieties began in 1966, with support from the Rockefeller Foundation. Based on germplasm from the Philippines, Latin America, India, and local sources, Suwan 1 was released in 1974, followed by Suwan 2 (1975), Suwan 3 (1978), Suwan 4 (1982), Suwan 5 (1988), and others. Prior to the availability of Suwan germplasm, downy mildew had been a major constraint to corn production in southeast Asia. The Suwan varieties became very popular throughout Thailand and southeast Asia and helped to significantly expand corn area and production. Hybrid corn varieties developed by private companies are based largely on crosses between Suwan varieties and superior inbred lines imported from the United States and Europe. Foreign multinational companies play a significant role in the Thai corn seed industry, either through wholly owned subsidiaries or through joint ventures with local seed companies.

Two vegetable companies, Chia Tai and East-West Seeds, have had vegetable breeding programs in Thailand for more than a decade. Recently, Seminis Seeds, a subsidiary of Empresas La Moderna, a Mexican-

Table D-11—Private plant breeding, Thailand, 1998

Seed company	Country of parent company	Field crop breeding	Vegetable and others
Charoen Seeds (CP/DeKalb)[1]	Thai/United States	Corn, sorghum	Orchids
Pioneer Hi-Bred	United States	Corn	Baby corn
Cargill Siam	United States	Corn	
Novartis[2]	Swiss	Corn	
Pacific Seeds (Advanta)[3]	United Kingdom	Corn, sorghum	Baby corn, sweet corn
Uniseeds	Thai	Corn	Okra, mungbean
Chia Tai (CP)[1]	Thai		More than 20 species
East-West Seeds	Thai		More than 10 species
Seminis Seeds (ELM)[4]	Mexico		5 species
Known-You	Taiwan		
Total annual research		$3.5 million	$2.0 million

[1] Part of Charoen Pokphand (CP) group of companies.
[2] Norvartis was recently formed by the merger of two Swiss companies, Ciba-Geigy and Sandoz.
[3] Advanta was recently formed by the merger of the United Kingdom-based Zeneca Seeds (parent company of Pacific Seeds) and Van der Haver, a Dutch seed company.
[4]Includes Petoseed, Royal Sluis, and Asgrow operations in Thailand, which were merging with Seminis. All of these companies were subsidiaries of Empresas La Moderna.

Source: Author's survey.

based multinational seed company, began conducting vegetable breeding in Thailand. Vegetable companies from Taiwan, South Korea, and Japan, along with several smaller locally owned companies, are also active in importing, multiplying, and marketing vegetable seed, although their investment in crop research in Thailand is believed to be small.

Plant breeding research conducted by multinational companies tends to be organized and managed on a global scale. A company is likely to have research facilities and staff in several countries who regularly exchange germplasm and scientific resources. Research stations in Thailand are likely to develop and multiply seed not only for the Thai market, but for other markets in southeast Asia with similar ecological conditions. For example, most if not all of the companies that had developed hybrid corn varieties in Thailand also market these varieties in Burma and Vietnam.

In addition to plant breeding research, private seed companies also promote improved agronomic practices to farmers through their marketing divisions. For farmers to realize the higher yield potential of improved varieties, they often need to adopt other new practices, such as higher seeding rates, increased fertilizer use, and improved pest and weed control. Several companies, especially the major hybrid corn companies, have established agronomy services to conduct field trials and work with customers to promote new practices along with the adoption of improved seed. This investment is not included in the estimate of research expenditures but may be as large as the research expenditure itself.

The major source of germplasm for the private-sector breeding programs is the companies' own elite lines. The multinational seed companies are continuously collecting and screening cultivated varieties from public and private sources around the world, but invest few resources in testing or adapting unimproved landraces. Developing new elite germplasm from unimproved landraces and wild relatives of cultivated crops is primarily undertaken by the public sector. Seed companies in Thailand screen elite germplasm provided by national and international institutions. Kasetsart University is the most important public-sector partner of the Thai hybrid corn industry. In addition to providing elite germplasm for private breeding programs, Kasetsart provides trained scientific staff through its teaching and training programs and technical services such as electropholisis for DNA fingerprinting. Private seed companies also test germplasm provided by international research centers, namely, corn germplasm from the International Maize and Wheat Improvement Center (CIMMYT), vegetable germplasm from the Asian Vegetables Research and Development Center, and sorghum germplasm from the International Crops Research Institute for the Semi-Arid Tropics. Kasetsart University and CIMMYT have also provided training for technical staff from private seed companies.

In 1995, Kasetsart University initiated a royalty payment scheme for its elite corn lines. Previously, corn germplasm was sold to private seed companies for a fixed fee. Under the royalty scheme, private companies will pay Kasetsart University a share of their seed sales from varieties that use Kasetsart parent material. As of 1998, the royalty scheme had not been applied because none of the current commercial corn hybrids use post-1995 Kasetsart germplasm.

Agricultural Biotechnology

Biotechnology, along with materials science and computer technology, has been identified by the Government of Thailand as a priority for science and technology investment to develop domestic capacity in these industries. In 1983, the Thai Ministry for Science, Technology and Energy established the National Center for Genetic Engineering and Biotechnology (BIOTEC) to develop research capacity in biotechnology and induce commercial development of new biotechnology products. In 1991, BIOTEC was transferred to the National Science and Technology Development Agency (NSTDA), an autonomous public corporation that has the authority and flexibility to conduct and fund research, license technology to the private sector, and invest in joint ventures to commercialize emerging technology. About 80 percent of BIOTEC's annual

Table D-12—R&D funded by BIOTEC, Thailand, 1984-96

Research application area	Funds provided
	1,000 dollars
Plants	3,337
Animals	3,289
Rural development	701
Sustainable development	2,788
Industrial products & processes	3,477
Human health	3,282
Total	16,874

Source: National Center for Genetic Engineering and Biotechnology.

research and development (R&D) budget of $10 million is devoted to agricultural biotechnology, with the balance in biodiversity conservation and tropical disease research. In addition to in-house activities, BIOTEC has provided nearly $17 million for competitive grants for biotechnology research to universities and other institutions since 1984 (table D-12).

BIOTEC has already established several joint initiatives with the private sector to commercialize agricultural biotechnology. The most significant of these is in aquaculture. In 1996, BIOTEC invested $1 million in a joint venture with several private-sector partners to form the Shrimp Culture Research and Development Company, Ltd. This consortium is conducting R&D in shrimp domestication and breeding, disease prevention and control, and production and environmental management. Revenues generated from product sales are shared by consortium members, including BIOTEC. In addition to aquaculture, BIOTEC has developed joint projects or granted exclusive licenses with private companies to commercialize other technologies, including blue-green algae for shrimp feed, biofungal pesticide for vegetables, viral pesticide for insect control, and micropropagation of disease-free plantlets for strawberries, onions, and potatoes.

Other tools—besides joint ventures and exclusive licensing—used by the National Science and Technology Development Agency to promote technology commercialization are: providing grants, subsidized loans, and consulting services to companies; providing technical training and information services; and establishing a science park, which was scheduled to open in 1998. While BIOTEC has made considerable gains in establishing a base for a biotechnology industry in Thailand and has developed several promising biotechnology applications, it appears to have been unable to induce much new private-sector research in biotechnology.

While most biotechnology research in Thailand as of 1998 had been funded and conducted by the public sector, private seed companies have made significant investments in testing transgenic crop varieties in Thailand. Thailand has adopted a biosafety protocol for testing transgenic crop varieties modeled on that of the United States and Australia. Applications for conducting field tests of transgenic varieties are reviewed by the National Biosafety Committee. Approved tests have included material that had already been field-tested in an industrialized country. The first field test of a transgenic variety was conducted in 1994, with a delayed-ripening tomato variety developed by Calgene. Since then, field tests have been approved for Bt-cotton, Bt-corn, and viral-resistant melons. Additional field tests of herbicide-resistant corn, herbicide-resistant soybean, quality-enhanced corn, and viral-resistant papaya and chili peppers are anticipated for the near future. Private biotechnology research, however, is limited to field testing. Actual gene transfers are made at the companies' research laboratories in North America or Europe. Private-sector expenditures for testing transgenic cotton varieties in Thailand were about $1 million in 1997.

Crop Protection

Research by agricultural chemical companies in Thailand is principally to fulfill the regulatory requirements for product registration and develop recommendations for timing and application rates for targeted crops. Only one company, Novartis, maintains its research station in Thailand. Other companies conduct trials in farmers' fields or at public facilities. New chemicals and chemical manufacturing processes are developed entirely in company laboratories located in the United States, Europe, and Japan.

Because research activity is often integrated with market development and promotion, many companies find it difficult to quantify their research investment. Survey estimates of research expenditures as a percentage of product sales in Thailand ranged from 0 to 3 percent, for an average of 2.3 percent, among four agricultural chemical companies interviewed. If that average is applied to total product sales by the R&D-based companies, it would imply an annual research investment of $5.23 million.

In addition to research and market promotion, the agricultural chemical industry has also taken steps to promote safe-use practices, partly in response to the growing concern regarding pesticide poisonings, contaminated food, and environmental hazards caused by pesticide use. In 1991, the Thai Crop Protection Association (whose members include the R&D-based agricultural chemical companies) began a collaborative effort to extend safe-use practices to farmers at a cost of $1.33 million per year. The Safe Use Project is one of three pilot projects worldwide, undertaken by the Brussels-based International Group of National Associations of Agrochemical Product Manufacturers. Besides Thailand, other pilot projects are in progress in Guatemala and Kenya. In addition to training farmers, product distributors, and agricultural extension workers, in appropriate practices, the project seeks to increase the availability of protective clothing for chemical applicators, provide information to medical professionals on the diagnosis and treatment of pesticide poisoning, and promote industry standards in product quality.

Farm Mechanization

The increasing demand for farm machinery in Thailand is met through direct imports of machinery from abroad and local manufacture. Local machinery manufacturing companies often modify equipment design and manufacturing processes in order to reduce costs and to make machinery more suitable for local conditions. However, none of these companies maintains a formal research division, and the companies interviewed were unable to provide precise estimates of staff or expenditures that could be classified as R&D. Through our survey, however, we collected information on some farm machinery advances made in Thailand and traced the source of these innovations.

In the 1970s and 1980s, local manufacturers modified the designs of Japanese power tillers and threshing machines developed by the International Rice Research Institute (IRRI) for rice production (Pray, 1987). These innovations resulted in more suitable and lower cost machinery than imported machinery. The adoption of these machines rapidly spread throughout Thailand. More recently, new innovations have developed mechanized harvesting equipment for rice, sugarcane, pineapples, cassava, soybeans, corn, and potatoes. Kaset Pattana, a machinery manufacturer based at Phisanulok in central Thailand, developed a mobile combine harvester-thresher for rice by combining elements from IRRI's rice thresher and John Deere's corn harvester. The result was a design very different from the main competing Japanese import and one more suited to Thai conditions. Chao Chalarinchai, a company located at Ayuttaya, developed a new small riding tractor, but efforts to commercialize it were unsuccessful due to competition from imports of second-hand tractors from Japan. Despite the limited quantitative information on private-sector farm machinery research, based on the evidence above of a few companies innovating their own machinery designs, a conservative estimate of private machinery R&D is $200,000 per year.

Many major innovations in farm machinery have come mainly from the public sector. The Agricultural and Mechanical Engineering Departments at the Department of Agriculture, IRRI, Asian Institute of Technology, Chulalongkorn University, Kasetsart University, and other Thai universities have contributed important innovations to Thai farm machinery manufacturers. Improvements continue to be made in tillage equipment as well. Research funded by the Ministry of Science, Technology, and Environment and conducted at Chulalongkorn University developed an improved transmission for power tillers that was adopted by at least three local manufacturing companies.

The lack of patent protection may be one reason why the Thai farm machinery industry has tended to rely on the public sector or foreign sources for major machinery innovations. Patenting of agricultural machinery was specifically excluded from the first Thai patent law passed in 1979. However, a new patent law passed in 1992 removed this exclusion (Subhadpholsiri, 1993). The new patent law allows for both invention patents and design patents. Design patents do not have the non-obvious criterion required of invention patents and are for a shorter period (10 years, instead of 20 years for invention patents). For example, a patent was obtained by the inventor of the modified power tiller transmission. However, because the research was funded by MOSTE, that company owns the patent and allowed manufacturers free access to it. Nevertheless, the new patent system, which includes a special patent court established in 1996 may encourage more explicit research and development by the local farm machinery industry.

Livestock, Poultry, and Aquaculture

Investment in technology development and transfer by the Thai animal industry can probably trace its origin to 1970, when Charoen Pokphand (CP) established a joint venture with a U.S. poultry breeding firm, Arbor Acres, to introduce grandparent broiler chicks to Thailand. CP developed its feed and integrated poultry business simultaneously. CP later expanded its poultry business to other countries in southeast Asia, China, and the United States. CP investment in animal technology was further enhanced through its purchase of the U.S. poultry genetics firm, Avian Farms. Other companies also established grandparent and parent poultry farms in Thailand, using imported chicks, mainly from the United States. However, no private company maintains pureline poultry in Thailand for commercial breeding. Swine production has relied primarily on importing parent lines from abroad, principally from Europe and Taiwan. CP also established a swine genetics program in the mid-1990s to develop its own breeds.

Private animal research in Thailand concentrates on poultry and swine, with a principal goal of improving feed efficiency. There are also efforts to improve poultry housing and animal disease management. Feed milling technology is based on foreign designs, and the rapid rate of expansion by the Thai feed mill industry implies that, on average, feed milling systems in Thailand are newer and more advanced than those in the United States and Europe. Because of the close link between feed efficiency and genetics, the major feed milling companies maintain feed and nutrition research units to find the lowest cost feed sources and mixes. Total private-sector livestock research in Thailand (including aquaculture, which is linked to feed and nutrition research) is probably at least $2.0 million annually.

Plantations and Food Processing

Private companies have played a significant role in developing plantation crops, especially fruit production for export. For example, Dole maintained agronomic and production research activities for its large pineapple production and canning operations and developed a forcing technique to stimulate year-round flowering and fruit growth in pineapple plants (Pray, 1987). However, Dole has since moved all of its food agricultural research programs for southeast Asia to the Philippines. There has also been some private research in oil palm, another plantation crop, although most new technology and varieties for oil palm originate from Malaysia. Our survey, however, of private research did not adequately cover the food processing and product development sectors. Instead, estimates of research by this sector were derived from a survey of private research conducted by Thai National Research Council. This survey reported total private research expenditures of 561 million baht in 1995 by private companies or nonprofit private organizations, with about 15 percent of that being food related (Ministry of Science, Technology, and Energy, 1997). This implies that about $3.4 million of total private research of $22.4 million was conducted in the food industry. This estimate is probably conservative.

Public and Private Investments in Agricultural Research

A summary of public and private agricultural research expenditures for Thailand is provided in table D-13.

Table D-13—Agricultural research expenditures, Thailand, 1985 and 1996

Private research by input sector	1985 companies	1985 research	1996 companies	1996 research
	Number	*US$1,000*	*Number*	*US$1,000*
Seed—field crop	5	1,500	6	3,500
Seed—vegetable	NA	NA	4	2,100
Biotechnology	0	0	3	1,000
Agricultural chemical	7	2,100	9	5,200
Poultry & livestock	2	2,400	6	2,000
Farm machinery	3	NA	5	200
Plantations & processing	6	4,600	NA	3,400
Total private agricultural research	23	10,600	33	17,400
Total public agricultural research		67,200		127,000
Total agricultural research		77,800		144,400
Agricultural GDP		9,350,000		18,120,000
		Percent		*Percent*
Private agriculture research intensity		0.113		0.096
Public agriculture research intensity		.719		.691
Private agriculture research		13.6		12.0

NA = Not available. Research and development and gross domestic product figures are in constant 1995 dollars. Results are based partly on extrapolating the research intensity (research as a percentage of market sales) of interviewed companies to other companies with research activities in Thailand. The extrapolations were done for the agricultural chemical and animal sectors. The estimates for private seed and biotechnology research are likely fairly complete. The estimates for the food sector are drawn from Ministry of Science, Technology, and Energy (1997) and are probably low. Thus, there is a significant margin of error in many of the estimates.

Sources: Private agricultural research for 1985 from Pray (1987); for 1995 from author's survey, except plantations and food processing, from Ministry of Science, Technology, and Energy (1997). Agricultural gross domestic produce from Thailand Development Research Institute (1997). Public agricultural research from Poapongsakorn (1996).

Private investment in food and agricultural research appears to have increased by two and a half times in nominal terms between 1985 and 1996. By 1996, total private agricultural research approached $19 million. Seed and biotechnology research increased most rapidly, with private-sector research reaching $6.6 million. The private sector was responsible for about 13 percent of total agricultural research in Thailand.

Public agricultural research increased at about the same rate as private research over this period, so that its share of total agricultural research remained about the same over the decade, at 87 percent. Despite the rapid growth in both public and private research investment, research intensity (R&D expenditure as a percentage of agricultural gross domestic product) may have declined slightly due to the even faster rate of growth in agricultural output. Together, public and private agricultural research were equivalent to about 0.80 percent of agricultural GDP in 1996, compared with 0.83 percent in 1985. But given the uncertainty in some of the estimates of private research, it is fair to say that research intensity did not change appreciably over this time period.

Effect of Private Agricultural Research

Three areas in which private investment in private agricultural research and technology transfer had significant effects on agricultural productivity in Thailand are: increasing yields for corn and horticultural crops, improving poultry and swine feed efficiency, and raising labor productivity through farm mechanization. However, many of the original improvements in farm machinery originated from the public sector or imported designs.

Crop Yield

One measure of the effect of private research in Thailand is the gain in crop yield. As documented earlier in this chapter, private plant breeding has concentrated almost exclusively on hybrid corn and vegetables, with minor investment in hybrid sorghum, sunflower, and soybeans. For corn, the public sector reduced varietal development research as private-sector capacity increased. Public breeding efforts for horticultural crops has never been large. Breeding and crop improvement research on other important crops such as rice, cassava, and sugarcane (the three principal crops of Thailand) are almost exclusively conducted by the public sector.

Table D-14 shows the rates of yield growth for selected crops between 1981 and 1995, during which time the private sector made important contributions to new varieties for corn and vegetable crops. Yield growth of corn exceeded the growth in yield of self-pollinated or clonal crops such as rice, cassava, and sugarcane. Corn yield increased by 1.75 percent per annum, or by more than 0.6 ton for each hectare over the 14-year period, compared with 1.2 percent for rice and 0.85 percent for sugarcane. Cassava yield declined by 0.94 percent per year.

The first Suwan variety, developed by Kasetsart University, was released to farmers in 1974. Suwan 1 is an open-pollinated variety with resistance to the most important corn disease in southeast Asia, downy mildew. Improved open-pollinated varieties rapidly spread to farmers in the 1970s. The first hybrid corn

Table D-14—Area, yield, and production for major crops, Thailand, 1981-95

Crop	Area	Yield	Production	Average annual growth: Area	Yield	Production
	1,000 hectares	*Tons/ hectare*	*1,000 hectares*	*-----------------Percent-----------------*		
Rice	9,248	2.10	19,449	-0.40	1.20	0.79
Cassava	1,352	14.56	19,558	1.62	-.94	.67
Sugarcane	674	47.73	32,382	4.84	.85	5.74
Soybean	302	1.27	392	9.33	1.60	11.07
Corn	1,522	2.54	3,851	-1.32	1.75	.41
Vegetables	250	14.00	3,500	NA	NA	NA

NA = Not available.

Source: Agrostat database, Food and Agriculture Organization, except for vegetable production, which was industry estimates of production in 1995 (published estimates of vegetable production are unreliable).

varieties were introduced by CP/DeKalb, Pioneer Hi-Bred, and Pacific Seeds in 1981 (Suwantaradon, 1989). These first hybrids were top-crosses and double-crosses and had a significant yield advantage over open-pollinated varieties when grown with appropriate agronomic practices. In 1987, the private sector released the first locally developed triple-cross hybrids, followed by single-cross hybrids in 1991. By 1996, almost all private hybrid corn varieties sold in Thailand were single-crosses, and hybrid seed supplied 70 to 75 percent of all corn seed planted. The change from open-pollinated to hybrid corn varieties is estimated to have increased the average corn yield in Thailand by 25 to 30 percent, and the switch from top-crosses, double-crosses, and triple-crosses to single-crosses increased it another 10 to 15 percent. From an average annual corn yield of around 2 tons per hectare in 1980, this implies a total yield gain of between 0.75 to 1 ton per hectare by 1996. By the mid-1990s, corn yields averaged 2.5 to 3 tons per hectare, with corn farmers in the corn-producing areas of Thailand's central plain regularly obtaining 4 to 5 tons per hectare with hybrid seed. Research station results have shown that 1998 varieties had a yield potential of 8 to 10 tons hectare.

The sustained increase in corn yield achieved in the 1980s and 1990s is due not only to the introduction of new classes of seed (i.e., double-cross, triple-cross, and single-cross hybrids), but also to a steady stream of new and improved corn varieties within each class. Since the first hybrid corn varieties were released in 1981, the private sector had introduced more than 90 new varieties of corn by 1998. Breeding efforts in 1998 promised continued improvements in single-cross hybrids.

One consequence of the yield advantage of hybrid corn over open-pollinated corn is that most indigenous corn seed companies were forced out of the corn seed industry during the 1980s and early 1990s (Morris, 1997). Only a handful of companies with access to enough capital and scientific resources necessary to maintain a viable hybrid breeding program survived. Corn breeding companies in Thailand spent more than $500,000 annually for research, on average. Indigenous companies specializing in multiplying open-pollinated Suwan varieties failed because of the competition from the superior hybrids.

Published data on the production of major vegetable crops are not very reliable, so it is difficult to examine trends. Nevertheless, hybrid seed varieties have made major contributions to yield and quality improvements since 1990. Seed companies typically found yield increases of 50 to 100 percent between hybrid and open-pollinated varieties (Groot, 1997). For many vegetables, hybrid varieties can also be planted in the off-season when prices are higher and provide more uniform quality than traditional varieties. Moreoever, there remains considerable potential for more yield increases as the use of hybrid vegetable seed expands.

Soybean yield growth (1.6 percent per year) was comparable to the high rates achieved by hybrid corn, despite the lack of private-sector interest. Soybean seed is exclusively self-pollinated, and most private companies have been unwilling to invest in soybean breeding without plant breeders' rights to protect their varieties. Nevertheless, Thailand's Department of Agriculture made a major commitment to increasing soybean production in order to reduce the demand for oilseed imports. The data indicate that with adequate support, a public breeding program can be as successful as private breeding in improving crop yield. The advantage for Thailand in having a private seed industry is that scarce public research resources can be concentrated on important national priorities.

Animal Feed Efficiency

Private investment in research and technology transfer has achieved significant productivity gains in poultry production and, to a lesser extent, in pig production. Locally adaptive research on poultry production systems multiplied imported hybrid crosses, developed better and lower cost feed rations, and improved the design of poultry housing units to significantly reduce production costs and expand output. Partly as a result, frozen poultry emerged as a major export commodity for Thailand.

From interviews with private animal scientists, the feed conversion ratio (FCR) for poultry (kilogram (kg) of feed for each kg of meat) improved by 10.0 to 12.0 percent in 1988 to 1998. FCR achieved on research farms improved from 2.2 to 1.7 percent, while that achieved in commercial farms was about 2.05 percent. In addition, the length of time needed to produce a fully grown bird was reduced by 10 to 15 days, and the size of a finished bird was increased to 1.5 kg for each bird, an increase of about 0.5 kg. The demand for larger birds increased with the growth of household income in Thailand. Since most birds are sold fresh and whole, bird size determines the purchase unit by food shoppers, and the purchase unit generally increases with income. Producing larger birds in the tropics, however, requires use of closed poultry houses. Local adaptations in poultry houses, based on evaporative cooling, plastic sheeting, and ventilation fans, significantly reduced the cost of closed poultry housing units and encouraged their use by farmers. Improvements were also made in feed efficiency for poultry layer (egg) and duck production.

In pig production, large commercial operations achieved FCR of 3 to 3.5 percent, using imported breeds and compound feeds, compared with 5 to 7 percent on small farms (Pray, 1987). Small farms still dominated the pig sector, however, accounting for 80 to 85 percent of total production in 1998.

These advances were almost entirely attributable to the private sector. Public expenditures for animal research were only around $4 million for each year in the early 1990s (Poapongsakorn, 1996, table 5). Public animal research also deals with a wider range of commodities, including cattle and dairy, commodities where private research is believed not to be large.

Farm Mechanization

A first wave of farm mechanization occurred in the 1970s and 1980s, with the diffusion of mechanized land cultivation and rice threshing. Power-tillers, or two-wheeled walking tractors, were introduced in rice production. Larger, four-wheeled riding tractors where widely adopted to facilitate the rapid expansion of area planted to nonrice crops, especially cassava and sugarcane. In the late 1980s and 1990s, a second wave of mechanization was underway to mechanize crop harvesting. The role of the private sector in machinery development is limited to minor modifications to design and manufacturing processes. Major design improvements originate mainly from imported machines and the public sector.

Policies and Private Agricultural Research

Government Investments in Research and Extension

Agricultural research policy in Thailand has explicitly sought to encourage private investment in agricultural research and technology transfer by focusing public resources on activities to complement, rather than compete with, the private sector. This is clearly evident in the seed sector, where the public sector maintains a large seed production capacity but avoids producing for markets where private seed companies are active. In corn seed production, for example, the public sector withdrew from seed multiplication as the availability and use of private hybrid seed expanded. In 1995, the public seed division of the Department of Agricultural Extension produced only 5 tons of corn seed, down from more than 2,000 tons annually during the 1980s (Department of Agricultural Extension, Ministry of Agriculture and Cooperatives, 1995).

The public sector plays an important role in encouraging farmers to adopt improved agricultural technology, including new crops and crop varieties, and improved agronomic practices, agricultural chemicals, and compound animal feeds. The Department of Agricultural Extension and the Bank for Agriculture and Agricultural Cooperatives distribute samples of new agricultural inputs to farmers at free or subsidized rates to encourage trial and adoption. These institutions were instrumental in promoting the use of hybrid corn seed, for example (Morris, 1997). The private sector sees these efforts as complementary to its own agronomy services and marketing operations.

From the public's perspective, encouraging private companies to develop new agricultural technology frees public resources for other priorities. The annual revenues of $45 million that private companies earn through the sale of hybrid corn seed provides the resources for $3.5 million in their corn breeding research. This allowed public-sector breeders to devote more resources to other crops such as rice and soybeans. In 1995, only about $250,000 was spent on public corn breeding, and the program was largely self-sufficient through its sales of elite germplasm to the private sector.

The close working relationship between the hybrid corn seed industry and government crop research and regulatory agencies resulted from a combination of close personal ties and a well-organized seed association. Seed companies recruited scientific and management staff from university and government offices, helping to solidify good working relationships between the public and private sectors. The hybrid corn companies organized the Seed Association of Thailand to promote their interests. In 1994, the Asia Pacific Seed Association (APSA) was formed with assistance from the Food and Agriculture Organization of the United Nations to promote the seed industry and improve seed supply in the region. APSA's headquarters is located within the Department of Agricultural Extension in Bangkok. The vegetable seed sector has been somewhat less successful in organization and promoting its own interests. Most vegetable seed companies remained outside the seed association (although the largest companies are members), and government research and extension policies have not significantly invested in this sector.

Tax, Credit, and Investment Incentives for Private Research

The Thai Government has established tax incentives and a subsidized loan program for private research (Thailand Economic Information Kit, 1990). However, none of the companies interviewed in this survey were aware of these programs or, if they were, saw them as little inducement for private research. Nevertheless, a special package of incentives introduced by the Central Bank's Board on Investment (BOI) for the private seed sector is seen by the private sector as instrumental in encouraging the development of the seed industry in Thailand. The BOI package included investment support and a 10-year tax holiday for new seed companies, a waiver of import duties on research equipment and materials, and permission for foreign companies to own agricultural land for research purposes.

Regulatory Environment for Seeds, Agrichemicals, and Biotechnology

Thailand's relatively lax regulatory environment has generally been favorable to private business. A low regulatory burden on private companies reduces business costs and encourages increased investment, including in research. However, at the same time, it imposes little incentive to develop technologies that conserve environmental resources or produce other nonmarket goods (Fuglie et al., 1996).

Regulations governing seed are stipulated in Thailand's Seed Act. This law describes seed labeling requirements and minimum allowable germination requirements for 20 species of seed. In contrast to many other countries, Thailand does not have a compulsory varietal registration program. Companies are free to introduce new varieties at their choosing. Market forces, through company reputation and brand-name recognition, provide incentives for companies to limit new introductions to the most promising lines. The lack of compulsory seed registration increases the speed at which new varieties can be introduced. Indonesia, by comparison, has a seed registration scheme in which each new variety must pass through two or three seasons of yield trials and be evaluated by a government committee before it may be legally sold. This process can add several years to product development time. In addition to the Seed Act, Thailand has a Plant Quarantine Act to control the importation of plant pests and diseases in planting materials.

The establishment of a biosafety protocol for biotechnology field testing has encouraged the private sector to develop and introduce transgenic varieties to Thailand. Nevertheless, the system is new and not yet entirely predictable. Several companies expressed concern over delays in obtaining permission to conduct field trials, although this did not appear to be a significant constraint to biotechnology development and transfer thus far.

For chemical production, government authorities require a series of environmental and toxicological tests before any new product may be sold and distributed in the country. Thai chemical registration regulations generally follow North American and European standards. Several agricultural chemical companies expressed concern over the lack of enforcement of truth-in-labeling laws for chemical products. Some companies, particularly generic producers, are thought to have poor quality control in product manufacture and formulation. As a result, many products sold on the market may be diluted or otherwise mislabeled. From a consumer's perspective, there is growing concern over the misuse of agricultural chemicals resulting in high levels of chemical residues on food products, chemical poisonings, and environmental contamination. In 1998, some shipments of exported agricultural products were reportedly rejected because of high levels of chemical residues detected. This has increased efforts to promote safer practices, at least for export-oriented commodities. A private sector response to this problem is the Safe Use Project initiated by the Thai Crop Protection Association to promote proper handling and application of chemical pesticides (see the "Farm Mechanization" section).

Conclusions

Investment in agricultural research by the private sector increased from $7.5 million to $17.4 million between 1985 and 1996, or by 130 percent. Despite this rapid rate of growth, overall private research intensity (research expenditures as a percentage of agricultural gross domestic product) remained about the same due to a similar rate of growth in agricultural production. About a third of private agricultural research is for plant breeding and biotechnology. Plant breeding by the private sector is heavily concentrated on hybrid varieties for corn and vegetables. Little or no private research is being devoted to Thailand's major crops of rice, cassava, and sugarcane, due to the difficulty in protecting intellectual property in open-pollinated or clonally propagated seed.

Government policy toward agricultural research and extension has generally been supportive of private research. Public breeding and seed multiplication programs have concentrated on commodities where the private sector is not present in order to avoid public-private competition. As private capacity in a seed market developed, the public sector gradually reduced its seed multiplication in that crop. This has most clearly been the case with corn seed. In addition, public extension and credit programs promote the diffusion of new agricultural technology, whether it originates from the public or private sector. A special package of investment incentives was instrumental in encouraging local and foreign companies to participate in the Thai seed industry.

Future trends facing Thailand's agriculture are likely to accelerate the demand for improved agricultural technology. The closing of the land frontier has shifted the principal source of agricultural growth to new technology that raises crop yields and develops higher-valued products. The rise in wages due to the rapid industrialization of the Thai economy has increased the demand for labor-saving technology, especially agricultural harvesting machinery and chemical weed control.

References

Agricultural Statistics of Thailand.

Feder, Gershon, Tronroj Onchan, Yongyuth Chalamwond, and Chira Hongladarom. *Land Policies and Farm Productivity in Thailand*. Baltimore, MD: Johns Hopkins University Press. 1988.

Food and Agriculture Organization of the United Nations. Agrostat database.

Fuglie, Keith O. "Vent-for-Surplus as a Source of Agricultural Growth in Northeast Thailand: 1958-80," *Journal of Developing Area.* Vol. 25. April 1991. Pp. 331-346.

Fuglie, Keith O., N. Ballenger, K. Day, C. Klotz, M. Ollinger, J. Reilly, U. Vasavada, and J. Yee. *Agricultural Research and Development: Public and Private Investments Under Alternative Markets and Institutions.* AER-735. U.S. Department of Agriculture, Economic Research Service. May 1996.

Groot, Simon N. "The Vegetable Industry of Tropical Asia." Paper presented at the IAMA Congress, Jakarta, Indonesia. June 1997.

Ingram, James C. *Economic Change in Thailand: 1950-1970*. Stanford, CA: Stanford University Press. 1971.

Ministry of Agriculture and Cooperatives, Center for Agricultural Information, Office of Agricultural Economics. *Agricultural Economic Indicators of Thailand* Bangkok. Thailand. 1996.

Ministry of Agriculture and Cooperatives, Department of Agricultural Extension. *Seed Division Annual Report 1995.* Bangkok, Thailand. 1995.

Ministry of Science, Technology, and Energy. *National Science and Technology Development Plan, 1997-2006.* Bangkok, Thailand. 1997.

Ministry of Science, Technology, and Energy. *Science and Technology Indicators for Thailand*. Bangkok, Thailand. 1997.

Narrod, Clare, and Carl E. Pray. "Technology Transfer in the Poultry Industry: Factors and Externalities Associated with Increased Production," *Animal Wastes and the Land-Water Interface.* K. Steely (ed.). Boca Raton, FL: CRS Press. 1995. Pp. 523-532.

National Science Foundation. *Human Resources for Science & Technology: The Asian Region*. Special Report NSF 93-303. Washington, DC. 1993.

Poapongsakorn, Nipon. "Thai Agriculture and the WTO Agricultural Agreements: Negotiating Objectives, Implementation and Implications for Public Expenditure." Paper presented at the Conference on Food and Agricultural Policy Challenges for the Asia-Pacific and APEC. Manila, Philippines. October 1-3, 1996.

Pray, Carl E. *Private Sector Agricultural Research and Technology Transfer in Thailand: A Preliminary Survey.* New Jersey Agricultural Experiment Station P-02001-3-87. Rutgers University, New Brunswick. March 1987.

Pray, Carl E., and Keith O. Fuglie. "The Private Sector and International Technology Transfer in Agriculture," *Public-Private Collaboration in Agricultural Research: New Institutional Arrangements and Economic Implications.* Keith Fuglie and D. Schimmelpfennig (eds.). Ames: Iowa State University Press. 1999.

Public agricultural research from Poapongsakorn (1996).

Siamwalla, Ammar, and Suthad Setboonsarng. *Trade, Exchange Rates, and Agricultural Pricing Policies in Thailand.* A World Bank Comparative Study, World Bank, Washington, DC. 1989.

Siamwalla, Ammar, Suthad Setboonsarng, and Direk Patamasiriwat. *Thai Agriculture: Resources, Institutions and Policies*. Thailand Development Research Institute. Bangkok, Thailand. 1991.

Subhadpholsiri, Dhajjai. *Background Reading Material on the Intellectual Property System of Thailand.* World Intellectual Property Organization. Geneva, Switzerland. 1993.

Suwantaradon, Kriangsak. "Private Sector Corn and Sorghum Seed Business," Paper presented at the 20th Thai National Corn and Sorghum Reporting Session. Bangkok, Thailand. August 1989.

Thailand Development Research Institute. *Thailand Economic Information Kit*. Bangkok, Thailand. March 1997.

Thailand Development Research Institute. *Enhancing Private Sector Research and Development in Thailand.* Bangkok, Thailand. March 1990.

Thailand Development Research Institute. *Thailand Natural Resources Profile.* Bangkok, Thailand. May 1987.

Thailand Development Research Institute. *Agricultural Diversification/Restructuring of Agricultural Production Systems in Thailand.* Bangkok, Thailand. August 1995.

World Bank. *World Bank Development Report*. Washington, DC. various issues.

Appendix D:

SURVEY OF PRIVATE-SECTOR CROP IMPROVEMENT RESEARCH IN THAILAND, May, 1997

sponsored by

Economic Research Service
U.S. Department of Agriculture
Washington, DC 20005

and

Department of Agricultural Economics and Marketing
Rutgers University
New Brunswick, NJ

1. Company name and address:

Your name and position	
Company name	
Address in Thailand	
Telephone number	
Fax number	
E-mail	

2. In what year did your company begin selling seed in Thailand?:_____________________________________
When did your company begin conducting crop improvement research in Thailand?:______________________

Definition of crop improvement research: any activity to improve varieties, agronomy, and pest control of crops, especially plant breeding.

3. What was your company's revenue from seed sales (all types) in 1996? : _______________ baht.

4. How many people does your company employ in crop improvement research? Please indicate the number by university degree. If an employee works part-time on research, please include only the fraction of his time devoted to research. How many new crop varieties has your company developed and released in Thailand since 1990?

Crop	Number of full-time staff for crop improvement research				Number of new varieties developed and released in Thailand since 1990
	Ph.D.	M.S.	B.S.	technicians	
Corn					
Sorghum					
Soybeans					
Other field crops (name)					
Vegetable crops					
Fruit crops					
Oil palm or rubber					
Flowers or ornamentals					
Others (name)					
Total					

5. What were your company's expenditures for crop improvement research in 1996?

Annual (recurring) research expenditure, including salaries	baht
Capital (non-recurring) research expenditure	baht
Fees paid for research contracted out	baht
Total research expenditure for 1996	baht

6. Has you company had any technical collaboration in crop improvement research with any of the following organizations in the last five (5) years? Please check (✓) all that apply.

Type of collaboration	government institute or university	international research center	other private company
Joint technology development			
Technology licensing			
Contract research			
Training			
Testing			
Crop germplasm supply			

7. Do the following government policies encourage, discourage, or have no effect on your company's willingness to investment in crop improvement research? Please check (✓) the appropriate column.

Policy	Encourage	Discourage	No effect
Tax deduction for research expenses			
Low-interest loans for research expenses			
Seed certification regulations			
Seed phytosanitary and biosafety regulations			
Seed sales and distribution by government agencies			
Crop improvement research by government agencies			
Agricultural extension by government agencies			
Policy toward foreign participation in the seed industry			
Policy toward plant breeders rights			

Comments:

Thank you very much for your cooperation.

List of Tables and Figures

Figures

Indonesia

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This chapter reports the results of the survey of private-sector investments in agricultural research and technology transfer in Indonesia. The purposes of this survey are to: (1) determine how much and what kind of agricultural research is being conducted by the private sector, (2) identify policy constraints and incentives to private research and technology transfer, and (3) assess major impacts of these private investments on agricultural productivity. The survey covered research and development (R&D) investments made in 1995 in the crop seed, biotechnology, pesticide, animal, and plantation industries. The results update an earlier survey by Pray for 1985.

The Indonesian survey consisted of interviewing representatives of eight companies in Jakarta, Surabaya, and Medan in June 1996. The companies included the major firms with research and technology transfer activities in plantation crops, seed, livestock, and agricultural pesticides. These interviews were supplemented with discussions with officials from the Indonesian government, U.S. Agency for International Development, U.S. Department of Agriculture, Food and Agriculture Organization, and non-governmental organizations.

Agricultural Development in Indonesia

Indonesia is the fourth largest country in the world in terms of population, with 195 million people in 1995. It is by far the largest economy in southeast Asia, with a total gross domestic product (GDP) of $198 billion in 1995. But in terms of per capita income, Indonesia lags behind Singapore, Malaysia, Thailand, and Brunei in the region.

The Indonesian economy underwent rapid growth between 1970 and 1997, averaging about 7 percent annual GDP growth. During this period, the agricultural sector grew 3 to 4 percent annually, less than the economy as a whole but still impressive given the size of the agricultural sector in the economy. Because of the more rapid growth of other sectors, agriculture's share of GDP fell from 45 percent in 1970 to 17 percent in 1995. Nevertheless, over 60 percent of the population resided in rural areas in 1998. Agriculture continues to provide the main source of employment for 44 percent of the labor force.[1]

Average per capita income has more than doubled in the past 20 years, although rural incomes remain substantially below urban incomes. A disproportionate number of those in absolute poverty live in rural, agriculturally dependent areas. Nevertheless, Indonesia has made great strides in reducing poverty rates by pursuing growth policies that seek to share the benefits of economic development. The proportion of the population living below the poverty line in 1996 was 11 percent. The number of poor people was reduced to about 22.5 million from 70 million in 1970 (Asian Development Bank, 1996). Policies that have been particularly important for poverty alleviation are agricultural policy, educational policy, and family planning policy.

Evidence of how agricultural policy has been used to reduce poverty is seen in the emphasis given to improving small-holder crop and livestock production. The government has intervened in the pricing of commodities, in the provision of inputs, and in trade (Jatileksono, 1996; Pengistu and Feridhanusetyawan, 1996). The most important example of this policy is the Mass Guidance Program (BIMAS) for rice production that was implemented in the early 1970s. Rice is by far the most important agricultural commodity and food staple in Indonesia and occupies more than half of all agricultural land (table E-1). Rice production has been the primary target of agricultural policy. Indonesia has sought to maintain stable producer and consumer prices of rice and at the same time achieve domestic self-sufficiency in production. Through the BIMAS program, government agencies supplied subsidized

[1] Figures on GDP, GDP growth, and agricultural GDP are from the World Bank (1997). Figures on population and employment are from Biro Pusat Statistik (1997).

Table E-1—Production of agricultural commodities in Indonesia, 1995

Crop	Area harvested	Production	Value
	1,000 hectares	*1,000 metric tons*	*Billion Rp*
Food crops			
Rice	11,439	49,744	49,848.0
Cassava	1,342	15,441	4,160.4
Corn	3,652	8,246	4,123.0
Soybeans	1,477	1,680	1,933.9
Peanuts	739	760	1,520.0
Sweet potato	229	2,171	796.7
Major fruits	NA	8,821	NA
Major vegetables	313	4,330	NA
Industrial crops	Estate area[1]	Small-holder area	Total area
		1,000 hectares	
Oil palm	992	656	1,648
Rubber	472	2,920	3,392
Coconut	138	3,574	3,712
Coffee	49	1,099	1,148
Cocoa	125	418	543
Tea	81	60	141
Sugarcane	497	555	1,052

Animals	Number (1995)	Slaughter (1995)
	1,000 head	
Beef	11,534	1,517
Buffalo	3,136	199
Dairy	342	NA
Pig	7,720	918
Goats and sheep	20,335	1,444
Poultry	933,458	NA
Domestic hens	250,080	NA
Layers	59,394	NA
Broilers	594,368	NA
Ducks	29,616	NA

NA = Not available.

[1]Includes private and state-owned estates. Estates are cultivated on state-owned land based on exploitation rights granted by the government. Small-holders cultivate privately held land.

inputs to rice farmers and purchased production at guaranteed prices. Less intrusive intensification policies were also implemented to promote small-holder production of other food crops, industrial crops, and animal products. Under the "nucleus estate" program, for example, a large plantation is given access to land and subsidized credit in exchange for establishing and supporting small-holder production around the estate. In addition, the plantations provide a market and processing facilities for the small holders. Similar schemes have been established in livestock and horticulture production. However, in many instances the nucleus estate schemes have not worked well and have been subject to diseconomies of scale. Enhancing the incomes of small holders in Indonesian agricultural policy appears in some cases to have been given greater weight than achieving efficiency gains in agriculture.

There has been some liberalization in agricultural policy in recent years. Restrictions on trade and prices for corn and soybeans have been removed. In the input sector, subsidies on pesticides were removed in the 1980s, and subsidies on fertilizers were eliminated in 1998. The government is also playing a smaller role in the procurement and distribution of agricultural inputs compared with a decade ago. Agricultural pesticides are now mostly distributed by the private sector, and a small domestic seed industry is emerging. In the livestock sector, new government regulations introduced in 1990 removed barriers to large-scale, intensive livestock and poultry production systems. The onset of the monetary crisis in 1998 led to further liberalization of agricultural markets under the terms of the International Monetary Fund assistance package. State trading monopolies on rice, wheat, and soybean trade were eliminated, and tariffs on several agricultural commodities were reduced. These trends carry significant implications for the role of the private sector in agricultural technology development and transfer in Indonesia.

Structure of Agricultural Input Industries

Seed Industry

The Indonesian seed industry is dominated by government agencies or state companies that produce and multiply seed for rice and other crops. Improved seed is distributed to farmers largely through government agencies and, to a lesser degree, through private marketing networks. Varietal improvement for food crops is carried out through the research arm of the Ministry of Agriculture, the Agency for Agricultural Research and Development (AARD).

The activity of the private seed industry is mostly limited to hybrid corn and some high-valued horticultural crops. In 1998, hybrid corn was planted on 7 to 10 percent of the total corn area, or on about 250,000 hectares out of 3.6 million hectares of corn. Total annual sales of hybrid corn seed were around $9 million. While hybrid seed still covers a relatively small share of the corn-growing area, the area planted to hybrids is steadily increasing, from less than 1 percent in 1985 and 5 percent in 1992 (International Maize and Wheat Improvement Center, 1994). Area planted to hybrid seed is expected to continue to grow in the future as corn use switches increasingly from food to feed. In 1998, less than 30 percent of the corn crop was used for livestock feed.

Three companies supplied the market for hybrid corn: one Thai multinational (Charoen Pokphand) and two U.S. multinationals (Cargill and Pioneer Hi-Bred International). The Thai company maintains a strategic alliance with a U.S. company (DeKalb Genetics) for its hybrid corn breeding program. However, none of these companies had breeding activities in Indonesia in 1998, but relied on varieties developed elsewhere. In Indonesia, they conduct yield trials in farmers' fields and at public research stations to select the best varieties and register them for local sale.

Hybrid corn varieties are multiplied locally and involve 3-way crosses. Seed companies import the cross between two parent (inbred) lines plus a third parent line and conduct a cross of these lines in Indonesia to produce F_1 seed for local sale. Since the hybrid seed itself cannot be used to reproduce seed with high-yield vigor, farmers need to purchase hybrid seed each year. By restricting access to their parent lines, seed companies can protect their investment in breeding.

Horticultural crops, namely vegetables and floriculture, are a second area where the private seed industry conducts breeding and supplies seed to farmers. These companies are particularly active in providing improved seed for production that is exported or processed into high-valued products. Marketing linkages are often through large agribusiness companies with processing facilities or international trade networks that contract with local farmers for the production of specific commodities. For example, one seed company provides viral-free microtuber potato seed to a private company that produces potato chips. The processing company multiplies the seed and distributes it along with other inputs and technical advice to contract farmers. The farmers produce potatoes and sell them back to the company at a price specified in the contract. In this way, the private company is assured of a steady supply of quality-specific raw material for its processing plant. The extent to which the Indonesian seed industry supplies improved seed to producers who provide fresh fruits and vegetables to local markets is not known.

At least 10 companies in Indonesia propagate seeds and seedlings for vegetables, floriculture, and some fruits. Of these, at least two companies have breeding programs. The largest vegetable seed producer with a breeding investment in Indonesia (East-West Seeds) is a joint venture with a Dutch firm. This company also maintains horticultural breeding programs in the Netherlands, Thailand, the Philippines, and other countries. Domestically produced horticultural seed competes with directly imported seed and farmers' saved seed.

Agricultural Chemical Industry

Indonesia is a large market for agricultural pesticides, with gross annual sales of around $200 - $225 million. About half of these sales are insecticides, a third herbicides, and the rest fungicides, rodenticides, and seed treatments (table E-2). Vegetables are the largest users of pesticides, accounting for about 30 percent of total

Table E-2—Private seed industry in Indonesia

Company	Seed production	Seed breeding
PT East West Seed (Netherlands)	Vegetables	yes
PT Bright Indonesia (Thailand)	Hybrid corn	yes
	Vegetables	NA
	Rice	NA
PT Fitotek Unggul	Vegetables	NA
	Flowers & ornamentals	yes
	Fruits	NA
PT Tanindo Subur Prima	Hybrid corn	yes
	Vegetables	NA
PT Selektani (Netherlands)	Vegetables	NA
PT Benih Prima Tani	Vegetables	NA
PT Pioneer Hibrida Indo (U.S.)	Hybrid corn	yes
PT Bibit Baru (Netherlands)	Fowers	NA
Cargill (U.S.)	Hybrid corn	yes
PT Asparagus	Vegetables	NA
PT Ganesha	Vegetables	NA
PT Mantrust	Vegetables	NA
PT Hortimate Utama	Fruit tree grafting	NA
Total seed research in 1995:	US$700,000	

NA = Not available.

Source: industry estimates from author's survey and Singh (1994)

sales. Peppers (an important export crop) account for 80 percent of pesticides used on vegetables. A large domestic and export market has emerged for processed chili pepper sauces. Rice and plantation crops each use about 25 percent of the total pesticides. The remainder of the pesticide market (20 percent) is for soybeans (8 percent), potatoes (5 percent), sugarcane (4 percent), and other crops. In 1993-97, use of herbicides grew steadily as plantation area expanded, while sales of insecticides remained stable or slightly declined in terms of real expenditures.

One of the most significant changes affecting the market for agricultural pesticides in Indonesia was the implementation of a national integrated pest management (IPM) strategy for rice in the late 1980s. In 1987, the government banned the use of 57 pesticide products for use on rice (although they could still be legally sold for other uses), phased out its pesticide procurement and distribution program, and ended subsidies by 1989. Pesticide companies in 1998 relied mostly on private channels for the distribution and sale of their products. The government also conducted a nationwide extension program emphasizing nonchemical IPM methods for insect control in rice. Despite the government policy initiatives, however, total pesticide sales for use on rice has not significantly diminished, although product formulation has changed. While there was apparently some decline in the amount of insecticide applied per hectare, it has been offset by expansion of the total rice area. Moreover, residues of banned pesticides were still detected on rice, indicating that the use-ban was not effectively enforced. The most important factor that caused a change in pesticide use and led to a decline in the intensity of insecticide use (i.e., amount per hectare) was probably the elimination of large subsidies (up to 85 percent) for pesticides.

Seven multinational companies were represented in the agricultural pesticide market. All had local affiliates or partners for product formulation and/or distribution. The elimination of pesticide procurement by government agencies forced pesticide companies to expand their local marketing efforts. Companies in 1998 maintained substantial sales and technical assistance teams to work with farmers on pest management technology.

Herbicides in Indonesia were until 1998 almost entirely used on plantation crops such as oil palm. But increasingly, farmers growing food crops were replacing manual labor used for weeding with chemical weed control. Chemical weed control has also facilitated the adoption of conservation tillage in rice and corn production. For dryland crops, conservation tillage reduces soil erosion. For paddy rice grown in terraced fields (where erosion is not significant), conservation tillage reduces water requirements and shortens the time required for land preparation, thereby enabling increased cropping intensity in some areas. Herbicide use in rice and field crops is increasing most rapidly outside of Java where land is more abundant relative to labor. Among the small farms of Java where family labor is abundant, herbicide use has been slower to expand.

Plantation Sector

Plantation or perennial crops, particularly oil palm and rubber, have been and continue to be major export commodities for Indonesia. Plantations were first established by European and American companies in the late 19th century. The plantation sector was severely disrupted in the 1940s by World War II and again in the 1960s when foreign plantations were nationalized by the Indonesian Government. Although foreign-owned and operated plantations were subsequently invited to return, one of the most significant developments of the past two decades has been the growth in large, locally owned plantation companies. Two Indonesian companies (PT Salim and PT Sinar Mas) were the largest oil palm producers in Indonesia. In addition, several Malaysian companies invested heavily in expanding plantation production in Indonesia. Indonesia is expected to surpass Malaysia as the global leader in palm oil production within 5 to 10 years.

Perennial crops were produced not only on large private plantations, but also on state-owned plantations and by small holders. Of the 1.65 million hectares planted to oil palm, private estates constituted about 40 percent of the area, state-owned plantations made up another 20 percent, and small holders accounted for the remaining 40 percent (table E-3). Growth in area planted to oil palm was increasing in private holdings while area in state-owned plantations remained stable. State-owned plantations were reportedly only 70 to 80 percent as productive as private oil palm plantations. Large, state-owned plantations were responsible for most of the tea production. Small holders, on the other hand, were the principal producers of coconut (96 percent), coffee (96 percent), rubber (86 percent), and cacao (77 percent).

To maintain stable domestic prices for vegetable oil, the government maintained a variable levy on exported palm oil. For crude palm oil, 40 to 60 percent of the value of exports above a target price was taxed. For olin (processed vegetable oil), the export levy on sales

Table E-3—Private plantation research in Indonesia

Major companies	Oil palm area
	Hectares
PT Salim	200,000
PT Sinar Mas	160,000
PT Londsum	50,000
PT Socfindo	48,000
Other plantations	200,000
Total private plantations	658,000
State-owned plantations	334,000
Small-holders	656,000
Total research by private plantations in 1995	US$2,000,000

Source: industry estimates from author's survey.

above the target price is 50 to 75 percent. The structure of these export duties has reduced the incentive to develop olin-processing factories locally, instead favoring the export of crude palm oil. Export taxes on palm oil and olin increased following the devaluation of the rupiah in late 1997.

Animal Sector

As in other southeast Asian countries, the animal industry in Indonesia features a dual economy. On the one hand are the small holders, the traditional and dominant component, who raise animals for multiple purposes, including cash sales, home consumption, draft power, manure, and as a means of household savings. The other component of the animal sector consists of medium and large commercial operations. These include local and multinational companies, often with links to foreign companies providing advanced breeding stock, veterinary services, and management methods to contract growers. These firms produce meat and animal products primarily for urban populations and export markets. The large commercial operations may also operate their own feedmills and processing plants in fully integrated systems. Despite government efforts to support and improve small-holder animal producers, the large-scale commercial sector continues to increase its market share.

The development of large scale, integrated animal production and processing units in Indonesia was a relatively recent phenomenon. The first commercial poultry operation was established in 1970 by a Thai multinational company (Charoen Pokphand). By 1995, the commercial poultry sector produced more than 650 million birds (layers and broilers), compared with 230 million native chickens in the traditional sector (table

E-1). The poultry industry includes one pure line poultry farm, 13 farms based on grandparent seeds, and 106 parent stock farms that produced 25 breeds of day-old chicks per year (McEvoy,1993). The industry was further supported by 34 veterinary drug manufacturing companies and 68 feedmills producing 2.8 million metric tons of prepared animal feed, mainly for poultry. However, the development of processing and distribution facilities has lagged behind the growth of commercial production as many consumers prefer to buy live poultry in order to be assured of freshness and quality. Thus, poultry processing continues to be performed mostly at the retail level.

A major impetus for growth in commercial swine production was expanding export demand from Singapore. Exports of swine to Singapore in 1993 consisted of 66,000 animals. Most of the 9.1 million pigs produced in Indonesia in 1993 were by small holders with under 50 sows. In the medium- and large-scale commercial enterprises, landraces were imported from abroad (Yorkshire, Hampshire, and Duroc) and raised either as pure breeds or were crossed with local types. The use of concentrated feeds for swine production was limited to medium and large producers. Small holders tended to rely on household or farm byproducts such as crop residues for livestock feed.

Some large commercial operations for beef cattle and dairy production were introduced in Indonesia. Beef cattle were imported primarily from Australia for fattening. But commercial feedlots remain relatively small, compared with the traditional sector. In 1994, about 80,000 out of a total of 11 million head of cattle were imported. Locally produced beef products also compete with imported meat. The dairy sector is small compared with the beef sector, at only 315,000 head. Foreign breeds were imported, with most milk produced on small-holder operations organized into dairy cooperatives. The productivity of local dairies is low due to poor management and low-quality feed, despite the importation and distribution of improved breeds.

Biotechnology

Agricultural biotechnology had been targeted as a strategic industry by the Government of Indonesia. Significant resources were being invested in research facilities and training of scientific staff. In 1998, however, few commercial products had been developed or transferred for use in Indonesian agriculture. No transgenic crops were grown in Indonesia in 1998, which lacks a regulatory protocol for their importation and use. However, a few companies in the commercial seed industry use micropropagation (tissue culture) to produce seedlings for horticulture, floriculture, and plantations. To facilitate biotechnology development and transfer, the government was developing a set of regulations for the importation and field-testing of transgenic crops.

Private-Sector Investment in Research and Technology Transfer

Plant Breeding

Most research by the nascent private seed industry in Indonesia is for varietal testing and improving seed propagation methods. Only three or four companies have small breeding programs (table E-2). Nevertheless, there has been gradual growth in the industry over the 1987-97 period. Private seed companies are testing varieties and propagating seed for corn, vegetables, fruit crops, and floriculture. Hybrid corn plantings increased from less than 1 percent of total corn area in 1985 to around 7 to 10 percent in 1995. Three companies active in 1985 dominated the hybrid corn market in 1995, all of them affiliates of foreign multinationals (PT Bright, a subsidiary of Charoen Pokphand, Cargill, and PT Pioneer Hibrida, a subsidiary of Pioneer Hi-Bred International).

The most significant growth in the Indonesian seed industry has occurred in horticulture. At least six companies were established over the past 10 years to propagate seeds and seedlings for vegetables, fruits, and floriculture, and two of these had breeding programs. Several of these companies are affiliates or joint ventures with foreign multinationals. Three Dutch firms have local affiliates which produce seed and seedlings for the domestic market and for export. East-West Seeds maintains a breeding program in Indonesia for vegetable crops.

The Indonesian private seed industry has engaged principally in technology transfer activities such as screening existing varieties and selecting the best ones for production and distribution. Breeding of new varieties in the private sector is still at an early stage. Most activity involves transferring varieties developed elsewhere for screening and production locally. Seed companies are also transferring improved seed propagation techniques, such as micropropagation methods (tissue culture). Formal linkages and alliances with foreign multinational companies provide the principal source of new technology.

Locally produced seed faces competition from imported seed and from varieties produced and developed by public agricultural research institutes. More than 20 companies import vegetable seed for direct sale, especially from Taiwan. Public research institutes have also engaged in seed production and distribution. Competition from public seed research reduced incentives for the private seed industry.

Crop Protection

Agricultural chemical companies do a substantial amount of applied research on crop protection in Indonesia. Novartis, a multinational chemical company, operates two research stations in Indonesia as part of its global network of crop protection research stations. One station focuses on tropical lowland crops such as rice, sugarcane, and chili, and has been in operation since 1980. A second station was opened in 1990 for horticultural crops in tropical highlands. The principal objective of the research at these stations is to test the efficacy of new chemical treatments that had been synthesized at the company's research laboratories in Europe. A second objective is to develop new products and integrated pest management (IPM) strategies for local and regional markets. IPM involves developing pest and disease scouting methods to determine economic thresholds for pesticide application.

Other companies conduct trials with public research stations, on rented land, plantations, or in farmers' fields. These field experiments include adaptive research and demonstration trials and are closely linked with marketing efforts. Some companies also synthesized their chemical formulations in Indonesia. Manufacturing technologies are quickly transferred from the research units maintained by these companies outside of Indonesia (i.e., in North America, Europe, and Japan). Total research spending by crop protection companies in Indonesia was estimated at $2.4 million in 1995 (table E-4).

Plantations

At least four private plantation companies maintain research facilities in Indonesia. Three of these are locally owned, while the fourth is a subsidiary of a French-Belgian firm (SOCFINDO). Virtually all private plantation research is focused on oil palm. Improved technology for other tree crops (rubber, cacao, coffee, and tea) is from public research in Indonesia or imported from abroad.

Table E-4—Agricultural chemical industry in Indonesia

Major companies	Country	Main products
Novartis	Switzerland	Insecticides, fungicides
Monsanto	United States	Herbicides
Zeneca	United Kingdom	Herbicides
Hoercst	Germany	
Rhone Poulence	France	
Cyanamide	United States	
Dupont	United States	
Total agricultural chemical sales in 1995		US$200-225 million/year 50% insecticides 35% herbicides 15% fungicides and other
Total agricultural chemical research in 1995		US$2,400,000

Source: Industry estimates from author's survey.

Most oil palm research is applied and location-specific in nature, such as trials on soil fertility management. Two companies (SOCFINDO and PT Londsum) maintained breeding and varietal screening programs that produced seed for their own plantings and for sale to other plantations. All companies with in-house research programs maintained or were developing links with research institutions outside of Indonesia. These linkages are an important source of applied technology and the sole source of basic scientific advances, since local research was wholly applied or adaptive. For example, some companies contracted research with CIRAD, a quasi-public French research institution that specializes in tropical agriculture. Public and private research conducted in Malaysia is another important source of new technology. The French-Belgian firm (SOCFINDO) maintained in-house research stations in a number of other countries where it has plantations, and also had a contractual research arrangement with CIRAD for a number of years. Surprisingly, the private oil palm plantations had only weak connections to the publicly supported Indonesian Oil Palm Research Institute (IOPRI) in Indonesia. Public oil palm research was viewed by the large plantations as either not very effective or focused on small holders and state-run plantations. The public sector is an important source of oil palm seed for the private plantations, however.

Animal Research

The presence of a pure-line poultry farm and several grandparent poultry farms by the private sector involve the employment of breeders and technicians capable of making selections during the multiplication phases of day-old chicks. It is difficult for private firms to estimate research expenditures on poultry research because they generally do not maintain separate accounts for research and production activities. A similar situation exists for swine production, although the degree of breeding and selection is less extensive.

Forestry

In the late 1990s, the private sector in Indonesia and other southeast Asian countries had begun to take interest in tropical forestry research. Growth in global demand for tropical forest products and environmental regulations on forest harvesting increased private interest in replanting harvested areas. As a result, several private companies initiated or planned research programs in tropical forestry. Most of these programs focused on the selection of the most productive species under different environments, with few efforts at breeding new forestry varieties. Another emphasis was on developing mass propagation methods for forestry seedlings. One U.S.-based multinational (Monsanto) has set up a joint venture with an Australian biotechnology firm (BIO) to mass-produce seedlings for fast-growing tree species. This research activity is based in Australia, although they were planning to develop research stations in Malaysia and Indonesia. Long-term goals are to develop transgenic forest plants with insect resistance and herbicide tolerance.

Impact of Private Investments in Research and Technology Transfer

As of 1998, few agricultural innovations could be traced to private-sector research in Indonesia. But the private sector has made important contributions in technology transfer, both importing technologies from abroad and diffusing those technologies among local producers. However, not all agricultural technologies developed in other parts of the world are well-suited for Indonesian conditions. To use such technologies locally may require either that the technology be adapted to the local environment, or that the local environment be modified to suit the technology. In crop production, adaptive research is often required to make the technology suitable to local conditions, though some environmental modifications, such as the expansion of irrigation systems, soil treatments, or the construction of greenhouses, may be made. In animal production, technology tends to be imported directly with little local adaptation. Significant economic efficiencies can apparently be achieved through large-scale integrated commercial units. Even in cases where companies contracted out some animal production with farmers, they found it necessary or desirable to maintain tight control over the management of the contracting farm. The new technology (i.e., modern breeds of poultry, swine, beef, and dairy) responds well to a package of improved inputs, included concentrated feeds, veterinary pharmaceuticals, sanitation, and close supervision. In this case, the private sector has found it more economical to change the environment under which the animals are produced rather than to breed animals for local conditions.

The most important impact of private-sector technology transfer has been in the poultry industry. Use of improved breeds has risen to 650 million broilers and layers per year, or about 75 percent of the total poultry produced in Indonesia. This entire increase occurred after 1970, when the first large-scale poultry operation was opened by a Thai multinational company (Charoen Pokphand) in Indonesia.

The seed industry has been successful at increasing farmers' corn yields by 20 percent or more among farmers who have adopted hybrid seed. Again, this increase was due to transferring technology developed under similar climatic conditions in other countries to Indonesia, rather than developing new varieties within Indonesia. In horticulture, private companies have been successful in obtaining advanced technology from abroad for rapid micropropagation of seedlings. For example, one locally owned company (Fitotek Unggul) licensed a bioreactor from a U.S. company (DNA Plant Technology) to increase production from 500,000 seedlings to more than 5 million seedlings per year of horticultural and floricultural crops. Unit production costs for seedlings declined by about 75 percent.

The private sector has played a major role in promoting new pest, disease, and weed management technologies in field crop production. An important example is the recent expansion of conservation tillage. Conservation tillage involves the use of herbicides to replace manual weeding. In areas outside of Java, where agricultural land is relatively abundant, chemical weed control enables a farm family to reduce labor inputs per hectare and increase the area on which it can grow crops using manual labor. The use of herbicides also increases cropping intensity (number and type of crops grown per year) by reducing the turn-around time between harvesting and planting the next crop. In irrigated rice production, chemical weed control significantly reduces water requirements by reducing the need for tilling and puddling the soil prior to seeding. Farmers cultivating thin soils have also found conservation tillage a useful means of preserving topsoil through reduced erosion. The use of conservation tillage is estimated to have expanded to around 250,000 hectares between 1991, when it was first introduced, and 1995. All of this area is outside Java, and includes mainly irrigated and upland rice, corn, and soybeans. Private-sector investment in technology transfer of this technology has been substantial. The company primarily responsible for transferring the technology to Indonesia (Monsanto) maintains a staff of 200 field workers to conduct demonstration trials and provide technical advice to farmers.

In the plantation sector, applied and adaptive research efforts have primarily supported the expansion of the oil palm area. As private companies develop new plantations, agronomic research helps determine optimal soil and fertility management under local conditions. Private-sector breeding programs have also been successful at identifying improved varieties. Indonesian oil palm varieties are noted for their high oil extraction rates (22 to 25 percent, compared with under 20 percent in Malaysia).

Policy Determinants of Private Research and Technology Transfer

Until 1998, the policy measures the government used to promote small-holder agriculture had served as a disincentive for private-sector investment in agricultural research and technology transfer. The government relied heavily on administrative prices and direct distribution and procurement of farm inputs and products to achieve its policy goals. The most notable examples of this were the BIMAS programs for rice, field crops, and livestock. Public research and extension were responsible for technology development and transfer under these programs. Partly as a result of these policies, investment by the private sector in agricultural research and technology transfer has lagged considerably behind other southeast Asian countries.

In the 1990s, policy changes began to provide greater incentives for the private sector. In the late 1980s, the government reduced its role in the procurement and distribution of agricultural chemicals, thereby encouraging the private sector to develop its own marketing and extension networks. In 1991, government restrictions on the size of livestock and poultry operations were lifted, enabling more efficient integrated systems to be developed. Agribusiness units have also been established in the Ministry of Agriculture and the Ministry of Industry and Trade to promote private-sector investments in agricultural production and post-harvest processing. Trade and price liberalization has occurred for a number of important commodities such as corn and soybeans. In 1994, a new research fund was established to encourage collaboration between public research institutions and private companies. Finally, the Indonesian Government was in the process of establishing plant breeders' rights and a biosafety protocol for the importation and use of transgenic crops. While the recent nature of many of these policy developments makes it difficult to judge their long-term impact, together they signal a changing government attitude toward the role of agribusiness in agricultural development.

Few policies have been enacted that were specifically designed to promote private-sector agricultural research. No tax incentives exist for private research, and no patent protection existed prior to 1991. Thus, companies cannot seek intellectual property protection on inventions made prior to the patent law. For example, while the herbicide glyphosate was protected by patents in North America and Europe, it did not have patent protection in Indonesia. At least two companies market various formulations of this chemical in Indonesia and sell it at a price about 40 percent lower than what it normally sells for in the United States. However, patents can and have been sought for new formulations of glyphosate.

While government policy has actively discouraged insecticide use in recent years, this policy does not extend to other chemicals. Furthermore, chemical sales have not changed substantially despite the IPM policy initiative. The main government policies to affect the agricultural chemical industry were the elimination of price subsidies and a reduction in direct procurement and distribution by government agencies. Government extension of nonchemical IPM alternative technologies appears not to have significantly affected research and technology transfer incentives on the part of agricultural chemical companies. Instead, private technology transfer in crop protection has probably increased as companies are forced to rely more on their own sales and distribution networks.

Probably the most important government policy supporting private research and technology transfer is the supply of skilled technical and scientific staff. Private companies make use of public-sector agricultural researchers as consultants or hire them as permanent staff. However, the availability of scientific personnel at the M.S. or Ph.D. level in agricultural fields is still very limited in Indonesia. Private companies have had difficulty in finding and hiring staff at this level. Many of the most prominent agricultural scientists in Indonesia are concentrated among the public research institutions and universities located in Bogor, West Java.

Linkages between public research and private research and technology transfer are limited but growing. Most private companies obtain most of their technological innovations from public and private research institutions or companies outside of Indonesia rather than from public research institutions within the country. Reasons for this include: (1) an emphasis by public agricultural policy, including research policy, on small holders and food crops, (2) varying quality in public research programs, with many of the best public researchers and research facilities concentrated in Bogor, West Java, and (3) the availability of technologies in other countries that could have been imported with relatively little adaptation to the technology. Since the early 1990s, however, new policy interest in promoting agribusiness is leading to some joint public-private activities, including with foreign firms. For example, AARD is working with the U.S. firm Monsanto to test genetically modified cotton in Indonesia, and with a Japanese tuna association to improve commercial tuna fisheries.

Summary of Agricultural Research Investment in Indonesia

Some summary statistics comparing agricultural research and development spending in Indonesia in 1985 and 1995 are presented in table E-5. Between 1985 and 1995, private investment in agricultural research increased from $2.0-$6.1 million, while research spending by AARD increased from $62-$81 million (in nominal terms using current exchange rates). As a share of total agricultural research conducted in Indonesia, private research increased from 3.1 to 7.0 percent over this period. Thus, private research, while still relatively small, grew more rapidly

Table E-5—Private and public agricultural R&D in Indonesia, 1985 and 1995

Item	1985 Companies	1985 Investment	1995 Companies	1995 Investment	SY
	Number	*$ Million*	*Number*	*$ Million*	
Seed	0	0	6	0.7	8
Crop protection	1	0.8	6	2.4	20
Plantations	3	0.6	4	2.0	
Animals	3	0.6	3	1.0	
Total private ag R&D	7	2.0	19	6.1	
Public ag R&D		62.0		81.0	
Total ag R&D		64.0		87.1	
			Percent		
Private R&D % of total ag R&D		3.1		7.0	
Agricultural value added		21,200		33,673	
Private R&D as % of value added		0.009		0.018	
Public R&D as % of valued added		0.292		0.241	
Total R&D as % of value added		0.302		0.259	

Note: Dollar values are not adjusted for inflation.

Sources: 1985 estimates from Pray (1987); 1995 estimates for private agricultural R&D from author's survey; 1995 public agricultural R&D from Agency for Agricultural Research and Development (1996); and agricultural value added from World Bank (1997).

than public research. Private research also grew relative to the size of the Indonesian agricultural sector.

References

Agency for Agricultural Research and Development, Ministry of Agriculture. *Organization, Resources and Research Program Pocket Book*. Jakarta, Indonesia. 1996.

Central Bureau of Statistics. *Statistical Year Book of Indonesia*, *1996.* Jakarta, Indonesia. 1997.

International Maize and Wheat Improvement Center. *CIMMYT 1993/94 World Maize Facts and Trends*. Mexico, 1994.

Jatileksono, Tumari. "Major Policy Instruments for Food and Agriculture in Indonesia." Paper presented at the Conference on Food and Agricultural Policy Challenges for the Asia-Pacific and APEC, Manila, Philippines, October 1-6, 1996.

McEvoy, Michael G. "Opportunities for Developing the Indonesian Livestock Subsector." ADP Working Paper No. 5, Indonesia Agribusiness Development Project, Jakarta, Indonesia, December 1993.

Menegay, Merle R., and Budiman Butabarat. “An Overview of the Fresh Vegetable Subsector in Indonesia.” ADP Working Paper No. 12, Indonesia Agribusiness Development Project, Jakarta, Indonesia, December 1993.

Müller, Klaus. *The Political Economy of Agricultural Trade of the ASEAN Countries*. Witterschlick, Bonn: Verlag M. Wehle, 1995.

Pangestu, Mari, and Tubagus Feridhanusetyawan. "Liberalization of the Agricultural Sector in Indonesia: External Pressures and Domestic Needs." Paper presented at the Conference on Food and Agricultural Policy Challenges for the Asia-Pacific and APEC, Manila, Philippines, October 1-6, 1996.

Pray, Carl E. “Private Sector Agricultural Research and Technology Transfer in Indonesia.” Report No. 3, Economic Development Center, University of Minnesota, October 1986.

Singh, S.B. *Indonesia: A Comprehensive Survey of the Seed Sector*. APSA Country Report No. 5. Bangkok: Asia and Pacific Seed Association, 1994.

Timmer, C. Peter. “Indonesia: Transition from Food Import to Exporter.” *Food Price Policy in Asia: A Comparative Study*. (Terry Sicular, ed.). Ithaca, NY: Cornell University Press, 1989.

World Bank. *World Development Report 1997*. Washington, DC. 1997.

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List of Tables

Malaysia

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This chapter presents the results of a survey of agricultural research spending by the private sector in Malaysia in 1995. The purposes of this survey were to (1) determine how much and what kind of agricultural research is being conducted by the private sector, (2) identify policy constraints and incentives to private research and technology transfer, and (3) assess major impacts of these private investments on agricultural productivity. These results update findings on private agricultural research reported in Pray (1987).

The Malaysian survey consisted of interviewing representatives of nine companies in Kuala Lumpur, Shah Alam, Sengalor, and Penang in May 1996. The companies were selected to include those with research and technology transfer activities in plantation, livestock, and agricultural chemical, and food industries. These interviews were supplemented with discussions with officials from the Malaysian Government, USDA's Foreign Agricultural Service, and agribusiness associations in Malaysia.

This chapter provides an overview of agricultural development in Malaysia and discusses agriculture's role in science and technology policy, reviews the major agricultural input industries in Malaysia through which private companies deliver improved agricultural technology to farmers, provides estimates of private research expenditures in each of these input industries, describes some of the major impacts of private agricultural research and the influence of policies on private incentives to invest in agricultural research.

Agricultural Development in Malaysia

By Asian standards, Malaysia is a relatively small country, with a population approaching only 20 million people. It has achieved remarkable economic progress over the past two decades and is well on the way to becoming a fully industrialized nation. In 1995, the economy as a whole grew at 9.3 percent, and agricultural value added increased by 4 percent. From the turn of the century until the 1970s, exports of primary products (especially rubber and tin) were a major component of national income and provided investment for economic development. Since then, manufacturing production and exports have risen rapidly, and the share of agriculture in the economy has steadily fallen. Agriculture accounted for 14 percent of GDP in 1995, down from 38 percent in 1960 (Asian Development Bank, 1996). Malaysia has taken an outward orientation to its development strategy. It maintains an open trading and investment regime and has sought and encouraged private-sector participation in all sectors of the economy. The government has moved to privatize many state-owned firms.

The sustained high rate of economic growth has led to steadily rising wages and incomes. Labor has increasingly shifted out of agriculture and into manufacturing, construction, and services. Until the recent economic downturn in 1997, the Malaysian economy was operating at full employment with a tight labor market. Labor shortages had emerged, particularly in agriculture and other low-wage sectors. As a consequence, large numbers of foreign workers had come to Malaysia from poorer neighboring countries. The Asian Development Bank (1996) estimates that there were 1 million foreign workers in Malaysia in 1995 out of a total labor force of 7.8 million. The plantation sector is particularly dependent on low-cost foreign workers.

The agricultural economy is dominated by the plantation sector. Oil palm and rubber currently account for 70 percent of all agricultural land use. Area expansion was the major source of agricultural production growth until recently. While agricultural land continues to expand at a modest pace, crop and plantation land is also being lost to urbanization. Pressure on land and labor resources is causing structural change in the agricultural sector. Within agriculture, production of oil palm and fruit crops are increasing, while production of rubber and cacao are declining due to their lower profitability. These trends have affected the direction of agricultural research investments by the private sector in Malaysia, as described below.

Malaysia has emphasized the production of plantation crops where it maintains a comparative advantage. As a consequence, it relies on imports for a large part of its food and feed needs. It currently imports about 35 percent of its rice needs, most of its corn and soybeans, and all of its wheat. It also is a net importer of horticultural crops. For many of the imported agricultural commodities, Malaysia adds value locally through livestock production and food processing. However, retail prices for the most important foods (rice, wheat flour, poultry) are administratively determined, and shortages may emerge if world prices rise above domestic prices. Nevertheless, trends toward greater reliance on imports for basic food and feed commodities are likely to continue (Rahman, 1996). In its 7th Development Plan (1996-2000), the Malaysian Government continued to pursue agricultural growth through more efficient resource allocation, emphasizing commodities in which it maintains a comparative advantage, such as plantation crops, and de-emphasizing self-sufficiency goals in food and feed crops.

Structure of Agricultural Input Industries

A principal way for new technology to reach farmers is to supply them with new and improved agricultural inputs, such as better seed, livestock feed, crop protection chemicals, livestock pharmaceuticals, and farm machinery. The private sector can be expected to invest in research to improve agricultural inputs when (1) the size of the market is sufficiently large, (2) technological improvements can be made relatively quickly and easily, and (3) individual companies have some means of protecting their intellectual property from copiers (Pray and Fuglie, 1996). Before examining private-sector investment in agricultural research, a brief review of agricultural input sectors is provided.

Plantations (Perennials)

Plantation or perennial crops play an important role in the Malaysian economy and a dominant role in its agricultural sector. They occupy 70 percent of the agricultural land and account for a similar proportion of agricultural value added. The most important perennial is oil palm, followed by rubber and cacao.

The origin of the Malaysian plantation economy dates back to the latter part of the 19th century, when colonial planters introduced rubber trees from South America and oil palm trees from West Africa. The growth of the automobile and electrical industries in western countries sparked an international rubber boom. Malaysia became the primary source of natural rubber for automobile tires, electrical wires, and other uses. To support the industry, the Rubber Research Institute of Malaysia (RRIM) was established in 1910 to develop improved technology for the industry (Pray, 1991). While rubber has lost its number one position in the agricultural sector to oil palm, it continued to occupy more than 30 percent of agricultural land in 1994, or 1.73 million hectares (table F-1).

At the time of Malaysian independence in 1964, most rubber and oil palm plantations were foreign owned. The Malaysian Government encouraged a process of "Malaysianization" to transfer ownership to local interests. Government investment bodies such as the National Investment Board (PNB) were instrumental in buying out foreign-owned plantations and transferring stock holdings to local ownership. By the early 1990s, the process of Malaysianization was largely complete. The PNB maintains large share holdings (30 percent or more) in three of the largest plantation companies in Malaysia (Guthrie, Sime Darby, and Golden Hope, formerly Harrison-Crossfield).

While rubber production was started by large plantations, it spread to small holders. By 1960, 60 percent of rubber area was held by small holders. By 1994, small holders' share of rubber area had further increased to 80 percent. The principal reason for the decline in the share of rubber area held by estates is the rising cost of labor. Rubber tapping remains a labor-intensive activity despite efforts to mechanize production. In a recent study of efficiency in the Malaysian rubber economy, Chew and Mohayidin found no evidence of economies of scale in rubber production. While some economies of scale probably exist in plantation establishment (land clearing and planting), there are no such economies at the labor-intensive tapping (harvesting) stage. Small holders may actually have a cost advantage in operating established plantations because the cost of monitoring hired labor is reduced.

Another major structural change in the Malaysia rubber sector is the development of a local processing industry to transform raw rubber (latex) into value-

Table F-1—Agricultural cropland in Malaysia (area harvested)

	1990	Share of total cropland	1995	Share of total cropland
	1,000 hectares	*Percent*	*1,000 hectares*	*Percent*
Industrial crops:				
Oil palm	1,746	35.5	2,235	43.5
Rubber	1,614	32.8	1,475	28.7
Coconut	316	6.4	265	5.2
Cacao	298	6.1	210	4.1
Sugarcane	22	0.4	24	0.5
Coffee	13	0.1	15	0.3
Food and other crops:				
Rice	681	13.8	673	13.1
Fruits	99	2.0	103	2.0
Vegetables	18	0.4	23	0.5
Cassava	39	0.8	42	0.8
Corn	20	0.4	23	0.4
Peppers	12	0.2	10	0.2
Tobacco	11	0.2	10	0.2
Total cropland	4,917	100.0	5,139	100.0

Source: FAOSTAT.

added products for domestic consumption and export. The share of rubber production exported as latex is shrinking, while exports of rubber products such as automobile tires and latex gloves is increasing. A similar trend can be seen in the palm oil industry.

Though oil palm was introduced into Malaysia in the late 1800s, it remained a relatively minor crop until the 1960s. Since then, production has expanded rapidly. Oil palm surpassed rubber as the principal agricultural commodity of Malaysia in the 1970s, and its share of total agricultural production is projected to continue to increase. Between 1960 and 1993, the production of crude palm oil (CPO) increased from 90,000 metric tons to 7.4 million tons per year. Currently, 2.4 million hectares are planted with oil palm, covering 42 percent of all agricultural land in Malaysia.

Unlike rubber, oil palm production remains largely an estate crop. Due to the high level of organization and large capital investment involved, there are significant economies of scale in oil palm production. Only about 10 percent of the oil palm area is operated by small holders, and the rest by large estates. Half of the oil palm area is in the hands of large private plantations, and the remaining 40 percent by state-owned plantations, the largest operated by the Federal Land Development Authority (FELDA).

As with rubber, Malaysia is gradually expanding its downstream processing capacity for palm oil products. Most palm oil is processed into food products such as cooking oil, but an increasing share is being used for nonfood products, such as soaps, detergents, and oleochemicals. In 1995, about 20 percent of Malaysian palm oil production went for nonfood uses, up from 10 percent in 1979.

Malaysian oil palm and rubber companies are expanding their plantation holdings in other countries due to declining land availability and labor shortages at home. Several Malaysian-owned corporations have invested in new plantations in Indonesia and Vietnam. So far, these investments have been primarily for raw material production of latex and crude oil palm. Further downstream refining takes place in Malaysia.

Cacao is a third estate crop that grew steadily in the 1980s but declined in Malaysia in the 1990s due to a sharp drop in world cocoa prices. Economic forecasts of world cocoa demand suggest that low prices will likely continue into the future, mainly due to the development of cocoa substitutes such as vegetable oils for cocoa butter in chocolates. Plantations that invested in cacao production are replanting these areas to oil palm, leaving cacao production primarily to small holders.

Other areas where the estate sector is active are in tropical fruit production, tropical hardwoods, and sugar cane. These are relatively small activities at present. Many of the oil palm and rubber plantation companies are diversifying into manufacturing and real estate development.

Animal Sector

Poultry is the largest component of the animal sector in Malaysia. The Malaysian poultry industry supplies domestic demand for poultry products and also exports some products, mainly to Singapore. Per capita consumption of chicken and chicken eggs in Malaysia is among the highest in the world (table F-2). Poultry products are the principal source of meat protein because local cultural and religious norms place no dietary prohibitions on chicken consumption, while some religious or ethnic groups will not consume beef and pork.

During the past three decades, the Malaysian poultry industry has evolved from small back-yard operations into relatively modern, large-scale commercial operations. One of the factors contributing to the growth of the poultry sector is the replacement of local breeds with high-quality poultry breeds from the United States, Europe, Canada, and Australia. A second factor is the growth of highly efficient integrated production systems. Six of the largest broiler operations are now fully integrated with breeder farms, feedmills, processing plants, and in some cases, retail outlets (table F-3). The integrated firms account for two-thirds of broiler production in Malaysia and are steadily increasing their market share. There are about 5,000 smaller broiler operations, nearly all of which also use modern breeding stock and production methods. Chicken egg production has also moved rapidly toward large-scale production, but has not seen the same degree of integration as in the broiler industry.

In 1994, there were two grandparent broiler breeder farms in Malaysia that produced 65 percent of day-old parent stock, the rest being imported. A third grandparent farm is expected to begin operation in the near future. There are also 82 parent broiler stock farms. For layers, all grandparent stock is imported. There are 14 parent layer stock farms in the country. There are no pure-line stock farms for either broilers or layers.

Table F-3—Integrated poultry firms in Malaysia

Company	Grandparent stock farm
Charoen Pokphand Jaya Farm	yes
Leong Hup Poultry Farms	yes
Dindings Broiler Breeder Farm	
Goldkist Breeding Farm	
KFC Breeder Farm & Hatchery	
Sinmah Multifeed	

Source: Agricultural Counselor, U.S. Embassy, Kuala Lumpur, Malaysia.

After poultry, swine is the next largest component of the Malaysian animal industry. Pork is consumed by non-Muslim Malaysians who make up a significant minority of the population. While pork production tripled between 1970 and 1993, future growth in swine production may be constrained due to environmental and religious concerns. Regulations limit the areas in which swine can be produced and how waste products are handled.

As with poultry, Malaysian pig farmers have adopted modern breeds and production methods. Genetic improvement has played an important role in the development of the Malaysian swine industry. Breeding stock are imported primarily from Taiwan, Europe, North America, and Australia. There is currently only one pig breeding farm in Malaysia (a joint-venture with a Taiwanese company). In 1994, there were about 4,000 pig producers in Malaysia. Twenty percent (800 farms) had over 1,000 head and accounted for 70 per-

Table F-2—Animal production in Malaysia, 1995

Type	Population	Production	Consumption per capita
	1,000 head	*1,000 metric tons*	*kg*
Poultry—broilers	377,000	661	32.91
Poultry—layers	20,000	5.9 billion[1]	331[1]
Swine	3,282	230	32.35
Beef (cattle & buffalo)	846	18	4.38
Mutton (goat, sheep & lamb)	570	1	0.97
Milk (cow & buffalo)		43	46.2

[1]Egg production and consumption in number of pieces.

Source: Production and number of live animals except poultry from FAOSTAT; Number of poultry broilers and layers and consumption per capita from Agricultural Counselor, U.S. Embassy, Kuala Lumpur, Malaysia.

cent of total pork production. Small operations are steadily being replaced by large intensive operations. Animal diseases remain a major problem and are exacerbated by increased rearing density of herds.

Cattle and ruminants are relatively unimportant in the Malaysian livestock industry, mainly because of the lack of pasture land. There have been some attempts to integrate livestock production with plantations using the undergrowth as pasture for cattle or sheep. But so far, these schemes have not been successful.

Agricultural Chemicals

The use of agricultural chemicals in Malaysia is dominated by the plantation sector, which accounts for three-fourths of all sales. Herbicides are widely used in plantations to reduce undergrowth so that the trees face less competition for soil nutrients and are easier to reach for pruning and harvesting. Herbicides account for about 75 percent of the total value of pesticide sales in Malaysia, and more than 90 percent of the pesticides used in plantations. Insecticides account for 15 percent of total sales, and are used primarily in vegetable and rice production. Fungicides are primarily applied to horticultural crops. Rodenticides are applied in oil palm plantations to protect fruit from damage by rats.

Farm Machinery

Increasing labor costs in the rapidly developing Malaysian economy have increased the demand for agricultural machinery (table F-4). Rice production is now mostly mechanized, with tractor tilling, mechanized seeding, and combine harvesting. Efforts have also increased to mechanize operations in the plantation sector, but progress has been slow. Rubber-tree tapping and oil palm harvesting remain manual activities. Transporting raw materials from the field to the mills has been mechanized.

Table F-4—Malaysian imports of agricultural machinery

	1985	1991
	US$1,000	
Tractors	25,494	49,177
Irrigation pumps	18,649	104,491
Chemical sprayers	3,198	23,093
Poultry incubators	1,665	12,516
Power tillers	2,638	12,419
Combine harvesters	3,083	4,278

Source: Nasarudin, 1995.

Several foreign agricultural machinery firms from Europe, Japan, and North America have affiliates or partner companies in Malaysia. Tractors Malaysia, for example, a part of the Sime Darby group of companies, has a Ford agricultural machinery franchise for Malaysia. Most agricultural machinery companies in Malaysia import foreign machinery or parts for assembly and distribution locally. Only one local firm designs and manufactures farm implements directly (Nasarudin, 1995). Recently, there have been some attempts to modify imported designs to suit particular local needs or requirements. For example, Tractors Malaysia modified some imported machinery to make them more suitable for in-field transport of oil palm fruit bunches.

Private-Sector Investment in Agricultural Research

Plantations

During the past 10 years, private-sector investment in research for plantation crops shifted almost entirely into oil palm, while private research on rubber and cacao was reduced. This trend was driven by expected future market potential for these crops. As discussed above, high labor costs in rubber production and low prices for cocoa reduced the prospects for these crops in Malaysia while the outlook for oil palm remains optimistic.

Private research on oil palm is closely linked to public research at the Palm Oil Research Institute of Malaysia (PORIM). PORIM is the world's premier research institute on oil palm production and utilization. For oil palm production, private plantations rely on PORIM for basic and pre-technology research. Plantations focus on applied problems, especially breeding, soil and fertility management, waste management, pest and disease control, and mechanization. PORIM collects, maintains, and evaluates oil palm germplasm from around the world. Private breeding programs can access this germplasm for promising new traits. For post-harvest processing and product development, PORIM plays a leading role in both pre-technology and applied research. The private sector has been reluctant to allocate research resources to new product development until the market prospects for these products are more certain.

Seven plantations account for most research conducted outside of PORIM (table F-5). The extent to which this research is classified as “private-sector research”

Table F-5—Private and public plantation research in Malaysia, 1995

Company	Crop	Research	SY
		1,000 RM/yr	
Golden Hope	oil palm (70%) rubber (20%) cacao, fruit (10%)	10,000	20
Guthrie	oil palm	5,000	10
United Plantations	oil palm	2,000	4
Sime Darby	oil palm	7,300	14
East Plantation Agency	oil palm	2,000	4
FELDA		7,500	15
KL Kepong	oil palm	2,000	4
Perlis Plantation	oil palm sugarcane fruits, tobacco	1,000	2
Total private plantation research		36,800	73
Cocoa Board	cacao	1,410	5
Palm Oil Research Institute of Malaysia	oil palm	45,422	130
Rubber Research Institute of Malaysia	rubber	research: 49,000 (extension: 21,000	77 33)
Total public plantation research		95,832	212
Total plantation research		132,632	285

Source: Industry estimates from author's survey.

requires some qualification. The government invests directly in many of these companies through stock holdings managed by the National Investment Board (PNB). PNB holds at least 30-percent ownership in three of the largest plantation companies (Golden Hope, Guthrie, and Sime Darby). Two more plantations are state-owned or state-run (East Plantation Agency and FELDA). The other two plantations with research programs are United Plantations and KL Kepong. Together, these seven companies are estimated to have spent about 36.8 million Malaysian Ringgits, or $14.7 million, on R&D in 1995. Nearly all of this was for oil palm research. A small amount went for rubber, fruit crops, and tropical forestry.

Three companies maintain their own breeding program and produce most of the improved oil palm seeds (Guthrie, Golden Hope, and FELDA). PORIM itself is restricted by law from selling seeds to plantations, although PORIM does provide oil palm seed for small holders. Due to the continuing expansion of oil palm area and the need for replanting old trees, there is a large demand for high-yielding oil palm seeds. Other plantations are beginning their own seed production programs.

Research on rubber production is increasingly dominated by RRIM, since private plantations account for less than 20 percent of total production and their share continues to decline. RRIM allocates about 70 percent of its scientific and technical resources to research and about 30 percent to extension. RRIM also conducts research on rubber post-harvest and processing. In addition, Sime Darby maintains its own in-house laboratory in tire research. The private sector is represented in RRIM research programs through the Malay Rubber Producers Council for production research and through the Malay Rubber Product Manufacturers Association for processing research.

The Malaysian plantation research institutes also maintain formal linkages with research institutes in other countries. Through collaborative research activities, new sources of technology and plant germplasm are introduced into the Malaysian plantation economy. RRIM is a member of the International Rubber Research and Development Board (IRRDB), which has its secretariat in the U.K. IRRDB has sponsored collections of landraces of rubber germplasm. The world rubber germplasm bank is maintained by RRIM in Malaysia and is accessible to all members. RRIM also supports research in other countries. RRIM has supported research since 1938 at a U.K. lab that focuses on rubber utilization and demand. For several years RRIM also maintained a research lab in Brazil (in collaboration with the Brazilian rubber research system) to study blight diseases; this lab was closed in 1990.

Agricultural Chemicals

Three agricultural chemical companies maintain research stations in Malaysia with a fourth reportedly to open possibly by 2002. For two of the companies (Novartis and Zeneca), their Malaysian research facilities form part of their worldwide testing network for agricultural chemical development. In addition to testing new chemical compounds, these research stations develop crop protection technology for local markets, primarily in the plantation sector. Local R&D also supports the registration of chemicals for sale in Malaysia. Agricultural chemicals must be reregistered every 3 years under the 1974 Pesticide Act.

The multinational linkages are important for technology development and transfer. For example, Zeneca holds 25-percent ownership of CCM Bioscience, a local chemical firm that manufactures agricultural chemicals and fertilizers. CCM Bioscience maintains a 23-acre research station in Malaysia (it will be moved to a larger, 43-acre site possibly by 2003). These research stations form part of Zeneca's global research system. Zeneca maintains research laboratories in the U.K. and United States for synthesizing new chemical compounds. These compounds are then tested for efficacy and environmental effects at Zeneca's global network of 12 field research stations. Four of Zeneca's stations are maintained in the Asia-Pacific region (Malaysia, Philippines, Thailand, and Japan). Zeneca's Malaysian station is designed to test weed and rodent control under tropical conditions.

Similarly, Novartis maintains a research facility in Malaysia as part of its global testing network for new chemical compounds developed at its Swiss laboratories. Novartis conducts field research in Thailand, Indonesia, and Japan in Asia, Egypt and South Africa in Africa, Brazil in South America, as well as in the United States and Europe. This network allows Novartis to test new chemical compounds year-round under different environmental conditions. The Malaysian facility focuses primarily on testing herbicides, fungicides, and insecticides for use on plantation crops (oil palm and cacao), rice, and horticultural crops.

Private agricultural chemical research in Malaysia was estimated at about 4.5 million RM in 1995 (table F-6), and likely increased in 1996 and 1997 when AgrEvo (formerly Hoerchst) opened a new station and CCM Bioscience moved its research to a larger facility.

Farm Machinery

Increased wages and labor scarcity in Malaysian agriculture have increased the demand for agricultural machinery. Most mechanization involves the direct importation of foreign machines or their designs for local manufacture with little or no modification. Rice production in Malaysia is now mostly mechanized. Rice paddies are tilled with tractor-based implements, seeded with motorized spreaders and harvested with combine harvesters. Rice mechanization reduced the labor component of rice production from 845 man-hours per hectare to 145 man-hours per hectare (Nasarudin, 1995). For oil palm and rubber, however, suitable equipment for harvesting, tapping, and field transportation of palm fruit bunches was not available. Three local companies, some plantations, and PORIM have experimented with design modifications or new designs for these specialized purposes. Engineering research by manufacturing companies is carried out in close collaboration with plantations. Tractors Malaysia, for example, is owned by the same holding company as Sime Darby plantations, and the two companies collaborate in research for oil palm mechanization. Tractors Malaysia is estimated to spend about

Table F-6—Private agricultural chemical research in Malaysia, 1995

Company	Foreign links
Novartis	Switzerland
CCM Bioscience (Zeneca)	United Kingdom
ACM (Agricultural Chemical Malaysia)	Japan
AgrEvo (Hoerchst): opened field station in 1996-97	Germany
Annual sales of agricultural chemicals	US$110,000,000 (76% herbicides, 15% insecticides, 9% fungicides and rodenticides)
Total agricultural chemical research:	US$3,900,000
SY	15

Source: Industry estimates from author's survey.

400,000 RM/yr on agricultural machinery design modification and testing.

Two other companies have also made investments in design modifications for plantation machinery. A small family company developed a “grabber” for palm kernel harvesting based on a Scandinavian design. A Jahore-based plantation firm built an in-field transporter based on a Taiwanese tricycle design that involved some machine design and modification.

So far there has not been much success in mechanizing oil palm and rubber harvesting. Some prototype models for in-field transportation of palm fruit bunches and a raised platform for palm fruit harvesting have been developed. But there had been no commercial sales as of 1998. Agricultural machinery manufacturers face an uncertain market for these products until their efficiency is convincingly established. This uncertainty is a major constraint to moving from the design stage to the commercialization stage. Total private-sector agricultural mechanization research is estimated to be 700,00 RM ($280,000) annually.

Another factor affecting the demand for agricultural mechanization (and therefore agricultural machinery R&D) is immigration policy. The agricultural sector (particularly plantations) has made extensive use of foreign workers to overcome rising local wage rates and increasing scarcity of agricultural labor. The Asian Development Bank estimates that 1 in 8 workers in Malaysia in 1995 were from other countries. Many of these are employed in the agricultural sector. To the extent that Malaysia is willing to allow (or unable to restrict) low-wage foreign workers, private investment in agricultural machinery research is likely to remain low.

Summary of Private Agricultural Research Investment in Malaysia

Table F-7 summarizes our estimates of agricultural research expenditures in Malaysia. Estimates from Pray's 1985 survey are also presented for comparative purposes. The estimate for total private agricultural research in 1995 is $16.8 million, most of which was conducted by plantations. In inflation-adjusted dollars, private research increased from $13.6 million in 1985, or by about 2.4 percent per year. Public agricultural research also increased over this period, but not as rapidly. As a percentage of total agricultural research in Malaysia, private-sector research increased from 19 percent in 1985 to 21 percent in 1995.

Table F-7—Private-sector investments in agricultural research in Malaysia, 1985 and 1995

Item	1985		1995		
	Companies	Value	Companies	Value	SY
	Number	*Mil. dol.*	*Number*	*Mil. dol.*	
Seed	0	0	0	0	0
Crop protection	3	0.5	3	1.6	15
Plantations	9	10.0	7	14.7[1]	69
Animal	NA	NA	NA	NA	NA
Ag machinery	NA	NA	3	0.3	
Total private ag R&D		10.5		16.6	
Total public ag R&D		44.4		63.5	
Total ag R&D		54.9		80.1	
Private ag R&D % of total		19%		21%	
Ag value added		6,600		11,090	
Private ag R&D as % of ag value added		0.16%	0.15%		
Total ag R&D as % of ag value added		0.83%		0.72%	
Private ag R&D in 1995 dollars		13.6		16.6	
Public ag R&D in 1995 dollars		57.7		63.5	
Total ag R&D in 1995 dollars		71.3		80.1	

NA = not available.

Note: Adjusted for inflation. Calculated at an exchange rate of 2.50 RM per $1.00 U.S.
[1]Includes $8 million and 19 SY's from parastatal estates (EPA and FELDA).
Source: 1985 estimates from Pray (1987). 1995 estimates of private agricultural R&D from author's survey. Estimates of 1995 public research from table 8.

Impact of Private Agricultural Research

The most significant impact of private-sector research in Malaysia has been in the plantation sector. The productivity of rubber and oil palm has risen steadily over the past several decades. It is difficult to separate out the impacts of public research by PORIM and RRIM from research by private plantations, however, given the close cooperation between public and private research. These public institutions are the leaders in developing improved germplasm, pest and waste management, and new industrial uses for oil palm and rubber. Plantations play a major role in finding the optimal varieties and agronomic practices for specific areas.

In oil palm, PORIM and the plantations have invested heavily in developing tissue culture methods for rapid multiplication of true clones of high-yielding palms. Despite more than 20 years of interest in this technology, tissue culture currently supplies only a small fraction of seed needs. Major technical difficulties, such as vegetative and reproductive abnormalities in clones, remain. Nevertheless, the use of tissue culture propagation continues to be an important goal for the oil palm industry, and six Malaysian companies are doing research in tissue culture along with PORIM. Successful cloning is expected to raise yields immediately by 20 percent and eventually lead to important traits such as uniform maturation and improved oil quality (Davidson, 1991).

Public and private research on oil palm increased yields from 14 fresh-fruit bunches (FFB)/hectare in 1960 to 25 FFB/ha in the early 1990s. Oil extraction rates in Malaysia remain low, however, at an average of only 18-19 percent, compared with about 23-25 percent in Indonesia. Utilization research has resulted in an increase in the proportion of oil palm production used for nonfood purposes, from 10 percent of production in 1980 to 20 percent of production in 1990.

Similarly, RRIM has an impressive history of developing and extending improved rubber technology for Malaysian producers. Pee (1977) estimated the annual rate of return on rubber research in Malaysia between 1932 and 1973 to be 24 percent. Average latex yields increased from only 200-250 kg/ha in 1976 to 1,400-1,500 kg/ha in 1996. Experiment station yields from improved clones reach 3,000 kg/ha. This compares with average yields of only 400-500 kg/ha in the second largest producer of natural rubber, Brazil.

RRIM has achieved important progress in research on rubber biotechnology. In addition to tissue culture propagation, RRIM has developed a capacity for producing transgenetic rubber varieties. It achieved the world's first successful genetic transformation in rubber and has applied for a U.S. patent for this technology.

Policies and Private Agricultural Research

The Government of Malaysia has taken an active role in promoting the development and transfer of agricultural technology. It supported the early establishment of specialized research stations, first for rubber and then for oil palm production and processing. In particular, it helped organize a system of commodity taxes on oil palm, rubber, and cocoa to support research. For rubber, a tax is levied on each kilogram of latex that is exported. The export tax provides most of the operating budget for the Rubber Research Institute of Malaysia. However, the research assessment as a percentage of total production has fallen as an increasing share of Malaysian rubber is exported in the form of processed products. In 1997, the research tax was extended to exported rubber products based on their rubber content.

In the 1970s, the government established a similar system for oil palm. A tax is levied on each ton of crude palm oil that is milled from raw palm fruit bunches.[1] This tax is the principal source of funds for the Palm Oil Research Institute of Malaysia, established in 1979.

The commodity taxes to support research for rubber and oil palm have worked well. These taxes have been supported by industry and have provided a stable source of revenue for research. An estimated 57 percent of the $63 million spent on agricultural research at public institutions in Malaysia in 1995 came from the private sector, mostly through the commodity taxes (table F-8). One reason for their success is that the private sector is actively involved in setting the research programs at RRIM and PORIM. The majority of the Board members at each institute are from the private sector, representing both large plantation estates and small holders. The government also appoints a share of the Board members of the institutes. A second reason for the success of the research tax is that it is relatively

[1] In 1995, the research tax, or cess, on oil palm was 5 RM/ton of crude oil palm processed.

Table F-8—Funding of public agricultural research in Malaysia, 1995

Agricultural research institute	Public funds	Private funds	Total
		1,000 Malaysian ringgits	
Malaysian Institute for Nuclear Technology Research (MINT)	400	NA	400
Rice Research Institute of Malaysia (RRIM)	5,770	43,230	49,000
Palm Oil Research Institute of Malaysia (PORIM)	1,272	44,150	45,422
Malaysian Cocoa Board (LKM)	1,410	NA	1,410
Malaysian Agricultural Research & Devel Institute (MARDI)	35,566	3,500	39,066
Sabah Agricultural Department (JTSB)	161	NA	161
Forest Research Institute of Malaysia (FRIM)	3,511	NA	3,511
Sarawak Forestry Department (JPSK)	1,000	NA	1,000
Sabah Forestry Department (JPSB)	461	NA	461
Fisheries Research Institute (IPP)	4,040	NA	4,040
Sabah Fisheries Department (JISB)	270	NA	270
Sarawak Fisheries Department (JISK)	134	NA	134
Veterinary Research Institute (IPH)	365	NA	365
Sabah Veterinary Department (JHSB)	240	NA	240
National University of Malaysia (UKM)	1,332	NA	1,332
Agricultural University of Malaysia (UPM)	10,292	NA	10,292
University of Malaysia (UM)	629	NA	629
University of Science Malaysia (USM)	1,080	NA	1,080
Total (1,000 Malaysian ringgits)	67,933	90,880	158,813
Total (US$1,000)	27,173	36,354	63,525
		Percent	
Allocation	43	57	100

NA = Not available.
Source: Public funds from National Council for Scientific Research and Development, Ministry of Science and Technology and the Environment, Annual Report for 1995. Private funds from author's survey and annual reports of RRIM, PORIM, and MARDI.

easy to collect. For oil palm, the raw harvested product must undergo primary processing quickly after harvest in order to assure quality and yield. Each of the 275 mills is monitored and a tax of 5 Malaysian Ringgits is levied on each ton of crude palm oil milled. For rubber, production and processing are more decentralized. The research tax is therefore levied on each ton of latex that is exported in raw or processed form.[2] For processed products, the tax is levied on each of the 81 Malaysian rubber processing factories producing rubber products for domestic use and export. These firms are registered with the Malaysian Exchange and Licensing Board, which also has responsibilities for negotiating trade issues, monitoring export quality of raw materials, and announcing daily price information.

The Malaysian Government placed increased emphasis on research and development in its seventh 5-year economic development plan (1996-2000). To accomplish this goal, the Ministry of Science, Technology, and the Environment established the National Council for Scientific Research and Development (MPKSN) to coordinate and prioritize research resource allocations in Malaysia. MPKSN has overall responsibility for allocating public R&D funds to priority research programs at research institutes, universities, and ministries.

Another part of this strategy is to increase technology transfer linkages between the public and private sectors. For agriculture, this led to a major reorganization of the Malaysian Agricultural Research and Development Institute (MARDI), which is responsible for research on all agricultural commodities other than oil palm and rubber. Under the reorganization, MARDI aims to generate 60 percent of its revenue from the private sector by 2002. In 1995, private sector sources accounted for 10-12 percent of MARDI funds. To achieve this goal, MARDI will change its principal emphasis from working with farmers to working with

[2] A research tax, or cess, of 3.75 RM/ton is levied on raw latex exports. In addition, a replanting cess of 9.5 RM/ton is levied to encourage the adoption of new technology. Planters get back this tax when they plant new trees and follow RRIM's technical recommendations.

agribusinesses. Greater emphasis will be given to food processing, industrial crops, livestock, horticulture, and resource management, and less to food crops such as rice. MARDI established a separate corporation called MARDITECH in 1992 to develop partnerships with private firms. MARDITECH offers joint equity participation with private companies to commercialize promising new agricultural and food technology. By the end of 1995, MARDITECH had invested 1.6 million RM as venture capital in four companies (Rahman, 1996). In addition, MARDI plans to use some of its research facilities (land and buildings) to develop science parks. MARDI will use 600 acres of land to establish an agroindustry park that will specialize in food processing. MARDI also encourages its research staff to work as consultants to private firms. About 40 percent of the consulting fees are kept by the researcher, 40 percent goes to MARDI, and 20 percent to MARDITECH. The "corporatization" of MARDI is likely to significantly alter the kind of agricultural research supported by the public sector in Malaysia.

The Malaysian Government offers a range of other policies to encourage private-sector research. In 1986, Malaysia passed a patent law and in 1987 enacted a copyright law. Enforcement of intellectual property rights is encouraged. Trademark infringement has not been a major problem for foreign companies in Malaysia. Malaysia also offers tax incentives for private research. Companies can write off 200 percent of the value of their research investments as a tax deduction.

The government has also sought to maintain Malaysia's competitive advantage in plantation crops by restricting the transfer of agricultural technology outside Malaysia. Until 1993, the transfer of oil palm and rubber seeds to other countries was prohibited. However, rising labor costs and declining land availability in Malaysia caused local plantations to look to other countries, principally Indonesia, to expand their plantation holdings. In 1993, the government allowed Malaysian plantations to invest in plantations in other countries and to transfer improved seed stock to their holdings in these countries. Malaysian plantations are still prohibited from selling improved seed to companies located in other countries, and the transfer of processing technology is still prohibited as well. Similar restrictions apply to rubber. While this policy may have helped Malaysia maintain its position as the world leader in oil palm and rubber production, it also served as a disincentive for local research. Limiting access to foreign markets for new technology reduces the potential returns to research.

Agricultural chemical research is affected by pesticide regulation. The Malaysian Pesticide Act of 1974 established standards for the storage, transportation, labeling, and use of agricultural pesticides based on WHO and FAO guidelines. These regulations are probably the most strictly enforced in southeast Asia. The main effect of these regulations on research is to require health and efficacy tests for periodic reregistration. Although there appears to be no policy pressure to reduce chemical pesticide use other than through enforcement of safe-use regulations, researchers have put some effort into developing integrated pest management (IPM) for rice and plantation crops. IPM for rice uses scouting tools to time insecticide applications. By far the largest agricultural chemical market is herbicide application in plantations. Legume cover is an important alternative weed control method on plantations. As a result, only about a third of the oil palm plantation area is treated with chemical herbicides in any given year. Treated areas receive 2 to 6 applications per year (Kon, 1996).

Government-supported higher education and research institutions are the primary training ground for professional and technical workers in the private sector. Successful researchers at PORIM, RRIM, and MARDI often move to the private sector in mid-career. During the past several years, these institutes have been important sources of human capital for the rapidly growing palm oil, rubber, and food processing industries.

References

Asian Development Bank. *Asian Development Outlook 1996 and 1997*. New York: Oxford University Press, 1996.

Basiron, Y., and Jalani Sukaimi. "The Oil Palm and its Products: Competitiveness and Opportunities in the 21st Century." 1995 National Outlook Conference, Malaysian Institute of Economic Research, December 5-6, 1995.

Chew, Tek-Ann, and M. Ghazali Mohayidin. "Plantation Agriculture: Its Genesis, Management, and Role in the Malaysian Economy," *Agribusiness* 11, 2 (1995): 139-45.

Davidson, L. "Management for Efficient Cost-Effective and Productive Oil Palm Plantations." Proceedings, 1991 PORIM International Palm Oil Conference, Kuala Lumpur, Malaysia, 9-14 September 1991.

Kon, K.F. Personal communication. R&D manager, Plant Protection Division, Novartis, Petaling Jaya, Malaysia, November 1996.

Nasarudin, Anas Ahmad. "Agricultural Mechanization in Malaysia." Paper presented at the APO Seminar on Agricultural Mechanization, Asian Productivity Organization, Tokyo, 7-17 March, 1995.

Pee, T.Y. "Social Returns to Rubber Research in Peninsular Malaysia," Ph.D. dissertation, Michigan State University, 1977.

Pray, Carl E. "Private Sector Agricultural Research and Technology Transfer in LDCs," Economic Development Center, University of Minnesota, Minneapolis, MN, March 1987.

Pray, Carl E. "The Development of Asian Research Institutions: Underinvestment, Allocation of Resources, and Productivity," in *Research and Productivity in Asian Agriculture* (R.E. Evenson and C.E. Pray, eds.). Ithaca: Cornell University Press, 1991.

Pray, Carl E., and Keith O. Fuglie. "Private Food and Agricultural Research and Public Policy in APEC Countries," Paper presented at the Conference on Food and Agricultural Policy Challenges for the Asia-Pacific, Manila, Philippines, October 1-3, 1996.

Rahman, Abdul Azziz Abdul. "Progress and Issues in Agricultural Trade Liberalization: Malaysian Case Study," Paper presented at the Conference on Food and Agricultural Policy Challenges for the Asia-Pacific and APEC, Manila, Philippines, October 1-3, 1996.

Tiong, Gan Lian, and Ho Chai Yee. "Impact of Rising Labour Cost on Choice of Plantation Crops for the Estate Sector." International Planters Conference, Kuala Lumpur. October 24-25, 1994.

Appendix F—Companies and Officials Interviewed, May/June 1996

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List of Tables

Philippines

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The demand for agricultural products is increasing in the Philippines, and, until 1997, foreign demand for Philippine exports of fruits and coconut oil was also growing. Little arable land is available for expansion of production, however, and that land is diminishing as a result of urban and industrial development. Thus, to continue to meet demand, the Philippines need to increase output per unit of land. This means applying better technology. Public sector research is one possible source of this technology, but government investments have been stagnant or declining. Thus, importing technology and developing new technology through research by private firms are likely to be important sources of growth in the future.

This chapter examines private sector research and technology transfer in the Philippines. After a brief introduction to Philippine agriculture, it describes and attempts to quantify how much research is being conducted in the Philippines. The impact of private research is also discussed.

We collected the raw data during two visits to the Philippines during 1996, when we interviewed 20 firms and met with officials from the Philippines Council for Agricultural Research and Resources Development, the Department of Science and Technology, the Patent Office, the International Rice Research Institute, the Philippines Institute of Development Studies, the Agricultural Attaché at the U.S. Embassy, and the U.S. Agency for International Development.

Agricultural Production and the Input Industry

Production

Agricultural production stagnated in the 1980s and the early 1990s growing an average of 1 percent per year during the 1980s and 1.4 percent in 1990-95 (David, 1996). The major areas of growth have been pork and poultry. Livestock and poultry production, which make up 27 percent of agricultural production, doubled between 1985 and 1995. Crop production, which makes up 56 percent, increased much more slowly—a 21-percent increase in the same period (table G-1).

The major factor leading to increased poultry and pork production has been demand. Demand for meat has increased with the increase in per capita income and population growth. Productivity also seems to have increased. About 30 to 35 percent of swine are produced in integrated operations that feature exotic breeds or mixed exotics and local breeds, commercial feed, and confinement management. Sixty to 80 percent of the poultry is produced in integrated operations featuring foreign breeds, commercial feed, foreign pharmaceuticals and vaccines, and confinement management.

The increase in field crop production was also driven by demand driven both by increases in per capita income and by government policies. Technology and increased inputs account for much of the increase in production. Table G-2 shows the rapid increase in use of hybrid maize and fertilizer during this period. The increase in these inputs helped boost maize yields from 1.1 metric tons (mt) per hectare (ha) in 1985 to 1.5 mt/ha in 1995, and rice yields from 2.6 to 2.9 mt/ha in the same period (lower part of table G-1).

Production of plantation crops was driven by foreign markets. Agriculture is no longer the major producer of exports from the Philippines. Total agricultural exports declined from US$4.6 billion in the 1979 to US$1.5 billion in 1994 in nominal dollars. In 1979, agriculture and forestry accounted for 49 percent of total Philippine exports (David, 1996). In 1994, they accounted for 11 percent of exports. The major agricultural exports of the Philippines were coconut oil and fruits—primarily bananas. Demand for fruit was growing largely because of the growing demand in Asia, chiefly Japan, Hong Kong, and South Korea, followed by China. Sugar exports, which were tradition-

Table G-1—Agricultural outputs and inputs

	1985	1990	1995
Agriculture production[1]	86.9	103.7	117.0
Crop production1	91.9	103.9	111.1
Livestock production1	66.6	101.7	137.7
Rice:			
Yield (metric ton/hectare)	2.59	2.98	2.86
Area (hectares)	3,402,610	3,318,720	3,951,140
Production (metric tons)	8,805,600	9,885,000	11,283,600
Maize			
Yield (mt/ha)	1.12	1.27	1.52
Area (ha)	3,510,910	3,,819,560	2,735,720
Production (mt)	3,922,000	4,853,891	4,161,330
Sugarcane			
Yield (mt/ha)	62.7	82.6	69.3
Area (ha)	368,547	318,403	375,098
Production (mt)	2,310,000	2,630,000	2,600,00
Coconut			
Yield (mt/ha)	2.63	3.54	3.98
Area (ha)	3,270,000	3,111,978	3,064,457
Production (mt)	8,600,000	11,023,000	12,183,090

[1] Values indexed to 1989-91=100 levels.

Source: FAOSTAT Statistical Database. *http://apps.fao.org.*

ally the largest exports, have declined in importance, and domestic demand for sugar has increased.

Plantation crops were produced not only on large plantations but also by small-holders. The share of production by small-holders varies by crop and has increased in most of these crops due to land reform. Bananas for export are mainly produced on large plantations. At the opposite end of the spectrum, coconuts are produced by thousands of small farmers, with a few large plantations in Mindanao. Sugarcane production falls somewhere between.

Productivity of fruits has increased somewhat, while sugar productivity has been stagnant. Coconut productivity has increased considerably—from 2.6 mt/ha in 1985 to 4.0 mt/ha in 1995 (FAOSTAT).

Agribusiness

Pesticides are supplied almost entirely through imports. All leading firms are subsidiaries of multinationals or joint ventures with multinationals. Most import the formulated product, with only one local company producing an active ingredient. That product was 2,4-D, one of the oldest herbicides. A few companies import the active ingredients and formulate the product locally in their own factory or contract the formulation out to another firm. The pesticide industry grew to $172 million in 1995, with insecticides accounting for 53 percent of sales, followed by herbicides (19 percent) and fungicides (16 percent) (see table G-3). The most rapid growth was in the "Other" category, while herbicide sales were next most rapid-more than doubling since 1980. Pesticides are used chiefly on rice (38 percent of sales), followed by fruits (33 percent) and vegetables (12 percent).

Most seeds are produced and saved by farmers. Only hybrid corn, vegetables, and hybrids or new varieties of rice are produced commercially in fairly large quantities. The main research and seed production firms are Pioneer, Cargill, Ayala, and Cornworld in corn; East-West Seeds for vegetables; Cargill and Cornworld also produce small amounts of hybrid rice. Pioneer sells its seed through a wholly owned subsidiary. Cargill has an alliance with Ayala for corn seed distribution. Cornworld distributes East-West's vegetables and its own corn and public hybrid rice. Government regulations ensure that most of the commercial seeds are also locally produced. For example, Ciba-Geigy (now Novartis) tested hybrid corn developed in Thailand but has been unable to obtain permission to sell it in the Philippines.

The livestock and poultry businesses are dominated by a few big integrators who had hatcheries, large com-

Table G-2—Agricultural inputs, 1985-95

Item	Unit	1985	1990	1995
Hybrid maize seed	Metric ton	1,100	NA	9,000
Fertilizer consumption	Metric ton	283,181	588,087	603,125
Tractors (Number in use)	Numbers	8,050	10,700	11,500
Irrigated area	1,000 hectares	1,440	1,560	1,580

NA indicates not available.

Sources: Maize data from survey. Rest of data from U.N. Food and Agriculture Organization. FAOSTAT Statistical Database. *http://apps.fao.org*

mercial pig farms, feed mills, poultry and meat processing facilities, and retail outlets. The main firms are 1995 Vitarich, San Miguel Corporation, Purefoods, Swift, and General Milling. All of them were connected to the large families who dominate Philippine business. Poultry breeds were supplied by the major international firms such as Arbor Acres, Cobb-Ventris, Avian Farms, and Hubbard in joint ventures with the integrators. The international firms supplying pig breeds were Dallard, PIC, Babcock, Seghors, and Hypor. One international firm (Ralston-Purina) has recently entered the feed business.

Plantations in the Philippines produce sugarcane, bananas, pineapples, rubber, and coconuts. The plantations are owned by and located near sugarmills, all owned by Philipinos. Bananas and pineapple plantations are mainly associated with Dole and Del Monte. However, local plantations have been increasing their production of bananas. Coconut milling, which had been controlled by Marcos ally Cojuangco, has now opened up to some foreign firms but does not own any copra plantations.

Policies

A number of policies affect agriculture. Economywide policies had kept the peso overvalued, which increased prices of exports and reduced the amount of agricultural exports. A number of agricultural policy changes were put in place starting in 1986. Export taxes on copra were abolished. Government monopoly control on agricultural trade on almost all commodities except rice was eliminated. Quotas and tariffs on agricultural inputs were lowered considerably (David, 1996).

Table G-3—Pesticide sales, 1980 and 1985

Pesticide	1980	1995	Change
	Millions of 1995 U.S. dollars		*Percent*
Insecticides	50	91	82
Herbicides	14	33	131
Fungicides	14	28	96
Other	5	20	273
Total	86	172	101

Source: Crop Protection Association of the Philippines.

Despite attempts to liberalize agricultural trade around 1990, the Philippines had been protecting agriculture and driving up prices in the 1990s. The attempts to liberalize trade were negated by the 1991 law called the “Magna Carta of the Small Farmers.” It placed quantitative restrictions on imports of products produced by Philippine farmers. These include sugar, corn, or other grains for livestock feed, and poultry and pork products. A seed law regulated the imports of seeds and planting materials.

The net result of the changes in macro policy and agricultural policy was that agriculture was protected much more than it had been in 1985 (David, 1996). In 1985, the estimated effective protection on agriculture was 9.2 percent, while effective protection was 74.1 percent on manufacturing. In 1993-95, effective protection on crops and livestock was 28.1 percent, versus 29.1 percent for manufacturing (David, 1996).

The commercial livestock industry had some of the highest feed prices in the world because of the barriers to grain importation. It also had some of the highest meat prices because of trade barriers. The worry of many companies in mid-1996 was that, due to the General Agreement on Tariffs and Trade, the prices of meat would come down faster than the prices of grain.

Land reform started breaking apart the large plantations in 1995. So the cost of getting information out to farmers and back to researchers was increasing. In addition, the type of management practices needed was changing. Small farmers had less access to credit, used lower levels of manufactured inputs, and grew many other crops compared with larger operations.

Public investment policies had been less favorable than other policies toward agriculture. Government investment in agriculture grew in real terms from the early 1980s until about 1990 when it reached a peak, declined from 1990 to 1994, then started up again in 1995, but most of the increase was for environmental management, rice price stabilization, and agrarian reform. The amounts allocated to productivity-increasing research declined or remained stable. Irrigation investment declined dramatically after the 1990 peak in spending.

Research and extension did better than irrigation. Real expenditures increased from 670 million pesos in 1987 (1994 pesos) to 1 billion pesos in 1990 and stayed at that level through 1994. Extension went from 1.4 billion (1994) pesos in 1987 to 1.7 billion pesos in 1990 and 2.0 billion pesos in 1994 (David, deflated by implicit GDP deflator). As a percent of agricultural gross domestic product (GDP) public research declined. The Philippines could have had a much larger investment in private research relative to the size of its agricultural economy. Its public sector research intensity was 0.23 percent of GDP only about one-third of the level of Malaysia and Thailand and lower than all of the countries in this study except Indonesia.

Public research in the Philippines was conducted primarily by institutes under the Ministry of Agriculture and the Agricultural Universities, which are funded and linked through the Philippine Council of Agricultural and Resource Research and Development. There are also public sector research institutes for sugarcane research and coconut research that are not part of the Ministry of Agriculture. In addition, the International Rice Research Institute (IRRI) is located in the Philippines but financed by the international donor community. Real funding of IRRI has been declining since the early 1990s.

Private Research and Technology Transfer

Private firms spent about $10.5 million on private research in 1995 (table G-4). This is 22 percent of all agricultural research in the Philippines. Relative to the size of agriculture, it was quite a small amount—about 0.1 percent of AgGDP. The plantation sector invested the most money in research, followed by agricultural chemicals, seeds, and livestock. Private research increased by about 60 percent in real U.S. dollars between 1985 and 1996, with almost all the growth in the livestock and plantation industries, which grew very rapidly. Agricultural chemical research also grew, while R&D in the seed industry declined. We were unable to gather data on agricultural machinery.

Research Expenditures and Growth by Industry

Fruit plantations provided the largest amount of research expenditure and the most growth in Philippine private agricultural research. Private research by one sugar milling company—Victorious Milling Company—continues to be important, but in 1996 was overshadowed by research of the fruit plantations. Research on sugarcane started during the colonial

Table G-4—Philippine private agricultural research, 1985 and 1995

Research expenditure	1985	1995
	1,000 1995 U.S. dollars	
Agricultural machinery	305	Unknown, but small
Agricultural chemicals	1,657	2,562
Livestock	708	1,480
Plant breeding	2,242	1,800
Plantations	1,610	4,680
Total private research	6,522	10,522
Public research expenditure	n.a.	37,000
Private research as a percentage of total research	n.a.	22%
Agricultural gross domestic product	11,054,000	16,319,000
Private research as percentage of agriculture gross domestic product	0.059%	0.064%

n.a. indicates not available.

Note: The peso-dollar exchange rate was P26.29.

Source: Private research: Survey by Authors and Pray, 1986. Public Research: David 1996. "Agricultural GDP from World Bank" World Development Report, 1997.

period, while research on bananas started in the late 1960s. In 1996, research was conducted by multinationals and local companies on sugarcane, bananas, pineapple, canning tomatoes, asparagus, coconuts, and mangoes. Most of this research was aimed at reducing the cost of production through better management. There was also a continual search for improving the quality of the product for export. The desired quality characteristics include the appearance and flavor of the fruit as well as low or nonexistent levels of chemical residues. Twin Rivers Research Center was working on biocontrol and manual techniques for reducing pesticides for a "chemical-less" brand of bananas, which is finding a good market in Japan. Some plant breeding and selection research is being carried out on sugarcane and bananas. Firms have also worked on hybrid coconuts in the past.

Agricultural chemical research, the next largest amount of research, is almost entirely conducted by foreign companies. They are testing new products or products that are in commercial production elsewhere. In the past, insecticides for rice had the most attention. In 1996, some of that research effort shifted to herbicides. The private sector worked some on Integrated Pest Management. In addition, a considerable amount of research is being done on the choice and management of pesticides for plantation crops. Plantations are trying to reduce their costs of production and produce a crop free of chemical residues, the presence of which would cause rejection of the crops in foreign markets. Two companies have experiment stations in the Philippines. The rest depend on experiment stations in other countries in the region for testing the newest compounds and then rent land to do local research in the Philippines. One foreign chemical company in the Philippines researches chemicals in the initial stages of testing.

Research by the seed industry concentrates on breeding new varieties of hybrid corn, hybrid vegetables, and, recently, hybrid rice. Pioneer has the largest corn research program, most of which was of yellow corn with about 10 to 15 percent white corn. Its breeding in the Philippines targets the middle and southern parts of the Philippines, as well as Indonesia, which has similar pests and climatic conditions. Pioneer's corn breeding for the northern Philippines is done in Thailand. Cargill is the other multinational with a corn breeding program. It also has close ties with a larger corn breeding program in Thailand. Cornworld, Ayala, and Asia Hybrids—all local companies—have corn breeding programs. DeKalb and Ciba-Geigy (now Novartis), operating from a research base in Thailand, have been testing hybrid corn in the Philippines also. Cargill has been monitoring the development of hybrid rice at IRRI since the early 1990s and has a small rice research program. Toward the late 1990s, East-West Seeds started a hybrid rice research project in the Philippines. East-West Seeds also has a large vegetable research program that includes three or four expatriot breeders and four or five Philippine scientists.

In 1996, no company reported working on genetically engineered crops in the Philippines, although Pioneer had just obtained permission to conduct some confined trials of Bt corn.

The decline in plant breeding research was due in part to the exit of San Miguel Corporation and Pacific Seeds from the seed industry. Another factor that reduced the expenditure on plant breeding was that Pioneer moved its off-season research and multiplication nursery for Japan out of the Philippines and its work on the northern part of the Philippines to Thailand. These declines were only partially offset by the entry of Ayala and Cornworld into corn breeding. In 1996, there was definitely more research on hybrid rice and vegetables than there was in 1985. East-West started its large vegetable research program after 1985 and started its hybrid rice program in the mid-1990s. Cargill seems to have increased the size of its hybrid rice program.

IRRI engineering staff reported that four local firms in the Philippines were researching how to improve small-scale agricultural machinery. They were unaware of any foreign agricultural machinery firm doing such research in the Philippines.

In the Philippines, livestock research was conducted by integrated poultry and swine corporations and by feed companies. San Miguel and its subsidiaries, such as Monterrey Farms, have an animal nutrition lab near Los Banos and experimental farms around the country. The improved poultry and swine breeds were all imported so integrators concentrated on improving management of livestock and identifying the most productive breed, feed additives, pharmaceutical, and machinery inputs. Feed companies have focused on identifying low-cost combinations of inputs into processed feeds and eliminating anti-nutritional factors. Integrators and feedmills are also evaluating new feed additives.

Impact of Research

Plantation research by local organizations, such as the Twin Rivers Research Center, allowed the Philippines to enter the banana production and export business. The plantations had imported the Cavendish variety, which is the standard for exports, but plantations had appropriate plant management. Without this research, local plantations would not have developed the management package needed to compete with the multinational firms such as Dole and Del Monte. Research by Dole and Del Monte had reduced the cost of production by tailoring the use of nutrients to local soil and climatic conditions, reducing potassium applications to zero in some places and adding zinc in some regions. In addition, they reduced fungicide applications and developed management techniques for pests found only in the Philippines.

Agricultural chemical research in the Philippines had resulted in the identification of two pesticides from American Cyanamid, a corn herbicide marketed in Europe in 1996 and an insecticide that was effective on the Diamond Back moth. The applied research needed for the introduction and registration of new pesticides led to a wide number of pesticides becoming available in the Philippines. In what is probably the most detailed study of the impact of pesticides anywhere in the world, Antle and Pingali (1995) found that insecticides and herbicides increased rice productivity in the Philippines, but that insecticides had a negative impact on farmers' health.

The primary effect of private plant breeding research had been to breed and/or identify yellow corn hybrids for the Philippines. This accounts for at least part of the increase in corn yields from 1.1 mt/ha in 1985 to 1.5 mt/ha in 1995. Plant breeders have also had some success developing improved vegetables, which has increased yields of some vegetables. Hybrid rice still has not been adopted widely in the Philippines. Thus, any improvements on IRRI hybrid rice technology by the private sector has not yet affected rice yields.

The very applied management research in livestock by private firms has undoubtedly led to increased livestock productivity in the Philippines, but as of 1996 no studies had measured the impact. Livestock research has reduced the cost of feed production by identifying local ingredients and their optimal proportions in feed. It has also identified useful feed additives, developed labor-saving equipment, and identified the nutritional requirements of animals in the tropics. For example, Ralston Purina claims to have cut $2.00/ton in costs of producing feed in the 4 years they were in operation.

Factors that Influence Private Research

The patterns of private research expenditure that need to be explained are the low amount of private research, the relative size of research expenditure by industry, and the rapid growth of plantation and livestock research while plant breeding research declined. We explain these patterns by looking at the demand for the product of research, the ability of firms to appropriate the benefits of research findings, technological opportunities for innovation, and relevant government policies.

Demand

Much of the explanation for the pattern of R&D growth is due to changes in demand for agricultural products. With livestock the most rapidly growing component of Philippine food consumption, it is responsible for much of the increase in livestock research. Firms already in the livestock business, such as San Miguel Corporation, increased their research and a few new firms, such as Ralston Purina, entered the business in response to increasing demand. The increased growth in plantation research can be traced to increased exports of fresh and canned fruits (see table G-5 for the value of exports). Almost all of the increased research was due to growth in research on bananas and pineapple, with a little research on processing tomatoes and asparagus. Research on other plantation commodities, such as sugar and coconuts, did not grow. The sugar market has experienced decreasing foreign demand, but the coconut market has not other factors, therefore, must explain low research in that area.

The combination of new agricultural and macroeconomic policies that raised effective protection for the agricultural sector made agriculture more profitable in the early 1990s thereby increasing farmers' demands for modern inputs. Table G-3, for example, shows a doubling of the value of pesticide sales between 1980 and 1995, with a particularly large increase in herbicide sales. Equally important for research-based chemical firms, the major government-subsidized firm Planters Products had its subsidies and other advantages eliminated when Marcos fell. The company soon went into bankruptcy, leaving pesticide markets open

Table G-5—Value of total Philippine exports, 1991-96

Commodities	1991	1992	1993	1994	1995	1996
			Million U.S. dollars FOB			
Fruits and vegetables	497.0	503.8	600.3	571.7	581.5	650.0
Sugar and products	146.4	121.8	137.8	85.1	88.8	100.0
Coffee, cocoa, etc.	25.4	16.6	16.6	29.8	31.2	35.0
Fats and oils	311.6	495.2	370.2	490.7	844.4	750.0
Total agricultural exports[1]	1,352	1,454	1,427	1,486	1,934	1,964
Total exports[1]	8,840	9,824	11,210	13,483	17,447	20,500

[1]Totals may not add up due to rounding.

Source: American Embassy, Manila, Philippines. Agricultural Situation 1996.

for other firms. In addition, the government started to restrict the use of the “dirty dozen” pesticides—those pesticides most dangerous to people and the environment. This significantly reduced the market share of older low-priced insecticides and increased the market share of new high-priced chemicals.

Appropriability

Demand is only part of the explanation for the patterns of growth and the levels of research expenditure. Industries in which demand is high and increasing, such as coconut, were not the focus of private research efforts unless there was some way that private firms could capture the benefits of research. Industry structure allowed firms in certain industries to capture the benefits of research. Until the latter 1990s, processors and exports also owned banana and pineapple plantations. They could benefit from plantation management research through lower costs on their large plantations and by reducing the prices they had to pay to procure more of the crop that they produced. In contrast, small farmers grow most of the coconuts. Since the Marcos government, oil processing has become more competitive. Thus, it was difficult for any big firms to capture a share of the benefits of coconut research, which left this crop with little private research. Recent land reform may force fruit processing and export firms out of controlling plantations, compelling them to buy fruit from small holders.

Most private livestock research concentrates on poultry and pigs rather than beef and dairy. A number of large firms are vertically integrated from feedmills and hatcheries to butcher shops and fast-food restaurants. Some dairy organizations are vertically integrated, but few beef operations are. Vertical integration allows poultry and pig firms to appropriate the benefits of research and technology imports through lower costs of procuring eggs, broilers, and pigs from contract growers and lower transaction costs in the marketing chain.

The agricultural chemical industry illustrates the importance of intellectual property rights. In the Philippines, pesticides can be patented using product patents, but in general, Philippine patents give very little protection. For pesticides, however, the regulatory system strengthens the protection given. Registration materials that companies submit to prove the safety and efficacy of new compounds are kept secret, and only one firm is allowed to produce the compound for a certain number of years after registration. This could give a firm protection for a compound in the Philippines even after it was no longer protected by patents elsewhere in the world.

The seed industry depended on hybrids to be able to appropriate the benefits from research. Their breeding activity was concentrated entirely on hybrids, such as corn, vegetables, and hybrid rice. A new patent law was passed in 1997, but plant varieties were still excluded and no separate plant breeders’ rights legislation has been passed. The Philippine Government signed the World Trade Organization treaty, which committed it to passing plant breeders’ rights legislation by 2000. As of 1996, several Plant Breeders’ Rights (PBR) laws had been proposed but none had passed. This kept multinational companies from bringing in double-cross hybrids of corn, and it ensured that no research was done on crops that were not hybrids. One firm suggested that PBRs would lead to more expenditures on banana breeding.

Cost of Innovation (Technological Opportunity)

Two industries show how technical opportunities interact with the other factors to encourage or discourage private research. There is little technological opportunity in fertilizers and thus little research, in spite of fertilizer's being a large and growing industry. In contrast, there is a lot of technological opportunity in biotech but little private research, even though biotech has stimulated billions of dollars of private agricultural research internationally. IRRI is conducting a lot of biotech research on rice, and private firms are interested in introducing insect- and herbicide-resistant corn. As of 1996, IRRI had almost no effect on the amount of private agricultural research in the Philippines. In this case, the reason is not appropriability or lack of market. Until 1998, lack of biosafety regulations prevented government scientists, IRRI scientists, and private firms from testing biotech in the field.

Biotech was slowed by lack of regulations, which reflects the controversy within the Philippines about the costs and benefits of biotechnology in agriculture. A number of firms would have liked to test products in the Philippines but were deterred by the lack of an established procedure. In 1995, a biosafety committee was established. Pioneer applied to do trials of Bt corn with the Institute of Plant Breeding of the University of the Philippines at Los Banos (UPLB) in an enclosed field. In May 1996, this committee approved those trials. In 1998, the government issued new rules to govern the release of a transgenic variety in field tests. No field trials have yet been approved.

Public sector research could stimulate private research. Public research at IRRI on tropical hybrid rice induced a few firms to start rice breeding programs. Private pesticide and livestock nutrition firms located their research stations near Los Banos to take advantage of the scientists and knowledge at UPLB and IRRI. Public banana research was limited and has had little impact, but some companies were finding the INIBAP germplasm collections in Los Banos and Davao useful. They were using this germplasm to identify varieties for niche markets abroad. Unfortunately, the low levels of public research and expenditure on higher education in the Philippines, as shown by the low research intensity, may help explain overall low levels of private research.

In the Philippines, there seems to be very little basic biotechnology research on which to build private research programs. Strong public biotechnology programs at U.S. universities produced technology that became the basis of a large number of agricultural biotech firms in the 1980s and induced some of the large agricultural chemical firms to invest in research. Public programs did not have the same impact in the Philippines. The strongest biotech research programs were at IRRI and the National Institutes of Biotechnology and Applied Microbiology (BIOTECH) at UPLB. IRRI and UPLB are parts of the Rockefeller Rice Biotechnology Network. IRRI has been concentrating its biotech research on increasing the productivity of rice research and increasing the resistance of rice to pests, diseases, and abiotic stresses such as drought. This has strengthened public research programs in Asia, but it has not led to private research. Biotech research at BIOTECH was very applied, working on microbial fertilizer, food and feeds, pest and disease control, as well as environment, industry, and plant biotechnology. BIOTECH has about 120 scientists of whom 16 have a Ph.D. It has produced a few technologies since being established in 1979, but none of the agricultural input firms that we talked to worked with BIOTECH. BIOTECH did not identify any private agricultural research that they had induced.

The cost of some private research has been affected by public funds and R&D tax credits. An example of R&D funds for the private sector is the PCARRD's (Philippine Council of Agricultural and Resource Research and Development) past funding of projects at Twin Rivers Research Center. PCARRD was also considering an application for funding for a project to develop management techniques to reduce chemical use in banana plantations.

Science and Technology Policies

Specific policies designed to stimulate private research appear to have had limited impact in the Philippines. The Department of Science and Technology (DOST) established a number of programs to stimulate R&D, but the funding for these programs is so small that they could not have much impact. DOST has invested in several science parks including one in Los Banos for food and agricultural technology. By 1996, DOST had invested 30 million Philippine dollars (about $1 million) for buildings, and the university had given 55 hectares of its land for the University of Philippines at Los Banos Science Park in Los Banos. As of 1996, the Park was only open to technologies from the UPLB. When we visited it, there were several buildings with two companies in operation but still no assured supply of electricity or water. Thus, little work could be done.

DOST is developing a Venture Capital fund in collaboration with the government-owned development bank, because while government-guaranteed loans from banks were available, equity financing institutions for small business were almost nonexistent. DOST also has a Technology Application and Promotion Institute to help small firms in all types of industries with export potential to market their products. Although we did not have time to evaluate these programs, their size and effectiveness appear to have been limited by low levels of funding.

These incentives must be balanced against weak intellectual property rights for most industries, except perhaps pesticides where they were reinforced by the regulatory system. The intellectual property rights (IPRs) laws were similar to the U.S. laws except that there is no plant breeders' rights law. Patent protection for micro-organisms and microbial processes was granted in the 1997 patent law. An additional difference from that in the United States was a weak patent system. The main problem is not the laws but the enforcement of the laws, which is quite difficult because neither the police nor the courts have enough resources to adequately deal with IPR cases.

The other policy disincentive, which was mentioned above, is that there was no system for judging the biosafety of genetically engineered organisms until the summer of 1998. Thus, it was impossible to conduct field trials of transgenic plants.

Summary of Determinants of Private Research Patterns

The industries that had attracted the largest investments in private research had large markets, a way of capturing benefits from new technology, and there was the possibility of producing new innovations without major investments. This set of conditions holds for fruit and vegetable plantations, pesticides, hybrid seeds, and poultry and pig production. These conditions did not hold for fertilizer (little opportunity for improvement), coconuts (little appropriability), or agricultural machinery.

Growth in private R&D was mainly due to growth in demand for livestock, pesticides, and fruit as indicated by the fact that research as a percent of AgGDP grew very little. The only changes in appropriability were that rice hybrids have moved closer to commercial feasibility and there were changes in industry structure as some Marcos allies lost some of their market power. Such changes, however, appear to have led to few additional opportunities to appropriate the gains from research. The IPR laws did not change until 1998, although the Philippines did sign the Uruguay Round of GATT, which requires them to eventually strengthen their laws and enforce IPRs. Technological opportunities for profitable applied research may have improved somewhat with the liberalization of input imports. However, as indicated above, the major technological breakthrough—biotechnology—has not stimulated research in the Philippines.

Policy Options

The Philippines was unlikely to have a very large absolute amount of private research because it is a medium-sized country. However, as a tropical country in a world where most research was conducted in temperate countries, there may be an opportunity for adaptive research to have important payoffs. The Philippines could have made a much larger investment in private research, relative to the size of its agricultural economy, than it did. Its private research intensity was about the same as India and considerably lower than that in Malaysia and Thailand. This section looks at the policy options for increasing private research.

There are three types of private sector firms or groups that could increase their research in the Philippines: the large Philippine business groups such as San Miguel Corporation and the Ayalas; the subsidiaries of multinationals; and the smaller firms in biotechnology or small engineering firms in agricultural machinery.

For these firms to invest more in research, four major government policy changes would be useful:

- **Government investments in basic research.** Strong basic research programs in biotechnology can attract science-based firms to work with strong public laboratories. Philippine firms are also looking for basic research that can be the basis of their research programs. Basic research generates ideas that are the basis of start-up firms.
- **Stronger intellectual property rights.** This gives all types of firms incentives to make money from research. Small start-up firms will seldom be able to raise venture capital without patents. Larger Philippine and multinational firms do research only where they can capture benefits. One way the government can help is through enforcing patents and protecting plant breeders' rights. The new patent regulations of 1997 were a step in the right direction. Enforcement remains the problem.

- **More science-based regulation.** Pesticide regulations have gradually been rationalized to make them more science based and transparent. The 1998 biosafety rules was another step in the right direction. These rules must now be applied in a consistent fashion and other rules have yet to be rationalized.
- **Policy that ensures competition in high-tech industries.** A certain amount of concentration in an industry can stimulate research, as it has in the livestock industry. But too much concentration can keep innovative foreign or Filipino firms out of food and agricultural markets and would be harmful to farmers and consumers. Entry into agricultural markets can be made easier through antitrust policy and limited barriers to foreign direct investment.

In addition, certain policies are important for specific industries:

- **Financing of research and extension for export crops.** For export and plantation crops, cess (tax on production or exports) funding of research could be increased. Some of Colombia's major export commodities (flowers and fruits), for example, were not covered by government research programs or by commodity research organizations, so Colombia is organizing such programs to do research. In Southeast Asia, the rubber and oil palm research in Malaysia are two excellent examples or cess funding for research. In the Philippines, sugar research was reorganized to be financed by a cess, and the banana research at Twin Rivers Research Centers was primarily funded by a cess.
- **Science parks, marketing assistance, and venture capital programs for start-up firms**. The availability of these programs is critical for assisting scientists in starting firms, but there must be strong basic research to produce the ideas and strong intellectual property rights laws and enforcement first. Further, the benefits of these programs are increased if they encourage not only UPLB scientists but also scientists from private firms in the Philippines or outside.

References

Antle, J.M., and P.L. Pingali. "Pesticides, Productivity and Farmer Health: A Philippine Case Study," *Impact of Pesticides on Farmer Health and the Rice Environment*. P.L. Pingali and P.A. Roger (eds). Kluwer Academic Publishers: Norwell. MA. 1995.

David, C. "Agricultural Policy and the WTO Agreement: The Philippine Case." Paper presented at the Asia-Pacific Economic Cooperation (APEC) Conference on Food and Agriculture Challenges in the Asia-Pacific. Manila, Philippines. October 1-3, 1996.

List of Tables

China

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The demand for agricultural products is growing rapidly in China due to per capita income growth and population growth. The primary way to increase production is to increase yield per unit of land through improved technology. This technology has to come from Chinese public and private research or from imports of technology by the public or private sector. In other research, we have shown that research outputs and inputs of public research institutes are stagnant or declining in China (Pray, Rozelle, and Huang, 1997). In developed countries, increasing private research has made up for declines in public research. In China, however, no one has examined whether any private research is taking place and, if there is any, what private research is doing. One of the main purposes of this chapter is to describe how much research is being conducted by private firms in China and the potential for further growth of private research. A second purpose is to assess the role of private firms in transferring food and agricultural technology to China.

We found that very little agricultural research and technology transfer is financed or conducted by private firms in China, which is not surprising considering the short period of time that private firms have been able to operate in China and the relatively small contribution of the private sector to China's GDP. Private research expenditure in China was estimated at $11-$16 million in 1995 (table H-5), which is a small amount relative to the $480 million of public research expenditures. It is also small relative to private research elsewhere in Asia. Private firms invest $50 million in India, $19 million in Thailand, and $17 million in Malaysia (see the applicable country case studies). Foreign technologies have had a limited impact on Chinese agriculture in recent years, chiefly in the areas of poultry genetics and pesticides. In addition, technology embodied in foreign direct investment appears to have had some impact on the food industry. Plant varieties, biotech products, and agricultural machinery from abroad have had little or no impact in recent years.

Given these findings, a third objective of this chapter is to ascertain why private research is so limited and what could be done to increase the contribution of the private sector. The conclusion is that the agricultural input sector is still dominated by state-owned enterprises and other government organizations which limits the role of private firms in marketing, importing, production, or research in the agricultural input industry. A second factor, which limits research by those private firms that are able to operate in China, is the weakness of intellectual property rights. A third factor is that rapidly changing industrial policy and regulatory structures add considerable risk to any investment—particularly a long-term investment like research.

The good news is that the potential for growth of agricultural research and technology transfer is great once the policy constraints are removed. The potential market is huge, and many biological inventions developed in the developed countries need relatively little adaptive research for the temperate climate of China. Allowing 20 percent of the pesticide market to foreign firms led to $5-$10 million annual investment in R&D in just 10 years. Nine seed firms are doing about $1.7 million of plant variety research per year despite the fact that their ability to sell seed profitably is greatly restricted. Allowing them a large share of the market, reducing regulations, and strengthening intellectual property rights could lead to a major expansion of private research.

The chapter starts with a general description of the agricultural sector and agricultural input industries in China. It then describes the types and quantities of the agricultural research and technology transfer activities of private food and agricultural input firms, documents the impact of these research and technology transfer activities on agriculture, examines the reasons for the low levels of private research and technology transfer, and discusses policy options for increasing private activity.

Agriculture in Transition to a Market Economy

Agriculture

Agricultural production has been growing rapidly since the reforms of the agricultural economy that started in 1978. Total value of production in the agricultural sector grew at an annual rate of 7.5 percent from 1978-84 and 5.6 percent from 1984-95 (table H-1). Within the agricultural sector, livestock grew particularly rapidly at about 9 percent for both periods. Livestock was led by poultry meat production, which increased five-fold between 1985 and 1994, egg production, which increased 3.5 times, and swine production, which doubled; fisheries production grew almost 14 percent per year. Among crops, fruit production grew very rapidly, while the major grain crops and cotton grew at much slower rates or declined.

Growth in demand due to per capita income growth has been the driving force behind these increases. It is projected that per capita income will at least double the demand for red meat, poultry, and fisheries products by the year 2020 but may reduce the consumption of food grains (table H-2). This means that the demand for animal feed and feed grains will also increase very rapidly.

Technology has allowed Chinese farmers to supply agricultural products to meet most of this demand. Huang and Rozelle (1996) have shown that improved

Table H-1—Growth rate of China's agricultural economy by sector and selected agricultural commodities, 1970-96

	1970-78	1978-84	1984-95	1996
		Percent		
Agricultural output:				
Total value	2.3	7.5	5.6	9.4
Crop	2.0	7.1	3.8	7.8
Forestry	6.2	8.8	3.9	5.6
Livestock	3.3	9.0	9.1	11.1
Fishery	5.0	7.9	13.7	13.92
Grain production	2.8	4.7	1.7	8.1
Rice	2.5	4.5	0.6	5.3
Wheat	7.0	7.9	1.9	8.2
Maize	7.0	3.7	4.7	13.8
Soybean	-1.9	5.1	2.9	0.1
Cash crops:				
Oil crops	2.1	14.9	4.4	-1.8
Cotton	-0.4	7.2	-0.3	-11.9
Rapeseed	4.3	7.3	5.4	-5.9
Peanut	-0.2	10.8	5.2	-0.9
Fruits	6.6	7.2	12.7	10.4
Red meats	4.4	9.1	8.8	11.9
Pork	4.2	9.2	7.9	10.7

	1978	1980	1985	1990	1994	1995	1996
				Billion 1985 yuan			
Value of real agricultural output	226	285	362	608	966	1,129	1,235
Crop	170	208	251	404	659	788	851
Forestry	8	13	19	32	44	49	52
Livestock	43	59	80	141	223	249	277
Fishery	4	6	13	22	39	43	49

Note: Growth rates are computed using regression method. Growth rates of individual and groups of commodities are based on production data; sectoral growth rates refer to value added in real terms.
Sources: Growth rates-from Huang Jikun FAO Report 1998.
Value of output—SSB, Statistical Yearbook of China, various issues; MOA, Agricultural Yearbook of China, various issues.

Table H-2—Projected annual per capita food consumption under baseline scenario in China, 1996-2020

Alternative scenario	1996	2000	2005	2010	2020
	Per capita food grain consumption (kg)				
Food grain	191	192	192	190	180
Pork	17	20	23	26	32
Beef	2	2	3	3	4
Mutton	1.2	1.5	1.8	2.2	2.9
Poultry	4	6	7	8	11
Aquatic	7	10	12	14	19

Source: Projections by Dr. Huang Jikun. Chinese Center for Agricultural Policy. 1998.

crop varieties, along with complementary inputs such as fertilizer and irrigation, were the major forces in the growth in crop production since 1978. The source of most of this technology has been Chinese national, provincial, and prefectural government research. Chinese scientists developed Green Revolution type rice varieties about the same time that the International Rice Research Institute developed them, and they developed the world's first commercial hybrid rice varieties, which are now grown on about half the rice area in China.

In addition, Chinese scientists and officials brought in technology from abroad and adapted it to Chinese conditions. In the 1940s and 1950s, Chinese scientists brought in cotton, corn, and sorghum varieties from the United States and elsewhere. These imported varieties and hybrids were gradually modified to be resistant to China's pests, diseases, and cultural practices (Stone, 1988). Chinese pesticides were copies of chemicals originally developed by private firms in the United States, Europe, and Japan but produced using methods of production developed in China. Agricultural machinery is based on Japanese, Western, and Soviet designs and modified to meet local needs.

Improved breeds, feed, and management techniques have made major contributions to the increase in swine and poultry production. Imported breeds have made a major contribution to swine production. In the early 1990s, 30-50 percent of all hogs slaughtered were crossbreeds (Simpson, Cheng, and Miyazaki, 1994). The foreign breeds were developed by private firms and imported by government institutions, which crossbred them with local breeds. Foreign poultry breeds started coming in during the 1980s. Private firms sold parent or grandparents to government and joint venture hatcheries or commercial producers. Private firms now account for almost all of the broilers and some 70 percent of the layers.

The major policy goals of the government have been to keep prices of basic foods low and to ensure that the country is self-sufficient in basic food and fiber production. The political importance of these often contradictory goals has led the government to continue to intervene in agricultural markets more than in other sectors of the economy. After a period of liberalization of agricultural produce and input markets in the early 1990s, the government seems to be intervening more in recent years.

Agricultural Input Industries

China is one of the largest agricultural input markets in the world. It is the first or second largest producer of seeds, pesticides, fertilizers, and tractors in the world. In value terms, it is not as highly ranked because of the low cost of many of the inputs. Growth in production has varied considerably between the different input industries (table H-3). Production of large and medium-size tractors has declined since the mid-1980s, while production of mini-tractors and implements for mini-tractors has doubled since the mid-1980s. Fertilizer use has doubled. Pesticide production increased by 2.5 times. Commercial feed production has increased by at least 7 times from 9 million Yuan in 1985 to 67 billion Yuan in 1995 (1995 Yuan; interview with Chai Tai, July 1998).

State-owned enterprises (SOEs) have a major share in the importation, production, distribution, and marketing of all modern inputs. Their share of production is almost 100 percent of commercial (not farmer-saved) seeds, agricultural machines, and nitrogen fertilizers. Joint ventures play a small but growing role in pesticide production, swine genetics, and imports of P and K fertilizer. Poultry genetics is the only area in which joint ventures are the main producers or importers of technology.

Table H-3—Characteristics of agricultural input industries

Industry	Quantity of production 1984	Quantity of production 1995	Value of production	Percent State-owned enterprise production	Percent of farmer purchases from government
Seed	2,500,000	3,500,000 mt (12,500,000 mt total)	$5 billion	100% of hybrids 5% of varieties	100% of hybrids 5% of varieties
Pesticides	135,000 mt (1986)	349,000 mts	$1.0-1.7 billion	80	100
Fertilizer	1,739,800 tn	3,317,900 tn (1994)		> 50	50
Agricultural machinery	853,914 large tractors 3,294,000 mini-tractors	693,154 large tractors 8,237,000 mini-tractors (1994)	$7.5 billion	100	50
Feed	Feedstuff imports 248,846 mt $50,168,000	Feedstuff imports 991,743mt $316,202,000 (1996) 3,458,124mt $993,087,000 (1997)	$8.4 billion	Limited	Limited

Source: Seed: H. Reddinger and Zhang Jianping 1997. *Planting Seed*. *Annual Report*. American Embassy, Beijing, China.
Pesticide quantity and value: Industry estimates.
Fertilizer and agricultural machinery quantity: China SSB, China Statistical Yearbook, 1995. *China Statistical Publishing House*.1995
Agricultural machinery value: Industry estimates
Feed imports: FAO AgroStats; Value: Industry estimates

Government institutions also control the distribution and marketing of most agricultural inputs. Almost all of the 4 million tons of commercial seeds are supplied by government enterprises. By law, government-owned seed companies must supply hybrid seeds of the major field crops. Seeds of non-hybrid field crops are primarily produced and saved by farmers with 10 to 20 percent of the total coming from SOEs (Reddinger and Zhang, 1998). Vegetable seeds are produced by farmers, SOEs, TVEs, and private firms. About half the fertilizer comes through government agencies. Pesticides can be purchased from many traders as well as the plant protection service, and agricultural machinery can be purchased from a number of different shops in towns.

State-owned input industries depended upon research institutes in the industry that they were affiliated with for process and product technology. In the pesticide industry, for example, there are 12 major state-owned synthesis research centers that develop active ingredients and better ways to produce existing active ingredients. In 1992, the Ministry of Chemical Industry (MCI) decided to form two major agrochemical research centers—Shanghai Pesticide Research Institute, funded and directed by the SOE Shanghai Zhongxi, and a northern research center based at MCI's Shenyang Chemical Research Institute with a satellite branch at Nankai U's Element Institute. The announced goal of the government at that time was to eventually spend Y1 billion per year on pesticide research to develop new chemicals that could compete in foreign markets with the international companies. The budgets for these research institutes now is about Y200 million.

The Ministry of Machine Building has four research institutes that are supposed to develop improved agricultural machinery and improved production processes.

Government policymakers in the agricultural sector believe that agricultural input industries still need assistance in competing with foreign competition. Local “infant industries” need time to consolidate, increase their efficiency, invest in research and start competing nationally and globally with foreign firms. This concern may have been heightened by the recent rash of mergers and acquisitions in biotechnology, seeds, and agricultural chemicals in the United States and Europe. Scientists and policymakers have expressed concern about being dependent on a few foreign companies for seed and other essential agricultural inputs of the grain and cotton sector. Iraq is brought up as an example of what could happen.

One result of these concerns is policies that restrict imports of agricultural inputs and joint ventures. Imports of agricultural inputs (table H-4), such as seeds and agricultural chemicals, have been limited by quotas, bans, and other types of barriers. For example, parent stock of poultry cannot be imported, no nitrogen fertilizer can be imported, and only 20 percent of the pesticide market is allotted to imports. In addition, imports of most inputs must be done by government agencies or government-designated firms. Regulations, such as phytosanitary requirements, compulsory testing of plant varieties, and biosafety regulations, can also be used as non-tariff barriers to imported technology.

Another result of these concerns and a general desire for more efficient industry is the recent government policies of consolidating SOEs into fewer, larger, and more efficient units. The government is cutting them off from subsidies and government loans unless the loans can be commercially justified. Many SOEs and new government-owned commercial units are investing in or at least forming alliances with research institutes. They are setting up joint ventures with government research institutes, funding contract research by government institutes, or starting their own in-house research by hiring scientists from government research institutes. In the agricultural machinery industry, for example, the agricultural machinery companies are being encouraged to consolidate into four or five groups, one of which concentrates on engines, another on large tractors, a third on combine harvesters, etc. Research is being incorporated into the leading firms in these groups. The Luoyang Tractor Research Institute joined the China No. 1 Machinery Engineering Company, and the Shanghai Diesel Engine Research Institute joined the Shanghai Diesel Engine and Tractor Industry Company. Likewise in the pesticide industry, the number of SOEs has been reduced drastically, and the Shanghai Pesticide Research Institute has become a part of Shanghai Zhongxi, a major firm with pesticide sales of about $80 million, of which $20 million come from exports.

Agricultural input industries have far less foreign direct investment than industry as a whole in China (table H-4) in part because of policy restrictions. As

Table H-4—Foreign direct investment and imports by industry

Industry	FDI value (billion yuan to end of 1995)	Foreign enterprise share of industry assets (Percent)	Value of imports, 1996
Food - Processing[1]	54.85	20.50	$2,900 mil (1994 SSB)
Manufacturing	39.51	32.19	
Ag. sector (farming)	21.33[2]	very small	$1,600 mil (1994 SSB)
Seed	NA	Very small	$42 mil. (exports $38 mil.)
Pesticides	1.55	7.49	$137 mil (1994) (exports $276 mil)
Agricultural machinery	1.72	3.46	
Fertilizer	1.58	1.38	$1,938 mil (1994)
Ag. sector (animal husbandry)	16.00[2]	very small	$816 mil (1994)
Feed industry	12.34	34.10	$316 million
Vaccines and veterinary medicine	0.19		
All industry (not just ag inputs and food)	2,500.00	19.09	

[1] Includes feed industry.
[2] Calculated based on Chen Chunlai (1998). Table H-7 shows about $8 billion FDI in agriculture of which 33% is in farming and 25% in livestock from his table 8 (the rest is forestry, fisheries, and agricultural services). Used exchange rate of 8 yuan per $1.

Sources: FDI and Foreign Enterprise share: "Foreign Direct Investment in China's Agriculture and Agriculturally Related Industries." Unpublished paper. University of Adelaide. 1998.
Value of food processing, ag.sector, pesticides, and fertilizer import: China SSB, *China Statistical Yearbook*, 1995. China Statistical Publishing House.1995.
Value of seed imports: H. Reddinger and Zhang Jianping 1997. *Planting Seed*. Annual Report. American Embassy, Beijing, China.
Value of feed imports: FAO Agrostats.

mentioned above, foreign firms are restricted to 20 percent of the pesticide industry and excluded from hybrid seed production. Foreign companies can operate only as joint ventures. In seeds and agricultural chemicals, the regulations on joint ventures are more restrictive. A 1997 seed industry regulation requires joint ventures dealing with grain, cotton, and oilseed to be majority Chinese owned, to make a minimum investment of $2,000,000, and to do all research under the joint venture. A 1996 regulation on the agricultural chemical industry required joint ventures to sell only products whose active ingredient and major intermediates are manufactured in China. A recent attempt by a large foreign agricultural machinery company to establish a joint venture was turned down by the Planning Commission because the foreign firm would have had the majority ownership.

Commercial Agricultural Research and Technology Transfer

A preliminary survey of firms, discussions with government scientists and officials, and a review of patent data in 1997 led to the conclusion that there was very little research by China's private agricultural input firms (Pray, 1997). Therefore this study concentrated on private research by foreign firms and joint ventures between foreign and Chinese firms. Since there are no government records or other studies of the amount and impact of private research, it was necessary to conduct a survey of private firms. Personal interviews or telephone interviews were conducted by the author in the United States with 14 U.S.- or Europe-based multinationals during the winter and spring of 1998.[1] Then in China in the summer of 1998, the author, with the assistance of Dr Chen Chunlai from the U. of Adelaide and Dr. Huang Jikun, the head of the Chinese Center for Agricultural Policy, conducted interviews with two Chinese firms 16 foreign or joint venture firms, and a number of public sector scientists and policymakers.[2]

[1]Cargill, Mycogen, Pioneer, KWS, DeKalb, Delta and Pineland, American Cyanamid, Monsanto, Busch Agricultural Foundation, Quaker Oats, PIC, Hubbard, Arbor Acres, and Avian Farms.

[2]Seeds: Cargill, Chai Tai Seeds, Delta and Pineland/Monsanto, Denghai Seed Co.
Pesticides: Agrevo, American Cyanamid, Bayar, FMC, DuPont, Monsanto, Shanghai Zhongxi
Poultry: Arbor Acres, Beijing Poultry Breeding Co. Ltd.
Ag. machinery: John Deere, New Holland, Kubota
Others: Simplot, Chai Tai Feed Mills.

Agricultural technology transfer into China is probably conducted by a much larger number of firms than those that have formal research programs. Therefore, the interviews were supplemented with data on the numbers of food- and agriculture-related patents and on foreign direct investment in food and agriculture.

Private Research

Private research has grown rapidly from zero in 1985 to $11-$16 million today (table H-5). This is impressive growth in a 10-year period. However, as mentioned above, this is still a small amount relative to public investments or private firms in other Asia developing countries. Table H-6 shows the amount of private research investment in six other Asian countries. China ranked fourth in the total amount of money invested in private research behind India, Malaysia, and Thailand. China ranked last in private research intensity (research/ agricultural GDP) and in private research as a share of total agricultural research.

The agricultural chemical industry spends more money on agricultural research than any other input industry (table H-5). All of the private firms conducting agricultural chemical research in China are joint ventures with foreign firms. Their agricultural chemical research consists primarily of testing pesticides that have already been commercialized elsewhere. These tests are for the efficacy of the active ingredient and formulations against pests and diseases. Some research is on combining different active ingredients into effective new products. There are also tests of the environmental impact of active ingredients and formulations. Some companies have set up their own experimental fields, but most hire local scientists to conduct the experiments for them. The results of the tests are used to register new chemicals. A few foreign firms test some of their early generation compounds here because it is inexpensive to do so. Four firms reported contracting government research institutes to synthesize new chemicals and to conduct some very preliminary early screening of these materials for biological activity. The new chemicals are then shipped to the United States or Europe for further screening.

The seed industry is primarily testing varieties that were bred outside China, although three or four companies are doing some breeding for local conditions. Research on major field crops is concentrated on corn and a few other crops. Of the nine seed firms about which we have information (eight joint ventures and one local firm), seven are working on corn.

Table H-5—Research and development by industry, 1995

Industry	Research objectives	Amount of research	Impact of new technology
Seed	Testing foreign hybrids, a few firms have breeding programs Corn, sunflower, sorghum, rapeseed, cotton, vegetables.	$1,700,000 (9 joint ventures + 1 local)	Small amount of impact in sunflower, cotton, corn, watermelon. Possibly larger impacts on sugarbeets.
Pesticides	Testing chemicals for efficacy and environmental impact. Current emphasis on herbicides but working on fungicides and insecticides also. Contract synthesis and early screening by a few firms.	$5 to 10,000,000 (9 joint ventures)	
Agricultural machinery	Testing new small-scale rice harvesters, improving quality production process of small tractors and harvester	Small amount (3 joint ventures)	
Fertilizer	More efficient application of phosphorus and potassium		
Poultry	Breeding for more dark meat	$3,000,000 (1 joint venture)	Broilers with higher percent dark meat
Feed	Reduce cost of feed production		Reduces cost of commercial feed.
Food industry	Improve quality of potatoes, barley, oats, for use in french fries, beer, and oatmeal	$1,000,000 (4 joint ventures)	Identified high-quality varieties.

Source: Survey by author, 1998.

Table H-6—Private and public research and research intensity in Asia, 1995

	Private R&D	Public R&D	Private R&D intensity	Public R&D intensity
	Million 1995 US$[1]		*R&D as % ag GDP*	
Large, low-income countries				
China	16.0 (3)	479.5	0.008	0.327
India	55.5 (14)	347.9	0.059	0.370
Middle-income countries				
Malaysia	16.6 (21)	64.0	0.150	0.577
Thailand	17.4 (12)	127.0	0.095	0.691
Mid-size, low-income countries				
Indonesia	6.1 (12)	44.4	0.018	0.132
Pakistan	5.7 (19)	25.0	0.036	0.159
Philippines	10.5 (22)	37.5	0.064	0.230
Total	127.8 (11)	1,125.3		

[1]Calculated using official exchange rates.
Parentheses show private research as a percent of total agricultural research expenditure.

Sources: Pray and Fuglie, 1999.

Sunflower, sorghum, rice, and rapeseed are each the subject of research by two companies, while one company works on sugarbeets and another on cotton and wheat. These companies hire Chinese and a few foreign scientists to conduct the research. The land is leased or owned by their joint venture partners. Some testing of varieties is contracted out to government experiment farms or by the seed testing stations. The main goal of the grain and oilseed research is to identify foreign or local hybrids or varieties that can increase farmers' yields. Pest and disease resistance is also an important research goal. Grain quality or fiber characteristics in cotton are an important but secondary breeding goal in some crops. These companies also conduct some agronomic research to develop the best cultural practices to go with the new varieties. One important Chinese practice, which they are working to change, is the extremely high seed rates, a residual from farmers' experience of cheap, poor quality seed from government institutions.

The only agricultural biotechnology research by a private firm that we were able to identify was by Monsanto in collaboration with the cottonseed company Delta and Pineland (which Monsanto is in the process of purchasing in the United States). They have been working on identifying the best varieties of genetically engineered cotton for Chinese conditions and developing the crop management practices that will give farmers the maximum economic benefits from these varieties. Some other seed firms may be experimenting with transgenic varieties in greenhouses but only Monsanto has applied to test transgenics in the field.

A few food processing firms are conducting agricultural research on barley, oats, and potato varieties. Food processing firms are interested in identifying local or foreign varieties that meet their quality standards and cost the same as or less than imports. High yield per unit of land is an important research goal in order to reduce cost of production.

The private vegetable seed industry does little research. No private firm reported any plant breeding. Almost all research by vegetable seed firms is the testing of foreign varieties. In contrast, public research organizations are conducting a lot of vegetable breeding research. Three public vegetable research institutes—CAAS in Beijing, the provincial academy in Hunan, and the prefectural institute in Tianjin—have set up successful commercial seed businesses to sell varieties that they bred.

A few foreign companies are doing very applied engineering research to improve local agricultural machines. John Deere is working on improving harvesters and combines to differentiate their products from the Chinese products. The wheat combines are small (55 hp) by international standards but are large in China. The small harvesters for rice, which Japanese firms have recently commercialized, are the subject of research by Yanmar and Kubota. Firms are also looking for ways to reduce the cost of machinery production.

One joint venture company is doing poultry breeding in China. That company, Beijing Poultry Breeding Company (a joint venture between the Beijing City government, the Thai firm Chai Tai, and Avian Farms in the United States) has a major broiler breeding program. It is trying to produce a bird with more dark meat and less white meat than the standard international breeds. Other firms import breeds from abroad after testing under local conditions.

In the mid-1980s, a joint venture between a foreign swine genetics company and the Animal Husbandry Bureau in Wuhan established a farm that was to breed improved swine. However, the partnership did not work out and the farm has now been downgraded to multiplying and supplying foreign breeds.

There is a scattering of privately funded research in other agriculturally related industries. The feed industry does some work on identifying the nutritional characteristics of new possible feed inputs. Pharmaceutical industries do trials on new veterinary pharmaceuticals and vaccines.

Private Technology Transfer

The chemical industry also appears to be the most important source of imported technology. Table H-7 shows the number of food and agricultural invention patents. The number of patents is one of the few quantitative measures of technology transfer in China. About 13,000 patents have been issued in China to the food industry and agriculture and agricultural input industries, but there has been more foreign patenting in agriculture (3,074) than in food (1,862). Agricultural chemicals account for two-thirds of foreign patents in agriculture followed by animal husbandry with about 400. Only a few foreign patents were taken out on agricultural machines, plants, or fertilizer. The data in table H-7 also show that, in general, food and agriculture had a lower percentage of foreign patents than was the case with all patents, about half of which were issued to foreigners. Twenty-three percent of agricultural patents and 15 percent of food industry patents were issued to foreigners. The pesticide industry is the one component of food and agriculture related industries in which foreign patents exceed the number of domestic patents.

Foreign investment is the primary means of transferring technology internationally. Technology is embodied in the technology that is purchased using the foreign capital. Thus, another indicator of technology

Table H-7—Chinese agricultural and food invention patents, 1985-97

Patent categories (international patent classification)	Total number of patents	Patents issued to foreigners[1]	Foreign/total
	--------------Number--------------		*Ratio*
Food industry	12,675	1,862	0.147
Ag. inputs			
Fertilizer	966	97	0.100
Pesticides	3,741	2,091	0.559
Plants	370	91	0.246
Machines	2,711	97	0.036
Animal husbandry	2,412	414	0.172
All agriculture (Most ag. inputs + forestry, fisheries, livestock)	13,281	3,074	0.231
All categories	148,336	73,465	0.495

[1]Citizens or corporations from the United States, Canada, Japan, Taiwan, Hong Kong, Australia, France, Germany, the Netherlands, Switzerland, and the United Kingdom.

Source: Data from Chinese Patent Office.

transfer is foreign direct investment (FDI) statistics (table H-4). The FDI data suggest that despite the relatively low number of patents, food manufacturing has received a considerable amount of foreign technology. The low number of patents may be due to the fact that technology can be better protected through secrecy or technical means rather than patents. Crop farming and animal husbandry received large amounts of FDI but, as a percentage of total assets in farming or the size of the agricultural sector, the amount of FDI was rather small. The agricultural input industries, with the exception of the feed industry, have had very little foreign investment. This fits with the patent data and information gathered in our interviews with firms. Among agricultural chemicals, most of the patented technology is imported pesticides. Only a few foreign companies have set up production facilities in China.

Current and Potential Impact

The main achievement of private research has been to identify foreign technology that would work well in China. Thus, in this section we mainly concentrate on the current and future impact of imported technology.

Recent Technology Transfer by Foreign Companies

In recent years, imported agricultural technology has been important in poultry and swine. Grandparent stock of most commercial broilers (chicken for meat) is imported or was developed based on U.S. poultry breeds. The joint venture Beijing Poultry Breeding Co. supplies 40 to 45 percent of the grandparent stock of broilers while Arbor Acres controls a third of the market. The layer industry is less concentrated, but it primarily uses foreign breeds also (CABS, 1998). Swine used in large commercial operations are primarily crosses with foreign breeds. In the early 1990s, 30-50 percent of all hogs slaughtered were crossbreeds (Simpson, Cheng, and Miyazaki, 1994). Most of the exotic breeds were imported from private foreign companies by government enterprises. In addition to improved genetic stock, feed additives, feed formulation technology, and pharmaceuticals are being imported.

Imported breeds and inputs have created a major new industry in poultry meat, which went from 1 million tons in 1980 to 6 million tons in 1995, valued at approximately $6 billion. The egg industry was already important before imported inputs came in: 3 million tons of egg were produced in 1980. But the new breeds and confinement management have boosted productivity and output considerably—17 million tons of eggs in 1995 (FAO).

More pesticides are used in China than in any country in the world. Almost all of the active ingredients were developed by private research outside China. As mentioned above, foreign firms account for 20 to 25 percent of the value (if you count the intermediate chemicals used in pesticide production), and the rest is sold by Chinese firms.

There have been no overall evaluations of the impact of pesticides on production, but companies provided some examples of the potential impact. For example, AgrEvo claims that its wheat herbicide, Puma, increases yields at least 10 percent and sometimes 20 to 30 percent in wheat yields on about 1 million hectares which did not use herbicide previously (or used 2-4D, which did not kill grasses). If the average wheat yield is 300 kg/mu, the increase in yield 10 percent, and the price of wheat Y1.1/kg, the increased value of wheat per mu will be Y33. The extra cost is Y2-3/mu. The net benefits are Y30/mu.

A few field crops have benefited from foreign varieties. The most high-profile foreign variety is Monsanto's and Delta and Pineland's genetically engineered cotton, an American cotton variety genetically modified to contain the Bt gene that makes it resistant to bollworms. It was planted commercially for the first time in 1995 on about 200,000 acres in Hebei province. Yields in 1994 on 10,000 acres grown for seed were 1,125 kgs.lint/ha while the provincial average was 825 kg/ha (Monsanto). Not only are yields higher but insecticide applications are reduced from at least 12 to one and the fiber is superior in strength and color to the local varieties. Seed cost goes from Y25/mu (5kg/mu * Y5/kg)—for purchased seed; most farmers keep their own seed—to Y52.5/mu (1.25kg/mu * Y42/kg), while the increased benefits will be at least Y288/mu (20 kg * 14.4Y/kg).

Other imported varieties grown commercially are sunflowers in western China and sugarbeets in the north. Approximately 1,000 tons of sugarbeet seed worth about $3 million are imported from Germany annually, which presumably has increased sugarbeet yields.

Vegetable varieties from Taiwan, Thailand, and Japan have been imported for a number of years. Food processing firms have also transferred agricultural technology. For example, Simplot, the firm that supplies partially fried, quick-frozen potatoes to McDonald's in China, is introducing American and Canadian potato varieties and a large number of improved management techniques to improve potato quality. Dole is producing citrus in southern China. BAT is producing tobacco. These companies usually bring in management technology and varieties.

U.S., European, and Japanese farm machinery firms have identified some technology that is appropriate for China's land/labor ratio. John Deere sold the design for a combine harvester to the Tianjin Tractor Factory. It has been produced for 10 years. In the early 1980s, Luoyang Tractor Works adopted tractor technology from Fiat/New Holland. More recently, New Holland and John Deere have sold a few large imported tractors. In addition, in the last few years, Kubota and Yanmar have started selling small rice harvesters in southern China.

Potential Impact of Foreign Technology

Are Chinese farmers missing out on technology because of government regulations and policies? It appears that they are, and we identify some of those missed opportunities here.

There is evidence from government trials that foreign technology could make major contributions to yields and quality of a number of major crops. Hybrid maize varieties from DeKalb have yielded 10-15 percent more than the check varieties in official yield trials, now that the government is testing at U.S. plant densities. In the past, when tests were conducted at the lower Chinese plant densities (but higher seed rates), the Chinese hybrids always yielded more. DeKalb has had two hybrids officially approved for use in China (DeKalb, 1997). Other companies that have corn hybrids equal good or superior to DeKalb's elsewhere in the world still have been unable to sell any seed in the Chinese market. For example, Pioneer, the world's leading seed company, has been trying to get into China for years and still has permission only to do research, not to sell its hybrids.

Potato production in general has increased rapidly in the last few years—faster than demand—with the result that prices were very low in 1995. Simplot, the supplier of potatoes to McDonalds, has been working on high-quality potato production for french fries here since 1986. After some early failures with American varieties, they are gradually increasing the contract production of several local varieties and one American variety. Pepsico was also working to improve potato quality and yield to produce good crops for chipping.

Private and public research programs in North America and Europe have invested a lot of money on improving rapeseed (canola), sugarbeets, and soybeans for climates similar to China's, so China should also be able to take advantage of these foreign technologies.

Most of the popular pesticides in world are available in China, although some of the newest are not. What Chinese farmers are missing from pesticides is the tacit knowledge—the information on efficient use of the chemicals—which should be provided, but often is not, when the chemical is sold. Local companies may not know about the best practices, and foreign companies have little incentive to educate people about a product that someone else is selling. The result is overuse of herbicides, which reduces crop yields, and overuse of chemicals, which wastes chemicals, creates environmental problems, and may encourage the development of resistance to the chemicals.

Biotechnology offers the potential to reduce insecticides and fungicides and increase yields of crops and productivity of livestock. In the United States and Latin America, where transgenic crops are grown on almost 30 million ha (James 1998), biotech has produced herbicide-resistant soybeans and corn (which increase the efficiency of herbicide use), Bt corn (which is resistant to borers), and corn with enhanced protein and oil quality for animal feed and human consumption. All of the international companies with major investments in agricultural biotechnology—Monsanto, Pioneer, DuPont, Novartis, and AgrEvo—have offices in China and (except Pioneer) sell other products there, but they are all waiting to see whether Monsanto is successful or not before making major investments in biotechnology.

Farmers are the ones who suffer from policies and regulations that restrict biotech. Despite the success of Monsanto's transgenic cotton in Hebei, transgenic cotton in 1998 still had not been approved by the Biosafety Committee for use in other provinces. Until this is done the only source of Bt cotton will be smuggled seeds from Hebei. These seeds may or may not be the real thing. Even if they are the real thing genetically, they may not do well because they have not been delinted and treated with pesticides like Monsanto's seeds. Thus, Chinese farmers outside of Hebei will be getting less yields, have greater pesticide costs, and create more damage to the environment than they would with transgenic cotton. In addition, Chinese farmers are missing out on the transgenic maize, soybeans, potatoes, and canola that have been commercialized elsewhere.

Determinants of Research and Technology Transfer

As mentioned in the introduction of this chapter, the main characteristic of Chinese private agricultural research and technology transfer that needs to be explained is the low level of private sector research and technology transfer. Government restrictions on the role of the private sector are the major factor explaining the limited private research. Uncertainty about the ability of foreign firms to control their proprietary technology due to weak intellectual property rights and uncertainty about rules on foreign ownership of joint ventures have also played an important role.

According to neoclassical economic theory, firms seek to maximize expected profits. The expected profits to a firm from investing in research are a function of the expected benefits and costs of research and development of a commercial product. The expected benefits will be based on the expected size of the market, the share of the market that they can capture, and the expected price of the new product. Firms will calculate the expected market size based on current market size and growth rates for this industry. They will estimate their expected share of the market by looking at their current market share in the industry, the strength of intellectual property rights in the country, and technical means of protecting their product from copying. The expected price will be based on current prices of similar products plus their ability to keep other firms from copying the product and competing against them. Economists call this ability to capture economic gains from research appropriability.

The expected cost of the private research needed to develop a new commercial product depends on the state of technology in China and elsewhere in the world. The salaries and benefits of scientists, engineers, and technicians will be important components of research costs. In addition, laboratories, experiment stations, and the supplies to run them are important expenses of research. The availability of technology from public institutes, which can be adopted or modified through local research, can substantially reduce the research needed to develop a commercial technology. Imports of technology, which can then be adapted to Chinese conditions, can also be an important stimulus to local research and can benefit farmers directly. Breakthroughs in basic science such as the advances in biotechnology can lead to a whole new set of possible technologies from transgenic crops, to new veterinary medicines, and plant and animal disease diagnostics.

Market Size

The major factor limiting the size of private investment is the continued dominance of state owned enterprises (SOEs) in the agricultural input production and supply. Only SOEs are allowed to sell seeds of major field crops; foreign firms are allowed only 20 percent of the pesticide market, and, until the late 1980s, were not allowed in at all. Seed of the major grains and cotton is the least liberalized input industry, followed by fertilizers, pesticides, and agricultural machinery. Food processing has had considerably more commercialization. In agricultural production, poultry, swine and fisheries present the greatest opportunities for commercial enterprises, with grain production having the least opportunity.

A related factor is that prices and the quality of most of the inputs produced by SOEs is low, which pushes down margins even on higher quality products. For example, the ratio of hybrid maize seed to grain prices in China is 6 to 1 while in the United States, it is more than 30 to 1. Local suppliers attribute the low prices to overcapacity and competition between SOEs in most industries. Foreign companies argue that many of the local inputs are of low and variable quality and that some, such as pesticides, are produced in ways that are dangerous to workers and the environment.

China is a market that major international agricultural input firms cannot ignore—it is the largest or next to largest market in world for hybrid seeds, pesticides, fertilizer, agricultural machinery, layers, swine, and other inputs. Some of these markets have been growing extremely rapidly, other have not (table H-3). There has been slow growth in seeds and declining production of large tractors. Herbicides have grown rapidly but not insecticides. Poultry and swine genetics and feed have grown very fast. Most large multinationals feel they need to have some sales and often some exploratory research in China, but government restrictions limit their growth.

The pattern of growth in investments in agricultural research and technology transfer also provides evidence of the importance of government restrictions as the major constraint on private research. As the government gradually opened industries to foreign firms, international companies came in. Thus, the earliest companies were the poultry genetics companies that were allowed in during the early 1980s. Pesticide firms were allowed in starting in the late 1980s and early 1990s. The latest firms are the seed companies. It is still not clear to what extent the government will allow them to operate.

A factor influencing the demand for quality inputs is the commercialization of agricultural services. Since every institution, whether it is research, extension, or regulatory, has to earn money to supplement the meager government contribution, unbiased research, extension, or regulation is increasingly rare. This makes it difficult for farmers to decide what technology they should buy. The seed stations, which were recently separated from the government seed companies so that they could do unbiased regulation of seed quality, are now going into the seed business with private firms. The government's Plant Protection Service (PPS) is supporting itself with sales of whatever pesticide gives them the largest profits. It is not likely that these organizations will give unbiased advice on plant varieties or pesticides. This increases farmers' risks and makes them less likely to invest in new technology.

Appropriability

The second most important factor (after restrictions on private participation in markets) leading to low investments in research is the lack of effective intellectual property rights (IPRs). IPRs and technical means of appropriating the gains from research have increased recently. There is still the perception, however, that IPRs are weak, and that perception has been reinforced by some high-profile cases like the copying of DuPont's sulfonylurea herbicides in the early 1990s, despite guarantees by the Ministry of Chemical Industries that no copying would be allowed.

The industries in which private research is greatest—chemicals, seeds, and poultry—are those with technical means of protecting their technology. Almost all of the plant breeding and screening research by private firms in China is on crops in which hybrids are sold commercially in China—corn, sunflower, sorghum, rice, sugarbeet, and cotton—because hybrid plant varieties cannot be easily copied by farmers or competing seed firms if the parents of the hybrid are kept secret. Rapeseed and wheat hybrids are not commercially grown in China, but companies are working to develop them. Cotton is the only crop in which private firms are working on varieties in China. In the case of cotton, the companies hope to control copying by buying back all of the seed. In the agricultural chemical industry, some chemicals (like seeds) are much more difficult to copy than others. Thus, some of the most profitable chemicals for foreign companies in China have not been widely copied because their active ingredient is a very complex molecule and/or the formulation is difficult to copy.

In the seed industry, the government-imposed market structure makes it difficult for local entrepreneurs, and even government-owned enterprises like seed firms set up by research institutes, to make money from developing new hybrids. Since government regulations give county seed firms a monopoly on production sales of hybrid seeds other than vegetables, research institutes or private firms have to turn their inbred lines over to the seed companies to produce the seed. Once they have done that, the firms can reproduce the hybrids with no problem and have no incentive to pay the agreed-upon royalties. There are no plant breeders' rights or patenting of hybrids, and it is difficult to get the courts to enforce contracts. Most government rice breeders we interviewed said that companies did not pay on the hybrid rice cultivars from the government breeders (see Pray, Rozelle, and Huang, 1998).

Legal protection of IPRs on pesticides has been strengthened recently, which stimulated investment in this industry. Three changes have taken place: stronger legal protection of intellectual property rights, better enforcement by courts and the administration, and the ability to set up joint ventures with foreign majority ownership. The Chinese patent law went into effect in 1985. New chemicals and pharmaceuticals were first protected by invention patents in 1993 for new chemicals which were patented outside of China in 1993 or later. In addition, in 1993, "administrative protection" was provided by the Ministry of Chemical Industry for pesticides patented elsewhere from 1986 to December1992. The protection lasts for 7.5 years.

Plant varieties are now protected by the 1997 plant breeders' rights law, but the office for taking applications had not yet opened for business in 1998.

Enforcement of IPRs has improved. There are two ways of enforcing IPRs. The first is administrative. If a violator is found, the Ministry of Chemical Industries (MCI) is informed, and it can withdraw the producer's permits to operate and close down the factory. Some foreign companies reported that they were quite happy with MCI because it responded to their needs. Others said that almost nothing had changed.

The other way of enforcing IPRs is through the court system. Foreign companies have started to win patent infringement proceedings in Chinese courts. No victories on patent infringement in the pesticide industry were reported during this study. However, Cyanamid recently won perhaps the first ruling in favor of a foreign agricultural chemical company on trademark infringement and fraud. In this case, a firm attempted to sell a Cyanamid chemical with the Cyanamid trademark claiming that it had been authorized to do so by the Cyanamid headquarters. Cyanamid was able to show that its headquarters had not authorized the Chinese company and that the product being sold was not up to Cyanamid's specifications or the specifications on the label. The court ruled that the Chinese company had violated Cyanamid's trademark and had fraudulently sold this product. Cyanamid received a lot of useful publicity from the case, which it hopes will deter copying in the future.

Allowing firms to be majority shareholders in joint ventures has increased their ability to appropriate benefits. In most industries, foreign firms must have a Chinese joint venture partner. Thus, they must share part of the returns with their Chinese partner. Local ownership requirements, however, have been relaxed. In the late 1980s, it was impossible for livestock breeders to have a wholly owned subsidiary in China. Now, some have been allowed to set up a representative office, and a few companies are being permitted to set up wholly owned subsidiaries. In the early 1990s, pesticide firms were allowed to set up majority-owned joint ventures. In the mid-1990s, a number of seed firms were able to do the same thing.

Some of these gains are threatened by new regulations, however. In the seed industries, according to 1997 regulations, foreign firms wishing to produce and sell seeds of the major grains, oilseeds, and cotton in China have to be minority shareholders. This means that they lose control over their most valuable asset—their technology. So far the Chinese Government has not enforced this regulation. If it decides to do so, the few seed companies now are in China may well leave or reduce their investments.

There is a similar threat in the agricultural chemical industry. A 1996 law says that joint ventures must produce in China the active ingredients of their pesticides and the intermediate chemicals that are inputs in the production of the active ingredients. This would make the technology for producing the active ingredient much more easily available and increase copying. So far this regulation has not been rigorously enforced either. If it is, agricultural chemical companies will be even more hesitant about investing in China.

Technological Opportunity—The Cost of Innovation

Government policies and scientific breakthroughs and geographic conditions have provided a number of technological opportunities and reduced the cost of doing research, which leads to more private research. This is in contrast to markets and appropriability in which government policies, while increasingly favorable, still are major constraints to private research.

The cost of research and technology imports by private firms is quite low because much of China's agriculture is in temperate regions similar to regions in the United States and Europe. Thus, the cost of developing and introducing new technology is primarily the cost of testing and occasionally adapting foreign technology to Chinese conditions. Most research by private seed firms, private pesticide firms, and poultry and swine breeders is very applied or is simply testing technology that was developed in the United States, Europe, and Japan. For example, American and European high-yielding hybrids and varieties with higher quality grain or fiber of cotton, maize, sunflower, sorghum, sugarbeet, and possibly rapeseed are the basis of private seed industry research. As mentioned above, most research by pesticide firms is testing the effectiveness and environmental impact of chemicals new to China but commercialized elsewhere. All of the poultry research is based on western breeds of poultry.

In addition to the limited need for adaptive research, the costs of research in China are low because of the low salaries and large numbers of well-trained Chinese scientists. Income at the best Chinese research institutes has risen dramatically over the last 10 years, but it is still between $150 and $500 per month. China has more agricultural scientists than any country in the world. Research reforms, which forced research institutes to earn money through commercial enterprises, have made the institutes more eager to contract work or go into joint ventures with private firms. The reforms have not been successful in keeping researchers' incomes near private firms' salaries. Thus, some of the best scientists are available to work in private research or in management positions in private firms. If the current privatization of housing takes place, even more government scientists will be willing to move to the private sector since access to housing was one of the main advantages of government jobs.

The recent reforms of the Chinese public research system have reduced the cost of starting private research and technology transfer companies in China. Chinese research firms, which now have to earn money from their commercial enterprises, have developed a number of small seed firms and some larger ones. In hybrid maize, Mr. Li Denghai, a government maize breeder, has established a commercial (but state-owned) hybrid seed firm in Laizhong City in Shandong province. In hybrid rice, the Hunan Hybrid Rice Research Center has established a joint venture with the U.S. firm, Ricetec, to work on hybrid rice in the American and Chinese markets. The reforms also made it easier for foreign firms to enter the market. Many of them were able to hire managers and technical staff from the Vegetables Research Institute of the Chinese Academy of Agricultural Sciences, which has one of the most successful commercialization programs.

While the breakthroughs in biotechnology have been a major stimulus to private research in the United States, Europe, and Japan, biotech has had only a limited impact on private research in China so far. Genetic engineering has stimulated some research by Monsanto and its partner Delta and Pineland. As of June 1998, they were the only private firms that had applied to the government biosafety committee for permission to do field tests of genetically engineered crops.

Biotech may be an important stimulus to private research in the near future, depending on Monsanto's experience with Bt cotton in Hebei and elsewhere. As described above, Monsanto has managed to get through the regulatory system (plant variety tests and biosafety committee). Monsanto sold enough seed to plant 200,000 acres in Hebei Province in1998. There are reports that farmers in provinces near Hebei are also growing Monsanto's Bt cotton without permission. The question now is how much Monsanto will be able to sell in the future and at what price and whether farmers will have multiplied a lot of this seed themselves. Agrevo and Novartis are watching this experiment carefully before they decide to invest in biotech in China.

The main factor reducing technological opportunity in China is the policy that restricts imports of foreign technology. Recent studies in Brazil (Johnson, 1998) and India (Basant and Fikkert, 1996, Fikkert, 1995) have shown that imported technology increases the productivity of industry and also stimulates private research or replaces research that is re-inventing the wheel. China restricts the imports of agricultural inputs that embody technology (seeds, pesticides, parent stock of poultry, and machinery) while attempting to import the technology (new breeds of crops, poultry and swine, active ingredients and intermediates of pesticides, and designs of farm machinery) through government institutions. This prevents potential Chinese entrepreneurs from working with the latest foreign technology as agents or employees of the foreign firm, improving the technology, and building businesses based on their improvements.

The commercialization of public research and agricultural services poses several negative impacts for the development of private research. First, declining public funding for research could reduce future opportunities for private firms to develop technology. Biotechnology is still doing well with government funding from the Ministry of Agriculture and a number of other Ministries, but other less trendy areas of agricultural research like enhancement of genetic stock of major grain crops like wheat and soybeans are languishing. In addition, research that has no immediate payoff to research institutes is neglected, like crop management research, even though it can increase farmers' returns from using modern inputs, thereby increasing farmers' welfare and demand for modern inputs.

A second problem is that there is more uncertainty about whether good new products will be approved for commercial use or not. The government scientists and officials who establish agricultural policies and make decisions about which plant varieties, chemicals, genetically modified plants etc. will be approved for use by farmers, are the same people whose incomes depend on these decisions. Thus, they can use regulations and policies to block competition from competitive local or foreign companies. A number of foreign seed firms reported difficulty getting their new hybrids officially approved, perhaps due to the fact that the hybrids are not good enough or perhaps because of biased officials.

Conclusions and Policy Options

So far private companies are not filling the gap in technology supply left by the decline of public sector research. Foreign firms are doing a small amount of research in China, and local commercial enterprises, whether they are owned by the public or private sector, appear to do even less research. As a result, the amount of private research in China is low relative to the size of its agricultural GDP and relative to other countries in Asia (table H-6). The low level of investment by local agribusiness firms in agricultural research is in dramatic contrast to India, where local firms do 70 percent of the private research, Malaysia, where local research is 90 percent of the private research, and Pakistan, where local firms account for 69 percent of the research (see applicable country case studies).

The impact of private research and technology transfer has also been very limited. In the few industries where foreign firms have been relatively free to supply inputs (for example, the poultry industry), they have made a major contribution to output growth. New foreign pesticides appear to have had a positive impact on the environment, workers' safety, and agricultural productivity. In other input industries that have more restrictions, such as the seed industry, there is evidence that foreign technology could make a contribution but so far has not.

The major constraints to private research and technology transfer are government policies. The potential markets for improved inputs and food are huge. The technological opportunities are great: firms can build on previous research in other temperate regions of the globe and in the Chinese public sector and research inputs are relatively inexpensive. Thus, if the government wants to encourage private research, it has to allow the private sector a bigger share of the markets and strengthen firms' ability to appropriate the gains from research. Table H-8 summarizes the policy and regulatory constraints that face foreign and Chinese firms. The last column lists some suggested reforms.

Why the Limited Amount of Private Research by Foreign Firms?

The main reason for the small amount of research and technology transfer has been government monopolies or near monopolies on production and distribution of most agricultural inputs and specific government

Table H-8—Policy constraints on private research and possible reforms

	Constraints on local enterprise	Constraints on foreign research and tech transfer	Possible reforms
Markets	State-owned enterprises' (SOE) monopoly on hybrid seed production & sale.	SOEs monopoly on hybrid seed production and sale.	Eliminate SOE monopolies
	Limits on who can import foreign inputs and how much can be imported.	Imports and foreign production restricted to 20% of pesticide Only CASIG can import seed. Imports of N-fertilizer limited.	Allow more imports of technology by private and foreign firms.
	SOEs have large share of production and sales in fertilizer, machines and other inputs		Continue to reduce government subsidies to SOEs.
	Regulation of new technology arbitrary or biased	Regulation of new technology arbitrary or biased	Reform funding of regulatory system & ensure regulators have no conflict of interest.
Appropriability	Difficult to enforce patents	Difficult to enforce patents	More government resources for enforcement.
	SOE monopoly of seed production	Joint ventures required; must be minority owner.	Allow foreign majority ownership.
	Plant breeders' rights passed but office not open	Plant breeders' rights passed but office not open	Start enforcing plant breeders' rights.
Technological opportunity	Input imports limited and foreign research limited.		Reduce barriers to input imports and research by foreign firms.
	Public research funding is declining.		Greater funding for research to assist local firms.
Other	Lack of capital for new firms		Government-assisted venture capital funds.

restrictions on foreign firms. For example, seed production and seed sales of grain, oilseed, and cottonseed must be by state-owned enterprises. Firms that have majority foreign ownership are legally prohibited from operating in the seed industry, with the exception of vegetable seed, and are legally prohibited from producing pesticides. No foreign companies have been allowed to set up their own network of dealers to sell inputs directly to farmers.

The second most important factor leading to low investments in research is the weakness of intellectual property rights. IPRs have been strengthened through extension of the law to cover new areas like pesticides and plant varieties, and enforcement through the courts and by administrative means has improved. However, foreign (and local) firms still have great difficulty enforcing their patents against infringement.

A third factor is the restriction on imports of agricultural inputs. Imports of agricultural chemicals are subject to quotas, and imports of some inputs such as hybrid seeds and the parent stock of chickens are virtually banned. Import restrictions limit the technology that firms can profitably bring in to technology that is profitable to produce in China. This limits what they will bring in to things for which there is a large market.

Why Limited R&D by the Chinese Input Industry?

Agricultural research by Chinese commercial firms could develop from four sources: state-owned enterprises (SOE), spinoffs from foreign firms, government agricultural research institutes, and individual entrepreneurs. Firms of each type face difficulties.

Some industries are still reserved for SOEs and face other government restrictions. For example, only government-owned companies are allowed to sell hybrid seeds and seeds of major field crops.

Weak intellectual property rights make spinoffs from SOEs, foreign firms, and government agricultural research institutes difficult. The government agricultural research institutes have the potential to evolve into commercial input firms. Entrepreneurs are ready to leave SOEs and foreign firms and start up new firms. However, limited intellectual property rights, which still do not effectively protect their plant varieties, new pesticides, and other products, means that profits are uncertain at best.

Commercialized research, extension and regulation have few resources and little incentive to help private research. Public research, extension, and regulation could stimulate, verify, and push new technology developed by local private firms, but reduced public funding for these institutions often means that the public sector cannot help.

Restrictions on imports of agricultural inputs prevents potential Chinese entrepreneurs from working with the latest foreign technology as agents or employees of the foreign firm, improving the technology, and building businesses based on their improvements.

SOEs and the related research institutes are reducing their research because the SOEs face overcapacity, overproduction, low prices, and too many employees. It is difficult for them to justify investments in research when their profits are low and they are laying off other staff. However, this means that they will have less research capacity when they are commercialized, and there will be fewer opportunities for spillovers to local private firms.

Capital for high-tech spinoffs from SOEs, foreign firms, and government agricultural research institutes is difficult to find. This is due to the combination of weak intellectual property rights, the weak capital markets in China, and government sources of capital, which are often not available to entrepreneurs who want to compete against the SOEs.

Despite these restrictions, a few small organizations like the maize seed company of Li Denghai and the rice seed company of the Hunan Hybrid Rice Research Institute are emerging as possible competitors to the SOEs and MNCs. In addition as mentioned above, some SOEs like the chemical firm Shanghai Zhongxi and the newly merged Shanghai Diesel Engine Research Institute and Shanghai Diesel Engine and Tractor Industry Company are investing in research.

Policy Alternatives To Encourage Private Research

A variety of reforms could be used to encourage more private research and technology transfer.

Dismantle SOE monopolies in the agricultural input industries. Reforms resulting in the dismantling of the SOE monopolies in production and marketing of many input industries have made considerable progress. Continued progress can lead to more private research.

Encourage foreign direct investment. Restrictions on foreign firms in the input industries reduce competition and at the expense of farmers. Progress has been made since the early 1980s when no foreign firms were allowed. Now they can come in but they must have local partners. However, in the seed industry the government took a step backward in the late 1990's when they issued new more restrictive regulations on foreign participation in the seed industry on the major field crops like grains and cotton. Agricultural chemicals also have had new restrictive conditions for foreign investment placed on them in the last two years.

Remove barriers to imports of agricultural inputs. The quotas on pesticide imports and bans on other imports restrict competition and opportunities for choice for farmers. By gradually reducing these barriers, more and improved inputs will become available for farmers.

Enforce intellectual property rights. Agricultural chemicals, biotech, and seed industry research would be strengthened by stronger IPRs. All agricultural chemical companies agree that the IPR situation has improved greatly for agricultural chemicals since 1990, but foreign companies would like it to become even stronger. Plant breeders' rights have been made into law but have not yet been enforced. The immediate future of private plant biotechnology research and products depends on Monsanto's experience with Bt cotton in Hebei and elsewhere. IPRs to protect this technology will be necessary. Plant breeders' rights and patents on biotechnology products need to be enforced for Monsanto and Chinese firms to be successful.

Rationalize regulations of new technology. A major problem is emerging in the provision of unbiased regulation of new products. Regulatory services cannot be expected to be unbiased if they are dependent on the industries they are supposed to regulate for a large share of their income. Regulatory services have to be financed well enough that they can hire and keep good people without being dependent on the industries they are supposed to advise and regulate for a large share of their income. Given the commercialization of the government's regulatory system, China's effort in this area would benefit by changing from mandatory variety testing and seed certification to voluntary testing and registration of varieties used by India and the United States.

Make capital available to small research-based agricultural input firms. The government financial system could set up something like a venture capital firm to assist new technology-based enterprises to get established.

Ensure the continued strength and independence of the public research system. Since private research is not taking up the slack for the decline in public agricultural research funding, one option is for the public sector to continue to supply farmers with new technology. In addition, services such as the provision of germplasm and unbiased testing of new technology that would strengthen private research could be provided. These activities require more funding and reforms, which are discussed in other papers (Rozelle, Pray, and Huang, 1998)

References

Basant, R., and B. Fikkert. "The Effects of R&D, Foreign Technology Purchase, and Domestic and International Spillovers on Productivity in Indian Firms." *Review of Economics and Statistics*, Vol. 78. 1996. pp.187-99.

CABS China National Animal Breeding Stock Company. Unpublished data. 1998.

Chen, Chunlai. "Foreign Direct Investment in China's Agriculture and Agriculturally Related Industries." Unpublished paper. University of Adelaide. 1998.

China, State Statistical Bureau (SSB). *China Statistical Yearbook*. China Statistical Publishing House, Beijing. 1995.

China, State Statistical Bureau (SSB). A *Statistical Survey of China*. China Statistical Publishing House, Beijing. 1996.

China. MOA, *Agricultural Yearbook of China*, various issues. Beijing.

DeKalb, personal communication, 1997.

Fikkert, B. "An Open or Closed Technology Policy? The Effects of Technology Licenses, Foreign Direct Investment and Domestic and International Spillovers on R&D in Indian Firms." Unpublished paper, Department of Economics, University of Maryland. College Park. 1995.

Huang, Jikun, and Scott Rozelle. "Technological Change: Rediscovering the Engine of Productivity Growth in China's Rural Economy," *Journal of Development Economics*. Vol. 49 (2). p 337-69. May 1996.

Huang, Jikun. Unpublished FAO Report, Rome, Italy. 1998.

James, C. *Global Review of Commercialized Transgenic Crops:1997*. (Preliminary Executive Summary and Principal Tables) ISAAA Briefs No. 8. ISAAA: Ithaca, NY. 1998.

Johnson, Daniel K.N. "Three Essays on Technology Licensing and R&D in Brazil." Ph.D. Dissertation. Economics Department. Yale University. New Haven. 1998.

Pray, Carl E., Scott Rozelle, and Huang Jikun. "Who Will Feed China? Can Chinese Agricultural Research do the Job?" Discussion Paper, Rutgers University. March, 1997.

Pray, C.E., Scott Rozelle, and Huang Jikun. "China." in M. Morris (ed.) *Maize Seed Industries in Developing Countries*. Boulder, CO: Lynne Reiner Press, 1998. Pp. 335-351.

Pray, C.E. "Final Report of the China Agricultural Research Funding Project." Report to the World Bank Research Committee, Washington, DC. September 22, 1997.

Reddinger, H., and Zhang Jianping. 1997. *Planting Seed*. Annual Report. American Embassy, Beijing, China. 1997.

Simpson, J.R., Xu Cheng, and A. Miyazaki. *China's Livestock and Related Agriculture: Projections to 2025*. CAB International. London, England. 1994.

Stone, B. "Developments in Agricultural Technology," *The China Quarterly*. No. 116. pp.767-822. 1988.

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