IV THE CHANGING CHARACTER OF TECHNOLOGY AND ITS IMPACT ON RESEARCH AND EXTENSION

> The “technology” of farming means “the way it is done.” It includes the methods by which farmers sow, cultivate and harvest crops and care for livestock. It includes the seeds, fertilizers, the pesticides, the medicines and the feeds they use, the tools, the implements and the sources of power. It includes enterprise combinations by which farmers seek to make the best use of their labor and land. For agricultural development to proceed, these must be constantly changing. When they stop changing, agriculture becomes stagnant. Production stops increasing and it may even decline due to decreasing soil fertility or to increasing damage by multiplying pests and diseases.
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> – Arthur T. Mosher (1966).

PATTERNS AND TRENDS IN TECHNOLOGY DEVELOPMENT

The central breakthrough of the green revolution, which had such enormous impact on rural Asia, was the successful breeding of the rice variety IR-8. After this event, the attitude of Asian governments toward agricultural development went through a major change. The profitability of agricultural research was dramatically demonstrated. Investments in research, irrigation, fertilizer production, and a host of other modern inputs were more willingly made, particularly by the public sector. At the same time, it is important to bear in mind that in very large areas of rural Asia, there was no green revolution. For these areas, research has in general borne very little fruit, because their natural resource base has proven to be insufficient to support the green revolution's extremely intensive form of agriculture. These less-favored areas will be discussed further below.

Among the case studies of collective action that are analyzed in depth in this and the next three chapters, agricultural research is unique because of its large international dimension. First of all, the fruits of agricultural research undertaken in one country may find widespread applications in and therefore reap benefits for other countries. In other words, the fruits of research are often *international public goods*. Consequently, there are international actors in addition to those discussed in Chapter II: within the nonprofit sector alone, the international agricultural research centers (IARCs) belonging to the Consultative Group on International Agricultural Research (CGIAR) have contributed mightily to the advancement of agricultural technology in Asia. Within the for-profit sector, multinational firms have always been suppliers of chemicals and are emerging as suppliers of seeds and of the technology embodied in the chemicals and seeds. Furthermore, developed-country governments also have also played a role, at the very least in providing funds to the IARCs. In addition, in various international forums, particularly the World Trade Organization, these governments exert considerable pressure on Asian countries to provide intellectual property protection, a subject intimately connected to agricultural research, and to be discussed below.

A Typology of Factors that Shape Agricultural Technology

In analyzing agricultural technology and the contribution of research to enhancing it, it is convenient to divide the factors influencing technology into the following three categories:

- *Genetic base*. This is what gives the plant its basic biological characteristics and yield potential. Much agricultural research is devoted to enhancing the quality of the genetic base, so that the plant is better adapted, not only to its natural environment, but to any other input that the farmer may introduce.
- *Resource base and environment*. These comprise the soil, water, temperature, and other external factors that provide what the plant requires for its sustenance (and also provide the plant's natural enemies). Agricultural research is devoted to understanding the nature of the relationships between the plant and its resource base in order to enhance that resource base and correct any imbalances that may exist, thereby increasing productivity.
- *Support and post-harvest inputs*. Besides the two basic factors that affect the plant, agriculture involves inputs that may modify the resource base and environment, such as fertilizers or pesticides, or help the farmer use his land more effectively, such as agricultural machinery. Each input has its own technology of production and use. In addition, once the crop is harvested and leaves the farm, its storage, transport, and processing have their own technologies. Such technologies may change because of agricultural research, or sometimes fortuitously through more general scientific and technological developments.

The above classification pertains to crop production. The classification of technologies in livestock production is somewhat different. There is also a genetic base to livestock technology, which will be touched on below; the fields of animal nutrition and health are subject to extensive research, but will be considered only briefly in this chapter.

A key feature of much agricultural research is its interdisciplinary nature; hence the above classification should not be construed as compartmentalizing the work done at agricultural research stations. When technologies are applied in a farmer's field, they come together and interact with one another, and it would be an incompetent researcher who ignores the interactions. Even in the case of the green revolution, where the central thrust of the work was genetic improvement, plant breeders were successful only because they enlisted the help of plant physiologists, soil scientists, and agronomists. Later on, when pest buildup became a problem, entomologists had to be brought on board. Moreover, a major goal in developing IR-8 was to find a rice variety that was responsive to nitrogen. This objective would not have been selected if the previous decades had not seen a sharp fall in nitrogen prices because of developments in the chemical industry (Hayami and Ruttan 1985).

Within each category in the above classification, the roles of the various actors in research have changed in response to developments in the concerned scientific disciplines. The remaining part of this section will trace these changes.

Genetic Improvement before Biotechnology

For as long as agriculture has existed, farmers have striven to improve the genetic base of their crops and livestock. The traditional method has been simple selection of seeds or stock from plants or animals with desirable traits. The selection would vary with growing conditions, which, in turn, vary with geography. The selections made by farmers in various growing environments gave birth to the diversity of plants from a given species. Crossing of plants of different varieties and breeding of animals from different stocks were also widely practiced on a trial-and-error basis. There was also the purposive movement of plant species across regions and continents during the colonial period and even earlier, when new plants were introduced from one region or continent to another. The most famous example, of course, was the bringing of the rubber tree from Brazil to Southeast Asia by the British (Plucknett et al. 1987).

The birth of Mendelian genetics allowed the exercise to become more systematic; the organization of research also became more formal. The classical process involves a crossing of two individuals from a given species in order to obtain progeny with the combined characteristics, followed by replication from which selection is made for further crossing. Once the desired traits are derived, the individuals are planted and replanted until the seeds obtained from the plants are genetically uniform and ready for distribution.

From the beginning, the organization of scientific work in genetic improvement has been carried out in publicly owned and operated experiment stations, both in market and centrally planned economies. Even the research into hybrid maize in the US, later to be carried forward by private firms, was initially conducted at public experiment stations, where the first inbred lines used in the hybrids originated.[1] This pattern has been more pronounced in crop genetic improvement work than in animal improvement (and there are variations also among types of crops, as will be discussed below). There are two reasons for the public sector to undertake this role: economies of scale and the public-goods nature of the outputs of much agricultural research.

For plant breeders to do their work effectively, they need access to as much genetic material as possible, so as to obtain the right kind of plant for the particular breeding objective desired. For them to be able to cast their nets widely, there must be a gene bank. This is a storehouse of seeds (or other forms of germplasm) of the vast varieties within a given plant species

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[1] With cross-pollinating plants, the chromosomes are heterozygous, that is, the genes on them that come from different parents are not necessarily the same. By interbreeding a particular variety within itself and selecting, the population can be made more and more homozygous (i.e., the genes from the different parents become more nearly the same). Inbred lines consist of plants that are made homozygous by such interbreeding. These plants are usually weak and unproductive, but the progeny obtained from crossing two different inbred lines are usually much more productive—the technical expression is that they have “hybrid vigor.” This phenomenon is the basis of the hybrid seed industry.

that can be reproduced for breeders to use in their work. It is clearly more convenient to have all the varieties in one place, with appropriate documentation of their characteristics. Hence, the economies of scale in a gene bank are such that it is more efficient for the public sector to operate it—although the use of information technology by now may have reduced the importance of this factor considerably.

In any case, the economies of scale in a gene bank are not by themselves sufficient to give the public sector the advantage in conducting genetic improvement work, for the public sector could easily run a gene bank (much as it does a library) and allow plant breeders access to it. Rather, the differing roles for the public and private sectors in research depend on how easy it is to capture the benefits of any new technology arising out of the research. Plant and animal breeders can capture the benefits arising out of their innovation in two ways: the first is when their "intellectual property" is naturally protected and the second is when it is legally protected. The use of the term "intellectual property" may be deemed to presuppose a legal protection of some sort. Here no such presupposition is being made, and the text will make clear what is meant by natural protection independent of the law.

The natural way to capture these benefits can be shown by dividing crops and animals into three categories:[2]

- self-pollinating crops and vegetatively propagating crops;
- cross-pollinating crops and small animals;
- tree crops and large animals.

Self-Pollinating Field Crops and Vegetatively Propagating Crops

If the plant is self-pollinating, the seeds will breed true; that is, they will reproduce exactly, or almost exactly, the

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[2] An alternative classification is to divide crops into food crops and export (or plantation) crops (Pray 1991). This alternative classification is discussed further below.

same genes as their parents, because both the male and female parents are from the same plant and the two sets of chromosomes will tend over time to be identical, or nearly so (homozygous). Their offspring will then have the same set of genes. Vegetatively propagating plants also reproduce the same set of chromosomes as their mothers, although the chromosomes will not be homozygous. In both these classes of plants, once the farmers obtain the improved germplasm, either in the form of seeds or of stock, they can obtain the next generation of plants quite easily. Consequently, the research organization responsible for the improved germplasm cannot easily recover the costs of its research and development from the farmers unless it charges a very high price for the first generation of material. In that case, farmers would simply wait to free-ride on other farmers' investments.

These two classes cover some very important crops of Asia. Rice, wheat, cotton, and soybeans are all self-pollinating crops, while cassava, sugarcane, and many fruit trees propagate vegetatively. For rice and wheat there is ample documentation of what has happened in Asia during the last three decades.

The first technological breakthroughs arose for rice and wheat, two of Asia's major food crops. The institution credited with the main breakthrough in rice is the International Rice Research Institute (IRRI), an internationally funded organization, originally supported by the Rockefeller and Ford Foundations. The same two foundations also supported the International Maize and Wheat Improvement Center in Mexico (abbreviated as CIMMYT from its Spanish name), which developed the new wheat varieties at about the same time that IR-8 appeared. The foundations were moved to act in Asia because of their concern over the impact of population growth on per capita food supply; it was also believed that improving agricultural productivity would have the political impact of arresting rural instability and hence the spread of communism (Anderson, Levy, and Morrison 1991).

Lest it be inferred that the CGIAR institutions were the sole originators of the green revolution, a bit of further history is in order. Actually, the PRC’s research system produced a fertilizer-responsive dwarf variety of rice in 1964, two years before IR-8 (Lin 1991). Even before that, in the 1920s and 1930s, Japanese researchers pioneered the kind of work that was later done at IRRI (Ishikawa 1967). The Japanese also distributed the seeds to their then-colonies, Korea and Taiwan. Some of the genetic material in IR-8 had its origins in this early Japanese research. Of course, all this work was done within public institutions.

After the initial success of the IR-8 and its adoption by farmers, national governments were moved to support similar research in the publicly funded national research systems. This work still relied a great deal on materials developed by IRRI and on IRRI’s large germplasm collection that circulates the material it develops, as well as on the “landraces,” or cultivars used in indigenous farming prior to formal breeding work, that IRRI had collected. In the beginning, much of this work involved adapting the parent material supplied by IRRI to local conditions: the most frequently observed breeding strategy was “one parent from IRRI and one from the national system.” Over time, the landrace content in the varieties released by the national systems has increased, but these landraces were brought into the genealogies through an IRRI ancestor (Evenson 1998).

Cross-Pollinating Field Crops and Small Animals

Once the seed of a self-pollinating crop like rice leaves the experiment station, it is replicated for distribution to farmers and grown in farmers’ fields. The harvested grain can be used as seed for future crops, with only a small loss in quality due to inadvertent outcrossing. Crops that propagate themselves by cross-pollination, however, have quite a high rate of outcrossing. Thus, the seed from an experiment station will lose its quality more rapidly during succeeding generations. This simple fact makes the history of improvement in these crops quite different from that of crops like rice or wheat.

Maize is one important food crop that propagates by cross-pollination. Normally, the pollen from a maize plant fertilizes the ear of some other plant a few meters away. But with strong winds, the seeds can and do travel longer distances; therefore considerable intermixing occurs. The improved varieties of maize that were released initially from the experiment stations are known as open-pollinated varieties. The production of seeds for such varieties is carried out under conditions that protect against contamination, in order to produce seeds that are "true to type," that is, they do not vary significantly in their genetic makeup. But once the seeds are used to grow crops in farmers' fields, outcrossing and contamination naturally occur. Unless farmers take precautions to prevent such outcrossing, they are well advised to obtain their seeds for each crop from specialized seed producers in order to continue to obtain good yields on their crops (CIMMYT 1987).

Because of this particular characteristic of the maize plant, maize was among the first commodities where a commercial seed industry arose to supply farmers' needs, at least in market-oriented economies. In Thailand, for example, commercial maize seed production emerged in the late 1970s (the development of the vegetable seed industry had come earlier). Interestingly, the maize industry came into being after a public university developed a new variety, Suwan, which was successful in resisting downy mildew, a fungus that had earlier plagued Thai maize production (Suthad, Saran, and Banlu 1991).

The existence, or potential existence, of a commercial seed industry is a precondition for greater involvement of the for-profit sector in research. Companies are drawn into research because the sale of seeds permits their capture of the benefits of that research. This is indeed what has happened in many Asian countries. As early as the mid-1980s, private national and multinational firms were investing tens of millions of dollars annually in agricultural research and development in Asia, mostly on maize, sorghum, and sunflowers, and largely in countries like India and Malaysia that had large commercial demand (Pray and Echeverria 1991).

While cross-pollinating crops are most amenable to private-sector involvement, it does not mean that only the private sector can do research in this area. As noted, the Thai hybrid industry came into being on the back of a variety developed by a State university. Even the US hybrid industry, in its earlier days, obtained its inbred lines from the public research system.

For private firms to be able to do their research competently, they must have access to inbred lines. Initially, the private sector would rely on the public system for the genetic materials, but, over time, successful firms have found it profitable to build up their own private collections of inbred lines. As with gene banks, there are economies of scale in such collections. It is not surprising that firms in the seed industry are usually very large and multinational. Moreover, concentration in the industry has increased with the advent of biotechnology (Grossman, Linnemann, and Wierema 1991).

There is a close parallel between cross-pollinating plants and small animals, since animals naturally crossbreed. Thus, the poultry breeding industry is organized somewhat similarly to the hybrid maize seed industry, i.e., with a few large, multinational firms dominating the field. Indeed, the spread of modern hybrid poultry has been far more rapid than even the hybrid maize sector, and now dominates the scene in countries such as the PRC, the Philippines, and Thailand. As will be considered further below, part of the reason for the more rapid advance in this sector is the fact that the modern poultry-raising process is essentially industrial rather than agricultural (i.e., more independent of the environment) and, therefore, has fewer location-specific demands.

Tree Crops and Large Animals

Tree crops and, to some extent, large animals do not lend themselves as easily as field crops to traditional methods of genetic improvement. The traditional method of crossbreeding and then selecting from among the progeny for further crossing and selection is already quite time-consuming for field crops, whose generation length is on the order of three to six months. For crops or animals whose generation length is counted in years rather than months, it is much more costly to crossbreed on a trial-and-error basis, which has tended to keep the private sector from becoming involved. However, the private sector's role promises to grow with the advent of modern cloning technology, which can accelerate the breeding process, particularly for animals.

Farmers have done some of the work in this area, playing a dominant role in fruit improvement in particular. But this kind of improvement in a given species is normally done within the center of diversity for that species,[3] where farmers have access to a large number of varieties in a natural gene bank. Thus, with most native fruit trees, farmers have been constantly and successfully developing new lines. With introduced or exotic species of tree crops, such as rubber, coffee, or cocoa, however, this option is not practical, as farmers would have to explore worldwide for the right kind of germplasm. The public research system would have to be enlisted in order to command the resources for producing any improvement.

Even where the farmers have themselves been at the forefront of genetic improvement, there is a role for the public research system. If farmers are successful, i.e., if the varieties they create are superior to existing varieties, then older varieties will gradually be replaced. If over time the innovation process stabilizes so that fewer new varieties are introduced, the well-known phenomenon of genetic erosion will be observed. Because fruit trees are vegetatively propagated, genetic erosion is apt to be more rapid than with seed-propagated species. Without a publicly-funded gene bank, there is a real danger that farmers' improvement would cease as new, locally available genetic materials are exhausted.

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[3] Vavilov, a famed Russian botanist, traced the origin and spread of each cultivated plant species by measuring its diversity. He reasoned that only a few varieties of the species would migrate from the place where they originated, so that the further away the species is, the less the diversity. Conversely, the place of origin of cultivation would be expected to have the greatest diversity in that species. This point is known as the center of origin or center of diversity.

Summary

The organization of research to improve each type of crop and animal will necessarily differ depending upon the natural protection offered to innovators, which in turn depends on each plant's or animal's genetic makeup and reproductive characteristics. For self-pollinating crops, no such protection is afforded: public-sector research is not only the preferred mode, it is absolutely essential. For cross-pollinating crops and for small animals, private-sector research is more of a possibility, although even here (at least for crops), some pioneering work by the public sector would facilitate work by the private sector. For tree crops and large animals, farmers themselves should ultimately be credited with the improvements, even well into the modern era. In the future, though, the public system will have to be involved more aggressively, both with respect to introduced species, mostly of commercial crops, and also to the preservation of germplasm of the native species.

Biotechnology

The Promise of Biotechnology

The revolution in molecular biology during the last two decades has blurred the relevance of the distinctions based on natural protection of the intellectual property discussed above; it has also broken down many constraints on genetic manipulation that exist in classical plant breeding. The first constraint is the knowledge base of the scientists themselves. In the past, detecting the location of a gene that expresses a particular trait was a hit-or-miss affair and normally very time-consuming. With new biotechnology tools, this knowledge is increasingly easy to acquire.

But biotechnology is not only increasing the productivity of the scientists, it is also breaking the previous limits as to how "wide" a cross can be made. When Taipei,China in the 1950s and, later, IRRI succeeded in crossing the Japonica and

Indica races of rice, this was considered a great achievement. Now, thanks to the new techniques, interspecific crosses within the same genus can be more easily carried out. This means that plant breeders have at their disposal a wider pool of traits to be drawn upon and put into the particular plant. In addition, the improvement of vegetatively propagated crops has been made simpler by biotechnology.

Equally significant, the molecular biologist can introduce genes from a totally unrelated species that code for specific traits, producing what is known as a transgenic variety. A well-known case is the introduction of a gene from the bacterium, *Bacillus thuringiensis* (Bt), into many plant species. This gene controls the production of a protein that is lethal to certain insect pests. In this way, the plant with the gene can be made resistant to the insects. Resistance viruses and fungi can be similarly incorporated. In general, the introduction of host-plant resistance, particularly toward insects, would tend to reduce the use of chemicals in agriculture. On the other hand, research is also leading to varieties that are herbicide-tolerant, so that herbicides can be applied without harming the crops themselves. This can lead to significant savings on cultivation costs, although of course, it entails increased use of chemical herbicides.

In livestock production, biotechnology has the potential to assist in tackling some serious animal diseases, such as foot-and-mouth disease, which is endemic throughout Asia. There currently exist vaccines to immunize animals, but there are two basic problems with the current methods. First, there are many strains of the virus causing the disease; to be effective, the vaccine has to be specific to each strain. Second, the vaccines must be stored under refrigeration to retain their potency, which presents a particularly serious problem in tropical Asia. Biotechnology research is uncovering the nature of the virus and is also advancing toward developing a vaccine that does not require refrigeration (Sasson 1988).

Biotechnology is no longer merely the promise that it had been over the last few decades; during the 1990s it proceeded well beyond laboratory work to widespread field trials and to the planting of transgenic crops in farmers' fields. The pattern of recent field trials gives an indication of the direction of agriculture in next decade. James and Krattiger (1996) compiled data on officially approved field trials across the world from 1986 to 1995. The data show that nearly all (92 percent) of the field trials were done in the developed countries, with the US alone accounting for more than half of the world total (here, the category of "developed countries" excludes the transitional economies of the former Soviet Union and Eastern Europe). Within Asia, almost all the field trials (97 percent) were in the PRC, with the remainder in Thailand. More recently, India entered the field in 1997 with trials of Bt cotton and herbicide-tolerant Indian mustard, while Malaysia tested transgenic rubber.

Table IV.1 shows the distribution by crop of field trials for biotechnology applications that are close to commercialization. (Transgenic crops are considered commercialized or near commercialization when more than 150 field trials have been conducted.) The table also shows the distribution of the area now planted to commercial transgenic crops This area totaled 12.8 million ha in 1997, having grown from 2.8 million ha in 1996. With such rapid expansion, big year-to-year jumps in the distribution among crops are to be expected. Thus, transgenic soybeans became the dominant crop only during 1997, overtaking tobacco, which had 35 percent of the area share in 1996.

Just as interesting are the traits that are being tested for in the field trials and that are being successfully commercialized. Table IV.2 has the same format as Table IV.1, but presents data on traits instead of crops. The predominance of herbicide tolerance as an objective of research and commercialization is striking, and reflects the dominance of the developed countries in biotechnology. Because of the prevalence of high wages in agriculture in these countries, there is a preference for chemical over mechanical methods of weed control. By contrast, the PRC has no field trials in this area at all, although the proportion of trials for herbicide tolerance in land-surplus Latin America is at least as high as in the developed countries. Furthermore, the fact

Table IV.1 Distribution of Potential and Actual Application of Biotechnology by Crops Worldwide

Crops	Percentage of Total Field Trials 1986–1995	Percentage of Area Planted to Transgenic Crops 1997
Maize	33	25
Rapeseed	21	10
Potato	11	<1
Tomato	11	1
Soybean	9	40
Cotton	7	11
Tobacco	5	13
Squash	3	n.a.
Total	**100**	**100**

Sources: Field trials, James and Krattiger (1996); area planted, James (1997).

Table IV.2 Distribution of Potential and Actual Application of Biotechnology by Traits Worldwide

Traits	Percentage of Total Field Trials 1986–1995	Percentage of Area Planted to Transgenic Crops 1997
Herbicide Tolerance	35	54
Insect Resistance	18	31
Virus Resistance	11	14
Fungal Resistance	3	<1
Product Quality	20	<1
Others	13	<1
Totals	**100**	**100**

Sources: Field trials, James and Krattiger (1996); area planted, James (1997).

that private firms, many of which have interests in agrochemicals, do most of the biotechnology research no doubt contributes to the dominance of herbicide tolerance as a desired trait.

Genetic manipulation has not been confined to the species of plants and animals that are directly used by man, but is now being contemplated for other species that affect the productivity of the crop and livestock operations. Insects in particular have become the focus of attention, as they inflict considerable crop damage. One common technique, predating the advent of biotechnology, involves inundating the pest population with sterile members, so that the majority of the matings become ineffectual.

This technique has been effective already against the screwworm, a pest that attacks livestock, and against the Mediterranean fruit fly in California. In these cases, sterile insects were obtained by conventional breeding plus radiation treatment, but this method is laborious. Transgenic technology promises a more efficient approach, involving the introduction of "piggybacking" genes onto "jumping genes," which have the capability of moving from one locus to another in the set of chromosomes. The technique allows a much faster replacement of the existing population with the modified population and with less effort. Similarly, an insecticide-resistant predatory species could be developed that preys upon the target pests. Such techniques can lead to a decrease in pest populations using considerably smaller amounts of chemical pesticides (O'Brochta and Atkinson 1998).

The Risks of Biotechnology

Biotechnology is new and naturally carries risks, as well as possible adverse effects on developing countries. The risk issues may be classified into three stages: first, the risks generated by work done in the laboratories or in the experiment stations; second, those that arise when the bioengineered products are in the fields; and third, those that arise when those products are ingested as food.

The first and third stages of risks are, or can be, subject to safety regulations, which are in place in many advanced countries and are being implemented in developing countries. In the research laboratories, the major risk is that some of the waste material may contain transformed microorganisms that could reproduce out of control, becoming a health hazard. The solution is to build containment facilities. The task of the Government is to ensure that such facilities are indeed up to standard, both in its own laboratories and in those belonging to private firms. In the case of food safety, similar considerations apply, although here public opinion in developed countries is considerably more cautious than the views of regulators, scientists, or companies promoting bioengineered products. Thus, the market introduction of bovine somatotropin (BST), a bioengineered hormone used in dairy production, has been held up in the European Union because of popular fears of its impact on human health. Similarly, the Flavr-Savr tomato, designed for a longer shelf-life, has run into considerable consumer resistance in the US.

It is in the second stage, the field application of biotechnology, that the risks are probably greatest and most complicated. The fear is that the introduced genes will run rampant. The potential environmental risks of genetically engineered organisms are summarized succinctly by Wyke (1988): "Their presence might disturb the balance of the environment in unintended ways; they might multiply uncontrollably and therefore become pests or weeds; they might be dispersed to areas far from their intended sites... they might transfer the new bits of DNA to other organisms." Even before biotechnology, there were examples of weeds, or microbes, introduced into a particular location from elsewhere and thriving all too well. The history of disease migration (say, from the Old World to the New or vice versa) is replete with such catastrophes. Such episodes fuel the fears of many who oppose the application of biotechnology in the field.

It is possible, however, to take a reasoned attitude toward this problem. A distinction should be made between the release of bioengineered genes belonging to a domesticated species and those belonging to a wild species such as insects or nematodes. The reason for the distinction is that domesticated plants or animals generally cannot survive without human intervention.[4] Consequently, the probability that genes attached to these organisms will unintentionally run rampant is low. However, with wild or semi-wild species (those only recently domesticated, such as pasture grasses and fishes), the risks are necessarily larger and more caution is required.

A concern raised by other authors is that commercial biotechnology developers, seeking "magic bullets" to deal with

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[4] There are exceptions, of course: domesticated cats and dogs have turned wild in Australia and are threatening the survival of native animals. To the authors' knowledge, however, no similar example can be found for plants.

specific crop problems, have focused narrowly on genetically uniform biological agents. Bt has been prominent among these. As of 1989, Bt was the genetic source of pest resistance in almost two fifths of all biotechnology research and was the active ingredient in 95 percent of all commercial biopesticides. If pest populations evolve rapidly to adapt to such a specific stress, the risk is that a generation of commercial biopesticide agents could become impotent over a period as short as three to five years, thus necessitating a return to the conventional chemical pesticides that the biotechnology was designed to replace. This danger exists, of course, whether the new varieties are obtained through biotechnology techniques or through classical plant breeding.

Possible Adverse Effects of Biotechnology

The risk aspect discussed above refers to the unintended and unexpected side effects of biotechnology. But biotechnology may also have adverse consequences for Asian agriculture that are inherent in the way it is currently being developed. Two salient facts should be noted. First, biotechnology research is carried out by private firms, which are investing enormous sums in the field. Thus, just one large company, Monsanto, has during the past few years been investing more than $1 billion annually in agricultural biotechnology (both directly in research and in the acquisition of other biotechnology firms), or more than three times what the entire CGIAR spends each year on all agricultural research in developing countries (somewhat more than $300 million). Second, the overwhelming preponderance of biotechnology research is carried out in developed countries (particularly the US), with developing countries making only a minor contribution so far. In fact, the carrying out of biotechnology research by private firms is the result of a conscious policy decision on the part of the US government, the pacesetter among the developed countries. Until a few decades ago, agricultural research there was conducted mostly within the public sector, but US policies have generally now shifted toward letting the private sector undertake more research. This shift can be detected in the strengthening of laws on intellectual property undertaken both by the legislative and the judicial branches, which will be discussed in the following subsection (Fuglie et al. 1996).

The combination of these developments with the expansion of chemical companies into the seed industry (Grossman, Linnemann, and Wierema 1991) produces the scenario of a bias in research toward a more chemical-intensive agriculture, e.g., the explosion of herbicide-tolerant varieties being released by companies involved in biotechnology research. For Asian developing countries to import the crop varieties resulting from this research would also mean an increased use of chemicals in their agriculture.

The second fundamental fact of biotechnology is that most of the research is being done in advanced countries by companies interested in commercializing the fruits of their research by selling both more seeds and more chemicals. As the purchasing power of Asian farmers is considerably less than that of developed-country farmers, the research from these companies will be biased towards the needs of the latter. Where developed-country biotechnology finds direct application in Asia—e.g., in commercial crops like cotton and tobacco—it is likely to be biased toward the region's commercial farming regions that have better endowments of soils, rainfall (or irrigation), capital, and technical skills. There may be adverse distributional impacts both among and within regions as wealthier, better-educated farmers innovate more rapidly. The cash costs of proprietary seeds and other inputs may be beyond the means of resource-scarce, subsistence-oriented farmers. There will be implications, both positive and negative, for farm-labor use. For example, herbicide-tolerant varieties should produce higher yields, thus tending to increase labor use, but could also lead to the substitution of chemicals for the labor, typically female, used in weeding. That said, these potential adverse effects of biotechnology are no different from those arising from the green revolution.

Commercially oriented research in developed countries will tend to overlook the need for research on certain tropical crops grown extensively in Asia, such as cassava, coconuts, and specialty crops such as spices and tropical fruits. Even for crops such as rice, the labor-saving technologies likely to be investigated by the multinational corporations will shift the comparative advantage away from Asia, not only vis-à-vis the developed countries, but also vis-à-vis land-surplus regions like South America and Africa. For example, during the past two decades there has been a major, technology-induced shift of developed-country demand in the international sweetener market away from the sugarcane-based products of the tropics to locally-produced high-fructose corn syrup (Hobbelink 1991). Similar transformations are possible in markets for vegetable oils and crops such as cocoa because of biotechnology research on, respectively, rapeseed and cocoa-butter substitutes. Technologies like BST, if widely adopted in the milk-surplus developed countries, could greatly restrict the future potential for economically competitive dairy production in the tropics. Persley (1990) and others argue that the developing countries, with support from the IARCs, should focus public resources on the so-called “orphan commodities” for which there is likely to be little private investment in the developed countries, either because the commodities are not important in temperate areas or because the expected returns are too small or too uncertain.

Assessment of Biotechnology

With the advent of biotechnology, genetic improvement has changed a great deal and will continue to change even more radically. For better or worse, Asia will have to live with the consequences. Of course, biotechnology has its risks, but many of the risks can be averted if proper regulations are in place. Biotechnology also has potentially adverse social and environmental effects, but those will affect Asia only if Asian governments let multinational corporations monopolize the research. For Asian countries, particularly the small and medium-sized ones, to be able to further their own social agendas, their public research systems must be engaged directly in biotechnology research. Since there is much research already going on in the world, they must be highly selective in their approach and prioritize their activities carefully. For major cereals, such as wheat, rice, and maize, they may cooperate closely with, finance, and participate in the strategies adopted by the IARCs, as a way of pooling resources regionally. For tropical commodities, they may have to set up regional arrangements whereby they can economize on their meager resources and scarce scientific talent.

But biotechnology *research* should not be the only focus. Even if a given country has to forego this activity, it still has to perform regulatory functions necessary to protect its population from the various risks of biotechnology. This means investing in human resources to develop biotechnology *capability* in a broader sense than just the ability to conduct research. Again, pooling of resources across countries should be seriously explored.

Should any Asian government encourage its domestic private sector to conduct biotechnology research? A necessary (although not sufficient) condition for entry of the domestic private sector into this arena is that there must be adequate intellectual property protection (IPP). To anticipate the discussion of this issue in the next section, Asian countries are ill-equipped to provide such protection effectively. Unless this changes, the private sector will have a relatively weak incentive to invest in biotechnology, which further emphasizes the need for capacity building within the public sector.

Intellectual-Property Protection

The discussion of biotechnology highlights the increased importance of the private sector in research. The private sector needs the expectation of profit if it is to engage in research, which requires, as described in Chapter II, that there be excludability in the consumption of the product that the research yields. In the case of agriculture, this assurance can be provided by what has been called above “natural protection” of intellectual property, for example in the cases of hybrid maize and poultry. The other means of protection is legal, followed by enforcement mechanisms to ensure that those who have succeeded in expanding the frontiers of technology can recapture part or all of their costs of research. Thus, where natural protection is not available, legal rights have to be established. But even if legal rights are provided, institutional and human resources must be devoted to enforcing those rights in order to give sufficient confidence to the private sector to invest in research. Enforcement is a far more difficult task for the developing countries, yet it is what must be accomplished if property rights are to be meaningful.

The laws on intellectual property are at present in a state of flux, not least in the United States, which has embraced this particular notion with enthusiasm and is now pushing other countries to follow suit. Asian countries are doing so, albeit not as enthusiastically. Since up-to-date information is not as yet available on the legislation in individual countries, the better strategy is to spell out the broad implications of the various forms of intellectual-property rights, as currently legislated in the US.

Trade Secrecy

The simplest and oldest form of IPP is trade secrecy. This is what US hybrid seed companies used and still use to protect their inbred lines from being stolen and used by others. Not all Asian countries have laws that protect trade secrecy, and hybrid seed companies have been seeking such protection, either from a version of the American trade secrecy laws, or from a plant-variety protection law.

Plant Variety Protection, or Plant Breeders' Rights

A plant variety law would, as the name suggests, provide protection to the plant breeders for coming up with a new variety of plants. It is also known as plant breeders' rights. To be protected under the law, a variety has to be

- stable (succeeding generations will be homozygous, or capable of reproducing the traits of the original);
- homogeneous (each generation will have a uniform set of traits);
- distinctive (it will be clearly distinguishable from any other variety "whose existence is a matter of common knowledge"[5]); and
- "novel" (to establish novelty, a variety may not have been offered for sale or marketed in the country of application for longer than four years, or in the case of the US, only one year).

At the global level, this form of protection is covered by an International Convention for the Protection of New Varieties of Plants, or UPOV after its French initials. First adopted in 1961, UPOV has been revised three times, the latest revision occurring in 1991. As of December 1999, however, UPOV had only 44 signatories, predominantly from the developed countries of the West, the former Soviet bloc, and most of South America, with the PRC being the sole member from Asia (UPOV 1999). Members of UPOV agree to provide each other with protection, the minimum duration being 15 years for annual crops and 18 years for perennials, although members may opt for more.

Because of the requirements for stability and homogeneity, this form of IPP applies to vegetatively propagating plants (before 1970, US law applied *only* to them), and to inbred lines of the sexually reproducing plants. It provides only a "mild" form of protection, because its novelty requirement is not as rigorous as that for patent protection (see below). Competitors can thus come up with very similar products and still obtain protection. Plant variety protection is essentially the equivalent of a trademark, and is used extensively to protect breeders of ornamentals. Plant variety protection laws always have a farmers' exemption clause. This

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[5] The wording is from the International Convention for the Protection of New Varieties of Plants (UPOV), as cited by Lesser (1991).

allows farmers to use their own seeds or stock to raise the next crop, but they may not resell the seeds to others.

Because plant variety protection has specifically been designed for innovations in plant breeding, it has some attractive features, at least relative to patent protection. Innovators obtain the protection only for the trait or traits they have added to a particular variety. Inasmuch as this allows them to build on the work of others, it reflects better than patents what plant-breeders (and to some extent, biotechnicians) do and for what achievements they should be rewarded.

Patents

For a long time, patents were not given for living organisms, because no living organism had been "invented" by man. But living organisms became patentable, at least in the US., after a landmark 1980 decision in the Diamond vs. Chakrabarty case in the US, where the inventor patented strains of bacteria that the defendant had engineered to decompose crude oil. Like plant variety protection, there are a number of requirements that have to be met before a patent is issued.

First, the patents apply to embodiments of ideas, not to the ideas themselves (Lesser 1991). Second, the patented item has to be useful. Third, it has to be novel. Finally it has to be nonobvious. The formula in US law used to define this last requirement is that the item must be nonobvious "to a person skilled in the art." This last requirement is what really gives a patent its power. By requiring the "inventive step" to be a major one, the law makes it difficult for competing claims to match closely the claims made in existing patents. And by making it thus difficult for competitors to enter the business, the resulting monopoly power serves as an incentive for the researcher or inventor to become a patent holder. This, at any rate is the theory behind the requirement.

Clearly, what constitutes a nonobvious inventive step is sufficiently judgmental to keep many patent lawyers happily in business. It also provides room for policymakers to manipulate the inventive step requirement. Making the requirement very strict means that competing patent applicants have a bigger hurdle to overcome and provides strong incentives to the researcher or inventor. A lax requirement, on the other hand, would encourage creative copying of inventions. At certain stages of development, countries may find it advantageous to have patent protection, but keeping relatively lax the "inventive step" requirement, so as to encourage imitative innovation. This is what Japan did, for example, before it became a technology exporter around the 1960s.

Unlike plant-variety protection laws, patent laws do not have a farmers' exemption clause. This would obviously be onerous—as well as unenforceable—for farmers who wish to retain patented seed for future use.

The opening up of US law to allow patenting of biological products has created concern among developing countries about whether the patent laws can be used to undermine their natural comparative advantage in tropical products. Thus, while it is clear that patent law is useful mostly for bioengineered products, the scope with which the law will be applied is an unresolved question. As examples of potential problems, here are three cases of patent suits in US courts involving India.

The first involves the medicinal properties of turmeric. Two expatriate Indians obtained a patent in the US for turmeric to be used to heal wounds. This prompted the Indian government to undertake a countersuit to have the patent withdrawn. It had to show that the use of turmeric to heal wounds had been known in India for millennia. Eventually, the Indian government succeeded in its suit, but only after considerable effort merely to defeat a frivolous claim.

The second case involves the use of neem, a plant that has many uses, one of which is as a pesticide. The W. R. Grace Company obtained two patents for improvements in the storage stability of neem-seed extracts that contain the key active ingredient (azadirachtin) from the tree. The Indian government again filed a countersuit because of the domestic outcry, but withdrew after it realized that the processes for which the patents were obtained were indeed patentable.

The third involves basmati rice, for which the Rice-Tec Company obtained a patent in the US. This case has certain features that deserve further examination. The patent document (US Patent Office 1997) first shows that basmati rice has certain desirable characteristics (and the document lays out the means to measure these traits), and then that its plant has certain traits that make it difficult and unprofitable to grow outside its normal habitat in India and Pakistan. It then proceeds to show that combining these characteristics and traits with those in a plant that is of short stature, not photoperiod-sensitive and high-yielding in temperate latitudes (all of which would make it possible to grow a plant producing rice with basmati-like characteristics in, say, the rice-growing areas of the United States) would involve a genetic manipulation of some complexity. These preliminaries (which are hardly original) are meant to show that a novelty would be created if the combination could be made. The heart of the innovation for which the patent was sought (and granted) is the use of classical methods of plant breeding to come up with a plant type that has the desirable traits and that can produce rice grain with basmati-like characteristics.

The legal basis of the patent lies in a number of specific claims, some of which are so worded as to enable the patent holders to have rights over a much larger domain than can be justified by their work. For what Rice-Tec is claiming is not a patent on the specific lines that it has obtained from its breeding work, but rather on *any* rice which that meets the following description (contained in claim 1):

> A rice plant, which plant when cultivated in North, Central or South America, or Caribbean Islands
> a) has a mature height of about 80 cm. to about 140 cm.
> b) is substantially photoperiod insensitive;
> c) produces rice grains having
>   i) an average starch index of about 27 to about 35
>   ii) an average 2-acetyl-1-pyrroline [the chemical that gives the aroma of basmati] content of about 150 to about 2,000 ppb [parts per billion]
>   iii) an average length of about 6.2 mm. to about 8.0 mm., an average width of about 1.6 mm. to about 1.9 mm. and average length to width ratio of about 3.5 to 4.5

iv) an average of about 41% to about 67% whole grains, and
v) an average lengthwise increase of about 67%

Other claims (except three, which refer specifically to three particular lines developed by Rice-Tec and their progeny) cover a somewhat narrower range of characteristics of the plant and grain, but a worldwide geographical range, instead of being confined to the Americas as in claim 1.

Observe what is being established under claim 1. Its key feature is the combination of grain characteristics and plant traits, that constitute a high-yielding basmati rice plant. These are *ideas* that are certainly not novel; any person "skilled in the art," such as plant breeders, could come up with the listing shown in the citation above. The basmati characteristics are well known and what it takes to produce a high-yielding plant is also well known. Even if original, what is in claim 1 is more in the nature of ideas rather than embodiments of the ideas. Rice-Tec is making a claim for certain plant and grain characteristics, even though these are well known.

Rice-Tec's achievements presumably arise from the successful breeding of particular lines that have the characteristics listed above. But because of claim 1 and the other three claims, other plant breeders cannot use the original or related varieties of basmati to cross with other parents (other than those used by Rice-Tec) to produce plants and grains that match with the traits and characteristics of those stated in the patent. If these stipulations apply to all patents, it is clear that this form of intellectual property confers a much broader protection to the holders than, say, plant variety protection. From the point of view of Asian countries, the granting of such patents by a foreign government (in this case the US) effectively lowers the value embodied in their genetic resources (in this case the basmati variety).

Benefits of Intellectual Intellectual-Property Protection

Consistently, across commodities and across countries, agricultural research has been shown to have a high payoff.

Evenson, Herdt, and Hossain (1996) summarize the incremental rates of return to rice research in different countries as estimated by various authors, showing figures that range from 30 to 165 percent. And these figures are by no means atypical. The consistency of the results suggests strongly that there is underinvestment in research. As the public sector has heretofore done most of the investment in research, and as the returns to this investment accrue only in the long run—longer at any rate than the time horizon of most politicians—such a misallocation should not occasion any surprise.

It was pointed out above that in the absence of any IPP, be it natural or legal, private companies would have little incentive to invest in agricultural research. Has the conferring of IPP in fact encouraged greater participation by the private sector in research, and has agricultural technology thereby been improved? There are two ways by which such improvement may occur.

The first would be through an in increase in private inventive activity in the developing countries. For patents, there is as yet little evidence one way or the other, as the history of patenting to cover agriculture has been very short. Even for the more general impact of patents in areas outside agriculture, the evidence is at best mixed (Lesser 1991). In the very few developing countries that have been studied (all in Latin America), protection of plant varieties has increased private-sector participation modestly. This could lead to some substitution between private and public financing for research, for which there is some evidence—again for Latin America—although the degree of substitution is modest (Lesser 1991).

The second way would be through an increase in the transfer of technology from developed to developing countries as the result of IPP. Two quite contrasting perspectives are possible on this matter. On the one hand, with IPP, international seed companies should be comfortable about bringing in their products without fear of being imitated. On the other hand, IPP lets seed importers acquire monopoly rights over their products, leading to a distorted market structure. Unfortunately, the question of which influence is the stronger is much more easily stated than answered. At this time, no empirical evidence can be brought to bear either way.

International Undertaking on Plant Genetic Resources and the Convention on Biodiversity

The expansion of the role of IPP, pushed vigorously by developed countries, particularly the US, has led to a sharp reaction in the developing countries. If IPP is to be granted to seeds emanating from developed-country laboratories and experiment stations, it is felt by the developing countries that their farmers should be entitled to claim some rights to the genetic resources that originate from them. These rights are sometimes called farmers' rights. However, there are legal, economic, and practical complications in establishing such claims.

A first step toward overcoming the legal complications is to be found in Article 15 of the Convention on Biodiversity (CBD),[6] in which the parties affirm that access to the genetic resources of a country is considered part of its sovereign rights. A country's Government now has a right to control access to these resources—possibly even if the genetic material itself has already been transported out of the country and deposited, say, in a gene bank. This confirms the evolution of the positions taken in the Food and Agriculture Organization's International Undertaking on Plant Genetic Resources (IUPGR), which was adopted in 1983 but subsequently qualified until the sovereign-rights principle was agreed to in 1991 (see Box IV.1). The CBD thus officially brings to a close the era of open exchange of

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[6] The Convention on Biodiversity (CBD) was signed at the Earth Summit in Rio de Janeiro in 1992. Its objective is to ensure the conservation of biodiversity, the sustainable use of its components, and the fair and equitable sharing of the benefits from their use (Article 1). The components of biodiversity are to include diversity within species, among species, and among ecosystems. The bulk of the Convention deals with various measures to promote biodiversity that are to be undertaken by the signatories. Developed countries are asked to provide financial resources for the implementation of the Convention by developing countries (Article 20), through some mechanism to be decided later (Article 21).

Box IV.1: The Flow of Genetic Resources across Borders: A Legal History

The 22nd Session of the Food and Agriculture Organization (FAO) Conference in 1983 adopted a legally nonbinding International Undertaking on Plant Genetic Resources (IUPGR), which based itself on the "universally accepted principle that plant genetic resources are a heritage of mankind and consequently should be available without restriction." This ringing endorsement of the free flow of genetic resources did not, however, command support among countries that protected plant breeders' rights. It was feared that the IUPGR might be incompatible with the protection of such rights. In 1989, therefore, the FAO qualified the free-exchange principle by an "agreed interpretation" that the plant breeders' rights provided for under UPOV are "not incompatible" with the IUPGR. This qualification was balanced by the recognition of a farmers' rights concept. In 1991, the free-exchange principle was further qualified by the endorsement that nations have sovereign rights over their plant genetic resources.

Parallel to these changes was the regularization of the gene banks run by the CGIAR centers, which is of great importance for developing countries. In the past, the control and ultimate ownership of these collections were a matter of agreement between the centers and their host governments. In 1994, the FAO signed agreements with all the centers holding plant genetic resources, stating that the centers hold their collections in trust for the benefit of the international community and shall not claim legal ownership over the germplasm or apply any form of intellectual-property rights to the material itself or related information.

Source: Leskien and Flitner (1997).

genetic material across borders, which has been the rule, particularly for staple food crops, ever since Mendelian genetics became the driving force behind technical change in agriculture. It was unfortunate that the CBD was negotiated during the same period as the Uruguay Round of trade negotiations, as developed countries pushed very strongly to include intellectual property as an item on the agenda during the negotiations on the CBD. Developing countries responded by using the CBD to attempt to protect their rights, but in the end, the attempt did not lead to a very strong Convention.

The retreat from the free-exchange principle toward the national-sovereignty principle embodied in the qualifications to the IUPGR and in the CBD has the following novel features. First, the exchange of genetic resources must be based on mutually agreed terms and subject to prior informed consent of the concerned parties, i.e., the governments of the countries in the transaction, and particularly the exporting country. Second, the CBD requires that parties to the transaction obtain the approval of and share benefits with the holders of knowledge, innovations, and practices, i.e., the farmers practicing traditional agriculture and using traditional seeds. This sharing of benefits is in line with the idea of farmers' rights endorsed by the IUPGR (note that in the IUPGR the notion of farmers rights differs from, and is less legally precise than, the concept of farmers' exemption discussed above on pp. 145–146).

What are the economic benefits of this change in regime? A simple answer would be that genetic resources are of value and the countries in which they are to be found should have some ownership claim over them and presumably obtain some revenues from those who make use of them. A more complex answer would be that to preserve these genetic resources over the long term requires resources and therefore those who make use of them should be made to pay for the "upkeep." This in turn will provide the incentive for those who possess the resources to conserve them.

How valuable actually are these resources? Here empirical evidence is rather hard to come by, particularly with reference to genetic resources that are useful for agriculture. For want of precise evidence, it is necessary to look into a related kind of genetic resource, for which some work has been done. A much-discussed use of biodiversity is "bioprospecting" in order to derive new products, in particular, new medicines. Examples of profitable uses of tropical plants and microorganisms abound. A few countries and companies hoped to profit from entering this arena: Costa Rica, for one, entered into long-term contractual arrangements with Merck, while Shaman Laboratories wanted to conduct bioprospecting in many countries and share the benefits with local communities that helped them in their work. These examples are often cited because other examples are hard to find, leading one to suspect that bioprospecting will not yield as much value as has often been touted. Extrapolating from successful hits is hardly an appropriate means of assessing the profitability of search.

Even multiplying the probability of discovering a commercially valuable substance by the value of a discovery is not adequate for the task at hand. As Simpson, Sedjo, and Reid (1996) put it: "By multiplying the probability with which an organism sampled at random contains *some* chemical compound of commercial value—whether unique to that organism or not—by the expected value of a successful commercial product, earlier researchers have failed to recognize the *possibility* of redundancy among natural products [italics in the original]." Incorporating these considerations into their exercise and assuming plausible values for some of the key parameters, the authors estimated an upper limit for the economic value of biodiversity for pharmaceutical research and found it to be quite modest.

The genetic resources used for bioprospecting by the pharmaceutical industry are mostly located *in situ* (i.e., in their original environments). In contrast, the genetic resources used for agriculture are cultivated all over the world. Furthermore, for most major agricultural crops, there are already in existence many *ex situ* collections that could provide resources for plant breeders. These collections already have within them a very large proportion of the genes for these crops. The marginal benefits of *in situ* sources of genes for these crops cannot be very large. Considerable skepticism must therefore be expressed about the value of the protection for indigenous sources of genes that could be used in agriculture.

Aside from the law and the economics of farmers' rights, the practical problems of enforcing such rights should not be overlooked. In cases where the genetic resources have been in use for some time and spread far and wide, how is their ownership to be established? And having established it, how are the presumed owners to collect on their rights? And if the Government is to collect on their behalf, how are the farmers who are the purported owners of the rights to be provided with the right incentives to maintain the resources?

Assessment

It is not clear what Asian governments stand to gain in return for providing IPP if the only impact considered is the incentive for research by the domestic private sector. With plant-variety protection, the gains are at best modest. Patent protection is usually provided for biotechnology research, but for the foreseeable future in Asia, domestic private involvement in biotechnology will remain small because of the field's high-tech, capital-intensive nature, which is extremely demanding of highly trained human resources.

Gains from IPP through technology transfer from developed countries and multinationals would take the form of imports of protected varieties or inbred lines. It is sometimes claimed that hybrid maize producers in Asia's developing countries—often exclusive local distributors of seed developed by multinational companies—are reluctant to import inbred lines, for fear of their being stolen by competitors. There is no doubt that the provision of even a mild form of protection, such as plant variety protection, would be sufficient to make hybrid producers sleep more soundly; to that extent, they would prefer such protection to having none. However, even without benefit of such protection, local hybrid producers in numerous Asian countries have already imported inbred lines in order to cross them. Pray and Echeverria (1991) assess the determinants of the location of the research and development units of these multinational companies. They identify three main factors that encourage location in a specific country: (i) the existence of a profitable affiliate, (ii) a growing and sophisticated market, and (iii) an adequate scientific and technical infrastructure for research. They also list as obstacles the scale economies of centralized research at headquarters and the difficulties of assembling adequate research staff in developing countries. Conspicuously absent is any mention of IPP.

Note also that the above discussion pertains to the location of research and development facilities, and perhaps of seed production. Where the nature of the crop permits (e.g., with cross-pollinating crops), developed countries can and do export hybrid seeds directly. Echeverria (1991) reports a lively trade in hybrid maize seed, although most is between sellers and buyers in developed countries.

With respect to biotechnology research, the key problem is the farmers' exemption. With a very large number of small farmers, firms in Asia, whether domestic or foreign-owned, will find it very difficult to ensure that farmers do not reuse the seeds from their crops. This will certainly wipe out the incentive to do research or even to import ready-made seed for self-pollinating crops. For example, Monsanto is finding it difficult to introduce its Bt cotton into Asian countries containing many small farmers, such as Thailand (TDRI 1996). It is difficult to envision Asian developing countries enacting laws on seed that would not have a farmers' exemption clause; even if they did, it is difficult to envision them enforcing such laws. For cross-pollinating crops, on the other hand, firms are in any case naturally protected against imitation or farmers' reuse, so that there is little net gain from providing patents or other forms of legal protection.

Overall, it must be concluded that the issue of IPP in agriculture is overblown. The benefits to developing countries of adopting IPP are at best minor. The nuisance from frivolous filing of patents (as in the turmeric case) in developed countries, and the need to be vigilant against such dubious claims, would be costly. Indeed, the cynical view that IPP is designed to protect the intellectual property of patent lawyers in developed countries is not altogether flippant.

Nevertheless, developing countries will be subject to unrelenting pressure from developed countries to enact legislation to protect intellectual property, and they will probably end up doing so. It is important, therefore, that they prepare themselves for a world in which multinational companies will dominate advanced agricultural technologies. They may have to buy these technologies, but they can have some choice about the terms on which they will have to pay. Their negotiations have to be based on a thorough understanding of the benefits and risks of the new technologies. This understanding will not be there unless the public sector has the capability that is built on a well-functioning research system. This reinforces the important point that a good research system, one with active public and private participation, would yield very high returns, as has been repeatedly shown in evaluation studies.

If the benefit of the existing forms of IPP to developing countries is small, the same could be said of the various defensive measures attempted by them, embodied in instruments such as the CBD or in concepts such as farmers' rights. While the controversy over intellectual property has mainly concerned its impact on investment, the problem with these new concepts is more fundamental, namely the possibility of implementing them at all. Not surprisingly, evidence concerning their impact has thus been hard to come by.

Sadly, the push by developed countries in favor of wider IPP application on the one hand and the pursuit by developing countries of the dubious benefits of farmers' rights on the other may well end the present era of open science in agriculture. Central to the conduct of open science is the free exchange of genetic resources among nonprofit (mostly tax-financed) institutions. Altogether, the regime of open science has brought enormous benefits to Asian farmers. Some Asians may regard the coming changes as retrogressive, but they cannot be ignored. Asian governments will have to adapt to the new regime, at the very least to minimize any adverse impacts of the rapidly changing environment of international agricultural research.

Research to Improve Resource Management

Up to now, discussion has centered exclusively on genetic improvement as a central strategy in enhancing agricultural technology. The priority and length of that discussion reflects the greater emphasis and financing given to genetic improvement than to other types of research, an imbalance rooted in the reality of agricultural research in Asia over the last two decades. Ultimately, this imbalance is due to the simple fact that genetic improvement is in some cases "closer" to productivity enhancement than is improvement in resource management. The objective of research on resource management would be, for a given genetic technology and natural resource base, to maximize productivity on a sustained basis. This involves much more extensive changes in farm-management practices, which may take a longer time to show results. Furthermore, in many areas, the basic science is less developed than that of molecular genetics. For example, the following is an observation on soils, which would be a central component of any research resource management program:

> Soil structure is still not well understood at a fundamental level, and much of the science is largely empirical... This rather weak theoretical basis means that much of the work on these subjects must be empirical, applied and adaptive, *as opposed to theoretical and revolutionary* [italics added], though absolutely essential. (TAC / CGIAR 1996).

Consequently, much of the work done in natural resources management is necessarily location-specific. Dramatic results equivalent to the breeding of IR-8 are, therefore, rather rare, although successful cases do exist. An example of the kind of work that leads to success illustrates the contrast between the work done in this area and work on genetic improvement. In 1991, the state of Rajasthan in India created a multidisciplinary Department of Watershed Development and Soil Conservation, which began to carry out conservation and development work on more than 100,000 ha spread among more than 250 locations. The Department's goals were to develop environmentally sound, socially acceptable farming system technologies. Organizationally, its approach emphasized local participation and the working out of rules and procedures for sharing costs and benefits among local residents and the Government. The work was done in a very decentralized fashion, with a team assigned to each subwatershed, whose average size was only 4,000 ha, and with the staff encouraged to experiment and innovate (TAC / CGIAR 1996). The difference between this sort of interactive, location-specific work and the work done by plant breeders is obvious, but it also has to be noted that the approach adopted in Rajasthan is distinguished by its rarity.

Broadly, it can be stated that the stress on genetic improvement has favored the areas where water supply is assured. Areas that are not so well endowed have tended to lag considerably behind (David and Otsuka 1994). Within the irrigated areas, the intensification of production (particularly for rice and wheat) has been profound—many farmers have moved from growing as little as two tons per hectare and one crop per year to growing 4–5 tons per hectare and three crops per year—and cannot but put considerable stress on the natural resources that sustain the production. The problem in the less favored areas is somewhat different. Not having benefited as much from genetic improvements, farmers in these areas have to manage their meager resources better in order to increase productivity. Since very different sets of problems face these two areas, the following discussion is divided between them.

Irrigated Areas

In irrigated areas, intensification has given rise to two sets of problems. The first is a very long-term one, namely that the genetic-based strategy has run into what appears to be a limit. As noted in Chapter I, the differences between experimental yields and yields on Asia's best farms have gradually narrowed during the past decade. The other problem, more short-term and more visible, is the increased infestation of pests and diseases, which appears to be a direct outcome of the intensification.

As to the first set of problems, long-term studies of rice yields in experiment stations and in farmers' fields in areas that switched over earlier to modern technology indicate that yields—for a given level of technology and input use—have actually been declining (Pingali, Hossein and Gerpacio 1997). The cause or causes of this worrying trend are still not fully understood and work is proceeding at IRRI on this important issue. This problem, at the moment, remains one of high science, which the science-based centers are best equipped to study. However, if the causes of declining productivity can be identified, it does not necessarily follow that these centers can or must formulate the solutions.

As to the second set of problems, a number of actors other than the research centers are involved. The increased infestation of pests and diseases following upon intensification should occasion little surprise and is certainly one of the reasons for the decline in yields cited above. There are two main approaches now used to combat the problem, plus another one that is emerging as an important addition to the pool of pest-control strategies.

The first approach is the use of chemicals. Unsurprisingly, chemical companies have almost exclusively carried out the research in this area. Not only do they conduct research, they also have marketing networks that reach down to the farmers; indeed in some countries, they have developed excellent connections with the departments of extension as well, not always with the public interest in mind.

Agricultural chemicals, if properly used, can prevent crop losses, and, in the case of herbicides, save labor. The problem is that there has been a lopsided dependence on their use and in many cases this has proved, at the very least, unnecessarily expensive. In some cases, they have even been counterproductive. That the farmers have gone along with such a counterproductive method of plant protection could be attributed to ignorance—but government officials have also not shown themselves any wiser. Intensification of agricultural production has been especially rapid over the last two decades; is not surprising that adaptation to the new technologies has reflected, at least initially, elements of irrationality and ignorance. This problem will be further discussed below in the section on extension and again in Chapter VI in the context of fertilizer subsidies.

The second approach to coping with increased infestation of pests and diseases is to go back to the plant breeders and get them to introduce resistance into the host plants. This approach is, of course, environmentally friendlier and to be preferred over the use of chemicals.

Both of these approaches, sometimes called collectively "kill or be killed," suffer from a fundamental flaw, however. Insects and other enemies of the plants have very short life cycles. It does not take a very long time for them to develop tolerance to the chemicals or to the built-in resistance of the host plants. The classic example in this respect is Indonesia in the mid-1970s. Following a heavy attack of the brown plant-hopper on rice farms, scientists came up with a new variety of rice that was resistant to it. Within a few years, the insect was found to have evolved into a new biotype that infested the new variety just as nonchalantly and thoroughly as the old one. A third variety was introduced, and a third biotype just as surely followed.

Because of these problems, a radically different approach is now being advocated widely and adopted in some countries: integrated pest management (IPM). Briefly, this involves an ecological approach to pest control: the cultivated plants, their enemies, the pests (including weeds), and *their* enemies, i.e., their predators and competitors, are viewed as sharing a habitat. An imbalance in one component, caused, say, by increasing the biomass of the plants, sets off other changes. Completely eliminating one of the plants' enemies would also introduce an imbalance in other components. In the case of pests, in particular, their elimination would open up an ecological niche that would be quickly filled in. In the Indonesian example above, for instance, it is the new biotype of the brown plant-hopper that stepped into the niche.

The correct strategy, according to advocates of IPM, is to replace the older "kill or be killed" strategy with a "live and let live" approach. Of course, the primary objective of agriculture remains the sustainable yield of usable crops from the land, but instead of eliminating the pests at first sight, a more careful look has to be taken at the other organisms on the farm. These include the pests' predators and competitors. In that way, some control is kept on the pest population without necessarily eliminating the pests altogether. The use of chemicals is particularly to be faulted, as they tend to kill the pests and their predators and competitors indiscriminately.

While IPM relies much more heavily on farmers' management skills, the central Government also plays a crucial role in setting the policy framework. One case where IPM has been successfully applied is Indonesia. Indonesia's IPM areas have achieved lower pesticide use while avoiding, by and large, major pest outbreaks (although it must be acknowledged that the 300,000 farmers who have been trained in IPM field schools constitute only a small proportion of the country's 16 million farm households [Untung 1995]). Probably just as effective was the elimination in 1988 of pesticide subsidies, which at one time amounted to 80 percent of their cost. Additionally, there was a ban on the "extremely" and "most" hazardous pesticides, as defined by the World Health Organization. In contrast, the policies pursued in Thailand have been somewhat lax. While there has been no direct subsidy to pesticides, tariff barriers do not tax farmers and there is also an emergency outbreak budget that allows the Department of Agricultural Extension to spray infested areas. Consequently, growth in the use of pesticides has continued unabated, as has the frequency of pest outbreaks, not only in rice, but in other crops as well (Jungbluth 1996).

It is clear that IPM involves a far more sophisticated approach by the Government and farmers than was practiced at the time when the modern varieties arrived in Asia. At that time, the Government aimed to ensure that farmers obtained a bundle of inputs: seeds, fertilizers, water, and perhaps pesticides, with credit as a facilitating mechanism. Under IPM, the farmer is supposed to understand the process of pest buildup, perhaps after being trained and assisted by pest ecologists. Byerlee (1998) called the earlier, more arm's-length type of knowledge *embodied*: what enhances productivity is the inputs. Technology transfer is easier with embodied knowledge, because all that the farmers need to obtain are the inputs themselves. The knowledge of IPM, on the other hand, is *disembodied*: farmers have to learn how to manage the various inputs in different circumstances, and this requires greater knowledge and judgment.

Fertilizer application is another area where disembodied knowledge is required. Byerlee (1998) cites research showing that the fertilizer response function in Asia has been shifting downward over the years as a result of deterioration in the soil resource base. This is yet another aspect of the yield decline story mentioned earlier. In Indonesia, which contains some of Asia's most intensive rice-growing areas, the farmer's response has been to increase the use of nitrogen (N) and phosphorous to levels that significantly exceed agronomic and economic recommendations (Roche 1994). Furthermore, the efficiency of N use—i.e., the percentage of applied N that is actually taken up in grain and straw—is also quite low among Asian rice farmers. The way to enhance that efficiency is to precisely time the application of N during the growing cycle to match the nutrient demand and root absorptive capacity of the plant. This, however, is a highly sophisticated approach, requiring, at the very least, soil and tissue testing, but possibly also the application of crop models, use of fertilizers other than prilled urea, and so on. Most problematic is that the technique is not generic, but highly location-specific, indeed, almost farm-specific.

Such an evolution implies that the older top-down model of research has to be substantially changed. Even more affected will be the extension system, which is discussed below. The earlier separation of research and extension or, more accurately, the one-directional relationship between them (with research supplying technology for the extension system to transfer to farmers) will have to end. Farmers will have to be brought directly into the process of technology development (see pp. 72–73). They will also have to become more sophisticated and critical, giving priority to getting the right kind of technical information for their specific circumstances.

Less Favored Areas

Intensification of the irrigated areas, aided by genetic improvement, has brought yields to the point where, in some regions, they are touching the ceiling imposed by resource constraints (including the downward pressure on the yield ceiling imposed by increasing pests, diseases, and other factors). In contrast, the resource constraints in less favored areas have been more binding from the beginning.

The elite agricultural research organizations, both the IARCs and the national systems, have always emphasized genetic improvement. At the same time, they have, over the years, been pressured to pay attention to the resource-constrained areas because of concerns about equity. Because of donor influence, this pressure has been probably been stronger on the IARCs than on national systems. But it is fair to say that all these research organizations have failed to deliver, or at least to have had as dramatic an impact, as they had in irrigated areas in the 1960s and 1970s. The fundamental problem is that the resource-constrained areas do not lend themselves to easy solutions; if there is any solution, it is unlikely to be delivered solely by the high science characteristic of these elite institutions. For if resources are the constraint, the solution will have be one of two kinds: either the constraint has to be lifted, or farmers will have to better manage their farming within the constraint.

The lifting of the resource constraint requires investment. Usually, but not always, the most limiting constraint is water. Irrigation moves land out of the unfavorable category and makes it amenable to the modern genetically-based technology. Thus, Asian governments have invested heavily in irrigation, particularly in the 1970s, but that investment has fallen off since the mid-1980s (see Chapter V).

Unirrigated land includes a vast category ranging from semiarid zones to fairly humid, even flood-prone regions. The already difficult problems of farming with severe resource constraints are compounded by the fact that the variations within these areas make it very difficult for scientists to devise new technologies that would be widely applicable. Agricultural scientists also point out that there is no research paradigm for resource management equivalent to Mendelian biology for genetic improvement. It is partly for this reason that elite scientific research has failed.

Two ways out of this impasse suggest themselves. One is to redirect the research system away from the genetics-driven commodity focus and toward a more interdisciplinary farming-systems approach. This approach has been advocated for many years, but unfortunately, despite the strong support it has received from the donor community, results on the ground are hard to come by, much less to generalize about (the Indonesian experience is presented in Manwan et al. [1998]).

The second way out, sometimes called diversification, is more promising, but actually requires much more than research. The term “diversification” is misleading, for it suggests that each farmer should grow a wide variety of crops to minimize risk. While that may itself be a wise course (particularly if farmers choose crops whose yields are negatively correlated with one another), it does not necessarily follow that farmers should move away from the basic food crops. People living in less favored areas tend to concentrate on the production of food crops because less favored areas also tend to have poor transport. For them to grow something other than food crops is to incur a double penalty: the cash crops will have to be transported out and the food will have to be transported in, both at high cost, while the farmer is exposed to the new risk that market prices may move adversely. Consequently, the choice facing these farmers is often limited to food crops, e.g., upland rice, even though the land is far from ideal for such crops.

If their choices could be broadened to include other crops, the resource constraint might not be as limiting as that for food crops. Which crops are appropriate for the resource conditions and which crops may find an adequate market are clearly far more subtle questions than can be handled by elite scientific research institutions with a mandate for just one commodity or only a few. In fact, the shift to new cropping patterns can often be induced without any new research. The key example is a good road that facilitates the shift by reducing transport costs, as illustrated by the experience of northeast Thailand in moving away from rainfed rice to cassava. Building better transport infrastructure also reduces consumption risks for households, as they can draw on a larger supply pool for food.

The role of the central Government is critical in formulating a correct development strategy for remote, resource-poor areas. Investments in infrastructure are essential to encourage the expansion of commercial markets and the involvement of the private sector. At the same time, the skill of the farmers is itself an asset that should not be overlooked. Technology in these areas will have to be highly location-specific. Consequently, the top-down approach from research to extension to farmers, which was appropriate for a program of genetic improvements in irrigated areas, cannot work here. Indeed, even in irrigated areas, as resource constraints are making themselves felt (at a much higher level of production), the old centrally-directed research system will have to deal with farmers less as passive recipients of technology and more as active interlocutors and partners.

Nongovernment organizations (NGOs), about which more below, can fill a particularly important role in applied research and extension in less favored areas. Throughout Asia, NGOs have conducted “action research,” which involves the participation of local communities. Two features distinguish these NGO efforts from the approach adopted by the conventional research and experiment stations. The first is the generally small-scale nature of their activities, which is altogether appropriate, given the location specificity of the task. Second, there is a much closer interaction between the biophysical and social science aspects of the research. The communities are asked to participate from the stage of designing the research, instead of being brought in after there is a finding to be adopted by the individual farmers.

Mechanization

As productivity in irrigated areas has grown, so has mechanization. In rice areas, there is a typical sequence. First, land preparation is mechanized, with small power tillers whose engines can also be used for pump irrigation. Next, as the timeliness peak at harvest becomes accentuated, threshers are introduced. The peak during transplanting does not lend itself readily to mechanization, however, so farmers have resorted to broadcasting pre-germinated seeds instead (substituting herbicides for labor). Finally, harvesters begin to come in. Parallel to these farm developments is the introduction of power milling. Within areas where rice is commercially grown, power milling is a feature antedating World War II. The main development in more recent times has been the expansion of small power mills in areas where most of the rice is locally consumed. A key factor that facilitates mechanization is obviously the level of wages (Pingali, Hossein and Gerpacio 1997).

Asian governments and international research institutions such as IRRI have had an ambivalent attitude toward mechanization. On the one hand, it is feared that mechanization would lead to considerable labor displacement, as well as an enhanced competitiveness and power of the larger landholders relative to the smallholders. On the other hand, if market prices reflect social scarcity values, mechanization undoubtedly increases economic efficiency (Pingali, Hossein, and Gerpacio 1997). Sometimes, for example, by breaking the bottlenecks in labor availability during the peak seasons, it helps small farmers as much as larger ones. Indeed, in some cases, breaking such peaks is a necessary step to increasing cropping intensity, which significantly increases labor demand. In accordance with this ambivalent attitude, policies toward mechanization have also been somewhat confused. While research by international institutions has been intentionally cautious, certainly in organizations such as IRRI, public policies in other areas, such as the setting of low interest rates for agricultural loans, inadvertently promote mechanization.

Most public research systems in Asia have modest programs in mechanization research. However, in most instances where new machinery has been successfully introduced, as in Thailand, it was done first through imports from the more advanced countries in Asia, then through the imitation of such design imports by local producers, followed by adaptation to fit local conditions. Therefore, probably more important than research for the growth of mechanization is an active machine-producing sector, often small-scale and rurally based, which can adapt and invent new machinery that is appropriate for the local environment. A dynamic agriculture sector with growing demand for labor-saving inputs is obviously the key to jump-starting this process.

Who Will Undertake and Who Will Pay for the Research?

In the above discussion, the research tasks were broken down into many categories and the roles of different actors were shown to have evolved over time in response to the changing science and environment. Table IV.3 summarizes the comparative advantages of the different actors. Where no distinction between local and central research institutions is made, the reader should assume that central institutes would take primary responsibility for basic research, while local institutes would be largely involved in adaptive research.

Pray (1991), in a survey of Asian research institutions, describes many different systems of research that exist, sometimes coexisting within the same country. Most of the research systems are publicly funded, but they vary according to how much autonomy the system has in the allocation of research funds. Further, during colonial times, for political and economic reasons, export and plantation crops received a disproportionately large share of total research funding relative to the value of their production. Investments in research on foodgrains became higher only during the 1970s.

Table IV.3 Comparative Advantage of Different Actors in Agricultural Research

Research Tasks	Products	Current Situation	Future Comparative Advantage
1. Genetic improvement	Self-pollinating crops	Public research system	Public research system
2. Genetic improvement	Cross-pollinating crops and small animals	Public research system plus private firms	Private firms
3. Genetic improvement	Local fruit trees and large animals	Farmers	Public system or private firms (with biotechnology)
4. Genetic Improvement	Introduced species	Public research system	Public system or private firms (with biotechnology)
5. Crop protection by chemicals	All crops	Private firms, public extension system, and farmers	Same, with greater regulation by public agencies
6. Crop protection by host-plant resistance	All crops	Same as 1–4 (depending on type of crop)	Same as 1–4
7. Crop protection by IPM	All crops	Public extension system, farmers, and NGOs	Same
8. Resource management (soils, cropping patterns)	All crops in unfavorable areas	Local public research, farmers, and NGOs	Local public research and extension system, farmers, and NGOs
9. Mechanization	All crops	Private firms	Private firms

Part of the reason for this was that during the colonial period, research on export crops was funded by the producers themselves. Since the benefits of research on export crops accrue mostly to the producers *as a group*, it is possible for the Government to ensure that they finance the activity, by levying a tax on the commodity. Of course, individual producers have no incentive to pay for research because of the public-goods nature of its outputs. But conveniently, export taxes are easy to collect. Where the entire production is exported, the incidence of the tax falls exactly on producers. If any amount is consumed domestically, then an export tax acts as a subsidy to domestic consumers. If the country is also a significant player in the world commodity market, part of the tax incidence will be shifted to foreign consumers. Thus, many countries finance research on export crops by means of such a tax. Table IV.4 shows the use of specific funding schemes for research in Asian countries.

An export tax earmarked for research can be turned into something more than just a financing mechanism. Since the industry—and by this is meant not just the growers of the commodity, but the processors and exporters as well—will be asked to pay for the research, its political support for such a mechanism will be more wholehearted if its members can contribute to determining the research priorities and strategies. Besides, their participation cannot but add value to the exercise. Therefore, a common feature in developed countries that use earmarked taxation is to set up a council consisting of representatives of the industry to direct the research agency involved.

Theoretically, as foodgrains are tradable, any cost reduction brought about by research should primarily benefit the producers. Most countries intervene heavily in the import and export of foodgrains, however (see Chapter VI), often making them effectively nontraded. Under such circumstances, the benefits of research accrue largely to consumers. As direct consumer taxes on foodgrains would be politically unacceptable as well as economically regressive, financing the research out of general tax revenues can be justified.

It has been conventionally assumed that agricultural research can and should be financed out of general tax revenue. But actual practice in Asia in the past has shown much more variety and, it must be said, more imagination in regard to how governments have tackled this problem. The following principles should guide the response to the question of who pays for the research:

- Beneficiaries of the research should pay for it;
- The number of collection points for taxes should be as small as possible;
- The allocation of resources should be distorted as little as possible; and

Table IV.4 Commodities with Producer-Funded Research

	Bangladesh	India	Indonesia	Malaysia	Pakistan	Philippines	Sri Lanka	Taipei,China	Thailand
Areca nut		1966							
Cashew							X		
Cocoa			X	X					
Coconut		1966			1981	X			
Coffee		X	X						
Cotton		1966			X				
Jute	1973	1966							
Lac		1966			1981				
Oilseeds		1966			1981				
Palm Oil			X	X					
Rubber		X	X	X			X		X
Silk	X	X							
Sugar	X	1969	X			X	X	X	X
Tea	X	X	X				X		
Timber						X			
Tobacco		1966	X		X	X		X	X
Agricultural Produce		X			1981				

Notes: An X indicates that an industry funding scheme is currently in operation (except for cocoa in Malaysia, for which there is legislation that has not been implemented). Cells with dates indicate that the schemes are no longer in operation; the figures indicate the year of cessation.

Source: Pardey, Rosenbloom, and Fan (1998).

- If the number of collection points or the distortion cannot be kept reasonably small, then general tax revenues should be used.

With these principles as background, the following observations may be made. First, the production, processing, and consumption of food crops and perishables like horticulture crops tend to be quite dispersed. Second, cash crops are mostly exported, or else tend to have only a few processing points through which most of the production flows. Third, economic distortions caused by any of the levies earmarked for research can be ignored, because the required tax rates are usually small, typically less than 5 percent of the value of the crops.

Given these observations, commodities may be subject to a two-way classification: first, they may be classified into food crops and cash crops, and second, they may be classified into export crops on the one hand and import-competing and nontraded crops on the other. Table IV.5 proposes effective research funding sources for the various types of commodities thus classified:

Table IV.5
Proposed Funding Sources Classified by Commodity Type

	Import-Competing and Nontraded	Export
Food Crops and Perishables	General Tax Revenues	Export Levy
Cash Crops	Processing Levy	Export Levy

In general, specific levies and other earmarked funding should be used wherever possible, as it is politically easier to devolve decisions on the direction of research to an industry group. (When the funding is obtained from general tax revenues, accountability would require central government supervision.) Clearly, devolution to the industry, which is aware of the problems it faces, will increase the efficiency and relevance of the research.

A final and very important caveat must be noted. The above breakdown implies that research will be organized along commodity lines, but as indicated earlier, this is appropriate only for genetic improvement research and perhaps for mechanization. Research to improve natural resource management requires a much broader, multidisciplinary type of organization, funding for which is probably best obtained from general tax revenues. Where local governments can raise adequate taxes, they may provide useful supplements to central government resources.

EXTENSION

Traditional Extension

Compared to the voluminous literature on the profitability of research, literature on the profitability of extension is meager. Hayami and Ruttan (1985) summarized a limited number of studies that examine returns to extension studies, of which four are from Asia (two in India and one each in the Philippines and Nepal). In the Nepal study, the returns were not significant, but the two Indian studies showed significant rates of return in the range of 15–20 percent. The study from the Philippines also showed a significant and "relatively high rate of return to extension contact" (Hayami and Ruttan 1985).

Evenson (1991) analyzed data on food crops in Africa, Asia, and Latin America, and concluded that extension services are generally productive, although their impacts are much more variable than the productivity of research (the rate of return on extension systems is, however, high—in excess of 80 percent). To explain the variability, Evenson hypothesized that many extension services are not well organized to disseminate the findings of research directly to farmers.

These findings are broadly representative of Asian countries, but are also rooted in a particular model of the extension system. Most of the studies examined data from the green revolution period, when the sequence of technological change was top-down. Scientists came up with better seeds, which were then produced at the seed stations (sometimes belonging to the extension departments) and distributed to farmers, usually with other inputs, i.e., fertilizers, pesticides, and credit. As already discussed, "packaged" extension was warranted during the green revolution, but that era is now drawing to a close. Farmers have absorbed most of the available technology; indeed, in some countries the extension goal should now be to decrease the use of pesticides (and even fertilizers in a few cases), as exemplified above in the case of Indonesia. Subsidized credit, if it was ever needed, is no longer necessary to induce farmers to adopt the technology. (Meyer and Nagarajan [1999] provide a detailed discussion of the adverse impacts of subsidized public credit on rural financial markets).

It would be wrong, however, to associate the top-down approach to extension exclusively with the period of the green revolution. This approach preceded the green revolution (Hayami and Ruttan 1985), and has remained alive and well since. Despite the intellectual influence of economists like Theodore Schultz (1964), most agricultural ministries remain steeped in the tradition of looking at farmers as backward and ignorant and assuming that technologies already exist on the shelf that can be distributed to farmers for their benefit. To counteract this image, extension agents have sometimes been referred to euphemistically as "change agents," but the behavior of the extension system has usually changed little as a result.

The evaluative studies cited above started from the perspective of the government extension system and asked how well it performs its mission. An alternative approach is to take the farmer's perspective and ask which of the various sources of information are most important in influencing the farmer's knowledge, practices, and performance. In a study of Northern Thai farmers, Mingsarn, Kanok, and Chaiwat (1989) found that they have a rich variety of information sources, including the local commodity trader, other farmers (particularly the more adventurous farmers who are always experimenting with new crops and new technologies), the mass media, and of course the extension agent. Information is conveyed in ways that are at times quite complex. The commodity trader in the Thai study was more than just a trader; his trading business was closely interlinked with credit provision. He was therefore instrumental in the farmers' choice of crops and even varieties, soybeans in this case. The trader took charge of distributing a new variety of soybeans, which was originally stolen from an experiment station.

The picture painted by this study shows farmers as active agents in their own behalf, rather than as passive recipients of information handed down to them. By and large, the private sources of information were reaching farmers somewhat faster than the public sources, particularly in regard to market demand and prices. It appears that in one respect both sources of information failed badly: that is in the use of agricultural chemicals. In the Thai study, farmers were experimenting mostly on their own, occasionally in consultation with extension officers. It is tragic that in many cases, despite their hunger for it, farmers appear unable to obtain information about pesticides from a disinterested source.

Private Contract Farming as a Means of Extension[7]

Technology transfer can also be achieved by the private sector through the system of contract farming. The Thai case depicting the soybean trader sitting astride the commodity, input, and credit markets is an example of informal contract farming. More formal systems of contract farming exist: a well-known example in the case of poultry farming was first pioneered in Thailand by the Charoen Pokphand company (CP), a firm that later became a large conglomerate, extending its reach to other Asian countries. Sompop and Suebskun (1992) studied this experience.

Farmers traditionally raised poultry on a very small scale, most often as a sideline. CP brought in a hybrid breed from the Arbor Acres Company in the US. They also set up large automated feedmills, which remain the core of their operations. The arrangements between the farmers and CP range from a guaranteed wage contract to a guaranteed price contract.

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[7] Another form of contract farming, not covered in this chapter, is the contract farming associated with public resettlement schemes. See the papers on Malaysia and Indonesia in Glover and Lim (1992).

Under both, the sheds in which the chickens are raised are owned and operated by the farmers, although their construction may be financed with loans from the contracting company. With a guaranteed wage contract, the firm bears both the production and price risks. Clearly, CP would prefer to avoid the production risk, but a guaranteed wage contract is offered as an opening inducement to farmers to join the firm, from which they may "graduate" as they acquire more expertise. With a guaranteed price contract, prices of inputs and output are fixed in advance, with CP bearing all the price risk, while farmers take on the production risk in return for the expectation of higher net income.

The intensity and quality of CP's performance in providing extension services is remarkable. The firm's extension staff, all of whom have veterinary degrees, visit the farms every two or three days to provide technical information, check on the animals' health, and ensure that the farmers follow the firm's regulations. It might appear then that these farmers are little more than wage laborers for the company. But in fact, they are relatively well off, particularly when operating on guaranteed price contracts. Many of them eventually graduate to fully independent status as contractors, although links to CP are usually maintained through purchases of the company's feed. Sompop and Suebskun (1992) also note that when agricultural cooperatives tried to enter the business, they failed, because they were unable to maintain the timeliness and precision required in the operation.

Poultry raising in Thailand has grown within two decades to a major export industry. CP's success has turned the firm not only into a major player in Asia outside Thailand, but also into a major voice advising the Thai Government in agricultural development. The Government has observed the successful technological transfer implemented by CP and believes that it provides a model that can be replicated elsewhere. CP also appears to believe its own propaganda and has tried to initiate similar arrangements in rice and maize. By and large, however, these schemes, along with similar ones initiated by the Government, have failed, except for hybrid seed production. Maize and rice are traditional crops; all inputs used in their production can be procured in arm’s-length markets and the technology is fairly standard. These characteristics combine to make farmers of these crops more self-reliant compared to the knowledge-intensive poultry industry.

Private contract farming is not a panacea. Indeed, it has only a very limited role to play. Where it has been most successful, there is usually a relatively rigid package of technical inputs and a high ratio of purchased inputs in total costs. In addition, because of economies of scale, companies like CP tend to work with the larger farms, and also to push small farmers into undertaking larger operations. The main lesson that it demonstrates, which has a wider applicability but which is not generally recognized, is that a very input-intensive agriculture such as poultry raising also requires very intensive input from a labor force that is suitably educated (in this case the extension staff of the contracting company and, over time, contract farmers who have acquired skills).

The Role of NGOs in Extension

The direct role of NGOs in research, particularly in resource-constrained areas, has already been touched on. Since there is a continuum between research and extension and also between work in the biophysical sciences and that in the social sciences, it is not surprising to see NGOs becoming quite active in these areas. The range of their activities is enormous: agroforestry in Nepal, tea production and vaccine research on cattle diseases in India, soil and water conservation techniques in the Philippines, to name just a few gleaned from the case studies cited in Farrington and Lewis (1993). The range of NGO inputs in the research-to-extension continuum is also quite wide, as is the range of their organizational frameworks.

In most countries, NGO activities are completely separate from those of the Government. Often the relationship between NGOs and the governments has been more adversarial than cooperative. Where the two actors have cooperated closely, as in Bangladesh, India, and the Philippines, the results have been extremely fruitful. In India and the Philippines, the Government has taken the initiative to establish close ties with NGOs. The Indian Council for Agricultural Research has set up farm science centers (known by their Hindi initials as KVKs) to serve as centers for demonstration and training in "scientific farming" (Farrington and Lewis 1993). While the structure is no different from a conventional extension system, the aim is to use this structure to open up NGOs' access to the public research system. Similarly, the Philippine Department of Agriculture has set up an NGO Outreach Desk (Farrington and Lewis 1993).

Devolution of Extension Services: a Wave of the Future?

As argued above, agricultural extension must evolve into a more localized, bidirectional system that answers technological questions posed by actual farming practices and that is more responsive to the farmers' needs. Two possible avenues have been explored, one involving contract farming with private corporations taking over many of the functions of the extension system, and the other involving closer cooperation with NGOs. The first has limited applicability outside specific sectors such as poultry, while the second holds more promise but has to be more widely applied before clear conclusions can be drawn.

A third avenue lies in the devolution or decentralization of extension services, a realm in which many countries are at present experimenting, although it cannot yet be said that a magic formula has been found. As was discussed in Chapter III, Indonesia's efforts to decentralize agricultural research and extension have been hampered by financial wrangling between the Center and the periphery, as well as inconsistent donor support. From the perspective of this chapter, the main problem with Indonesian extension remains its lack of responsiveness to the needs of the farmer, or even to the demands of local governments, because it still takes its orders from the central Government. Inadequate funding of devolved extension has also occurred in the Philippines, where the extension system is now managed largely at the local level. Although judgments vary on the effectiveness of the Philippines' reform, the experience so far suggests that there has been a trade-off between the effectiveness of technology transfer, which seems to have suffered, and the accountability of the system to its clients, which seems to have improved. Indonesia and the Philippines must both grapple with the overlap in central and local services that has arisen in the absence of a clear division of responsibilities. Despite these difficulties, the widespread popular support for decentralization leads to the prospect that these teething problems may eventually be overcome.

Another possible option is for the central Government to pay for (or subsidize) the extension services, but to make the agent accountable—ideally to farmers, but as a compromise, to a local unit of government. In this area, it is the former socialist countries that have gone furthest. Thus, in Viet Nam, the extension agent is hired, fired, and paid by the District People's Committee. Alternatively, a government could contract for, or subsidize, the activities of the NGOs, provided that the NGOs are demonstrably delivering a service that farmers in a given locality demand and use.

A final alternative is to have the provision of extension services completely privatized, as has been done in Chile. In such a situation, the extension agent becomes a professional or a consultant, selling his or her services to farmers for a fee, much as a doctor does. No Asian country has gone this far and it is not expected that many will follow the Chilean example.

CONCLUSIONS

There is clear evidence that investment in agricultural research is highly profitable for society, so much so that one must conclude that there is underinvestment in it. Since much of the knowledge it produces is essentially a public good, the Government has to be centrally involved. Yet, with the exception of the period surrounding the green revolution, political support for agricultural research has been tenuous, and much of the pressure for putting in greater resources has actually come from foreign donor institutions. Before more investment in agricultural research is once again advocated, the question of what is wrong with agricultural research as actually practiced must be addressed.

The World Bank, which has funded a good part of the agricultural research investments in developing countries, has conducted an evaluation of this support (World Bank 1996a) that is useful in summarizing many of the points raised in this chapter. It found that apart from a lack of sustained funding, there is, firstly, inadequate research planning and prioritization, which is attributed to inadequate economic and social analysis by the research agencies. Secondly, there is no clear attempt to make the research more relevant to the farmers' needs. Underlying these two shortcomings is a lack of clear articulation of what it is that scientists in the research institutions are doing and why they are doing it. It is small wonder then that research institutions are finding it difficult to convince their own governments to finance their activities, even though, quantitatively, research in most countries takes up only a small proportion of the total agricultural budget, easily overshadowed by irrigation or extension.

These shortcomings are those of traditional commodity-focused research, with a top-down approach to extension. This chapter has described how technology has been changing and making this approach increasingly irrelevant except in the area of biotechnology. In both irrigated and rainfed areas, resource-management issues are becoming the dominant themes, leading to a much more knowledge-intensive agriculture than before. Whether it is in the area of crop protection or nutrient management, the research that needs to be done will be much more location-specific and the interaction with farmers much closer than it has been. This implies a total restructuring of both the research and extension systems. The key elements of such restructuring will be a decentralization of research activities and a much greater responsiveness to the needs of the farmers, whose participation will have to be much more actively solicited.

Change has to be in the direction of increasing the system's accountability to the farmers who are meant to be its beneficiaries. One approach is to decentralize the authority over extension agents to local governments. This approach is being tried in the Philippines and Indonesia. Unfortunately, in both cases the transfer of functions is being bogged down by strictly bureaucratic issues of personnel policy and resource control, but it is hoped that the basic soundness of the concept will not be undermined by what surely is a transitional administrative problem.

Asian governments need to increase their investment in biotechnology research, at the very least to overcome some of the inherent biases in an area where multinational corporations are dominant. Aside from the benefits of the research itself, the public sector needs to have a trained cadre in this area for the tasks of regulation and risk assessment; such a cadre would be necessary, regardless of whether the research task is to be done by the multinational corporations or by the Government.

On the vexing issue of intellectual property protection, pressure is likely to be exerted on Asian developing countries by developed countries, particularly the US, to extend such protection to the fruits of agricultural research. The benefits to Asia are likely to be rather small. If, however, some sort of protection is deemed necessary to placate the developed countries, then plant variety protection should be the form provided, for two reasons. First, it gives the reward exactly for the value added by the scientists. Second, it is a form of damage control, for the alternative (patent protection) is liable to be much more costly.