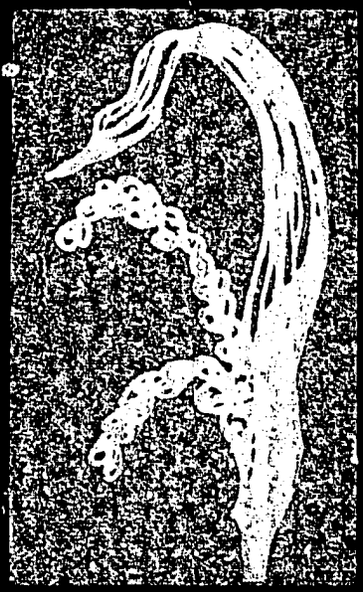
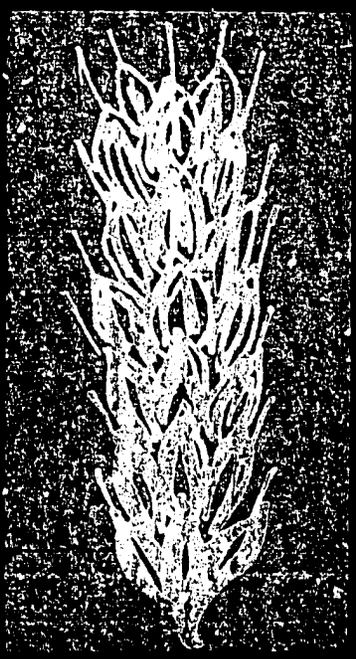


A Framework for Seed Policy Analysis in Developing Countries



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A FRAMEWORK FOR SEED POLICY ANALYSIS IN DEVELOPING COUNTRIES

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1

Introduction

The seed industry is crucial to agricultural development. Seed was perhaps the most important form in which the technology of the green revolution was transferred to farmers. As the new biotechnology moves from the laboratory to the field and seeds incorporate functions such as the ability to resist pests and generate nutrients that were previously supplied by other industries, the seed industry may become even more important.

After several decades in which seed policies were relatively noncontroversial and largely unacknowledged in the literature on agricultural development, the seed industry became the center of a number of debates in the 1980s. In the international arena the debate centered on how to preserve the genetic resources of plants, who owned these resources, and how the access of poor countries to such resources could be ensured. At the national level declining government budgets, pressure from donors and the local agribusinesses, and the failure of some government seed corporations are forcing policymakers to privatize the seed sector. At the same time concern is growing about the ability of the local private sector to supply adequate seed to farmers.

This paper is based on the available literature on the seed industry in developing countries. Chapter 1 lists some of the main issues and definitions. Chapter 2 provides an overview of the world seed industry. Chapter 3 presents a framework for analyzing the issues and policies of the seed industry. Chapter 4 reviews what is known about government seed policies. The conclusion summarizes the policy lessons contained in the literature and poses some of the major questions that need to be researched further.

KEY ISSUES FOR POLICYMAKERS IN DEVELOPING COUNTRIES

How does a country build a seed industry? Inefficient or weak seed industries are often cited as major constraints to spreading new crop varieties in developing countries. Policymakers must decide whether the seed industry is an important constraint or whether the so-called improved varieties are actually inferior to the local farmers' varieties.

If they determine that the seed industry is inadequate, is government seed supply necessary? Policymakers must decide whether private firms would rapidly increase the supply of improved varieties of seed or whether the government should supply commercial seed. Policymakers may have other options for increasing the supply of improved seeds such as subsidizing seeds or providing technical assistance to private seed firms.

How much privatization is optimal in more developed seed industries? In countries where the seed industry is more advanced, governments are being pressed by the local private sector and by foreign donors to privatize the production of seeds, the system of distributing seeds, and the breeding of plants. Government officials must decide what, if anything, should be privatized.

What is the relation among genetic diversity, yields, and crop failure? As modern varieties replace traditional landraces,[1] scientists and environmentalists have become concerned about declining genetic diversity in farmers' fields. They fear that reducing the genetic diversity will produce disastrous disease or insect epidemics that could devastate poor

farmers in developing countries. They are also concerned that we will lose genes that could increase yields in the future. What is the relationship between seed industry policy, genetic diversity, yields, and crop failures? Can policies on seeds reduce the probability of crop failures and the loss of genes that might increase yield?

Would granting plant breeders' rights, a form of patenting, improve the welfare of farmers? Such rights are being promoted in developing countries by private seed firms and the governments of the United States and some European countries as a means of encouraging more private research and transfers of technology. Its opponents view such legislation as a way for private companies—particularly European and U.S. multinational companies—to extract money and genetic resources from farmers in developing countries. The opponents of breeders' rights have proposed strengthening farmers' rights instead. They propose that developed countries compensate farmers in developing countries for the use of their genetic resources in the past by financing the research and conservation of genetic resources in those countries. Policymakers must decide what position their countries will take on these issues in international forums such as annual meetings of the Food and Agriculture Organization of the United Nations (FAO). More important, they must decide whether supporting the rights of plant breeders or strengthening their patent laws will increase or decrease the amount of technology available to farmers. This decision may be particularly important as biotechnology and stronger property rights in developed countries make more agricultural technology proprietary.

Does restricting seed imports and foreign seed companies help farmers? Many countries wish to be self-sufficient in the production and research of seeds because seeds are an essential ingredient in agriculture. This goal is reinforced by shortages of foreign exchange. As a result developing countries restrict seed imports and foreign investments in the seed industry. Donors and some local interest groups are now pressing these governments to liberalize their policies on trade and foreign investment. Will farmers gain from liberalization? Will society as a whole gain? These questions must be answered before a policy on seed imports and multinational seed companies can be formulated.

DEFINING THE SEED INDUSTRY

The seed industry can be considered to consist of all enterprises that produce or distribute seeds. At a minimum, this involves the following activities:

1. Plant breeding research. This research seeks to improve the varieties of seed through introduction of exotic varieties, pure-line selection, and hybridization. Plant breeders produce breeder seed of the new varieties. Breeder seed,[2] which embodies the improved genetic characteristics, is the basic input of the seed production process.

2. Seed production and multiplication. A seed enterprise multiplies the breeder seed into commercial seed that will be distributed to farmers. The type of commercial variety depends on how it was bred and produced and can thus be a pure-line, open-pollinated, clonal, or hybrid variety. Table 1 shows the three major types of crops—self-pollinated, cross-pollinated, and both—and gives examples of important crops that fall into these categories, shows how they can be improved, and lists the main commercial types of seed. The commercial seeds of wheat and rice are primarily pure-line varieties. Improved varieties of cross-pollinated crops are both open-pollinated varieties and hybrids. Most hybrid varieties in the market today are cross-pollinated crops such as maize and sunflowers. Some crops, such as potatoes, cassava, and sugarcane, are clonally propagated using parts of the plant rather than seed. The companies that supply clonal seed are generally considered to be part of the seed industry.

3. Processing and storage. The seed that is produced is processed and saved. Processing involves drying, cleaning, treating with chemicals, packaging seeds, and assuring internal quality.

4. Marketing and distribution. Marketing involves promoting the seed produced by the enterprise, and distribution is the physical and logistical exercise of getting the seeds at the right place and the right time.

Table 1—Improvement methods and seed types of major field crops

Indicator	Normally Self-pollinated[a]	Self- and Cross-pollinated[b]	Normally Cross-pollinated[c]
Crop	Wheat, rice, peanuts, soybeans, potatoes	Cotton, sorghum	Maize, pearl millet, sunflower, cassava, sugarbeet, mustard, sugarcane
Methods of varietal improvement	Introduction, selection, hybridization	Introduction, selection, hybridization	Introduction, selection, hybridization
Main type of commercial seed	Pure-line varieties, clonal varieties (potatoes)	Open-pollinated varieties, hybrid varieties	Open-pollinated varieties, hybrid varieties, clonal varieties, (cassava, sugarcane)
New types	Hybrid varieties, true potato seed, artificial seeds	...	Artificial seeds

[a]Corresponds to Simmonds (1979) inbreeding crops.
[b]Roughly 5 percent natural outcrossing is found in these crops, but the percentage varies with variety.
[c]Corresponds to Simmonds (1979) outbreeding crops.

The overall performance of the seed industry is measured by sales, profits, or growth and depends on the efficiency of all these components. It also depends on certain activities that are upstream from, parallel to, or downstream from it. Plant breeding research, a basic input of the seed production process, is itself the result of more basic research and development. Advances in science therefore have great bearing on the productivity of the seed industry. Varietal tests and activities that control quality, such as certification schemes that help assure genetic purity and good seed quality, can be important parallel programs that increase the industry's efficiency. Downstream, the efforts of extension and rural development agencies help the seed industry to diffuse and farmers to adopt improved seeds.

The seed sector or system, as opposed to the seed industry, includes the upstream, parallel, and downstream activities of research and development and certification and extension, as well as the seed industry itself.

2

Overview of the Seed industry in Developing Countries

The value of all seed used by farmers in developed and developing countries in 1988 was estimated to be about US$50 billion (Hobbelink and Vellve 1988). Farmers supplied 36 percent of this themselves by saving seed from previous harvests; the seed industry supplied the rest. The biggest markets for the seed industry are in the developed countries of the world (the United States and Western Europe). In 1988 the value of seed sold commercially in developing countries amounted to US$3.8 billion, representing only about 12 percent of global sales. Since more land (area harvested) is farmed in developing countries than in the developed countries for all the major grain crops with the exception of wheat (see Table 2), one would expect the developing countries to have a larger share of the world market.

The developing countries' share of the world seed market is small for several reasons. First, in developing countries, the area is only partially covered with improved seeds. For all developing countries, modern varieties were grown on slightly more than half of all the area planted to rice, wheat, and maize in 1982-83. (See Table 3 for rice and wheat and Table 4 for maize.) Second, in developing countries more farmers save more of their seeds than in developed countries. Farmers are the source of an estimated 80 percent of the seed in developing countries (Delouche 1982). In the United States farmers supply about two-thirds of the quantity (one-third of the value) of the seed planted (Kania and Goldberg 1982). In the United Kingdom farmers supply only 15 percent. Tables 5, 6, and 7 show the sources of seed in Mexico, Thailand, and India. Even though these countries have relatively well-developed seed industries, the bulk of their seed supply still comes from farmers. Third, the value of seed sales in developing countries is low because the high-value segment of the seed industry (vegetables, horticultural crops, and hybrids) is not as important as in the developed countries.

Table 2—Harvested area of major cereal crops, 1985

Crop	World Total	Developed Countries		Developing Countries	
		Area	Percent of Total Area	Area	Percent of Total Area
	(1,000 hectares)			(1,000 hectares)	
Rice	144,674	4,537	3.14	140,137	96.86
Wheat	230,066	130,733	56.82	99,333	43.18
Maize	132,986	52,860	39.75	80,126	60.25
Sorghum	50,191	8,244	16.43	41,947	83.57
Millet	42,621	2,857	6.70	39,764	93.30
All cereals	729,818	304,513	41.72	425,305	58.28

Source: FAO (Food and Agriculture Organization of the United Nations), *1985 FAO Production Yearbook* (Rome: FAO, 1986).

Table 3—Share of area planted with high-yielding varieties of rice and wheat, by region, 1982-83

Region	Wheat	Rice	Wheat and Rice
		(percent)	
Developing market economies			
Asia	79.2	44.9	54.6
Near East	30.6	8.4	29.6
Africa	50.6	4.7	13.3
Latin America	77.6	32.9	59.0
Subtotal	60.9	41.6	49.8
Communist Asia	30.6	81.0	58.0
All developing countries	51.9	53.6	52.9

Source: Dana G. Dalrymple, *Development and Spread of High-Yielding Rice Varieties in Developing Countries*, (Washington, D.C.: Bureau for Science and Technology, Agency for International Development, 1986).

Table 4—Share of area planted with hybrids and improved open-pollinated varieties of maize, by region, 1985/86

Region	Hybrids	Improved Open-pollinated Varieties	Total
		(percent)	
Eastern and Southern Africa	25	11	36
West and Central Africa	1	21	22
North Africa and the Middle East	32	15	47
South Asia	11	23	34
Southeast Asia and the Pacific	3	34	37
East Asia	71	1	72
Mexico, Central America, and the Caribbean	26	16	42
Andean countries and South America	20	9	29
Southern Cone of South America	70	6	76
All developing regions	38	13	51

Source: David H. Timothy, Paul H. Harvey, and Christopher R. Doswell, *Development and Spread of Improved Maize Varieties and Hybrids in Developing Countries* (Washington, D.C.: Bureau for Science and Technology, Agency for International Development, 1988).

Table 5—Seed requirements and imports in Mexico, by crop, 1981 and 1986

Crop	1981 Seed Required	1981 Certified Seed	1981 U.S. Imports	1984 Certified and Basic Seeds	1984 Total Imports	Certified Production, 1986 Public	Certified Production, 1986 Private	U.S. Imports 1985/86
	(1,000 metric tons)							
Maize	175	60	1	25	8	18	10	24
Beans	193	50	4	16	3	19	5	4
Sesame	47	0	0	0	0	n.a.	n.a.	...
Sorghum	37	37	16	30	14	2	50	16
Wheat	113	113	20	168	0	41	107	...
Safflower	7	7	0	5	1	2	3	...
Soybeans	31	31	17	37	15	21	33	6
Cotton	16	16	2	13	0.4	n.a.	3	...
Barley	40	15	5	29	0	2	20	...
Rice	24	24	0	20	0	18	17	...
Total	683	353	65	343	41.4	123	248	50

Sources: For 1981, Louis W. Goodman, Arthur L. Domike, and Charles Sands, The Improved Seed Industry: Issues and Options for Mexico, Center for International Technical Cooperation, The American University, Washington, D.C., 1982. For 1984, Food and Agriculture Organization of the United Nations, *FAO Seed Review*, 1984-85 (Rome: FAO, 1987). For the certified production in 1986, Ruben Echeverria, Public and Private Sector Investments in Agricultural Research: The Case of Maize (Ph.D. diss., Department of Agricultural and Applied Economics, University of Minnesota, 1988). For U.S. imports, U.S. Department of Agriculture, *Seeds for Planting: U.S. Seed Exports*, Foreign Agricultural Circular (Washington, D.C.: USDA, 1987).

Notes: Ellipses (...) indicate a negligible amount. n.a. means not available.

Table 6—Seed requirements and imports in Thailand, by crop, 1986

Crop	Seed Required	Commercial Seed Sales	Government Production[a]	Imports
	(1,000 metric tons)			
Rice	293.0	73.0	5.1	0.00
Maize	40.0	18.0	2.5	0.01
Sorghum	4.5	1.0	0.0	1.50
Mungbean	11.2	3.0	0.6	0.00
Soybean	13.0	3.0	1.4	0.00
Groundnut	20.0	5.0	0.4	0.00
Cotton	3.0	1.0	0.2	0.00
Vegetable	2.0	1.0	0.0	0.55
Total	386.7	105.0	10.2	2.06

Source: Suthad Setboonsarng, Saran Wattanutchariya, and Banlu Phutigorn, "The Structure, Conduct, and Performance of the Seed Industry in Thailand," Agriculture and Rural Development Program, Thai Development Research Institute, Bangkok, Thailand, 1988.

[a]Includes maize sales by Kasetsart University.

Table 7—Seed requirements and commercial supply of major field crops in India, 1987

Crop	Total Seed Planted	Commercial Seed Quantity	Commercial Seed Value	Public Supply
	(1,000 metric tons)	(1,000 metric tons)	(Rs million)	(1,000 metric tons)
Wheat	2,088	158	650	105
Paddy	1,025	132	550	52
Sorghum	992	25	400	19
Maize	150	13	150	4
Pearl millet	110	15	150	6
Pulses	677	23	250	14
Groundnuts	635	38	300	14
Other oilseeds	176	16	200	9
Total	5,853	420	2,650	223

Sources: For total seed planted, S. S. Johl, "Seeds Industry: Some Policy Issues," in *Indian Industries Problems and Prospects 1987-88* (New Delhi: Patriot Press, 1988). For commercial seed, Pramod K. Agrawal, *Seed Industry in India: History, Policies, and Perspectives*. Research Report 33 (Tilburg, the Netherlands: Development Research Institute, 1988). For public sector seed, World Bank, "Staff Appraisal Report: India Third National Seeds Project," Washington, D.C., 1987.

The development of the seed industry varies widely by country and crop. FAO (1985) rated seed industries on the basis of three activities: the improvement of varieties, quality control, and production and distribution (see Table 8). The seed industry in South America has reached an advanced level in food and industrial crops.[3] About half the countries in Asia and Central America have also reached advanced levels in their ability to improve varieties and control the quality of seeds in food crops. Central America is behind Asia in production and distribution of seed for food crops. Asia and Central America are less developed than South America in industrial crops. In Africa, the majority of countries have pilot activities in food crops, but only a few have attained advanced status. The situation is worse in industrial crops: many African countries report no efforts to control the quality, production, or distribution of seeds. All regions report low levels of development in vegetables and pasture crops.

The industrial structure of the seed industry in developing countries is a mix of organizational forms including public research institutions, public sector seed corporations, private local firms, farmer associations, multinational companies, and nongovernmental development agencies. Research to develop new varieties, particularly in rice and wheat, is mainly performed by public institutions and international research centers. In some countries, local- and foreign-owned firms are conducting research on hybrid crops and vegetables (Pray et al. 1989; Goodman, Domike, and Sands 1982).

Many developing countries invest in public seed corporations that multiply and distribute seed. One survey of the maize seed industry found that the majority of developing countries produce at least some seed in the public sector (Table 9). As the same survey shows, private seed firms are also important in supplying seed and in fact supply the bulk of commercial maize seed (including open-pollinated varieties; see Table 10). The private sector (including cooperatives and farmer associations) also plays an important role in the production of seed for crops like rice and wheat that do not have commercial hybrids. This can be seen from Tables 5, 6, and 7, which reveal the sources of commercial seeds in Mexico, Thailand, and India, respectively.

In most developing countries imports are not an important source of commercial seed (Tables 5 and 6). The United States and the countries of the European Community are the major exporters of seed to developing coun-

Table 8—Level of development of seed industries, by region and activity, 1985

Type of Crop, Region, and Number of Countries	Category A			Category B			Category C		
	Variety Improvement	Quality Control	Production and Distribution	Variety Improvement	Quality Control	Production and Distribution	Variety Improvement	Quality Control	Production and Distribution
	(percent of countries)								
Food									
Africa (37)	22	28	28	72	61	72	6	11	...
Asia (30)	59	47	41	31	33	48	10	20	11
South America (11)	100	80	100	...	20	...	...	...	...
Central America (14)	58	43	21	14	28	43	28	28	36
North America (2)	100	100	100	...	...	...	...	...	...
Europe (17)	94	100	100	...	...	...	6	...	...
Oceania (5)	80	40	60	20	...	20	...	60	20
All countries (116)	58	51	50	33	34	42	9	15	8
Industrial									
Africa (37)	8	20	11	56	22	25	36	58	64
Asia (30)	35	23	28	10	23	11	55	54	61
South America (11)	72	70	82	9	...	...	18	30	18
Central America (14)	36	14	14	21	14	21	43	72	55
North America (2)	100	100	100	...	...	...	...	...	...
Europe (17)	88	94	81	...	...	...	12	6	19
Oceania (5)	60	40	60	...	...	20	40	60	20
All countries (116)	40	37	36	24	15	14	36	48	50
Vegetable									
Africa (37)	...	5	...	39	28	36	61	67	64
Asia (30)	24	27	21	35	23	21	41	50	58
South America (11)	27	20	...	18	10	36	55	70	64
Central America (14)	7	7	...	43	21	50	50	72	50
North America (2)	100	100	100	...	...	...	...	...	...
Europe (17)	77	88	75	...	...	...	23	12	25
Oceania (5)	40	40	20	20	...	20	40	60	60
All countries (116)	25	27	21	29	19	19	46	54	60
Pasture									
Africa (37)	3	8	3	14	8	14	83	84	83
Asia (30)	14	13	14	14	10	7	72	77	79
South America (11)	36	50	18	46	20	55	18	30	27
Central America (14)	...	7	...	7	7	14	93	86	86
North America (2)	100	100	100	...	...	...	...	...	...
Europe (17)	94	100	100	...	...	...	6	...	...
Oceania (5)	40	40	40	...	...	...	60	60	60
All countries (116)	26	29	24	13	8	13	61	63	63

Source: Food and Agriculture Organization of the United Nations, *FAO Seed Review* (Rome: FAO, 1985).

Notes: Category A is an advanced level; category B, fragmentary or pilot operation; and category C, no activity reported. Ellipses (...) indicate 0.

Table 9--Public sector involvement in maize seed industries, by region, 1986

Region	Number of Countries Reportinig	Number of Countries with: Seed Regulating Agency	Seed Quality Agency	Public Seed Enterprises	Private Seed Enterprises
Africa	12	9	9	10	9
Asia	12	11	11	11	8
Latin America	13	9	11	11	12
All developing Countries	37	29	31	32	29
Eastern Europe and U.S.S.R.	4	4	4	4	0
Developed market economies	7	6	6	0	7
All countries	48	39	41	36	36

Source: CIMMYT (Centro Internacional de Mejoramiento de Maiz y Trigo), *1986 CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Product in Developing Countries* (Mexico City: CIMMYT, 1987).

Table 10—The private sector's share of maize seed sales in noncentrally planned countries, 1986

Region	Number of Countries Reporting	Share of Total Seed Sales: Improved Varieties	Hybrid	All Commercial
Africa				
Eastern and Southern Africa	4	45	96	92
West Africa	6	9	77	61
North Africa	1	73	100	78
Total	11	57	95	83
Asia and the Middle East				
Middle East	2	0	45	38
South Asia	3	38	63	54
Southeast Asia and the Pacific	4	69	99	73
East Asia, excluding China	2	69	38	39
Total	11	62	62	62
Latin America				
Mexico, Central America, and the Caribbean	6	66	71	68
Andean region	4	65	91	86
Southern cone of South America	3	81	98	97
Total	13	70	96	92
Developing countries	35	65	92	85
Developed market economies	7	100	100	100
All noncentrally planned countries	42	65	98	94

Source: CIMMYT (Centro Internacional de Mejoramiento de Maiz y Trigo), *1986 CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Production in Developing Countries* (Mexico City: CIMMYT, 1987).

tries, but this trade is limited by differences in agroclimatic conditions, disease and pests, and government trade barriers. Trade among developing countries is limited by the underdeveloped seed industry and trade barriers. The United States and the European Community shared an estimated 90 percent of the US$1.2 billion global trade in commercial seeds at the beginning of the 1980s (Groosman, Linneman, and Wierma 1988). Developing countries import 47 percent of the United States' seed exports and 27 percent of those from the European Community. They import principally seeds of hybrid maize and sorghum, vegetables, and grasses from the United States and seeds of oats, vegetables, and potatoes from the European Community (Groosman 1987).

Although imports of commercial seed are limited, exotic germplasm, exotic crops, and breeding techniques have played an important role in agricultural development. Table 3 shows the importance of high-yielding varieties of wheat and rice, which are semidwarf varieties by definition. The most important genes for dwarfing in these varieties came from the Japanese Norin varieties of wheat and the Taiwanese/Chinese varieties of rice (Dalrymple 1986). One of the most important contributions of the international agricultural research centers has been to strengthen and regularize the exchange of germplasm between countries. Multinational firms also transfer germplasm among their subsidiaries.

Multinational firms participate in the seed industry of developing countries to varying degrees. In Argentina they control about 80 percent of the maize and almost all of the sorghum seed market, but local companies control most of the wheat seed market.[4] In contrast India kept almost all multinational corporations out of the seed industry until 1987 (Pray et al. 1989). In all countries they concentrate on hybrid seeds of major field crops and on hybrid vegetable seeds. They export commercial seed to developing countries. Most large multinational seed companies prefer, however, to grow part of their commercial seed in the country where it is sold and to import part.[5] This strategy saves transportation costs, takes advantage of inexpensive labor to produce labor-intensive seeds, and diversifies production risk. Multinational corporations may sell the parent seed in return for a royalty on the commercial sales. In other instances, they may decide to invest in a local partnership or a wholly owned subsidiary (Kania and Goldberg 1982).

Despite a large number of acquisitions and mergers, seed companies still compete fiercely for world markets. Table 11 describes some of the major seed companies. Despite the publicity accompanying the acquisition of seed companies by chemical companies, many of the largest companies are primarily seed companies or are owned by food companies. These three types of companies have different goals, and their competition is based on differences in technology, price, and services.

In most countries, governments intervene to control quality, seed imports, seed prices, and ownership of varieties. Quality can be controlled at different stages of the production process. At an early stage, varieties may be tested in trials and identified as superior because they possess desirable characteristics. These varieties may be subjected to a system of field trials and seed inspection to maintain genetic purity known as seed certification. This certification process may be voluntary or mandatory. At the marketing stage, certified and uncertified seed may be tested for purity and germination quality according to standards established by law.

Almost all countries have some restrictions on seed imports. Many forbid commercial imports of certain crops.[6] Most countries restrict the importation of parent seed less than commercial seed, although some countries even ban them. Imported seeds are usually subject to quarantine regulations and other quality-control laws applicable to local seeds.

Seed prices of maize are subject to government control in 22 of the 34 noncentrally planned developing countries that replied to the 1986 survey conducted by Mexico's Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT 1987). Seed prices are subsidized in 11 of the 34 countries, but the subsidy is often subject to the vagaries of state budgets. Patenting of varieties is a controversial issue in developing countries. A weak form of patents known as plant breeders' rights have been in existence in Western Europe and the United States for some time. Except for Chile and Argentina, however, developing countries either have not passed legislation endorsing plant breeders' rights or do not enforce it (Siebeck 1990).

Table 11—The principal international seed groups, 1987

Group	Country	Primary Activity	Sales (US$ million)
Pioneer	United States	Seeds	692
Sandoz	Switzerland	Chemicals	382
Limagrain	France	Seeds	234
Cargill	United States	Food processing	200-250
Upjohn	United States	Chemicals	217
Provendor (Volvo)	Sweden	Food processing	213
Ciba-Geigy	Switzerland	Chemicals	213
DeKalb-Pfizer	United States	Seeds	154
R-D Shell	Great Britain-Netherlands	Petroleum	150-200
Orsan (Lafarge)	France	Biochemicals	139
KWS	Federal Republic of Germany	Seeds	127
ICI	Great Britain	Chemicals	98
Lubrizol	United States	Chemicals	83

Source: Pierre-Benoit Joly, "Should Seeds be Patentable? Elements of an Economic Analysis," in *Patenting Life Forms in Europe: Proceedings* (Brussels: International Coalition for Development Action, 1989).

3

An Analytical Framework

In order to examine systematically the policies that affect the development of the seed industry, it is useful to look at the supply and demand conditions that govern the industry. The purpose of this section is to provide a conceptual understanding of the supply and demand process in the seed industry, to highlight the economic variables that may be special to the seed industry, and to discuss, in light of the conceptual framework, the seed sector in developing countries.

FACTORS AFFECTING DEMAND

The demand for the seed of a particular crop and a particular variety is the outcome of decisions regarding the selection of a variety, the use of saved seed versus commercial seed, and the allocation of land. An important characteristic of seed is its ability to reproduce itself. Farmers, therefore, have the option of using seed saved from the previous crop or choosing commercial seed. They choose commercial seed for two reasons: because it is a new variety with more desirable characteristics than their current variety or because their own seed has deteriorated due to disease, poor storage, or mixture with dirt, weeds, and other varieties.

The demand for seed is also affected by how farmers decide to allocate their land. Farmers must allocate the available land to different crops and uses (they may even need to leave it fallow) and decide how much seed to plant per unit of land. The second decision is tied closely to the selection of a variety because different varieties perform optimally at different levels of seeding.[7]

A discussion of some of the individual factors affecting the selection of varieties and the decision on how to allocate land follows.

Farmer-Saved Seed

The demand for commercial seed (that is, seed purchased) depends on the extent to which farmers recycle seed from the previous crop. The costs of producing and saving seed are the normal costs of production plus the costs of taking extra care to reduce weeds and off-types in the field and of cleaning and storing the seeds.[8] These costs are usually less than the price of new seed. On the other hand, yields from farmer-retained seed may decline over time; hybrids decline the most because they lose their hybrid vigor.[9] The decline will be moderately high for cross-pollinated crops such as open-pollinated varieties of maize because they become genetically mixed with local varieties in nearby fields. Self-pollinated crops like wheat deteriorate less, although they become susceptible to diseases and pests and can be mechanically mixed with weed seed and dirt.

The few available estimates of yield lost due to disease and mechanical mixture suggest a slow deterioration, which implies that farmers do not give up much yield by using their own seed for self-pollinated crops. Heisey and Brennan (1989) cite sources suggesting that the annual rate of yield loss ranges from 0.25 percent for Pakistani wheat to 1.6 percent for rice in India. Unless plant breeders produce many new varieties with improved yield or quality characteristics or the cost of producing and storing seeds is relatively high, farmers do not have much incentive to buy seeds every year. Even in the United States, where new varieties are introduced frequently, the seed industry supplied only 30 percent of the total wheat seed consumed in 1975; the rest came from farmer-saved seeds (Table 12). Commercial seed makes up almost 100 percent of the crop only in crops like maize and sorghum where hybrids are universally used.

Table 12—Commercial seed as a percent of total seed used in the United States, by crop, mid-1970s

Crop	Share
	(percent)
Seed maize	95
Grain sorghum	95
Forage and silage sorghum	100
Sorghum sudangrass	95
Soybeans	55
Wheat	30
Oats	40
Barley	50
Rye	80
Flaxseed	90
Vegetables	85
Cotton	50
Tobacco	90
Rice	70
Sugar beets	100
Peanuts	70
Packet seeds	
Vegetable	100
Flower	100
Bedding plant	100
Cut flower	100
Lawn	100

Source: I. J. Butler and Bruce Marion, *The Impacts of Patent Protection on the U.S. Seed Industry and Public Breeding* (Madison: Wisc., U.S.A.: University of Wisconsin, 1985).

Heisey and Brennan (1989), in a study of the demand for wheat seeds in Pakistan, found it optimal for farmers to change seeds every 13 years. The slow optimal rate of change of wheat seed is due to the slow rate at which the yield of retained seeds declines, the modest rate at which the yield of new seeds improves due to research, and the high cost of switching varieties due to learning and risk. Indirect evidence about the rate of varietal turnover (that is, the length of time it takes for farmers to replace all their seed) is provided by using a measure of the weighted average age of varieties (Brennan and Byerlee 1991). The measure in year t is computed as follows:

$$WA_t = \sum_i p_{it} R_{it},$$

where WA_t is the weighted average age of varieties, p_{it} is the proportion of the area sown to variety i in year t, and R_{it} is the number of years (at time t) since the release of variety i. Brennan and Byerlee estimate this measure for wheat varieties in a number of different countries for different periods. The results are reproduced in Table 13. Regions with high average age of varieties have slow turnover rates. The actual figures reflect, however, both demand and supply factors, and in some cases varieties are old because the supply and distribution system are inefficient.

With hybrids, however, varietal degradation is rapid, and new seeds yield much more than old seeds. Although farmers in poor countries may use seeds from hybrid varieties for a second year, this occurs much more often with self-pollinated varieties where varietal turnover could take as long as 10 years (Heisey and Brennan 1989). Therefore differences in the ability of farmers to produce seeds lead to major differences in the size of the market for self-pollinated varieties and hybrids. Thus hybrids are much more attractive to private firms than self-pollinated varieties.

Yield or Quality Advantages of New Varieties

Besides the ability of farmers to produce and save seed, their demand for new varieties is determined by the type of seed available (hybrids or open-pollinated varieties) and the genetic improvements in yield, quality of output, speed, and time when the crop reaches maturity that are due to plant breeding. The advantages of different varieties change as growing conditions or prices and availability of complementary inputs change.

An important incentive to adopt improved varieties is the improvement in yield. A CIMMYT study of maize indicates differences in the yield of different types of seed and their local agricultural conditions. Across the spectrum of growing conditions, the productivity of various seed types generally progresses as

Table 13—Weighted average age of varieties of wheat, 1970-86

Country/ Location	Period Covered by the Data	1970s	1980s	Mean, 1970-86	Trend, 1970-86
			(years)		
Pakistani Punjab	1978-86	11.8	10.9	11.1	−0.12
Indian Punjab	1970-86	5.4	5.3	5.3	0.05
Yaqui Valley, Mexico	1972-86	2.6	3.7	3.1	0.13
Farana, Brazil	1979-85	7.3	10.5	9.9	0.5
Region II North, Argentina	1970-80	6.7	7.9	6.8	−0.06
Kansas, United States	1970-86	6.6	6.9	6.7	0.06
New South Wales, Australia	1970-85	7.7	7.4	7.6	−0.11
New Zealand	1970-86	12.0	7.9	10.3	−0.46
Winter wheat, Netherlands	1970-86	5.4	7.6	6.6	0.29

Source: John P. Brennan and Derek Byerlee, "The Rate of Crop Replacement: Measures and Empirical Results for Wheat," CIMMYT (Centro Internacional de Mejoramiento de Maiz y Trigo), Mexico City, 1989 (mimeo).

follows: local varieties, improved varieties, nonconventional hybrids, double crosses, three-way crosses, and single crosses. As the same study notes, however, such a ranking of varieties occurs more consistently under extremely good growing conditions. Under the less favorable environmental conditions found in many developing countries, the yield advantage of hybrids and improved varieties is diminished and farmers are thus less likely to adopt them (CIMMYT 1987).

The yield improvements from new varieties have been extensively documented in the United States, Europe, and developing countries. Long-term gains in yield of 1.0 percent a year in wheat and maize are quite common in countries with well-established research programs like the United States and Australia. About half of that increase can be attributed to genetic improvement, the rest to increased imputs. In countries recently affected by the "green revolution," the gains have been greater. Wheat yields grew 2.5 percent annually in Pakistani Punjab and 5.1 percent in the province of Parana, Brazil (Brennan and Byerlee 1991). The contribution of genetic improve-

ment to wheat yields has been 0.5 percent or less in dry areas and around 2 percent in irrigated areas (CIMMYT 1989).

Qualities other than yield also affect the decisions that farmers make. The importance of improved eating quality in rice in Asia and varieties of cotton with higher-quality lint in Pakistan have been documented (Unnevehr 1986; Pray 1978). Early-maturing varieties are favored in many regions because they allow a second crop to be grown or produce higher yields of the second crop.

Price of Seed

Because improved varieties and hybrids cost more to produce, their seeds are also more expensive. Does that prevent farmers from adopting them? One view, with wide anecdotal support in the literature, is the following:

> It has been demonstrated many times during the past 25 years that truly superior seed will almost "sell" themselves. Marketing difficulties, however, are encountered when the seed represent a solid, demonstrable, but only modest improvement over the seed presently planted by cultivators (e.g., yield advantage of less than 20%) (Delouche and Baskin 1989, 290).

The implication of this statement is that the demand for improved seed is very elastic if the substitutes (farmer-saved seed) are close in yield and quality characteristics. In other words, a small increase in the price of improved seed will lead to a large decline in the quantity purchased. The demand is less elastic if the seed is truly superior. For example, Indian farmers are willling to pay 30 times the price of conventional cotton seed to acquire some hybrid cotton varieties.

Price is more of a constraint for poor farmers in crops that require a large amount of seed such as groundnuts and potatoes. In this case, seed is a major component of the costs of production, and farmers are quite sensitive to seed prices.

Many governments regulate seed prices and, at least implicitly, believe that the price of seed is an important determinant of adoption behavior (CIMMYT 1987). No one has actually estimated the price elasticity of demand for improved seed. Limits are placed on subsidies, however, because most seeds can be eaten. If the subsidies on seed push prices too low, people will buy seed to eat rather than to plant.

Price of Other Inputs

The use of improved seeds is often associated with the use of other purchased inputs such as irrigation, fertilizers, and pesticides. Since seeds cost less than these other inputs, the demand for seed is likely to be affected by their price or availability (as is the case when inputs are rationed). The role of subsidized credit in facilitating the adoption of new technology has been well documented in the literature (Feder, Just, and Zilberman 1985).

Relative Price of Crops

The demand for seed depends on the output plans of the producer. The demand for sorghum seed, for example, depends on the market incentives for crops competing with sorghum for the same land. In Kenya, the demand for maize seed fluctuates as the price of maize (relative to other crops) changes according to government policy (Lynch and Tasch 1981).

Farmers' Forecast of Weather Conditions and Prices

The demand of farmers for seed is conditional on their forecast of weather and prices at the time of planting, so the demand for seed varies year to year. This variation is important to seed enterprises, which need to project demand accurately in order to avoid being saddled with unsold stocks or being unable to meet demand. Some uncertainty is unavoidable, however, since firms make their seed production decisions many months before farmers decide on their demand for seed.

Costs of Reaching Distribution Outlets

In developing countries, the density of retail outlets is sometimes so low that farmers incur significant transportation costs if they wish to obtain seeds from the outlets. This can substantially reduce the demand for seed sold through an organized distribution network, as illustrated by Pakistan's experience with diffus-

ing improved wheat seed. In their survey of farmers using improved varieties, Tetlay et al. (1988) found that when farmers change varieties, their most important source of seed is other farmers (see Table 14). Retail seed outlets are important for the initial introduction of seeds, but not for diffusion, which takes place largely through transfers of seed from farmer to farmer. Seed transfers are highly localized and therefore probably reflect the high transportation costs of contacting the formal seed system.

Table 14—Initial source of new varieties of seed in Pakistan

Source	Rice Zone	Cotton Zone	Marden District
		(percent)	
Other farmers	56	47	46
Seed depot	37	52	14
Research and extension	...	...	18
Shopkeeper or grain merchant	5	2	...
Other	2	...	21

Source: Paul Heisey, ed., "Transferring the Gains from Wheat Breeding Research and Preventing Rust Losses in Pakistan." CIMMYT (Centro Internacional de Mejoramiento de Maiz y Trigo), Mexico City, 1988.

Notes: The survey areas are in the irrigated rice-wheat cropping system of northeastern Punjab; in the irrigated cotton-wheat cropping system of southern Punjab; and in Mardan district, representing the irrigated Peshawar Plain.
The ellipses (...) indicate a negligible amount.
Numbers may not add to 100 due to rounding.

FACTORS AFFECTING SUPPLY

The costs of producing and distributing seed can be broken up into four basic components corresponding to the stages of seed production. If C_i is the total cost of producing seed of variety i, then it can be written

$$C_i = C_{1i} + C_{2i} + C_{3i} + C_{4i},$$

where

C_{1i} = the costs of research and development to produce variety i,
C_{2i} = the costs of farm-level multiplication of seed of variety i,
C_{3i} = the costs of conditioning, processing and transporting the commercial seed of variety i, and
C_{4i} = the costs of distributing and marketing commercial seed of variety i.

Besides the above costs, the supply of seeds is also affected by the risks of the business. The cost of these risks may be implicit or explicit, depending on whether the seed enterprise bears the risk or transfers it to others through insurance or other means.

Research and Development Costs

The basic input in seed production is the breeder seed, which embodies the improved genetic characteristics. The costs of producing the breeder seed are essentially the costs of research and development plus the cost of multiplying enough breeder seed to distribute to seed companies. The key inputs are scientists; germplasm; the stock of scientific knowledge; laboratories; and land, labor, and other farm inputs. Private sector seed industries in the United States spend 3-4 percent of the value of their sales on research and development. In India private companies spend about 4 percent (Pray et al. 1989), while in Argentina they spend about 5 percent of sales (Jacobs 1986;[10] Gutierrez 1985).

The costs of research and development exhibit the following characteristics: (1) Since an improved variety cannot be produced without breeder seed, but once this is developed it can be multiplied indefinitely, research and development costs are essentially fixed. (2) Research and development involve years of testing and selection. The gestation lag from the initial expenditure on a plant breeding project until a variety is ready for the market can be more than 12 years. (3) Improved varieties developed by research are often superior to local varieties only in a limited agroclimatic region. (4) Expenditures made for research and development do not assure that improved varieties will be developed.

The economic consequences of these characteristics are profound. Owing to the fixity of costs and gestation lags in research, the natural barriers to entering the seed industry may be formidable. Although plant breeding is more easily divisible than some other types of research that require large laboratories, large investments may be required to develop a competitive program of research and development for major markets. Smaller firms often depend on public research and development to provide them with new varieties or basic research to overcome their disadvantage. Since research is also crop- and region-specific, smaller firms sometimes survive by breeding for market niches. Agroclimatic specificity limits the transfer of finished varieties from the advanced seed industries of the developed countries to those of the developing countries. However, advanced breeding lines and other genetic material from developed and other developing countries can greatly reduce the cost of producing new varieties. In addition, because basic biological science is much less location specific than applied technology, basic scientific advances in developed countries can also reduce the cost of developing new varieties.

The lags and the uncertain payoffs mean that firms will probably require a substantial risk premium on their returns to investment in research and development. More important, once the breeder seed of a variety of a self-pollinated crop is available, anyone can copy it. Therefore, companies cannot capture all the potential economic benefits from breeding a new variety, and these benefits are passed on to farmers and consumers. Because investing in research and development is risky and companies cannot capture all the benefits, private firms will invest less than the socially optimal amount in plant breeding research.

Multiplication Costs

Several rounds of seed multiplication are involved once the initial quantity of seed leaves the breeder. At least one stage intervenes between the production of breeder seed and commercial seed. The output of the intervening stage is referred to as foundation seed or basic seed (see Table 15 for the nomenclature used in several Asian countries). Multiplication costs frequently account for the largest share of the total cost of production. In the United States they make up 30 percent of the price of hybrid maize (Leibenluft 1981). In India between 40 and 60 percent of the price of pearl millet and sorghum seed is accounted for by multiplication costs (see procurement price in Table 16).

Seed enterprises usually subcontract farmers to multiply foundation seed into commercial seed. The price of grain sets the minimum floor that contract farmers receive for multiplied seed. The actual payment is usually higher than the minimum, however, because growers must take more care and observe special precautions when growing seed. Significantly more labor and supervision is involved in producing hybrid seed, and so labor costs are one determinant of how much of a premium over the price of grain is needed to induce farmers to grow seed instead of grain. Besides grain prices and wage rates, the costs of producing commercial seed also depend on its yield or multiplication ratio. Seed yield depends on a number of factors, including management practices and environmental conditions. Seed yield also depends on the yield potential of the seed parent. It is lowest for single-cross hybrids because the parent lines are inbred. This adds to the cost of producing single-cross hybrids. Seed yields can be increased and costs lowered by producing three-way crosses and double crosses, where one or both of the parent lines are single crosses. Even then, the cost of producing a double-cross hybrid is greater than the cost of growing an open-pollinated variety of seed (see Table 17).

Postharvest Cost

After the seed is harvested it is dried, cleaned, chemically treated, packaged, and stored until it is distributed. These operations account for about 15 percent of the price of hybrid maize seed in the United States and for between 8 and 18 percent of the price of hybrids and between 20-30 percent of the price of varieties in India. Many postharvest activities require a reasonably well-developed infrastructure to operate efficiently. For instance, electric dryers make severe demands on the electrical system in developing countries with poor infrastructure. However, traditional floor-drying methods are cumbersome and inefficient (Delouche and Baskin 1989). Since har-

Table 15—Comparative seed nomenclature in selected developing countries

Definition	Multiplication Step	China, Indonesia, Japan, and Thailand	India	Korea, the Philippines, and Sri Lanka	Nepal	Pakistan
First generation supplied by plant breeder for multiplication	...	Breeder seed	Nuclear seed	Breeder seed	Breeder seed	Prebasic seed
Second generation supplied for multiplication	First step	Foundation seed	Breeder seed	Foundation seed	Foundation seed	Basic seed
Third generation supplied by seed farms	Second step	Stock seed	Foundation seed	Registered seed	Certified seed	Approved seed
Fourth generation supplied by seed growers	Third step	Extension seed	Certified seed	Certified seed	Certified seed	Certified seed

Source: Masanobu Yamashita, "Regional Report on Cereal Seed Industry in Asia and the Pacific," in *Cereal Seed Industry in Asia and the Pacific*. Tokyo: Asian Productivity Organization, 1987.

Table 16—Estimated production and marketing costs, prices, and margins in the public and private seed industries for pearl millet and sorghum, India, 1987

Crop/Type of Company	Procurement Price[a]	Processing and Packaging	Margin: Seed Company[b]	Margin: Distributor[c]	Retail Price
Sorghum					
Private company					
Private hybrid					
Rupees/kilogram	5.7	1.5	5.3	2.2	14.7
Percent of retail price	38.8	10.2	36.1	14.9	100.0
Public hybrid					
Rupees/kilogram	5.2	1.5	1.5	2.0	10.2
Percent of retail price	51.0	14.7	14.7	19.6	100.0
State seed corporation					
Public hybrid					
Rupees/kilogram	5.8	1.5	2.0	0.8	10.1
Percent of retail price	57.4	14.9	19.8	7.9	100.0
Public variety					
Rupees/kilogram	2.8	1.5	0.3	0.4	5.0
Percent of retail price	56.0	30.0	6.0	8.0	100.0
Pearl millet					
Private company					
Private hybrid					
Rupees/kilogram	7.6	1.5	7.0	3.2	19.3
Percent of retail price	39.4	7.8	36.3	16.5	100.0
Public hybrid					
Rupees/kilogram	5.8	1.5	2.1	2.5	11.9
Percent of retail price	48.7	12.6	17.7	21.0	100.0
Public variety					
Rupees/kilogram	3.6	1.5	1.0	0.6	6.8
Percent of retail price	52.9	22.1	14.7	8.8	100.0
State seed corporation					
Public hybrid					
Rupees/kilogram	5.1	1.5	1.0	0.9	8.5
Percent of retail price	60.0	17.7	11.8	10.6	100.0
Public variety					
Rupees/kilogram	3.6	1.5	1.0	0.6	6.7
Percent of retail price	53.7	22.4	14.9	9.0	100.0

Source: Carl E. Pray, Sharmila Ribeiro, Rolf A. E. Mueller, and P. Parthasathy Rao, "Private Research and Public Benefit: The Private Seed Industry for Sorghum and Pearl Millet in India," Economics Group Progress Report 89, International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India, June 1989.

[a]Price seed companies pay to their contract farmers for producing seed.

[b]Difference between the wholesale price and the costs of procurement, processing , and packaging.

[c]Difference between the retail and wholesale price.

Table 17—Selected costs of growing maize seed in developing countries and the United States, 1986

Input/ Activity	Developing Countries: Improved Variety, Cost/ Hectare	Developing Countries: Improved Variety, Percent of Total Cost	Developing Countries: Double-Cross Hybrid, Cost/ Hectare	Developing Countries: Double-Cross Hybrid, Percent of Total Cost	Single-Cross Hybrid, United States, Cost/ Hectare	Single-Cross Hybrid, United States, Percent of Total Cost
	(US$/hectare)		(US$/hectare)		(US$/hectare)	
Parent seed	17.10	7.21	26.90	8.45	100.00	18.18
Fertilizers	100.00	42.19	101.40	31.87	100.00	18.18
Pesticides	37.00	15.60	41.50	13.04	70.00	12.73
Herbicides	20.00	8.43	22.50	7.07	60.00	10.91
Roguing[a]	7.70	3.25	9.00	2.83	15.00	2.73
Detasseling	0.00	0.00	44.10	13.86	115.00	20.91
Supervision and inspection	19.50	8.22	23.60	7.42	15.00	2.73
Harvesting	35.90	15.13	49.20	15.46	75.00	13.64
Total	237.20	100.00	318.20	100.00	550.00	100.00

Source: CIMMYT (Centro Internacional de Mejoramiento de Maiz y Trigo), *1986 CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Product in Developing Countries* (Mexico City: CIMMYT, 1987).

[a]Roguing is removing off-type plants from fields.

vesting, processing, and storage occur at different locations, transportation is always an essential element of cost. In developing countries, however, inadequate infrastructure makes transportation costs even more important. As Table 18 shows, transportation costs as a proportion of processing costs are four times more important in developing countries than in the United States. Inventories need to be held because of the lag between harvesting and selling the seed. Inventory costs can be quite high in developing countries, however, because credit tends to be expensive.

Distribution and Marketing Costs

Distribution and marketing costs are largely determined by transportation costs, publicity costs, dealer margins, and overheads. Together they account for more than 10 percent of the price of hybrids in the United States (Leibenluft 1981). In India, they vary from 8 to 20 percent (Table 16) (Pray et al. 1989).

As mentioned earlier, transportation costs tend to be high in developing countries. Transportation bottlenecks often seem to pose a severe problem in getting seed to the distribution (retail) outlets from the multiplication and processing centers.

In many developing countries, distribution is in the hands of government seed corporations. Chaudhury and Heisey (1988) have criticized the Pakistan Seed Corporation for its ineffective distribution and marketing network. Part of the distribution failure, they say, is due to artificially low dealer margins (below 10 percent), which reduce the incentive for private dealers to distribute the corporation's seed. Where private seed companies compete with public sector seed corporations, their dealer margins are consistently higher (above 10 percent) than the dealer margins of state seed corporations (see Table 18 from Pray et al. 1989). The state-run Kenya Seed Corporation is an exception: its success in distributing hybrid maize has been attributed to its policy of offering attractive margins to retailers (Lynch and Tasch 1981).

Public sector seed corporations are not always tightly managed, and in the absence of competitive pressure they tend to run up high overhead costs. The Tanzanian Seed Corpora-

Table 18—Selected costs of processing maize seed in developing countries and the United States, 1986

Processing Activity	All Types, Developing Countries: Cost/ Ton	All Types, Developing Countries: Percent of Total Cost	Hybrids, United States: Cost/ Ton	Hybrids, United States: Percent of Total Cost
	(US$/ton)		(US$/ton)	
Transport	12.00	12.37	4.00	3.33
Drying	17.00	17.53	19.00	15.83
Certification	5.00	5.15	1.00	0.83
Conditioning, chemical treating, and packaging	63.00	64.95	96.00	80.00
Total	97.00	100.00	120.00	100.00

Source: CIMMYT (Centro Internacional de Mejoramiento de Maiz y Trigo), *1986 CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Product in Developing Countries* (Mexico City: CIMMYT, 1987).

tion (TANSEED) earns a huge margin on its seed operations, but runs a loss year after year because of the high overhead at its headquarters. In many countries, the government absorbs most of the overhead costs without passing them on to the consumer (farmer).

In order to increase their market, firms and their dealers spend a substantial amount of money on demonstration plots in farmers' fields, field days for farmers, and advertising on radio and television and in print. Companies that breed their own varieties may have a team of technicians that sets up demonstrations, trains dealers and farmers, and deals with complaints about the seed.

The Risk Premium

Seed enterprises face three kinds of risks. By its very nature, the outcome of research efforts cannot be predicted with certainty. Firms that do not undertake research can escape the uncertainty of research investments. Firms that supply seed also face the same types of weather and disease problems that any agricultural producer faces. Companies attempt to decrease the risk of insufficient supply by diversifying the location of seed production and storing greater quantities of seed.

All firms face the uncertainty of demand. The demand for seed is the result of the farmers' assessment of weather conditions and forecast of output prices before planting. Since breeder seed has to be made available at least a couple of growing seasons before certified seeds are produced, decisions to multiply a variety have to be made well in advance of anticipated demand.

It is not known how private seed firms cope with the uncertainty of demand. Economic theory posits that if the seed firms are risk averse, they will, however, demand a higher price for assuming the risks of increasing supply (known as the risk premium). Extreme uncertainty may force a firm to drop out of the business or reduce the scale of its operations. Public sector seed corporations, on the other hand, may have no choice but to bear the costs imposed by the inability to forecast demand. In the words of one former official of the Kenya Seed Company,

> To perform the seed multiplication and distribution functions properly requires immediate commercial decisions which involve a significant element of risk taking. An example of the typical decision which involves

risk is: How much to produce? In a developing country, especially one in which you are the sole source of seed, you must not produce too little. Politically, adequate seed production is a sensitive issue . . . That's one reason we choose to over-produce and go to the banker when we have problems financing our inventory of seeds.[11]

THE DEVELOPMENT OF THE SEED INDUSTRY

The development of a seed industry proceeds through four stages.[12] In stage 1, no seed industry exists because no improved varieties exist. In stage 2, farmers begin to use varieties developed by formal research and development. Most seed is still produced by the farmers themselves, but the new varieties are produced and distributed by government or commercial seed companies. In stage 3, the use of improved varieties spreads as the private sector begins to be a significant source of new technology. Both public and private enterprises produce and market seed. In stage 4, most of the varieties planted by farmers are bred in private research programs and all of the commercial seed is produced and marketed by private firms.

In the first stage, formal research and development has not produced new varieties that have had an impact on farmers, but farmers themselves have gradually improved their varieties over time by selecting the best grain in the fields, trying off-types found in their own fields, and experimenting with varieties brought from other regions (Richards 1986). Many villages or regions have households that specialize in selecting, producing, and storing seed. No demand exists for commercial seeds because they are not superior to farmers' seeds.

In the second stage, superior varieties are developed by local research or introduced from outside the region. The seeds of these varieties have to be multiplied and distributed if they are to increase production or improve crop quality. Institutions are established to produce and distribute seed.

In most cases, the force behind the movement from stage 1 to stage 2 is government research. The government's motivation to invest in agricultural research is a combination of broad political pressure to increase food production and the specific interests of groups of merchants, processors of agricultural products, and large farmers who are organized around a commercial commodity. In a few cases, the commercial interests may themselves be organized into a coalition large enough to undertake direct research activities in commercial crops.[13] Due to the long gestation lags and inherently risky nature of research, formal research and development can only be initiated by an organization that has access to finance and can bear the risk. In many developing countries the government is the main institution that can do this.

Once public research produces improved varieties—particularly varieties with clearly superior yields like the green revolution wheat varieties—the demand for improved seeds increases significantly, which provides opportunities for private firms to supply seed. Large farmers and seed traders are the most likely to sell improved varieties developed by the government or imported from other countries. The government may train new seed firms to produce seed and provide future seed firms with markets for their crops. Governments may also respond to the demand for improved seeds by directly undertaking the production and distribution of seeds.

In the third stage, private companies, through their research and development, successfully develop commercial crop varieties. The private varieties are almost always hybrids.[14] Public research maintains a dominant role in the development of improved open-pollinated varieties. Private companies produce foundation seed of both private and public varieties. The demand for improved seeds in general, and private hybrids in particular, increases. The availability of complementary inputs like fertilizers and pesticides is less of a constraint. Since more of the improved varieties are hybrids, farmers cannot produce them as easily as they can produce improved varieties. Therefore the demand for commercial seed increases. Between 5 and 40 percent of the seed planted is commercial seed produced by

government agencies or private companies. If the main crops of the country are self-pollinated, the percentage of commercial crops (that is, the proportion of seed planted that is purchased from the seed industry) will be lower. If they are cross-pollinated, the commercial percentage will be higher. With the growth of private companies that have proprietary hybrids, private advertising and technical services increase as a means of improving their competitive position. The widespread use of hybrids increases the average cost of seed. The popularity of improved varieties may also have environmental consequences. Planting genetically similar varieties over large areas and using higher doses of fertilizers and more irrigation may lead to more disease and pest problems than in the past and require farmers to replace their varieties much more often.

The dynamic factor that moves countries from stage 2 to stage 3 is the profit that firms make producing and distributing seed. Credit markets are imperfect everywhere, particularly in developing countries. The ability of a firm to generate an investable surplus is therefore critical in allowing it to take on risky projects with long gestation periods.[15] If in stage 2 government policies allow seed firms to make sufficient profits, and if there is scope for producing hybrids of the major crops, some firms will start to invest in plant breeding programs. The success of private research and development in producing new hybrids and the expansion of private seed production and distribution mark the beginning of stage 3. At the same time, continued public investment in extension and rural infrastructure contributes to increasing the demand for improved seeds.

The fourth stage is distinguished from the third in that private companies do most of the research on plant breeding, produce most of the breeder seed, and produce virtually all of the foundation and commercial seed. In Western Europe, most governments leave the breeding of finished varieties to the private sector. In the United States, the Department of Agriculture recently stopped producing finished varieties, but state agricultural universities continue to be important sources of new varieties. The public research institutions that continue to do research arrange to have the seed multiplied and distributed by groups of seed companies or farmer cooperatives. The public sector puts greater emphasis on basic science and other activities that do not interest the private sector (for example, open-pollinated varieties or minor crops).

Once again, profits from the activities of the earlier stage are the dynamic force that moves the private seed industry to venture into new areas. Private firms become more active in developing pure-line varieties, especially if, as a result of their lobbying, the government enacts a plant variety protection act. In a mature seed industry, the investment in research is large enough to produce a rapid turnover of varieties. In fact, maintaining a technological edge by quickly developing new varieties becomes a major basis of competition.

4

Government Policies

The analysis of the stages of seed industry development suggests that the key issues proposed in the introduction are particularly important in certain stages of the development process. The first issue—the seed industry as a constraint to development—is really a question of how a country can move most efficiently from stage 1 to stage 2. The issue of privatization is an issue in stage 3. The preservation of plant genetic material becomes increasingly important as landraces are replaced by commercial varieties in stages 3 and 4. Property rights are primarily an issue in stages 3 and 4, although farmers' rights are concerned with funding research and preserving germplasm in all stages of industrial development. Self-sufficiency can be an issue in stages 2-4.

Table 19 shows government interventions in the different stages in the development of the seed industry. The components of supply and demand for commercial seed are listed along the left side. The cells of the table are stylized facts describing the major government institutions and policies at different stages of development. Government policies affecting the seed industry fall into one of seven categories:

1. Government research and germplasm preservation,

2. Government incentives for private research,

3. Government seed production and distribution,

4. Government incentives for and regulation of private seed production and distribution,

5. Promotion of seed demand through extension, subsidies to farmers, and government procurement,

6. Trade and foreign investment restrictions, and

7. Public investment in rural infrastructure and public policies toward agriculture.

In a market economy, the governments act to increase economic efficiency because of externalities, incomplete markets, and problems of supplying public goods. Government intervention can also be justified on the basis of income distribution and other societal goals. Below, each policy is assessed on the basis of whether economic theory suggests that it contributes to economic efficiency. Then, anecdotal evidence and empirical studies are examined to determine what is known about the impact of these policies on efficiency and income distribution.

GOVERNMENT RESEARCH AND GERMPLASM PRESERVATION

Public agricultural research or subsidies for private research can lead to efficiency gains for a number of reasons. Economic theory suggests that private companies will not spend the socially optimal amount on research. The output of expenditures for research and development in the seed industry yields large positive externalities, and companies that develop new varieties only capture part of the benefits. Most of the benefits are captured by farmers and ultimately by consumers. Further, the outcome of research and development investment is uncertain, and the payoffs are realized only after a long gestation period. Thus government investment may be needed to bring research near an optimal level.

In stages 1 and 2 public research on plant breeding is particularly important. Access to technical personnel and finance and the ability to bear risk are the key attributes of an organization capable of mounting a research effort.

Table 19—Important policies in the development of the seed industry in developing countries, by stage

Elements of Supply and Demand	Stage 1, Farmer Selection and Supply	Stage 2, Introduction of Improved Varieties	Stage 3, Widespread Use of Improved Public Varieties and Early Spread of Private Varieties	Stage 4, Mature Seed Industry
Components of supply				
Research and development (R & D)	Farmers experiment, public R & D occurs near the end	Public R & D produces new varieties; private companies start R & D on hybrids	Both public and private firms produce new varieties and hybrids	Private firms produce most new varieties; public does basic R & D and minor crops
Seed production				
Breeders seed	None	Public R & D institutions	Public and private R & D institutions	Private firms; public firms for cooperatives and minor crops
Basic and foundation seed	None	Government farms	Government farms; government organized cooperatives of farmers; farms of private companies	Private companies and farmer cooperatives for public varieties
Commercial seed	None	New varieties of government farms, contract growers organized by the public or private sectors	Public and private firms, with share of private firms increasing	Private companies, farmer cooperatives
Marketing and distribution	Local trading of farmers seed	Distribution by public and private firms	Public and private firms, with the share of private firms increasing	Private companies; farmer cooperatives
Determinants of demand				
Superiority of new varieties	Not applicable	High-yielding varieties superior with fertlizer	Public and private varieties superior	Private superior to public, few public varieties produced
Availability of complementary inputs	Some fertilizers and irrigation	Fertilizers available but limited because of government supply	Fertilizers and other agricultural chemicals available	Fertilizers and other agricultural chemicals available
Farmer's ability to produce and save seed	Not applicable	Improved varieties, easy to save	Farmers cannot produce hybrids; more disease accompanies new varieties due to high plant population and fertilizers	Farmers cannot produce hybrids; better genetic resistance and more processing facilities
Information about new varieties	Other farmers	Extension	Other farmers; extension; private advertising	Extensions provide consumer information, advertising
Transportation and communication	Poor transportation	Poor transportation	Improved transportation	Developed transportation
Seed prices	Not applicable	Close to grain prices	Private hybrids have higher prices	Private hybrids have high prices
Overall agricultural policy	Agriculture taxed	Agriculture taxed	Transitional stage	Subsidized agriculture

The availability of technical personnel depends largely on public investment in education and training since the externalities involved are too significant for a large amount of private involvement. The availability of finance and the ability to take on risky projects are derived from an organization's size and access to functioning credit markets. When scientists are in very short supply and credit markets are imperfect, the government is often the only entity capable of transcending the market failures and initiating the research process.

Even at later stages, when the private sector has started to do research, public research can increase efficiency. By investing in research the public sector can bring the total amount of agricultural research closer to the optimal level. In addition, the characteristics of research and development that prevented private initiative in the first place may also be a barrier to competition. Public research, whose results are available to small firms as improved germplasm or inbred lines, is an important mechanism for neutralizing the technological edge of large firms.

The empirical evidence confirms the social profitability of public research. Many of the studies of rates of return to agricultural research—particularly those that use the index number approach—measure the returns to plant breeding research (see Hayami and Ruttan 1985). These studies show very high rates of return to different types of public plant breeding research at each stage of seed industry development.

Colonial breeding programs in India early in the twentieth century are examples of productive government research programs in stages 1 and 2. In the Punjab, the British were able to develop improved cotton varieties that were higher quality and received a price premium over old varieties and wheat and sugarcane varieties that yielded more than the local varieties. The rates of return to research during the colonial period were over 30 percent (Pray 1983).[16]

Recent research by the Indian public agricultural research system and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) on pearl millet and sorghum shows that government research can play an important role even in stage 3, when the private sector has started plant breeding programs. The government and ICRISAT have provided disease-resistant male sterile lines of pearl millet that the private sector has used to develop some popular hybrids. In sorghum, government hybrids continue to compete effectively with hybrids produced by the private sector and probably help keep seed prices down.

U.S. public research and development is an example of research at stage 4. Huffman and Evenson (1991) have calculated the benefits derived from U.S. government plant biological research, which consists primarily of plant breeding. In their analysis they held private sector research constant and then estimated the impact of public research. They found that public research was a significant explanatory variable and that the rate of return to public research was very high.

INCENTIVES FOR PRIVATE PLANT BREEDING

The results of research have the characteristics of a public good. This is especially true of the research directed toward improving open-pollinated varieties. Since the seeds of such varieties can be reproduced and sold by farmers or competing firms, private firms cannot appropriate all the economic gains. Private profitability therefore is not a guide to social profitability of investments in variety research. One way to increase appropriability and private profitability is to introduce *and enforce* patents or plant breeders' rights. Patents, however, restrict the exchange of research results. In industries like the seed industry that have high technological spillovers, public subsidies of private research may be preferable to introducing patents (Spence 1984).

In stage 2, after the private seed industry has started to produce and distribute seed, incentives for private research may have some effect. The one policy that has clearly encouraged private sector research in developing countries is government research on hybrids. The joint research program undertaken by Kasetsart University, the Rockefeller Foundation, and CIMMYT on downy mildew in maize in Thailand was the basis for private breeding of hybrid maize in Thailand and the Philippines (Pray 1987). The Indian government's research on hybrid maize, sorghum, and pearl millet,

supplemented by ICRISAT's work on pearl millet and sorghum, stimulated private plant breeding in India (Pray et al. 1989). Research on hybrid rice by the Chinese government and by the International Rice Research Institute stimulated private sector research on hybrid rice in India, Pakistan, the Philippines, and the United States.

Another policy that has stimulated private research in some countries is the recognition of plant breeders' rights. Countries that have private sector breeding programs in self-pollinated crops like wheat and soybeans—the countries of the European Community, the United States, Argentina, and Chile—also have plant breeders' rights. Two studies of the U.S. seed industry showed that private breeding of wheat and soybeans increased around 1970 when the Plant Variety Protection Act was passed (Perrin, Hunnings, and Ihnen 1983; and Butler and Marion 1985). No study has been able to isolate plant breeders' rights as the cause of private breeding, however, because changes in technology[17] and prices were taking place in the United States at the same time as the introduction of plant breeders' rights.

Public investment in training plant breeders at home and abroad increased the number of plant breeders and other scientists available to private firms. Most of the plant breeders working in private companies in Asia had previously worked for government research institutions.

The effects of other policies to stimulate private research and development have been uncertain. Some countries have tried tax rebates for private research. India had offered tax incentives for private research, but eliminated them in 1985 because some policymakers felt that companies were labeling other expenses as research and development in order to receive tax breaks. No study has been done on their effectiveness.

A number of countries have restricted private research. Pakistan only allowed private plant breeding recently. Other countries do not formally restrict private plant breeding, but discourage the involvement of private companies by making public germplasm collections inaccessible or instructing extension agents not to recommend private varieties. Excessive testing of privately developed material by public agencies and slow varietal release procedures have also been constraints.

GOVERNMENT SEED PRODUCTION AND DISTRIBUTION

Seed production and distribution do not appear to possess the characteristics of public goods or externalities that justify public intervention. In stages 1 and 2 of seed industry development, however, private firms may not have accurate information about the risks and benefits of multiplying and distributing seed. This market failure would lead private companies to underinvest in seed production and distribution. Therefore government investment in pilot seed production programs and market development may have positive benefit to cost ratios. Alternatives such as technical assistance and training on seed technology, coupled with subsidized inputs, especially capital, might be equally effective in moving a seed industry from stage 1 to stage 2.

Some government seed programs, such as the Thai rice seed program, seem to have been quite effective in producing and distributing seed (Setboonsarng, Wattanutchariya, and Phutigorn 1988). Some of the Indian state seed corporations, like the Andhra Pradesh State Seed Corporation and the Maharashtra State Seed Corporation, also seem to be quite effective. Indonesia has developed an effective rice seed production program, and the Kenya Seed Company seems to do a good job (Ruigu 1988). Unfortunately, a larger number of government seed programs have been less successful. Many farmers complain about the quality of seed sold by PRONASE in Mexico. The National Seed Corporation and the Haryana State Seed Corporation in India annually incur massive operating deficits that must be financed by the government. In Tanzania the government seed monopoly, TANSEED, supplies only one-third of the demand for certified maize seed and charges farmers two times what private seed companies say they could sell hybrid maize seed for and still make a profit. It operates at a loss every year despite the high prices farmers pay (Friis-Hansen 1988).

There are enough examples of rapid distribution of high-yielding varieties in countries with no government production and distribution of commercial seed to put into question the necessity of government production. A variety named Pajam, which was developed in the

Philippines, was introduced into Bangladesh (then East Pakistan) around 1965 by the Academy for Rural Development in Comilla. The government would not officially approve the variety so that the Agricultural Development Corporation did not multiply Pajam and extension agents were supposed to discourage its use. Yet because of its high yield and relatively good eating quality, it was the most popular improved rice variety in Bangladesh in 1978 (Pray 1979). The farmers of the Indian Punjab replace their wheat varieties more often than most farmers in the world (except Mexican farmers in the Yaqui Valley) (see Brennan and Byerlee 1989), yet their state seed corporation is the smallest in India, and they buy the smallest percentage of their seed from the state seed corporation (India, Ministry of Agriculture 1989). The secret of their success seems to be that the university distributes good foundation seed through farmer fairs and demonstrations on farmers' fields, and then farmers rapidly multiply their own seed.

The United States and Argentina are examples of countries that have never had large government programs to produce commercial seed. Before 1900 the U.S. government did distribute small packets of new varieties that had been introduced from other countries, but their role ended in the early part of this century (Kloppenberg 1988). The state experiment stations produced breeder seed and sometimes foundation seed of the varieties they bred. They rarely produced commercial seeds. They organized groups of farmers and seed companies into crop improvement associations that multiplied seeds and ran the seed certification programs. In the 1930s with the spread of maize hybrids, some small seed companies established their own maize breeding programs and expanded quite rapidly.

In Argentina private companies and large farmers started producing seed of government-developed varieties and selling them to other farmers in the 1920s and 1930s (Gutiérrez 1985). In the 1950s hybrid maize was introduced and popularized by private companies like Morgan and Cargill. Hybrid sorghum was introduced by DeKalb. The semidwarf wheat varieties adapted to Argentina were developed simultaneously by the government breeding program and private companies. The government encouraged the multiplication and distribution of its varieties through an association of farmers called Productores de Semillas Selectas Coop. Ltd. (PRODUSEM).

In stages 2 and 3 government production of seed cannot be justified on grounds that private firms have insufficient information. It may be justified, however, as a means of preventing a monopoly, although there may be better ways of fighting a monopoly than by government seed supply. A stronger case may be made for producing public seed on grounds of equity rather than efficiency. Selling seeds to large commercial farmers growing hybrids, vegetables, and cash crops is easier than selling them to small farmers growing subsistence crops in marginal rainfed areas. The latter do not represent a high-value, high-growth market and will likely be ignored by the private sector. Private firms will breed subsistence crops if hybrid varieties can be developed (Pray et al. 1989), but in most subsistence crops hybrids have not been developed. Therefore government involvement in the production and distribution of seeds may be necessary to meet income distribution goals. Recent work at CIAT and in several national programs indicates that increased attention to developing small farmer seed production and sales can help meet farmers' needs.

The actual consequences of government action may not, however, improve the distribution of income. For instance, the state seed corporation in Tanzania, which has a monopoly on the production and distribution of seed, is so inefficient that farmers simply do not have enough hybrid maize seed to plant. In such a situation, small farmers have the least access to seed (Friis-Hansen 1988, 40). Since state agencies are also political institutions, they, like the private sector, tend to direct their activity toward agents with large endowments.

GOVERNMENT INCENTIVES AND REGULATIONS

In addition to directly producing and marketing seed, the government can encourage the private sector to undertake some of these activities. At the same time, some government policies discourage the private sector from playing a larger role. Incentives for the private sector include government research programs, training programs, subsidies on inputs and outputs, and government procurement.

Most countries that now have a private seed industry had government programs to train seed technicians. These programs usually trained technicians for government seed programs, some of whom were hired by the private sector as the seed industry developed. In India, the National Seed Corporation, working with the Rockefeller Foundation and the Agency for International Development, trained private seed firms how to produce and process seed. This program also enabled firms to purchase seed processing machinery at subsidized prices. In the early stages of many firms' development, the National Seed Corporation provided a guaranteed market for their seed. Furthermore, its prices, which were considerably higher than farmers traditionally paid for seed, also allowed private companies to charge enough to make a profit and expand. Finally, private Indian companies with the assistance of the Rockefeller Foundation and the Agency for International Development were able to keep certification voluntary rather than mandatory, which kept government seed corporations from acquiring a monopoly on the development of new varieties. More recently, the Indian government provided subsidized credit to private seed companies for capital investments.

Restrictions on the size of the market open to private companies are probably the most common constraint on the development of the private seed industry. In extreme cases, like Kenya, Tanzania, and (until recently) Mexico, government monopolies completely exclude private companies from selling improved varieties of major crops. In other cases, the government gives subsidies or other advantages to government corporations that compete with private companies.

In some countries, private varieties are difficult to get approved in government certification schemes. If certification is mandatory this may keep private varieties off the market entirely. If voluntary, lack of certification may reduce the demand for private varieties because farmers will be reluctant to buy them and government extension agents will be unable to promote them. In India the certification system also creates problems in moving seed from one part of the country to another.

One major way in which governments attempt to control private economic activity in the seed industry is through price controls. The CIMMYT survey found that in 22 of 34 noncentrally planned developing countries "the government exercises control over seed prices" (CIMMYT 1987, 19). In most countries, the government negotiates with the seed industry to determine prices, but in some, such as Mexico and India, the government only sets the price of seed sold by public institutions and allows the private sector to set prices as it wishes. Governments undoubtedly try to keep prices down, which subsidizes farmers who have access to the seed. The success of the policy depends on how much seed is available and the elasticity of demand for improved seed.

The problem with price policies that keep seed prices low is that they reduce the supply of seed in the short run and reduce incentives for private firms to invest in seed production, marketing, and research. Low prices can substantially slow the dynamics of movement between stages by reducing the profits that firms can capture from expansion and from research and development. In some countries retail prices are so tightly controlled that corporations cannot meet processing and distribution costs (CIMMYT 1987). In that case private companies stop producing, and government corporations continue producing, but do so at a deficit.

Some government seed programs appear to raise seed prices above market prices. As reported above, in Tanzania the government seed corporation sells seed at twice the price at which one large private company feels it could supply the seed (Friis-Hansen 1988). In India the prices of the National Seed Corporation are important guidelines for those of private seeds. Their prices are set on a cost-plus basis, and since they are not efficient producers their prices may be higher than those at which private companies could produce seed. If so, they may be providing a price floor that helps private firms increase their profits at the expense of farmers.

PROMOTION OF THE DEMAND FOR SEED

Most government extension services demonstrate new varieties on government farms and in farmers' fields, hold meetings to describe the benefits of new varieties, and use television, radio, and newspapers to publicize those benefits. They may also offer incentives

for using improved varieties, such as prizes for the highest yield or subsidized credit for the purchase of improved seeds. Publicity and benefits are initially restricted to public varieties.

As the private sector starts to develop improved varieties, some extension services start to conduct and publicize the results of field trials that compare the yields, quality, and disease and pest resistance of public and private varieties. These trials provide farmers with information on which to base their decisions about which varieties to use. An important determinant of the demand for improved seeds is the farmers' perceptions of the yield (or quality) gap. If the farmers' perceptions understate the yield difference or if companies' advertisements overstate the yield gap, the information from trials will help farmers make better decisions. Better decisions lead to higher yields and thus benefit society.

The potential role of extension was brought out in a recent survey of farmers' awareness of wheat varieties in Pakistan (Heisey et al. 1988). Even several years after the new varieties were introduced, more than one-third of the farmers were not aware of them. Surveys indicate that other farmers are a more important source of information about new varieties than extension. Extension is, however, usually the second or third most important source (Heisey et al. 1988; Ribeiro 1989). Even when aware of them, farmers may not have enough knowledge of the yield characteristics on their own farms to commit themselves to growing new varieties extensively. Farmers may resort to active systems of learning by pursuing a cautious strategy of adoption. The Heisey survey of wheat farmers in Pakistan found that the most common reason for planting old and new varieties simultaneously was that farmers wanted to compare the performance of each (Heisey et al. 1989). In Europe farmers find this type of information sufficiently important that they are willing to pay for organizations that will conduct such tests, such as the National Institute of Agricultural Botany in the United Kingdom (Garner 1986). In the United States, state experiment stations often conduct statewide tests of varieties and publish the results for use by farmers.

There are a number of empirical studies of extension systems (see Birkhaeuser, Evenson, and Feder 1988). During the green revolution in Asia the extension systems were particularly successful in promoting high-yielding wheat and rice. Several empirical studies show high rates of return to extension during this period, which is partly a return to their promotion of new varieties. However, apparently no studies of extension have isolated its role in promoting varieties in the early stages of seed industry development or in providing consumers with information in the later stages.

POLICIES ON TRADE, FOREIGN CAPITAL, AND TECHNOLOGY TRANSFER

Many developing countries prohibit or restrict commercial seed imports, but encourage the transfer of germplasm and knowledge to promote local seed industries and save foreign exchange.[18] National governments support the transfer of germplasm and knowledge through public research projects that exchange germplasm on a bilateral basis and through multilateral agencies such as international agricultural research centers and FAO. The same countries that restrict imports usually restrict the entry of foreign-owned seed companies. Under pressure from the World Bank and other donors, and perhaps also in recognition of the technical opportunities that farmers have forgone, India, Mexico, Pakistan, Turkey, and other countries are reducing the barriers and allowing foreign companies to play a larger role in the seed trade. In Latin America seed producers have formed an association that is attempting to reduce trade barriers.

Standard neoclassical trade theory shows that gains can be made from trade and foreign investment. This is supported by a large body of empirical economics literature. Some recent studies of the East Asian newly industrialized countries reveal, however, that their policies were not free trade policies, but a combination of judicious import barriers, some restrictions on multinational corporations, borrowed technology, and support for exports. Thus the empirical literature does not give a clear answer to the value of restricting the flow of trade and capital.

In the seed industry a number of developing countries have large, locally owned companies. Argentina, Bolivia, Brazil, Chile, Colombia, El Salvador, Guatemala, Uruguay, and

Venezuela in Latin America all have several locally owned seed firms.[19] India has built up a large locally owned seed industry: its largest local companies sell US$10-15 million of seeds annually. The industry is based on a strong public sector program of plant breeding technology borrowed from temperate regions through international agricultural research centers, government programs to train and provide equipment for seed production, agroclimatic differences from the United States and Europe that prevent most imported seed from being successful, and restrictions on imports and foreign companies. Indian firms now appear to be able to compete with the multinational companies that have recently been allowed into India's seed industry.

There is other evidence, however, that barriers to imports and foreign capital can reduce the flow of improved technology and produce a loss of income to farmers. Mexico allowed multinational corporations to operate freely in sorghum, but retained maize as a government monopoly until about five years ago. The production of sorghum has grown rapidly, while that of maize has grown slowly. No study has examined the reasons for the differences in productivity growth, but a likely candidate is the difference in seed policies. Anecdotal evidence suggests that vegetable seed prices declined in India when import restrictions were lifted, but so far no empirical studies have examined the impact of these policy changes on the price of seeds and the availability of technology. Recent cross-sectional studies of major maize-producing countries have shown that maize seeds imported from the United States contribute to higher yields in temperate regions of the world. They have also shown that the location of a multinational corporation's research program in a country is associated with higher yields of maize in tropical regions (Echeverría 1988). The differences in agroclimatic conditions of tropical and temperate regions mean that imports cannot substitute for local research.[20]

The technology transfer activities of government research organizations and international agricultural research centers have been very successful. Quantitative and qualitative studies have provided convincing evidence of the value of these activities (Anderson, Herdt, and Scobie 1988). Plant breeders from developing countries went directly to American land grant universities and to international agricultural research centers for samples of advanced breeding lines for the most important food crops.

Developing countries fear that new technology, from both conventional plant breeding and from the new biotechnology, will not be available in the future or that they will have to pay excessive charges to get access to it. They fear this because of several related trends. First, the seed industry is being consolidated as large chemical, pharmaceutical, and food companies in the United States and the European Community purchase seed firms. Second, intellectual property rights are being strengthened in the more developed world, and the governments of the United States, Japan, and Europe are pressuring developing countries to do the same. Third, in more developed countries the private sector share of biotechnology research is higher than its share of conventional plant breeding research. And fourth, universities in the United States, which were traditionally important sources of agricultural technology for many developing countries, are patenting their products of biotechnology.

This fear of losing access to new technology or of having to pay excessive prices for it is part of the reason a number of developing countries are opposed to extending patents to living things and to extending plant breeders' rights. Some feel that since the developing countries are the centers of genetic diversity and many major field crops are based on their germplasm, U.S. and European companies have no right to charge royalties for varieties based on that germplasm. In fact, they argue, the United States and Europe should pay royalties to developing countries in the form of "farmers rights" that would be placed in a Food and Agriculture Organization fund for germplasm preservation and research (International Coalition for Development Action 1988).

Although multinational corporations are unlikely to pay money to FAO for farmers' rights, the debate has focused attention on the need for more germplasm preservation in developing countries and on farmers' traditional practices of plant improvement, seed production, and storage.

One policy that is justified by the historical evidence: increase public support of technology transfers by investing in strong government research programs and in international centers

like those of the Consultative Group for International Agricultural Research and the United Nations Industrial Development Organization (UNIDO) biotechnology research center in New Delhi, India.

RURAL INFRASTRUCTURE AND AGRICULTURAL POLICY

The policies discussed above are largely aimed at improving the seed industry. Investments in rural infrastructure and general agricultural policies have more general goals and are determined fairly independently from the needs of the seed sector. They can, however, exercise a profound influence on the growth and structure of the seed industry.

Government investments in rural roads, markets, and communication systems can substantially reduce the cost of producing improved seed. They allow seed to be produced where it can be produced at the lowest cost. They reduce the transportation costs of processing and distributing. Better transportation also reduces the costs that farmers must pay to reach markets where they can purchase improved seed. It may also break local monopolies that drive up the price of seed sold to farmers. However, in most developing countries infrastructure investments are still low, and transportation costs are a far greater share of the costs of processing and distributing seeds in developing countries than in the United States (Table 18).

Governments of poor countries tend to overvalue exchange rates, restrict imports of foreign goods, and hold down the price of agricultural products. The net effect of these policies is to tax the agricultural sector. These policies reduce the demand for modern agricultural inputs and make investing in production, distribution, and research and development of seeds less profitable for private companies.

Studies of the benefits of reducing policy discrimination against the agricultural sector are numerous. Recent studies by Raisuddin Ahmed have shown the importance of infrastructure (Ahmed and Hossain 1990). None of these studies specifically look at the impact of better infrastructure on the seed industry, but the lesson is clear: better infrastructure cannot be justified simply on the basis of the seed industry, but the seed industry will certainly benefit from it.

5

Conclusions and Priorities for Future Research

Most of the literature on seed industries in developing countries is descriptive rather than analytical. There is enough evidence, however, to support the following conclusions about seed industry policy.

CONCLUSIONS

Farmers must be the basis of seed policy. Any effective seed policy must recognize what farmers can and cannot do. Farmers *can* efficiently reproduce and store seeds of most varieties of self-pollinated crops, such as wheat and rice. They can reproduce and store some varieties of open-pollinated crops and some clonal varieties. Many farmers will experiment with new varieties on small plots in their fields. They can learn of new varieties from relatives, neighbors, and merchants who sell agricultural inputs. Even poor farmers can afford to buy small amounts of expensive seeds, which they can use to reproduce enough seed to plant their entire farm with a new variety in a few years.

Farmers cannot efficiently do some activities. Only very large farmers can profitably conduct plant breeding research. They cannot efficiently reproduce and store seeds of certain varieties and crops. They cannot produce hybrid seed equal to the seed they purchase commercially. They cannot produce seed of certain forages or pastures or of vegetables that need special disease-free regions or agroclimatic conditions that are different from conditions where the crops are grown. Small farmers may have difficulty buying new varieties if the seed is not easy to reproduce and large quantities of seed are required, as is the case with potatoes and groundnuts. Governments can subsidize the price of seed of these crops, but these subsidies are limited because people will start buying seed for consumption if the price is too low.

One implication of these facts is that governments or large commercial companies will have to do much of the plant breeding research. Farmers will, however, experiment to determine which varieties work best given their particular conditions. The second implication is that for many self-pollinated crops only a small percentage of the total seed planted must be supplied by the government or commercial seed companies. Another implication is that farmers need government or commercial firms to supply seeds of crops they cannot reproduce, such as hybrids and crops that will not set seed in a particular region.

Development of the seed industry requires public plant breeding research and the technology for producing and processing seed. Improved varieties are a necessary but not sufficient condition for the development of a commercial seed industry. In the industry's early stages of development, improved varieties are almost always produced by public plant breeding research. Applied plant breeding research is a very productive public investment in the early stages of seed industry development. A second requirement for seed industry development is the technology for producing and processing seed. The amount of technical training and equipment needed will depend on the crop. Governments have almost always provided training and equipment. In many cases the training and equipment go to government companies, but in others they go to private companies.

These are the only types of interventions common to all successful seed industries. Although many developing countries have established government institutions for supplying seed, countries such as Argentina have developed successful seed industries without a

government agency for producing and distributing it. At the other extreme, China has successfully spread high-yielding varieties through government agencies that have a monopoly on seed production and distribution. In between these extremes farmer cooperatives of northern Mexico have received some public sector assistance and successfully supplied improved wheat seed.

Governments must recognize the limitations of private firms. The most efficient mix of public and private activities in the seed industry varies among countries and stages of development. The optimal mix has not been established at any stage. There are, however, limits to what developing countries can expect the private sector to do. Private companies will conduct research on hybrid crops like maize, sorghum, and sunflowers that have large markets, but will rarely breed self-pollinated crops like wheat and rice unless plant breeders' rights can be enforced. Large private companies will not invest much in the production and distribution of most self-pollinated crops because they cannot compete with farmers. Nor will large commercial companies invest in the production and distribution of hybrids for small markets.

Therefore at a minimum the governments of developing countries must continue to breed self-pollinated crops and produce enough foundation seed to ensure that farmers can spread new varieties. Some type of relationship will have to be worked out between government research and private seed producers so that breeder seed and foundation seed are kept pure and available to private companies for multiplication and sale to farmers.

Farmers lose if technology transfer is restricted. Restrictions on seed imports and on the role of foreign seed companies are common throughout the developing world. The gains from liberalizing import policies depend on how much technology is available from regions with similar agroclimatic conditions. Greece, Italy, and Chile have benefited greatly from importing as much as half of their hybrid maize seed from the United States, which has similar growing conditions. Developing nations in the tropics cannot benefit greatly from seeds imported from temperate regions, where the most developed seed industries exist. As seed industries in developing countries mature there will be greater benefits from increasing trade with other countries in the tropics. Some of the gains from increased imports may be lost if disease or pests are imported along with the seed. Thus, to get maximum benefits from seed imports, reduced barriers to imports must be coupled with improved plant quarantine facilities.

The transfer of varieties for use in breeding programs has been more important than seed imports as a means of transferring technology. In government research on wheat and rice, developing countries have been able to use varieties from Mexico, the Philippines, and elsewhere as parents for breeding successful high-yielding varieties. Governments and multinational corporations have adapted improved lines of maize to the tropics by breeding them with locally developed varieties. Recent studies show that tropical countries in which multinational corporations are conducting more research have a higher yield of maize than those in which they are conducting less. This indicates that multinational corporations can have a positive impact.

Although trade offers limited opportunities for growth, public and private sector research to adapt exotic varieties has large payoffs. Governments should encourage rather than restrict such research.

Governments should monitor the impact of infrastructure and price policies on the seed industry. The existence of more effective property rights apparently provides an incentive to private research on self-pollinated crops, but no estimates indicate how large that impact would be. Developing rural infrastructure would decrease transportation and communication costs and increase the productivity of the seed industry. Price and exchange rate policies that are more favorable to the agricultural sector should increase demand for improved seed. Theory and common sense support these statements although empirical studies of the impact of infrastructure and policy on the seed industry have not been conducted.

The model presented of the stages of development highlights the importance of sequencing properly the government's policies toward the seed industry. For example, a government seed company is unnecessary if improved seed is not available.

PRIORITIES FOR FUTURE RESEARCH

The modeling of the seed industry presented here is crude. More sophisticated modeling of supply and demand is essential before more empirical work can be done on the seed industry. Particular attention must be paid to modeling the decisions that farmers make about producing their own seed or purchasing seed. The quality of seeds and how farmers judge that quality are important issues. One issue that affects supply is the relationship between the structure of the seed industry and the investments that firms make in research and development, distribution, extension, and advertising.

A major gap in the literature is the lack of quantitative analysis of the benefits and costs of government seed production programs at different stages of the seed industry's development. If properly done, this research would help determine the amount of government production that is needed to start an improved-seed industry and the amount of privatization that should be done if the government already conducts research and distributes seed. This gap is a problem for policymakers who are trying to develop a seed industry or to extend that industry to new crops and for policymakers in developing countries who are under budgetary and donor pressure to reduce the role of government in supplying seed.

Conducting studies of successful seed programs confronts two important analytical problems. First, isolating the contribution of seed production and marketing from the contribution of research and extension is difficult. Careful modeling and large data sets with international research, extension, and government seed production may help solve this problem. The second problem is setting up the proper counterfactual scenario. What would the supply of seed have been in the absence of government programs? Most casual discussions of the necessity of setting up a government seed production program assume that in the absence of government programs farmers would not reproduce varieties and that private seed companies would not produce hybrids. This is not necessarily the case.

To calculate the benefits of a government seed program in self-pollinated crops requires an estimate of how fast farmers and seed companies would multiply improved seed and how fast farmers' seed would deteriorate in the absence of government seed production and distribution. This estimate requires village-level surveys of farmers' sources of seed, varietal experimentation practices, seed production and storage practices; studies of markets for seeds; and studies of the impact of government production and sale of seeds. India, where some regions still have traditional seed production and distribution practices while others have large government supplies, would be ideal for such a study. Studies of countries that have privatized government seed operations in recent years would allow an estimate of how fast private companies could replace public supplies. Senegal and Turkey have privatized their operations recently. Others privatized a number of years ago. Studying both would allow this impact of the policy change to be estimated quantitatively.

To calculate the benefits of government supply of hybrids and other varieties that are difficult for farmers to reproduce requires estimating how fast a private sector seed industry to produce hybrids would have developed in the absence of government programs. Perhaps the only way to estimate how fast this would occur is to study the way private industries have developed in countries with minimal government production of hybrids. A comparison of Argentina, which has never had government production, with Mexico, which has had a large government program, might be revealing. Another possibility would be to concentrate on Mexico and compare the supply of sorghum seed, which was left to the private sector, with that of maize, which was under the auspices of the public corporation PRONASE.

Another important gap in the literature is the lack of discussion on how to encourage the private sector including large commercial companies, small companies, private cooperatives, and small farmers to invest in the production, distribution, and research and development of improved seeds. Country case studies should be chosen from successful and unsuccessful programs. First, a detailed understanding of the policies and their timing would be needed. Then firm-level data on the seed industry would be necessary to look empirically at the impact of government programs. Pray et al. (1989) were able to collect data on 24 private firms in India and to analyze the impact of recent Indian programs in two crops. The Bolivian seed program has been described as a

successful government program encouraging cooperatives and small-scale private sector seed production and distribution (Garay et al. n.d.). Garay et al. collected data and calculated the benefits of the program, but did not analyze the costs, which would also be useful. The cooperatives in northern Mexico appear to be a successful example of public sector assistance to cooperatives. This assistance has been described, but not analyzed quantitatively.

Public sector research and development and training of plant breeders clearly stimulate private research and development. However, no one has tried to determine how public research and development resources should be allocated to germplasm collection and preservation, basic biotechnology research, and applied plant breeding in order to encourage private research. The limited quantitative evidence available suggests that plant breeders' rights may also be useful in more developed countries. Given the amount of controversy that surrounds plant breeders' rights and patents in FAO and the General Agreement on Tariffs and Trade, a solid empirical study is needed of their impact on investments in research and development, seed production, and supply. Argentina and Chile are the only developing countries that have attempted to enforce the rights of plant breeders and they are therefore the logical focus for case studies.

Another important gap in the literature is that the effects of trade and foreign investment restrictions on the seed industry and farmers in developing countries have not been studied. These restrictions have apparently had some impact in maize (Echeverría 1988), but no comprehensive studies have examined the impact of rapid liberalization on one country. Turkey eliminated most of its restrictions on seed imports and foreign participation in the seed industry about five years ago. Many multinational seed companies started doing business there and reportedly hired almost all of the government plant breeders; this left the government research system very weak. Turkey would seem to be an ideal place to look at the effects of liberalizing seed policy on farmers, on the structure of the seed industry, and on government plant breeding research. Since the impact of import policies would be much more important in a small than in a large country, a case study of a small country such as Chile, where seed policies were liberalized long enough ago to provide data on the effects of liberalization, would also be useful.

Notes

1. Landraces are early cultivated forms of a crop species, evolved from a wild population (Poehlman 1979, 466).

2. Breeder seed is the seed of a newly developed variety that is produced under the supervision of the plant breeder or owner of the variety. Foundation seed is the progeny of the breeder seed. It consists of the generations of seed between breeder and commercial seed and is known as basic seed in some countries. Commercial seed is the seed that is produced to be sold to farmers. See Table 15.

3. FAO's "advanced" level is advanced relative to other developing countries, but it does not imply that these seed industries are as advanced as those in the United States and Europe.

4. Estimates are based on interviews with multinational companies including DeKalb, Cargill, Pioneer, and Morgan, and leaders of the government agricultural research institution, Instituto Nacional de Technologia Agropecuaria (INTA).

5. Pioneer reportedly prefers to grow 70 percent of its seed locally and to import 30 percent (Kania and Goldberg 1982).

6. India, for example, does not allow imports of wheat or rice seed.

7. The quantity planted per hectare is also tied to other technological choices such as whether to plant transplanted rice or broadcast rice or to grow irrigated or unirrigated maize. The quantity may also be affected by weather. In some unirrigated regions of northern India, for example, pearl millet may have to be planted several times if the amount of moisture is insufficient for the seeds to germinate.

8. The ease of on-farm storage of farmer-saved seeds varies from crop to crop. For example, rice seeds are easier to store than soybean seeds (Delouche and Baskin 1989, 53).

9. The yield of hybrid maize declines 30 percent if the seed is resown (Heisey and Brennan 1989).

10. Eduardo Jacobs, personal communication, March 1986.

11. W. H. Verberght, quoted in Lynch and Tasch (1981). Consider also the experience of the National Seed Corporation in India. Responding to the shortage of wheat seeds during 1983-84, the National Seed Corporation increased its production in the following year, but ended up with a substantial carryover and losses of Rs 22 million (Agrawal 1988, 59).

12. Douglas (1980) found it useful to divide the development of a seed industry into four stages. Desai (1985) also developed a four-stage model for the Indian seed industry.

13. These coalitions are large only in economic size. Largeness in the sense of numbers is probably a disadvantage. Small numbers of large farmers can organize producer groups easier than large numbers of small farmers can.

14. In a few cases, private varieties are developed for crops, such as tobacco, in which commercial processors do the breeding.

15. Of course, firms also gain valuable experience and knowledge about market opportunities by participating in production and distribution.

16. In a case study of stages 1 and 2 plant breeding research in Colombia, Hertford et al. (1975) showed that not all plant breeding research programs have positive rates of return. Of the four crops studied, cotton breeding had a negative rate of return, while that of the other crops was positive and the returns were positive overall.

17. Methods of producing hybrid wheat were discovered in the early 1960s, and many companies started research programs in wheat to try to take advantage of that development.

18. India does not allow imports of rice, wheat, or cotton seed and places serious restrictions on imports of oilseeds, coarse grains, and pulses (Pray 1990). Kenya and Zimbabwe restrict the importation of seeds of major grain crops. Mexico and Brazil restrict imports when they have a shortage of foreign exchange.

19. Johnson Douglas, personal communication, July 1990.

20. Also, tropical crops that are not important in developed countries would attract little attention from the major exporters in the world market.

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