Public and Private Agricultural Research

Issues

Many policies related to agricultural biotechnology are directed toward the output, intended or unintended, that results from using biotechnology products. Such policies include those that affect market segregation for quality-enhanced products, consumer information, and environmental issues. But other public policies are aimed directly at influencing the amount, pace, and direction of agricultural research performed by both the public and the private sectors. What policies are available to influence this research toward greater public benefits?

Context

Many studies on the returns to agricultural research focus on the amount spent on research. The public policy tools used in this instance are the funding of public-sector research and the allocation of those funds to different activities and institutions. Other public policies, however, are very important in influencing the overall scope and direction of agricultural research, particularly the research performed by the private sector. Among the most important of these policies are those that focus on intellectual property rights (IPR), such as plant varietal protection and patent policies, and those that address market concentration, such as antitrust policies. In fact, these two sets of policies, although usually administered by different government agencies, are quite interrelated.

Specfic Policies

Intellectual Property Rights and Scientific Advance

As biotechnology becomes increasingly important in agricultural research and product development, public policy on intellectual property rights becomes increasingly important in shaping the pace and direction of agricultural research. At the first level, IPR's trade off some monopoly power for greater incentives for private research and innovation, which leads to differing distributions of benefits from new technology and "deadweight" losses. At the second level, greater market power from industry concentration and stronger IPR's can enhance incentives for private innovation. But IPR's can also inhibit technological progress by creating barriers to new firms entering the research arena and associated markets and limiting their access to new innovation, including innovation from academic research.

An optimal patent policy would try to balance these conflicting trends to maximize social benefits, but the elements of such a policy are difficult to discern in a rapidly evolving industry based on accelerated scientific advance (Evenson). Even the ideal patent policy is what economists call a "second-best" solution for encouraging innovation (Deardorff).

Consolidated firms with large market share and strong patent portfolios may motivate private research efforts because these firms are often in a better position to capture the economic gains from research investments. Greater ability to appropriate new technology through such vehicles as the establishment of plant breeders' rights and the development of hybrid seed technology can also motivate private innovation. Hybrid seed technology, in which investment is protected through trade secrets, provides a good illustration of this. The private sector is able to appropriate more of the gains from hybrid research efforts because the yield vigor of hybrid crops decreases in subsequent growing seasons, requiring farmers to repurchase seed every year. As a result, private-sector research investments in hybrid crops, such as corn and sorghum, as a share of seed sales have been much greater than research spending on nonhybrid crops, such as wheat, soybeans, and cotton (Fuglie et al.).

Too much market power, however, may inhibit technological advancement. Concentrated firms with strong patent portfolios may have greater access to capital and markets than smaller, startup technology firms (Barton). There is already evidence that entries of startup agricultural biotechnology companies have declined dramatically (Kalaitzandonakes and Bjornson). These startup companies are important because they often conduct midlevel research, or more specifically, they develop technologies that bridge the gap between knowledge produced by basic research and new product development (U.S. House of Representatives). Greater market power from ownership of intellectual property may limit access to new technology that could affect both private- and public-sector innovation if it inhibits the right to use certain technology. Conflicting claims and "reach-through" patents (in which firms claim ownership to both the upstream and downstream stages of research) may lead to a "tragedy of the anti-commons" in which innovation is delayed or deterred altogether (Heller and Eisenberg).[6] As a result, improved technologies or technologies with public benefits may not be developed.

As we have noted, the empirical record concerning the economic effects of intellectual property protection in general and in agriculture is inconclusive. At the retail level for corn and soybean seed, foundation seed companies generally have access to herbicide-tolerant and Bt technologies through licensing, and thus, even the smallest seed companies can use these technologies if they wish (Duvick, 2000). At the more fundamental research level, however, whether the current intellectual property regime is stimulating or hampering research is unclear.

Concentration in the Agricultural Input Industry

Antitrust policies generally address excessive market concentration, but several important changes in the agricultural input industry merit attention. Advances in science represented by biotechnology and changes in IPR regimes contribute to varying degrees of concentration in the seed industry, but they are not the only factors. Historical data (tables 10-13) reflect the effects of both IPR and other factors, but these cannot yet be interpreted as indicators of the effects of biotechnology. Soybeans, cotton, and wheat are all self-pollinating crops for which research spending has been a smaller proportion of seed sales than spending for hybrid crops. Each of the three crops, however, has a different history of private-sector involvement in the seed industry's concentration of seed sales. Despite greater market concentration in corn seed, by some accounts, U.S. farmers and consumers have been well served by the

[6]In Hardin's (1968) original "tragedy of the commons," too few property rights led to overuse of a common pool resource. In a "tragedy of the anti-commons," too many property rights may lead to underuse of research resources.

Table 10—U.S. corn seed market shares

Year	Share of seed sales by leading four companies
	Percent
1950's	≅ 50
1973	60
1980	60
1991	≅ 65
1997	69

Sources: Duvick (1998); Hayenga; Butler and Marion.

Table 11—U.S. soybean area market shares

	Share of area planted			
Year	Unknown	Public-sector varieties	Private-sector varieties	Leading four private companies
	Percent			
1980	22	70	8	7
1997 estimated[1]	n.a.	10-30	70-90	37-47

n.a. = Not available.

[1]Smaller figure for public sector (and larger figure for private sector) assumes planted areas are roughly proportional to seed sales. Larger figure for public sector (and smaller figure for private sector) assumes most farmer-saved seed is from public-sector varieties. About 25 percent of soybean seed in 1997 was estimated to be farmer-saved.

Sources: Hayenga; Butler and Marion.

Table 12—U.S. cotton seed market shares

	Share of seed sales		
Year	Public-sector varieties	Small private companies	Leading private company
	Percent		
1970-74	29	42	29
1975-79	37	25	38
1980-84	28	25	47
1985-89	18	20	62
1990-94	12	6	82[1]
1997	≅ 7	≅ 21	72[1]
1998	≅ 7	≅ 22	71[1]

[1]Many earlier estimates for 1997 and 1998 assumed Monsanto was the owner of Delta & Pineland, Stoneville, and several smaller cotton seed companies. Monsanto did own Stoneville, but never completed the purchase of Delta & Pineland, which was called off at the end of 1999. Furthermore, Monsanto has divested itself of Stoneville. The 1997 and 1998 figures now give the market share of Delta & Pineland alone. It is also likely that the 1990-94 figure should be reduced somewhat, but the raw data allowing disaggregation are less readily accessible.

Sources: USDA, Agricultural Marketing Service, as reported by Traxler (personal communication); Hayenga.

Table 13—U.S. wheat area market shares

Variety/ year	Share of area planted: Unknown	Public-sector varieties	Private-sector varieties	Leading four private companies
	Percent			
Hard Red Winter Wheat:				
1981	36	58	6	n.a.
1997	n.a	85	15	n.a.
Hard Red Spring Wheat:				
1981	37	57	7	n.a.
1997	n.a.	85	15	n.a.
Soft Red Winter Wheat:				
1981	37	63	0	n.a.
1997	n.a.	35	65	n.a.

n.a. = Not available.
Sources: Sears; Butler and Marion.

seed industry, especially when viewed in a world context (Morris). However, some features of current industry organization are new and merit further analysis.

First, the vertical coordination that will become necessary with the introduction of many value-enhanced biotech products is not new within agriculture, but it will involve the seed industry to an unprecedented extent. (Related issues are discussed elsewhere in this publication.)

Second, the seed industry itself may be concentrated at different levels, at different degrees of vertical integration, and in different parts of the market. For example, the corn seed industry could be broken down into trait suppliers, foundation seed suppliers, retail seed suppliers, and distributors. The estimates in table 10 report concentration only at the level of retail seed supply and do not say anything about concentration at other levels or about vertical integration (Goodhue et al.).

Third, antitrust policy in a rapidly evolving industry driven by technical change is still a contentious subject, as recent experience in the software and computer industries indicates.

Fourth, many consumer advocates are uneasy about the domination of agriculture by a few large, international life sciences companies. Finally, the very longrun commitment to agriculture by these life sciences giants may change. Pharmaceuticals and other health-related products are characterized by a high income elasticity of demand, whereas basic agricultural products have relatively limited income elasticities[7] (we are grateful to R. Herdt of the Rockefeller Foundation for this observation). This is one of the reasons for the strong likelihood of success for many value-enhanced products. However, markets for many of these products are likely to be niche markets, which could lead to further industry reorganization. Furthermore, some means will have to be found to continue to direct scientific advancements toward worldwide benefits and to apply new technologies to the production of basic staples (see "Meeting World Food Demand—The Role of Biotechnology" on p. 47).

Agricultural Research Policy

Even though policies are in place to monitor antitrust behavior, public research policy may still need to address implications from the increasing role of the private sector in agricultural research. In response to increased private-sector activity, public research institutions have been directing more resources to research that offers the greatest overall benefit to society and to areas where private incentives are weak. For example, USDA is targeting more resources toward basic science and applied science with a public goods component (National Science Foundation). Public goods include environmental protection, natural resource conservation, and food safety and nutrition. The private sector has little market incentive to conduct this research.

Differences between the public and private sector can be seen specifically in agricultural input research, such as plant breeding. A recent comprehensive survey of plant breeding research in both the public and private sectors showed that USDA's Agricultural Research Service (ARS) concentrates most of its research on long-term pre-breeding activities, while the private sector devotes most of its resources to short-term varietal development (Frey). ARS has terminated most of its research on variety development, preferring to concentrate on areas of research not pursued as intensely by the private sector.

USDA's research agenda has increasingly accounted for private-sector research as ARS sets its research priorities. At the same time, USDA has also sought to

[7] Corporate ambiguity about the synergies to be derived from a broad life sciences portfolio is illustrated by the recently announced Novartis/Astra Zeneca and Monsanto/Pharmacia & Upjohn mergers. In both cases, the merged companies intend to spin off or sell some or all of their agribusiness operations.

strengthen research collaborations with the private sector. Joint research with the private sector—for example, patent licensing, research consortia, contracted research, and Cooperative Research and Development Agreements (CRADA's)—can promote the use of public-sector research results, while providing additional resources for public research. USDA uses research collaborations to bring a particular invention or line of research inquiry to the private sector, thus fostering certain types of research. Day-Rubenstein and Fuglie compared public, private, and joint public-private research, using CRADA's as the measure of joint research. The pattern of research suggests that closer research and development cooperation between USDA and the private sector may have enabled the public sector to focus resources on areas where private incentives for research are relatively weak.

Public research can also foster market competition more directly. One way that public researchers promote market competition is by "inventing around" technologies held by companies. If a critical agricul-

Seed Technology

Genetically modified organisms (GMO's) are mostly characterized by inserting a single new trait into a given crop. Continuing applications will feature "stacked" traits—for example, varieties featuring both the Bt gene and herbicide tolerance. Other genetic technologies, however, are also of scientific interest and have the potential to be applied commercially. For example, scientists would like to understand more about gene interaction and about complex traits that are governed by more than one gene. Two areas of particular interest are control of plant reproduction and inducible traits—that is, traits that can be turned "on" or "off" by human intervention. Apomixis and the Technology Protection System (TPS, popularly known as "terminator" technology) illustrate these lines of research [see boxes, "Seed Technology: Apomixis" and "Seed Technology: The Technology Protection System ('Terminator')"]. Scientists at USDA's Agricultural Research Service (ARS) have contributed to the development of both technologies.

Both apomixis and the TPS technology are being developed with the help of public-sector funding. Both apomixis and TPS allow greater human control over plant reproduction. This control, however, could be put to quite different ends with either of the two technologies. A dramatic difference between the two is that apomixis could be used to reduce farmers' dependence on seed companies while the TPS could be used to increase their dependence on seed companies.

Apomixis is potentially a much more drastic change than the TPS, as it would imply major changes in both breeding and seed production. The TPS would be unlikely to change the actual processes of breeding and would change seed production very little. Both might imply some changes in farmers' practices, particularly in less industrialized agriculture. At the seed industry level, a feasible apomixis aimed at poor farmers would make those farmers depend more on the providers of apomictic seed. Because in this case financial rewards to the institutions that develop and provide apomictic seed would be relatively low, these providers would likely be in the public sector. Thus, such a strategy would rely on strong support for public-sector plant breeding efforts, which appears to contrast with current trends in plant breeding. One argument in favor of the TPS is the incentives it might create for private-sector investment.

The juxtaposition of the two technologies illustrates one policy issue: Should public funds be used to develop a technology that appears to shift the benefits to the private sector as with the TPS, if, as some argue, apomixis can shift benefits to farmers? At the same time, should a technology such as apomixis be seen as a solution for poor farmers if it is not linked with firm long-term commitments to strong public-sector plant breeding programs directed at their needs?

But there are also other broad similarities between the technologies. Given they both become technically feasible, the probability of their widespread use and the desirability of certain forms of that use are likely to differ between industrialized agriculture and semi-subsistence farming. With either technology, the size of economic benefits and the distribution of those benefits between biotechnology suppliers, seed companies, farmers, and consumers are likely to be determined by both the institutional configuration of the parties generating the technology and the distribution of intellectual property rights.

In a very broad sense, the social benefits of apomixis, the TPS, and other genetic use restriction technologies are likely to be maximized if the technological components are widely accessible at the same time that private companies receive a reasonable return on their research investments (Bicknell and Bicknell). The policies that will lead to these results are currently quite unclear, however, and will doubtless be subject to considerable debate over the years ahead.

tural technology is protected by a patent, for instance, public researchers may work to develop new technologies that perform similar functions.[8] This can limit the effects of a concentrated input market. For example, USDA conducts research on apomixis traits (see boxes, "Seed Technology" and "Seed Technology: Apomixis") (Adams). Apomixis provides a way of circumventing the hybrid barrier and could be a boon for farmers in developing countries who cannot always afford to repurchase seed.

[8]In some cases, other private firms would also have incentives to "invent around" a critical patented technology.

Apomixis, however, could also be useful in seed production, and a number of large companies have shown interest in the technology. For the moment, USDA has decided to develop the technology in-house so that it is more widely available. At the same time, USDA is co-holder of the patent for the technology protection system, known commonly by the derogatory label "terminator," which could be used by seed companies to restrict access to their materials [see boxes, "Seed Technology" and "Seed Technology: The Technology Protection System ('Terminator')"]. These two technologies provide a good illustration of the complexities surrounding public-sector research in an era of rapidly evolving technology.

Seed Technology

Apomixis

Apomixis is a naturally occurring trait in some plant species. Most plant species reproduce sexually through the fertilization of an egg cell by a pollen cell to form the embryo within a seed. Other plants can reproduce artificially through some method of asexual reproduction, or cloning. Apomictic plants combine the characteristics of reproduction through seed and clonal means. In apomixis, as in cloning, the daughter plant is genetically identical to the mother plant, but reproduction is effected through seed. There are different forms of apomixis, and apomixis and sexual reproduction are not always mutually exclusive within the same species. Except for a few tropical fruit trees or some forage species, very few economically valuable plants are natural apomicts.

If apomixis could be introduced into other crops, it could have many benefits. In crops traditionally propagated through seed, apomixis could lead to faster development of new hybrid varieties; large reductions in costs of hybrid seed production, possibly allowing the profitable production of hybrid seed in crops that currently do not support hybrid technology; and hybrid seed that could be maintained indefinitely by a farmer without losing hybrid vigor (see illustration on next page). In crops propagated vegetatively, apomixis could reduce the transmission of disease from one generation to the next and make handling of propagation material much easier (Bicknell and Bicknell).

Apomixis could have a few drawbacks. First, it is not universally agreed that apomixis would reduce the cost of breeding, as recombination of genotypes could be considerably more difficult with apomicts. Second, widespread and continuous planting of crop varieties that are genetically uniform could make breakdowns in resistance to diseases and pests more likely. Third, particularly in open-pollinated crops like corn, gene flow from apomictic crops to landraces or wild relatives could result in reductions in genetic diversity and, conceivably, to the development of "super weeds." Fourth, in vegetatively propagated crops, the advantages of apomixis (such as much reduced bulk in propagation materials) might be countered by the disadvantage of longer time in the reproductive cycle if seed were involved.

So far, public-sector research organizations in a number of countries have taken the lead in transferring apomixis to certain crops, although private companies have also researched some of the processes involved in apomixis (see Bicknell and Bicknell for a partial listing of patents related to apomixis). Scientists at USDA's Agricultural Research Service (ARS) have been particularly active in apomixis research for corn and pearl millet (Becker).

Commercial applicability in any crop may be at least 15 years away. But apomixis poses some interesting issues for both public- and private-sector agricultural research. On the one hand, because rights to many biotechnology techniques, some of which may be necessary for developing apomictic crops, are now held by the private sector, commercial development will proceed faster with private-sector participation. On the other hand, the private sector would clearly wish to develop *inducible* apomixis—for example, apomixis turned "on" to reduce seed costs but turned "off" after delivery to farmers so that farmers would purchase seed in subsequent years. Even in such a case, some of the benefits of reduced seed costs and other desirable traits fixed in the apomictic crop would probably be shared with farmers and consumers. Clearly, however, the private sector's proportion of the economic gains would be higher than they would be if superior apomictic crops themselves were distributed to farmers.

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Public research can also foster competition by providing competing technologies. In the past, public research has enhanced competition in the agricultural input industry (Ruttan). One example is the hybrid corn industry. Before the 1980's, State agricultural experiment stations and USDA released parent lines of hybrid corn varieties, which benefited small companies that relied heavily on these public-sector lines (Huffman and Evenson; Duvick, 1998). If growing concentration in the input industry were to have negative effects, USDA and other public research entities, such as State agricultural experiment stations, could direct public-sector research in such a way as to encourage competition. Public-sector institutions must guard, however, against transforming themselves into profit-seeking entities at the expense of conducting more fundamental research that does not have immediate market applicability.

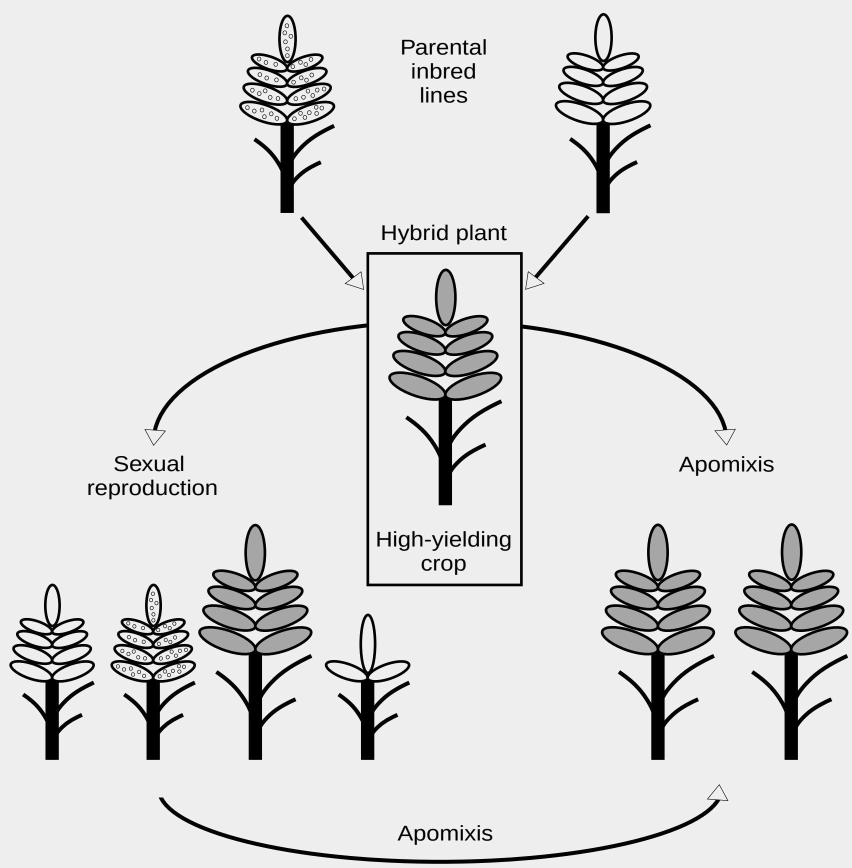
Policy Issues

The debate over IPR, concentration and antitrust, and public agricultural research policy will continue for years to come. Does the current system of patents and plant varietal protection stimulate or hamper the public benefit from private agricultural research? Could welfare-increasing changes be made to this system? How

Seed Technology

Apomixis

Apomixis in plant breeding



Hybrid plants are more vigorous and produce higher yields than their parents. Sexual reproduction creates variability among the progeny, resulting in lower crop yields. Apomixis will allow the fixation of hybrid vigor and the immediate production of a cultivar starting with any exceptional individual plant. (Courtesy of S. Lolle, Harvard University)

Seed Technology

The Technology Protection System ("Terminator")

Many of the earliest genetically engineered (GE) organisms have been in nonhybrid, self-pollinating crops, such as soybeans and cotton. With these crops, farmers can replant seed from the first-generation crop without losing expected yield, and they still can enjoy the benefits conferred by the transgene. When farmers replant saved seed, however, the total rents obtained by the seed producer are reduced. So far, seed producers have relied on contracts, signed by the farmer and enforced through contract law, to restrict replanting and sale of seed to other farmers. Although, to date, enforcement costs have not appeared to be too high, there have been some widely publicized cases concerning farmers who are suspected of breaking the contract, and enforcement that is considered too harsh may cost seed producers good will in the future. Private biotechnology-related companies, therefore, have begun to develop alternative, technical means of protecting their investments in research.

The best known technology directed at protecting research investment is the Technology Protection System (TPS), which received a U.S. patent in early 1998. The patent is jointly held by USDA's Agricultural Research Service (ARS) and Delta & Pineland, the Nation's dominant cottonseed company. The TPS is a multiple-gene technology. Plants that contain TPS genes can be grown and reproduced normally. However, pretreatment of seeds from a TPS plant with a specific chemical inducer before planting causes that crop to produce seeds that cannot germinate (see illustration on next page). This technology has been highly publicized and has been christened "Terminator" technology by some of its opponents.

The TPS allows production of viable seed, as long as the repressor gene is active. After the seed is produced, it is treated with the regulator, which inactivates the repressor, and sold to the farmer. The farmer plants the seed, which germinates normally, and the plant is productive. However, seed saved from the farmer's crop will not germinate when planted.

Successful commercial deployment of a TPS-like system may be possible in about 5 years. For one thing, current transgenic technology does not provide very reliable control of introduced gene expression, which means meeting quality control standards of a seed industry is difficult. For example, incompletely expressed genes could result in the producer's seed crop not germinating; on the other hand, poor expression of the recombinase gene could lead to fertility of many seeds sold to farmers, thus, perhaps, defeating the purpose of the TPS (Jefferson et al.). In the latter case, however, even a partially effective TPS could keep farmers from saving seed, particularly in more industrialized agriculture.

These technical difficulties may be greatly reduced. Furthermore, the TPS is only one example of possible technologies for achieving desired fertility or sterility in seed. There are other possible inducible technologies that act on plant traits, and not on the entire plant. In one example, application of a regulator would be necessary for the value-added trait to be expressed. For example, a corn variety might contain an insect-resistance gene, but this gene would be activated (for example, by spraying the standing crop with an environmentally benign substance such as ethyl alcohol) only in years when insect populations happened to be unusually high. Otherwise, the trait would not be expressed, but the seed would germinate normally. Jefferson et al. describe all these technologies as "genetic use restriction technologies" (GURT's). They define technologies that act at the level of the entire variety as "V-GURT's," or Variety-Level Genetic Use Restriction Technologies. Technologies that act at the level of an individual trait or traits are "T-GURT's," for Trait-Specific.

These technologies, in particular the TPS technology, have provoked considerable opposition on the part of some nongovernment organizations with interests in agriculture. The technology has been criticized on the grounds that it makes farmers dependent on seed companies, that gene flow from fields planted to TPS seeds could make plants growing in other nearby fields sterile, and that regulator chemicals or antibiotics could have adverse environmental consequences.

The TPS has often been compared with hybridization, another means companies have used for many years to protect their research or seed development investment in certain crops. Hybrids, however, provide a yield advantage to the farmer through the phenomenon of hybrid vigor, and although replanting F1 hybrid seeds results in yield losses, this practice is sometimes used by farmers in developing countries.

The TPS technology in and of itself does not convey an advantage until it is coupled with other desirable traits. This distinction may not be very important in commercialized agriculture, since hybrid vigor in a given crop does not appear to increase over the years, but it is crucial in understanding the relative incentives for the first-time adoption of hybrids or TPS crops. In industrialized agriculture, reducing the cost of producing hybrid seeds might be a more feasible way than the TPS to achieve technical protection of intellectual property for such crops as wheat, where hybrids are very infrequently grown at present.

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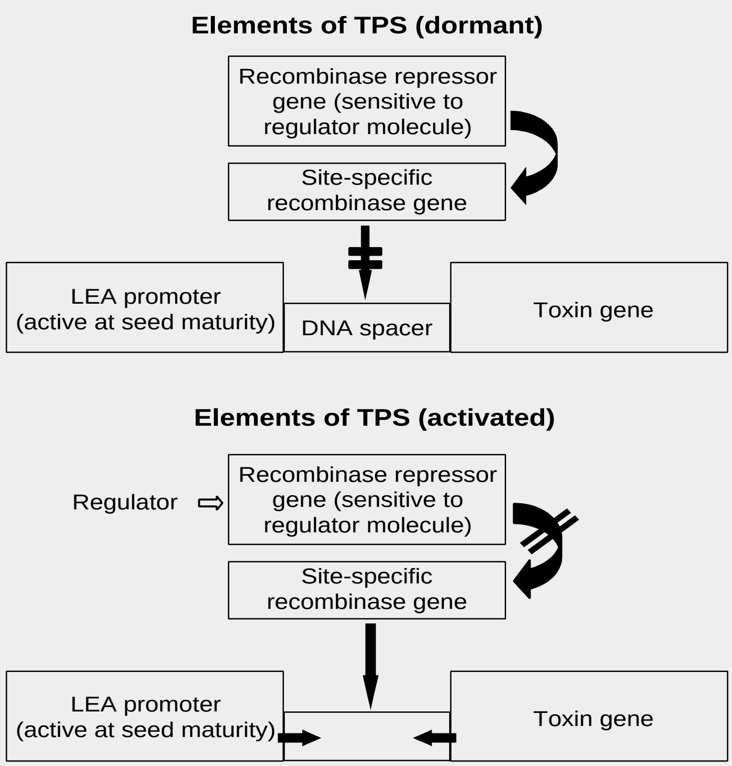
Seed Technology

The Technology Protection System ("Terminator")

On the other hand, supporters of the TPS argue that it will induce more private-sector investment in crop improvement research, particularly in self-pollinated crops, such as soybeans, cotton, and wheat, or in specialty crops for which planted area is small. Furthermore, the TPS might provide a means to prevent other transgenes from spreading to other plants in wild populations (Radin). In nearly all farming situations, germination is never 100 percent, and it is probably lower when farmers save their own seed. Gene flow from TPS fields is unlikely to reduce germination percentages very much for biological reasons.

In light of the concerns raised about TPS and similar GURT technologies, however, the developers have expressed some desire for further studies of the social and economic implications of their introduction. Monsanto, for example, which had planned to buy Delta & Pineland, stated in early October 1999 that it would not commercialize the TPS. At the same time, Delta & Pineland announced it would continue to finance TPS research as long as it remained independent. The implications of the recent announcement that Monsanto would not acquire Delta & Pineland are still unclear. In the medium term, the major determinants of the use of GURT technology will probably be the rapidity with which the technologies can be made robust and the value of the traits that are coupled with these technologies in new crop varieties.

Technology Protection System



One basic element of the TPS is a gene that codes for a toxin (several different plant-produced toxins are possible), which works in combination with a LEA (Late Embryo Active) promoter. The promoter is separated from the toxin gene by a DNA spacer; as long as the spacer is present, the toxin gene will not produce the toxin protein. A second element is a site-specific recombinase gene, which, when activated, will code for a recombinase enzyme that will cut the DNA spacer and allow the LEA promoter to cause the toxin gene to work. A third element is a recombinase repressor gene, which is sensitive to a regulator molecule. When the recombinase repressor gene is active, it will not allow the recombinase gene to activate. When the regulator (in the TPS patent, this is an antibiotic) is introduced, the recombinase repressor gene will become inactive; the site-specific recombinase gene will code for the recombinase enzyme, which will, in turn, cut the DNA spacer; and the LEA promoter will be activated. Since the promoter is a "late" promoter, it will be active only at seed maturity, at which time it will produce the toxin that will kill the embryo in the seed, which as a result will not be able to germinate (Jefferson et al.; Crouch).

can IPR and antitrust policies affecting agricultural research best be coordinated? Given the current dynamism and complexity of the agricultural input industries, policies aimed at fostering competition might be directed less at concentration ratios and more at accurately describing relevant markets, identifying key "choke points" in technology flow, and assessing barriers to entry at those choke points.

Public research policy begins with allocating public funds to agricultural research, directing the funds to selected research themes, and choosing institutions to carry out the themes. Many questions can be raised here.

- Is total funding for public-sector research adequate? Is the research portfolio balance of basic and applied research optimal?

- Are current methods of funding agricultural research appropriate? Or would changes, such as more competitive grant funding, be beneficial? On the one hand, more competitive grant funding could lead to better agricultural science through open competition that might attract more than the traditional agricultural science community and through peer review (National Academy of Sciences; Rockefeller Foundation; Alston and Pardey). On the other hand, competitive grant funding in agriculture may direct resources toward flashy, shortrun projects at the expense of research requiring steady effort over many years. In addition, competitive grant funding has resulted in an inordinate amount of scientists' time being spent in writing proposals (Buttel; Just and Huffman; Huffman and Just, 1994, 1999).

- Is the current public-sector institutional configuration—research conducted by State agricultural experiment stations and USDA—suitable? Or would different arrangements, such as regional research coordinated by State agricultural experiment stations or agriculturally oriented research performed by basic science departments in non-land-grant universities, bring benefits?

- Is the prospect of addressing issues of competition through research policy—for example, "inventing around" patents—feasible? Or would correctly allocating research resources and addressing concentration issues primarily through antitrust policy better serve the public? In this, as in other areas of research policy, there are arguments on both sides of the issue. On the one hand, to be able to "invent around" crucial technology bottlenecks, the public sector might need to be more nimble and familiar with cutting-edge technology than it has been accustomed to. On the other hand, antitrust policy is, in essence, reactive and does little to stimulate new research.

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