AGRICULTURAL BIOTECHNOLOGY: PRODUCTIVITY, BIODIVERSITY, AND INTELLECTUAL PROPERTY RIGHTS

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Abstract

This paper argues that current forms of agricultural biotechnology have significant potential for developing countries; the challenge is to realize this potential. We develop a conceptual model that explains why the yield effects of GMVs (genetically modified varieties) tend to be significant and reduce chemical use, contributing to human welfare, and present results from empirical studies that support these findings. We demonstrate that the adoption of GMVs might not necessarily lead to elimination of many varieties. Instead, crop biodiversity may be enhanced. Finally, we discuss how IPR constraints can be addressed, and new institutions that are already emerging may be used to allow developing countries more access to IPRs.

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The value and potential of agricultural biotechnology in developing countries have been the subject of concern and debate. Its proponents argue that it may enhance the productivity of agriculture in developing countries, and allow the expected growth in food demand from population and income growth (Paarlberg) to be met. New agricultural technologies, however, are not perceived to be essential to the developed countries experiencing chronic excess supply of food. Critics of the current wave of agricultural biotechnology, mostly the pest-resistant and herbicide-resistant genetically modified varieties (GMVs) that have been adopted extensively in the United States, Canada, Argentina, and to some extent China, argue that these varieties are of limited value for the developing world for several reasons (Altieri). First, these varieties have resulted in small yield increases in the North and, thus, may not contribute much to increased food production in the South. Second, these technologies pose a threat to crop biodiversity in the developing world. Finally, GMVs were introduced by private companies thathave intellectual property rights (IPRs) to the main components of the technology. Development of GMVs that meets the needs of the farmers in the developing world will be constrained by the lack of access to these IPR protected technologies.

This paper argues that the current generation of pest-controlling GMVs can contribute significantly to the developing world and addresses the arguments of critics of the technology presented above. Using economic logic and available empirical evidence, we propose that GMVs have yield-increasing potential in the developing world, that adoption of such varieties does not necessarily reduce crop biodiversity, and that IPR barriers to accessing these technologies can be resolved by the introduction of specific institutions and policies.

The Economics of the Yield Effects of GMVs in Developing Countries

A simple model of pest control technology choices at the farm level is useful to illustrate our main arguments about the possible impacts of biotechnology on yield in developing countries and to address issues of biodiversity. This is a simple version of a model introduced in Ameden and Zilberman, and it will show that the same technology may have different impacts at different locations depending on prevailing economic and environmental conditions. Thus, pest-controlling GMVs that primarily reduce pesticides use in the United States are effective in increasing yield in developing countries where pesticides have not been used or have had limited effectiveness.

Consider the case where a farm is growing a crop with a constant return-to-scale technology. Let i be an indicator of a crop variety and assume that the farmer can choose among three varieties: a non-GMV local variety with $i = l$, the genetically modified version of the local variety with $i = m$, and a generic GMV with $i = g$. The generic variety may be imported from another region or may be a regional variety that is modified for use in several localities.

Following Lichtenberg and Zilberman, we assume that pesticides and the GMVs are "damage control" agents. Let y_i denote output per acre of variety i. It is equal to the potential output y_l^p multiplied by the fraction of the output that is undamaged. The potential output of the non-GMV local variety is y_l^p and $y_m^p = y_l^p$. A fraction α, of the potential output, is lost when a generic GMV is used instead of the non-GMV, so $y_g^p = (1 - \alpha) y_l^p$. The damage depends on the initial pest infestation N_0, the pesticide use per acre with variety i, x_i, and whether the variety is genetically modified. The fraction of crop lost to pests is denoted by $D_i(x_i, N_0)$, and we assume that smaller pest populations or larger pesticide applications will reduce pest damage.[1] With the same pesticide use and initial pest population, the damage with the GMVs is smaller than with the non-GMV ($D_l(x,N_0) > D_m(x,N_0) = D_g(x,N_0)$). With this notation, the output per acre is $y_i = y_i^P(1 - D_i(x_i,N_0))$.

Let the price of output and pesticides be denoted by p and w, respectively. The farm also has a variable cost per acre denoted by c_v and seed cost per acre for variety i is denoted by v_i. We assume that $v_l = 0$, and that the seed cost per acre of the generic GMV is smaller than the local GMV, $0 < v_g < v_m$.

The farmer has to choose a crop variety for each field and a pesticide application level with this variety. The maximum profit with variety i is denoted by $\pi_i = \underset{x_i}{Max}\left\{py_i^P(1 - D_i(x_i,N_0)) - wx_i - c_v - v_i\right\}$. The optimal pesticide use for variety i is determined when the value of the marginal benefits of pesticides (resulting from reducing damage) is equal to its price ($-py_i^P \frac{\partial D_i}{\partial x_i} = w$). Ameden and Zilberman show for a similar model that use of pesticides increases as the price of output rises, as the price of pesticides declines, and as the potential output and the size of the initial pest population increase.[2] The reduction in pest population from using GMVs decreases the marginal productivity of pesticides used with the GMVs and, thus, less pesticides will be applied with the modified local variety and with the generic GMV under most likely conditions.[3]

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[1] $\frac{\partial D_i}{\partial x_i} < 0, \frac{\partial D_i}{\partial N_0} > 0.$

[2] $\frac{dx_i}{dp} > 0, \frac{dx_i}{dw} < 0, \frac{dx_i}{dy_i^P} > 0, \frac{dx_i}{dN_0} > 0.$

[3] $x_l > x_m$ and, under plausible conditions, $x_l > x_m > x_g$.

The adoption of either local or generic GMVs under most circumstances is likely to reduce pesticide use significantly as the pest control properties of the GMVs are substituted for the chemicals (Ameden and Zilberman). Let $\Delta x_m = x_l - x_m$ and Δx_g denote the pesticide-use reduction associated with the adoption of the local and generic GMVs, respectively. Because the potential yield of the generic GMV is smaller, we expect less pesticide use with the generic GMV, $\Delta x_g > \Delta x_m$. Let the local and generic GMV be denoted by $\Delta y_m = y_m - y_l$ and $\Delta y_g = y_g - y_l$, respectively. When the local variety is genetically modified, Ameden and Zilberman show that the combination of the genetic modification and chemicals will reduce pest damage and, thus, output will increase $(\Delta y_m > 0)$. When a generic GMV is introduced, the damage reduction will tend to increase yield, but the lower potential output will tend to reduce it. Thus, the net effect of the generic GMV cannot be determined. The generic GMV will increase yield if the damage reduction effect is greater than the yield loss effect (i.e., $\Delta y_g > 0\, if\; y_l^P D_l - y_g^P D_g > y_l^P - y_g^P$).

A farmer will adopt the local GMV if (1) extra profits due to yield gain and pesticide cost reductions are greater than the extra per acre cost of adoption ($p\Delta y_m + w\Delta x_m > v_m$) and (2) the gain from adopting the local GMV is greater than adoption of the generic GMV. This will occur when the extra revenue of the local GMV is greater than the pesticide and per acre cost savings of the generic GMV (i.e., $p(\Delta y_m - \Delta y_m) > w(\Delta x_g - \Delta x_m) + v_m - v_g$). The local GMV is more likely to be adopted the higher the output price and potential yield difference between the local and generic technology. The generic GMV is more likely to be adopted the higher the price differential is between the local and generic GMV.

This analysis is useful in explaining the differences in the impact of pest-controlling agricultural biotechnology in developing vs. developed countries. First, it is reasonable to assume that in developing countries in humid regions, pest infestations are much more severe than in developed countries in temperate zones. Second, the ratio of pesticide price to output price (*w/p*) in developing countries is much higher than in developed countries. This may lead to much lower application rates of pesticides and higher levels of pest damage. Thus, the introduction of agricultural biotechnology has the potential to increase yield, as pest damage levels in developing countries are substantial. On the other hand, the relatively low cost of pesticides in developed countries may result in high pesticide use levels that eliminate most pest damage. The net effect will be a high yield effect of pesticides in developing countries and a high cost-saving effect of pesticides in developed countries.

Several other factors may contribute to the high yield effect of GMVs in developing countries, for example, constraints on credit availability. Access to credit in developing countries, especially for small farms, may be restricted, the interest rate may be substantial and, even when pesticides pay for themselves, farmers may not obtain the credit to pay for this expensive input. Lack of credit and the associated low levels of pesticide use is another reason for the higher potential of yield effect with agricultural biotechnology. Of course, the yield effect associated with adoption is likely to be smaller when a local variety is replaced with a generic GMV rather than a local GMV. Another factor that may result in the high yield effect of GMVs is risk. Pest populations vary across seasons, and thus the cost of control and pest damage varies between seasons. While it does not eliminate the variation of costs, the introduction of GMVs serves to reduce it. Thus, GMVs can be viewed as an insurance technology, and their likelihood of adoption is likely to increase as farmers are more risk averse.

There is a wide body of empirical evidence that supports some of the conceptual results. In particular the impacts of the adoption of Bt cotton have been investigated across countries. Studies by Frisvold, Sullivan, and Raneses as well as Marra, Hubble, and Carlson suggest that adoption of Bt cotton in the United States has drastically reduced pesticide applications in cotton (60% and more), but the yield effects were on average small (below 10%). Pray et al.'s study of the impacts of adoption of Bt cotton in China, where pesticides are highly subsidized, shows that modest increases in yield but drastic reduction in pesticide use that led to improvements in farmers' health. Traxler et al. finds that substantial reductions in pesticide use and pest damage in their study on the impacts of Bt cotton in Mexico, and Thirtle et al. reveal yield effects of 40% and above in combination with substantial reductions in pesticides resulting from the adoption of the technology in South Africa. In all of these studies, there is evidence that the technology benefited small farms, and its simplicity was an appealing feature for adopters.

Several authors have studied the impacts of Bt cotton in India. Qaim and Zilberman compare results of field experiments conducted in 2002. They analyze results from 157 farms, each of which has one plot planted with a traditional variety, another with a GMV of the traditional variety, and a third with a generic GMV. They find that the GMVs reduced pesticides use by 67%, the local GMV increased yield on average by 87%, and the generic GMV by 80%. These results are not surprising given that even with pesticides about 60% of the cotton yield in India is lost due to pests, and thus in theory there is potential for a 150% yield effect if a pest-controlling technology will eliminate all the damage. Qaim and Zilberman suggest that the high yield effects in 2002 were the result of especially high levels of pest infestation and the impacts were smaller in other years. The Herring study of the introduction of Bt in India find that indeed there are significant variations of yield effects between seasons. They were lower in 2003 than 2002. Yet, the adoption of the technology seems to be profitable, and Herring argues that one of its main advantages is that it will reduce the credit pressure and bankruptcies that may be associated with loans for the purchase of chemicals in bad years. Roy follows up with reports on adoption of Bt cotton in some locations in India in 2003 and finds that in some locations adopters had low yields and suffered losses. She argues that in most of these cases the poor performance of Bt cotton occurred when the local variety was replaced with an imported variety that was water intensive and could not perform adequately in dry regions. Her findings stresses that the extent to which the introduction of GMVs is successful depends on the varieties.

The Impact of Biotechnology on Biodiversity

The genetic materials used for most agricultural lands have been manipulated using advances of scientific knowledge from the last century. Genetic modification replaces selective breeding as a technology used to improve seeds and hybrids. While selective breeding generated “green revolution” varieties introducing genetic materials that were a distinct departure from traditional varieties, biotechnology slightly alters existing varieties, modifies a few genes (sometimes only one), and leaving the others intact. Once a new modification has been discovered, all the traditional varieties can in principle incorporate this modification. Modification of all the existing varieties allows crop biodiversity to be maintained with only a slight change. As Traxler and Falck-Zepeda argue, the process required to modify most varieties in many of the crops is neither difficult to manage nor expensive. It is done routinely in societies with an advanced genetic modification infrastructure, such as the United States and China. There can be significant loss in crop biodiversity once a generic GMV is used to replace a large number of local varieties. However, the extent of losses in biodiversity due to the introduction of GMVs depends on the degree in which local GMVs are adopted rather a single generic GMV. The model presented in the previous section can be used to analyze the conditions that lead to adoption of generic vs. local GMVs.

Threshold models have been used increasingly to analyze the economics of diffusion and adoption of new technologies among producers (Sunding and Zilberman). These models assume that the population of potential adopters is heterogeneous, and the parameters of heterogeneity may be size, productivity, human capital, etc. The producers follow the same micro-level decision rules, but at each moment there will be a threshold level of the parameters of heterogeneity that separate between adopters and nonadopters. The threshold level may vary over time as a result of processes like learning by doing or learning by using. This approach is useful to assess the adoption of GMVs.

In this model, we assume that a country has many locations, and each has its own local variety. The land within the location is heterogeneous, and the parameter of heterogeneity is q. Assume that q can assume values from q_L to q_H. Potential output under technology i increases with q thus profits increase with q.

Before the introduction of the GMVs, only the lands with $\pi_l \geq 0$ were utilized. Since profits increase with y_l^p and, if $\pi_l(y_{lL}^p) < 0$, then there was a critical level y_{lc}^p with $\pi_l = 0$ that separated land qualities that were utilized from the ones that were idle. Now suppose that a local GMV is introduced.[4] As we saw earlier, the gain from

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[4] The analysis is based on the models of Qaim and Zilberman.

adoption increases with the potential output. The GMV will not be adopted if even at the highest quality land, it is less profitable than the traditional variety, $i = l$ if $\pi_l(y^p_{lH})$ $< \pi_m(y^p_{lH})$. If the GMV is more profitable than the traditional variety at the highest quality land, but it is less profitable at the critical quality, then the technology there will be partially adopted. The traditional variety will be grown on low-quality land, from quality q_{C_l} to q_S where at the switching quality, q_S, $\pi_l(q_S) = \pi_m(q_S)$. The GMV will be fully adopted if at the critical quality under the traditional technology it generates positive profits. In this case, the introduction of the GMV actually increases the utilized acreage and the critical land quality is where $\pi_m(q_{C_m}) = 0$.

If only the generic technology is available, there may be no adoption if $\pi_l(y^p_{lH}) < \pi_g(y^p_{lH})$, partial adoption if $\pi_l(y^p_{lH}) < \pi_g(y^p_{lH})$ with $\pi_l(y^p_{lC}) > \pi_g(y^p_{lC})$, and full adoption if $\pi_l(y^p_{lC}) < \pi_g(y^p_{lC})$. If both technologies are available, there may be no adoption if both $\pi_m(y^p_{lH})$ and $\pi_g(y^p_{lH}) < \pi_l(y^p_{lH})$. If either GMV variety dominates the other for all the relevant lands and it is more profitable than the traditional variety at the highest quality lands, then this technology will be adopted either partially or fully. Because the profitability of the local GMV relative to the generic GMV improves with y_l^p, it is possible that the generic GMV will be adopted on lands with low y_l^ps and associated low potential output while the local GMV will be adopted on lands with high potential output. It may be possible to have outcomes where the traditional technology will be adopted on lands with low y_l^p, the generic GMV on lands in a medium range of y_l^ps, and the local GMV on lands with relatively high y_l^ps.

We do not develop formal measures of biodiversity here, but we assume that an increase in the acreage of the generic biotechnology, and especially replacement of traditional varieties with the generic GMV, is undesirable from the crop biodiversity perspective. Our analysis of adoption patterns shows that factors leading to adoption of the generic GMV will increase as the price differential between the local GMV and generic GMV ($v_m - v_g$) increases. Qaim, Yarkin, and Zilberman develop a formal model to analyze the formation of the GMV seed prices in a model similar to ours. They consider two types of institutional arrangements to establish seed prices. . Under the first arrangement, the public sector obtains the rights or develops and registers the specific biotechnology crop, and competitive seed companies then sell it to farmers. This arrangement has been used to distribute modern seed varieties developed by CGIAR and other public sector agencies using classical breeding. It has not been used with GMVs, but it is likely to be used for some seed crops appropriate for developing countries.

Under this arrangement, the price of GMV seeds is likely to be the marginal cost of the competitive sellers. Under the second institutional arrangement, the GMV seeds are sold by monopolies (multinationals like Monsanto). In this case the price is decomposed to include the marginal cost to the seller and monopoly profits.

The introduction of each local GMV may also entail some fixed costs. Obtaining access to the traditional seed varieties and the right to modify them may be a source of transaction costs to the monopolists. The monopolists will determine which local varieties to modify and how much to charge for GMV seeds in each market so that its profits are maximized. Qaim, Yarkin, and Zilberman suggest that public sector choices of which varieties to modify will take into account both the surplus to sellers and consumers of the seeds. They find that under the same conditions, there will be more adoption of

GMVs under the competitive public sector regime, and it will introduce more GMV local varieties than the private sector. Thus, public sector control of seed markets will benefit biodiversity. The results also suggest that adoption of GMVs is likely to increase when both the variable and the fixed costs of the modification are declining. Having a low fixed cost to modify local varieties will lead to increased tendency to introduce local GMVs rather than generic ones, benefiting biodiversity.

The variable cost of genetic modification and the fixed cost to modify local varieties vary between nations. The variable cost of modifications in countries with a strong seed sector, like the United States, most of the other developed countries, and China and India, is likely to be rather small. While the variable cost to modify local varieties in countries with a limited seed sector capacity is likely to be high. The high cost of genetic modification of the local varieties may lead to introduction of generic GMVs and loss of biodiversity. High transaction and access costs to local varieties may be another reason for an increased likelihood in introducing generic GMVs

The analysis suggests that in a country like the United States, with a developed seed sector and relatively low transaction cost, there will be significant introduction of local GMVs even under the private industry. In China, where the seed sector is developed and the seed industry is competitive, we expect very high adoption of local GMVs (in terms of varieties). However, in Africa, where the local capacity of genetic modification is very limited, there may be a higher likelihood of importing generic GMVs, and crop biodiversity will suffer. Thus, one policy challenge is to develop the infrastructure at the local level in Africa so that modification of GMVs will not be so difficult and expensive.

Qaim, Yarkin, and Zilberman present data that support our general results concerning biotechnology and crop biodiversity. They show that a large number of varieties were genetically modified in the United States, and the area per variety is smaller than in some other countries, perhaps because of the lower modification and transaction costs in the United States. In the 2001-02 season, more than 1,100 varieties of Roundup Ready (RR) soybeans were planted in the United States, with about 20,000 ha. (hectares) on average for each variety. More than 700 varieties of Bt corn were planted, each variety on 10,000 ha., on average. In Argentina, 45 varieties of RR soybeans were planted on 10 million ha., with 200,000 ha. per variety, and 700,000 ha. of Bt corn were planted, with 15 varieties, so 45,000 ha. were planted per variety. In the case of Bt cotton, the United States has 19 varieties grown on 2 million ha., while China, with its public sector development of GMVs and subsidized seed sector, has 22 varieties on 1.5 million ha.

Our conceptual analysis and data suggest that the introduction of GMVs will not necessarily lead to wholesale loss of biodiversity and drastic reductions in the number of varieties grown. Actually, an efficient seed sector and low transaction cost may lead to preservation of a modified version many local varieties. Adoption of GMVs may be partial in many cases, with some land allocated to traditional varieties. The risk of loss of biodiversity is larger in locations where lack of capacity or transaction costs may make it easy to import GMVs from abroad or introduce a small number of varieties for a large acreage. Strengthening the capacity of the seed sectors in developing countries and introducing simple mechanisms to allow developers of GMVs easy access to local varieties will increase the biodiversity of GMVs.

The biotechnology choices of the individual farmers and the private sector companies that affect biodiversity are economic choices. Biodiversity can be preserved and enhanced by incentives. For example, environmental services payments can subsidize farmers to continue and grow traditional varieties when a generic GMV is replacing this local variety. Alternatively, some of the private costs associated with developing or introducing a local GMV should be shared by public agencies and by groups concerned with crop biodiversity preservation. Design of appropriate incentives to preserve crop biotechnology will require quantitative analysis evaluating the benefits of crop biodiversity and identifying the main beneficiaries. When the main beneficiaries of crop biodiversity preservation are not the farmers who grow it, the beneficiaries should have to pay. This is especially pertinent in cases where preservation of local varieties by peasants in developing countries serves the interests of growers and others in the developed world.

Not only can biodiversity be preserved through biotechnology, these methods may help to restore previously lost crop diversity. Biotechnology already provides alternative sets of tools to address problems that were treated in the past through use of chemicals or classical breeding. The new capacities that have been and will be introduced by GMVs may allow “restoring” of some local varieties that were replaced in the past by generic ones because of vulnerability to pests that now can be addressed by genetic modification. This may lead to a “ Jurassic Garden” where biotechnology is a vehicle for restoration of forgotten varieties and enhancement of biodiversity.

Overcoming Access to IPRs for Developing Biotechnology in Developing Countries

Thus far, we have argued that GMVs can be beneficial in developing countries by enhancing their crop yields and reducing pesticides use, and their introduction need not affect crop biodiversity negatively. However, given such potential benefits of the technology, there is a very different kind of growing concern: that access to any beneficial forms of agricultural biotechnology may be constrained because of the private ownership of IPRs over many of the scientific tools and techniques needed to develop these technologies. This general concern has been amplified by the introduction of the trade-related aspects of intellectual property right (TRIPS) agreements of the World Trade Organization (WTO), and by the high cost in terms of time and money required to obtain the legal rights to use the technologies needed for the development of "Golden Rice." We argue here that the economics and institutional setup of the agricultural technology sector can lead to solutions that will allow IPR barriers to be overcome.

Biotechnology is not a unique case of an agricultural technology where essential IPRs are controlled by the private sector. Private companies own the rights and control, to a large extent, the development of mechanical and chemical agricultural technologies. Classical plant breeding was in many ways a unique category of technology where the development of new products was largely controlled by the public sector with open access to key components of the technology. In the case of chemical and mechanical technologies, however, the resources required to develop, produce, and market the technologies were significant enough that mostly just multinational corporations were able to carry the financial burden. It was a similar economic logic that led to the private development and ownership of agricultural biotechnologies. Monsanto and the other multinational corporations invested billions to develop the Bt and RR varieties, to fulfill the regulatory requirements to register them, and to develop production and marketing networks. To protect this investment they accumulated the rights to most of the IPRs of agricultural biotechnology.

Nevertheless, the private-sector companies do not own or control all of the IPRs crucial for biotechnology product development. Actually, many of the crucial elements of crop biotechnology have been discovered by scientists in the public sector, in many cases by scientists in Land-Grant universities. These universities hold patents over a number of the crucial technologies but have transferred them in many cases to private companies. The expansion of technology transfer activities by government research agencies and research universities has played a crucial role in establishing the medical and agricultural biotechnology industries.

Historically, university innovations have played an important role in development of new commercial technologies, firms, and sometimes entire industries. Efforts over the last 25 years to formalize this process and provide some financial returns to the universities were made in the Bayh-Dole Act of 1982 and the establishment of offices of technology transfer (OTTs) in most research universities (Graff and Zilberman). While university scientists can make major discoveries that may lead to new product lines, there is typically a long period between the initial discoveries and the implementation and commercialization. Companies are not inclined to invest in developing most early-stage university innovations without the security of patents, which then enable them to protect their market position against copycat inventors once the product is developed. A major reason for the establishment of technology transfer arrangements was to increase the utilization of university innovations by established firms. Yet, to further enhance the commercialization of university innovations, OTTs often facilitate the formation of startups in order to develop these innovations. The development efforts of startups often lead to the accumulation of new patents by the startup firm building upon the initial patent licensed from the university. These IPRs may be the most important assets of the startups. Some of the major players in medical biotechnology (Gennetech, Amgene, Chiron) were originated as such startups, but many other successful startups were taken over by established multinational firms. This has been the pattern followed by most of the successful agricultural biotechnology startups (Calgene, Agracetus, Mycogen).

The only organizations to have established the organizational structure for access to needed IPRs to provide their scientists with “freedom to operate” for new product developments are the major seed and chemical corporations in agricultural biotechnology. The private sector, however, targets development of biotechnology products that are profitable and inevitably underinvests since it ignores consumer surplus. In particular, the private sector is most likely to neglect biotechnology products that serve the poor in the developing countries, or biotechnology products that target small specialty crops with a low volume or revenues. Thus, much of the adaptation of agricultural technologies to the needs of developing countries will be done by scientists in the public sector. They however lack much of the organizational structures needed for access to IPRs and therefore would benefit from institutional arrangements that reduce IPR transaction cost and allow them some degree of “freedom to operate.”

Graff and Zilberman provide a framework and develop the main features of such an institutional arrangement that they called an “intellectual property clearinghouse” for agricultural biotechnology. The activities of such an organization would include:

(1) <u>Information About Property Rights</u>. First, scientists may be uninformed about IPR requirements for product development. If, for example, a new variety is introduced mostly for domestic consumption in a country where the patents are not registered, there is no need to license technology. When there is a need for technology licensing, especially for products that are exported, then the informational challenge is to

determine the exact ownership of patent rights in order to negotiate the rights to use the technology.

(2) A Commonly Accessible Pool of Key IPRs. Graff et al. show that 24 percent of the biotechnology patents registered in the United States belonged to the public sector, the five major multinationals (Monsanto, DuPont, Syngenta, Bayer, and Dow) controlled 41 percent, and startups and small companies controlled 33 percent. Furthermore, they decomposed the agricultural biotechnology patents into several major subgroups and argued that the technology component owned by the public sector is sufficient to meet most of the requirements for developing new biotechnology products. Furthermore, some of the missing technology components may be unpatented innovations that have been published in the scientific literature. The establishment of a technology pool shared among public sector organizations from which components are available for public sector technology developers will provide a source of technology that will reduce their dependence on the private sector and the associated transaction costs of obtaining permission to use their IPRs. Furthermore, private technology developers might also attain access to the pool in exchange for providing agreed upon access to their technologies to other members of the pool.

(3) Negotiation and IPR Management. Private companies may be willing to donate the rights to use their technologies to develop biotechnology products that they would not have developed themselves. They may gain some tax or public relations benefits from such activities. However, obtaining these rights may be constrained by concerns over technology stewardship, liability, and other transaction costs. In some cases, private sector companies hold exclusive rights to technologies patented by the universities and, thus, obtaining access to use these university technologies may require approval of both organizations. The clearinghouse could negotiate access to a range of different public sector technologies and could manage the resulting web of financial transactions associated with obtaining access.

A number of major public universities have agreed to establish an organization called the Public Sector Intellectual Property Resource for Agriculture (PIPRA) (Atkinson et al.) which aspires to the properties of the clearinghouse mentioned above. The African Agricultural Technology Foundation, established by the Rockefeller Foundation, is another organization that aims to facilitate the access to technology for the development of agricultural biotechnology in Africa. Thus, while IPRs may be a constraint in developing agricultural biotechnologies for the poor in developing countries, there are emerging mechanisms that be used to overcome that constraint and correct the distortions caused by the private sector's incentives to exercise IPRs over the technology.

Conclusions

The commercial application of agricultural biotechnology started in North America and spread to China and South America. This paper argues that there are strong reasons why it should be ardently pursued in many parts of the developing world, that current forms of agricultural biotechnology have significant potential for developing countries. The challenge facing society and the global community is to realize this potential.

We show that the yield effects of GMVs in developing countries tend to be significant, and they also contribute significantly to human welfare by reducing chemical use. We demonstrate that adoption of GMVs might not necessarily lead to elimination of many varieties. It actually can serve to maintain and even enhance crop biodiversity.

Finally, we show that IPR constraints can be addressed, and new institutions that are already emerging can be used to allow developing countries more access to IPRs.

Admittedly many other issues have to be dealt with as biotechnology is introduced to developing countries. While we address concerns about crop biodiversity, there are still unsolved issues related to possible negative side effects on wildlife and problems of gene flow. The lack of significant evidence of severe side effects in the last several years in which large amounts of land were planted with GMVs is encouraging, but the challenge is to monitor the side effects of GMVs and, more importantly, to better understand their impact on the environment.

The main role of the regulatory process is, of course, to screen out possible negative impacts that will impede the introduction of products that are socially beneficial. However, we cannot presume that we will be able to eliminate all risks through registration requirements and regulation. The notion of precaution that precludes risk taking leads to risky outcomes of its own. In assessing the environmental side effects of biotechnology, we should also consider the economic and environmental cost of not introducing biotechnology and the effects from relying on alternatives, including the use of chemical pesticides and an increased acreage allocated to farming.

Agricultural biotechnology is more than GMOs, and at present its applications are only in the early stages of development. The process of technological innovation is the process of adaptive learning. Shortcomings of existing technologies inspire research that will lead to new solutions, and improved scientific knowledge may result in new technologies. However, introduction of these technologies often require private investment. Commercial success of current biotechnology will lead to investment in second-generation biotechnology that may serve to improve the quality of food and may even be more environmentally benign than current technologies. In addition to providing direct benefits, the adoption and success of GMOs will provide the impetus to develop alternative molecular approaches.

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