Journal of Agricultural & Food Industrial Organization

Volume 2 2004 *Article* 3

CONTROVERSIES OVER THE ADOPTION OF GENETICALLY MODIFIED ORGANISMS

Agricultural Biotechnology: Productivity, Biodiversity, and Intellectual Property Rights

David Zilberman[*] Holly Ameden[†]
Gregory Graff[‡] Matin Qaim[**]

[*]University of California-Berkeley, zilber@are.berkeley.edu
[†]University of California-Berkeley, ameden@are.berkeley.edu
[‡]University of California-Berkeley, ggraff@are.berkeley.edu
[**]University of Hohenheim, qaim@uni-hohenheim.de

Agricultural Biotechnology: Productivity, Biodiversity, and Intellectual Property Rights*

David Zilberman, Holly Ameden, Gregory Graff, and Matin Qaim

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.

KEYWORDS: biotechnology, productivity, biodiversity, intellectual property rights

---

*David Zilberman, Holly Ameden, and Gregory Graff are, respectively, professor, doctoral candidate, and visiting postdoctoral researcher, Agricultural and Resource Economics Department at the University of California-Berkeley. Matin Qaim is a professor at the University of Hohenheim in Stuttgart, Germany.

1. Introduction

The value and potential of agricultural biotechnology in developing countries have been the subjects of considerable concern and debate. Proponents of agricultural biotechnology argue that it may enhance the productivity of agriculture in developing countries, and it may allow the expected growth in food demand from population and income growth to be met (Paarlberg, 2001). Critics of the current wave of agricultural biotechnology, mostly the pest-resistant and herbicide-resistant genetically modified seed varieties (GMSVs)[1] that have been adopted extensively in the United States, Canada, Argentina, and to some extent China, argue that GMSVs are of limited value for the developing world for several reasons (Altieri, 2001). First, GMSVs have resulted in small yield increases in the North, thus they may not contribute much to increased food production in the South. Second, GMSVs pose a threat to crop biodiversity in the developing world. Finally, GMSVs were introduced by private companies that have intellectual property rights (IPRs) to the main components of the technology. Development of GMSVs that meet the needs of the farmers in the developing world will be constrained by the lack of access to these IPR-protected technologies.

This article argues that the current generation of pest-controlling GMSVs can contribute significantly to the developing world and can address the arguments of critics of the technology presented above. Using economic logic and available empirical evidence, we propose that GMSVs 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.

2. The Economics of the Yield Effects of GMSVs 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 (2003), 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 GMSVs that primarily reduce pesticide use in the United States

---

[1] We use the term GMSV (genetically modified seed varieties) and not GMO (genetically modified organisms) because GMSVs are a subset of the GMOs, and that is what we are addressing.

are also effective when increasing yields in developing countries where pesticides have not been used or have had limited effectiveness.

Consider the case of a farmer growing a crop with a constant returns-to-scale technology. Let i be an indicator of a crop variety and assume that the farmer can choose among three varieties: a local non-GMSV variety with $i = l$, a genetically modified (GM) version of the local variety with $i = m$, and a generic GMSV 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 (1986), we assume that pesticides and GMSVs are damage-control agents. Let y_i denote per-acre output of variety i, which is equal to the potential crop output y_i^p multiplied by the fraction of the crop output that is undamaged. The potential crop output of the non-GMSV local variety is y_l^p and $y_m^p = y_l^p$. A fraction of the potential crop output α is lost when a generic GMSV is used instead of a non-GMSV, so $y_g^p = (1-\alpha) y_l^p$. The crop damage depends on the initial pest infestation N_0, the per-acre pesticide use with variety i, x_i, and whether or not the variety is genetically modified. The fraction of crop lost to pests is denoted as $D_i(x_i, N_0)$, and we assume that smaller pest populations or larger pesticide applications will reduce pest damage.[2] Since the same genetic modification applies to the local and generic GMSVs, given the same level of initial pests and pesticides, the percentage of crop damage is assumed to be the same with both types of GMSVs: $D_m(x, N_0) = D_g(x, N_0)$.[3] With the same pesticide use and initial pest population, the crop damage with the GMSVs is smaller than it is with the non-GMSV $\left[D_l(x, N_0) \geq D_m(x, N_0)\right]$. With this notation, the per-acre crop output is $y_i = y_i^P \left[1 - D_i(x_i, N_0)\right]$.

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

The farmer has to choose both a crop variety for each field and a pesticide application level with this variety. The maximum profit with seed variety i is $\pi_i = \max_{x_i} \left\{ p y_i^P [1 - D_i(x_i, N_0)] - w x_i - c_v - v_i \right\}$. The optimal pesticide use for seed variety i is determined when the value of the marginal benefits of pesticides

---

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

[3] A more general assumption may change some of the results, but will not affect substantially the general outcome of the article.

(resulting from reducing damage) is equal to its price $(-py_i^P \frac{\partial D_i}{\partial x_i} = w)$. Ameden and Zilberman (2003) show for a similar model that use of pesticides increases as the price of output escalates, as the price of pesticides declines, and as the potential output and the size of the initial pest population increases.[4] The reduction in the pest population from using GMSVs decreases the marginal productivity of pesticides used with the GMSVs, thus less pesticide product will be applied with the modified local GMSV as well as with the generic GMSV under most likely conditions.[5]

The adoption of either local or generic GMSVs under most circumstances is likely to reduce pesticide use significantly, because the pest-control properties of the GMSVs are substituted for the chemicals (Ameden and Zilberman, 2003). Let $\Delta x_m = x_l - x_m$ and $\Delta x_g = x_l - x_m$ denote the pesticide-use reduction associated with the adoption of the local and generic GMSVs, respectively. Because the potential yield of the generic GMSV is smaller, we expect less pesticide use with the generic GMSV, $\Delta x_g > \Delta x_m$. Let the change in yield from the local and generic GMSV be denoted by $\Delta y_m = y_m - y_l$ and $\Delta y_g = y_g - y_l$, respectively. When the local seed variety is modified genetically, Ameden and Zilberman (2003) show that the combination of the genetic modification and chemicals will reduce pest damage, thus output will increase $(\Delta y_m > 0)$. When a generic GMSV is introduced, the pest-damage reduction will tend to increase per-acre output (i.e., yield) but the lower potential crop output will tend to reduce per-acre output. Thus, the net effect of the generic GMSV cannot be determined. The generic GMSV 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 GMSV 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 GMSV is greater than the gain from the adoption of the generic GMSV. This will occur when the extra revenue of the local GMSV is greater than the pesticide and per-acre cost savings of the generic GMSV (i.e., $p(\Delta y_m - \Delta y_g) > w(\Delta x_m - \Delta x_g) + v_m - v_g$). An increase in the output price amplifies the incentive for either GMSV. When the yield gain for the local GMSV is greater than the yield gain for the generic GMSV, an increase in the output price magnifies the likelihood that the local GMSV will be adopted. Alternatively, if the yield gain for the generic GMSV is

---

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

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

greater than the yield gain for the local GMSV, an increase in the output price increases the probability that the generic GMSV will be adopted.

This analysis is useful when explaining the differences in the impact of pest-controlling agricultural biotechnology in developing as opposed to developed countries. First, it is reasonable to assume that in developing countries for humid regions, pest infestations are much more severe than they would be in developed countries for temperate zones. Second, the ratio of pesticide price to output price w/p in developing countries is much higher than it is 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 from 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 GMSVs 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 are other reasons for the higher potential of yield effect with agricultural biotechnology. Of course, the yield effect associated with the adoption of GMSVs is likely to be smaller when a local variety is replaced with a generic GMSV rather than by a local GMSV. Another factor that may result in the high-yield effect of GMSVs is risk. Pest populations vary across seasons, thus the cost of control and pest damage varies between seasons. While it does not eliminate the variation of costs, the introduction of GMSVs serves to reduce costs. Thus, GMSVs can be viewed as insurance technology, and their likelihood of adoption by producers is likely to increase as farmers are more risk averse.

There is a wide body of empirical evidence that supports some of these conceptual results. In particular, the impacts of the adoption of B*t* cotton have been investigated across countries. Studies by Frisvold, Sullivan, and Raneses (2003) as well as Marra, Hubble, and Carlson (2001) suggest that adoption of B*t* cotton in the United States has reduced drastically pesticide applications in cotton (60 percent and more), but on average the yield effects were small (below 10 percent). The study by Pray et al. (2002) on the impacts of adoption of B*t* cotton in China where pesticide use is highly subsidized, shows modest increases in yield but shows drastic reductions in pesticide use, which leads to improvements in farmers' health. Traxler and Flack-Zepeda (1999) find substantial reductions in pesticide use and pest damage in their study on the impacts of B*t* cotton in Mexico; and Thirtle et al. (2003) reveal yield effects of 40 percent and above in combination with substantial reductions in pesticides resulting from the adoption of the B*t* 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 B*t* adopters.

Several authors have studied the impacts of B*t* cotton in India. Qaim and Zilberman (2003) compare results of field experiments conducted in India in 2002. They analyze results from 157 farms, each of which has one plot planted with a traditional seed variety; another planted with a GMSV of the traditional variety, and a third with a generic GMSV. They find that the traditional seed variety (i.e., the local non-GMSV variety) reduced pesticide use by 67 percent; the local GMSV increased yield on average by 87 percent; and the generic GMSV increased yield by 80 percent. These results are not surprising given that, even with pesticides, about 60 percent of the cotton yield in India is lost due to pests, thus in theory there is potential for a 150 percent yield effect if a pest-controlling technology can eliminate all the damage from pests. Qaim and Zilberman (2003) suggest that the high-yield crop effects in 2002 were the result of especially high levels of pest infestation and the impacts of GMSVs were smaller in other years. The Herring (2003) study of the introduction of B*t* in India finds that indeed there are significant variations of yield effects between seasons; they were lower in 2003 than they were in 2002. Yet the adoption of the technology seems to be profitable, and Herring (2003) argues that one of the technology’s 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 (2003) follows up with reports on the adoption of B*t* cotton in some locations in India in 2003 and finds that in some locations the adopters had low yields and suffered losses. She argues that, in most of these cases, the poor performance of B*t* cotton occurred when the local seed variety was replaced with an imported seed variety that was water intensive and could not perform adequately in dry regions. Her findings stress that the extent to which the introduction of GMSVs is successful depends on the variety of crop used by the farmers.

3. 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 seed varieties by introducing genetic materials that were a distinct departure from traditional varieties, biotechnology slightly alters existing seed varieties, modifies a few genes (sometimes only one), and leaves the others intact. Once a new genetic modification has been discovered, it can be inserted in all the traditional crop varieties by back crossing. This genetic modification of all the existing seed varieties allows crop biodiversity to be maintained with only a slight change in the original genetic structure of the altered seeds. As Traxler and Falck-Zepeda (1999) argue, the back-crossing required to modify seed varieties that multiply sexually is neither difficult to manage nor is it expensive. There can be significant loss in crop biodiversity once a generic GMSV is used to replace a large number of local seed varieties. However, the extent of losses in biodiversity due to the introduction of GMSVs depends on the degree in which local GMSVs are adopted rather than on a single generic GMSV. The model presented in the previous section can be used to analyze the conditions that lead to the adoption of generic GMSVs as opposed to the adoption of local GMSVs.

Threshold models have been used increasingly to analyze the economics of diffusion and the adoption of new technologies among producers (Sunding and Zilberman, 2001). These models assume that the population of potential adopters of a new seed variety is heterogeneous, and the parameters of heterogeneity may include size, productivity, and human capital. 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 the adopters of the seed variety from the 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 GMSVs.

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

Before the introduction of the GMSVs, only the lands with positive quasi-rent $\pi_l \geq 0$ were utilized. Since profits increased with q and, if, at the lowest-quality land, the quasi-rent was negative $\pi_l(q_L) < 0,$ then there was a critical level q_{C_1} with zero quasi-rent $\pi_l(q_{C_1}) = 0$ that separated land qualities that were utilized from the ones that were idle. Now suppose that a local GMSV is introduced.[6] As we saw earlier, the gain from the adoption of the technology increases with the technology's potential output. The local GMSV will not be adopted if, even at the highest-quality land, the local GMSV is less profitable than the traditional variety would be, $i = l$ if $\pi_l(q_H) < \pi_m(q_H)$.. If the local GMSV is more profitable than the traditional variety at the highest-quality land, but is less profitable at the critical-quality land, then the local GMSV will be partially adopted at the highest-quality land. The traditional variety will be grown on the low-quality land, from quality q_{C_l} to q_S where at the switching quality q_s, the two varieties have the same quasi-rent $\pi_l(q_S) = \pi_m(q_S)$. The local GMSV will be

---

[6] The analysis is based on the models of Qaim and Zilberman (2003).

fully adopted if, at the critical-quality land under the traditional technology, GMSV adoption generates positive profits. In this case, the introduction of the GMSV actually increases the utilized acreage, and the critical-land quality is where the quasi-rent is zero, $\pi_m(q_{C_m}) = 0$.

If only the generic GMSV is available, there may be no adoption of the technology if this variety is less profitable at the highest-quality land $\pi_l(q_H) > \pi_g(q_H)$; there may be partial adoption if the generic variety is more profitable than the traditional variety at the highest-quality land but less profitable at the lowest-quality land $\pi_l(q_H) < \pi_g(q_H)$ with $\pi_l(q_{C_l}) > \pi_g(q_{C_l})$; and there may be full adoption if the traditional variety is always less profitable than the generic GMSV $\pi_l(q_{C_l}) < \pi_g(q_{C_l})$. If both local GMSV and generic GMSV technologies are available, there may be no producer adoption if the quasi-rent of both GMSVs is lower than the quasi-rent of the traditional variety at the highest-quality land $\pi_m(q_H)$ and $\pi_g(q_H) < \pi_l(q_H)$. If either GMSV variety dominates the other for all the relevant lands, and the dominant GMSV is more profitable than the traditional variety at the highest-quality lands, then this dominant GMSV will be adopted either partially or fully. Because the profitability of the local GMSV relative to the generic GMSV improves with q, it is possible that the generic GMSV will be adopted on lands that have a low q and associated low potential output, while the local GMSV will be adopted on high-quality lands that have a high potential output. It may be possible to have outcomes in which the traditional technology will be adopted on land that has a low q, the generic GMSV will then be adopted on the land that has a medium range of q, and the local GMSV will be adopted on lands that have a relatively high q.

We do not develop formal measures of biodiversity here, but we assume that an increase in the acreage that uses generic GMSV biotechnology, and especially replacement of traditional varieties with the generic GMSV, is undesirable from the crop-biodiversity perspective. Our analysis of adoption patterns shows that factors leading to the adoption of the generic GMSV will increase as the price differential between the local GMSV and generic GMSV $(v_m - v_g)$ increases. Qaim, Yarkin, and Zilberman (2003) develop a formal model to analyze the formation of GMSV prices in a model similar to the one in this article. They consider two types of institutional arrangements to establish seed prices. Under the first institutional arrangement, the public sector obtains the seed property rights or develops and registers the specific biotechnological crop, and competitive seed companies then sell the seed to farmers. This arrangement has been used to distribute modern seed varieties developed by the Consultative Group on International Agricultural Research (CGIAR) and other public-sector agencies using classical breeding. The first institutional arrangement has not been used with GMSVs, but it is likely to be used for some seed crops appropriate for developing countries. Under the second institutional arrangement, the price of GMSV seeds is likely to be the marginal cost of the competitive sellers. Under this arrangement, the GMSV seeds are sold by monopolies (e.g., multinational corporations like Monsanto). In this case, the price is decomposed to include the marginal cost to the seller and the monopoly profits.

The introduction of each local GMSV may also entail some fixed costs. Obtaining access to 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 GMSVs in each market to maximize their profits. Qaim, Yarkin, and Zilberman (2003) suggest that public-sector choices of which varieties to modify will take into account the surplus of both the sellers and consumers of the seeds. They find that under the same conditions, there will be more producer adoption of GMSVs under the competitive public-sector regime, which will introduce more local GMSVs than will the private sector. Thus, public-sector control of seed markets will benefit biodiversity. The results also suggest that adoption of GMSVs is likely to increase when both variable and fixed costs of the modification are declining. Having a low fixed cost to modify local varieties will lead to increased tendency to introduce local GMSVs rather than generic GMSVs, benefiting biodiversity.

The variable costs of genetic modification and the fixed costs required to modify local varieties vary between nations. In countries with a strong seed-sector capacity, like the United States and most of the other developed countries including China and India, the variable costs of modifications are likely to be rather small. On the other hand, the variable costs of modifying local varieties in countries with a limited seed-sector capacity are likely to be high. This high cost of genetic modification of local varieties may lead to the introduction of generic GMSVs and to the loss of biodiversity. High transaction costs and high access costs to local varieties may be other reasons for an increased likelihood of loss of biodiversity when introducing generic GMSVs.

Our analysis suggests that in a country like the United States, with a developed-seed sector and relatively low transaction costs, there will be significant introduction of local GMSVs 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 GMSVs. However, in Africa, where the local capacity of genetic modification is very limited, there may be a higher likelihood of importing generic GMSVs, and crop biodiversity will suffer. Thus, one policy challenge is to develop the infrastructure at the local level in Africa so that modification of GMSVs will be neither difficult nor expensive.

Qaim, Yarkin, and Zilberman (2003) present data supporting the general results of this study about biotechnology and crop biodiversity. They show that a large number of varieties were genetically modified in the United States, and that the per-variety area was smaller than it was in some other countries, perhaps because of the lower modification and transaction costs within the United States.

In the 2001/02-crop year, for example, more than 1,100 varieties of Roundup Ready (RR) soybeans were planted in the United States, with approximately 20,000 hectares of land seeded to each variety. Also, in the United States, more than 700 varieties of B*t* corn were planted, and each variety covered an average of 10,000 hectares. In Argentina, 45 varieties of RR soybeans were planted on 10 million hectares of land with an average of 200,000 hectares per variety. Also, in Argentina, 700,000 hectares of B*t* corn were planted to 15 varieties that had an average of 45,000 hectares per variety. In the case of B*t* cotton, the United States has 19 varieties grown on 2 million hectares, while China, with its public-sector development of GMSVs and its subsidized-seed sector, has 22 varieties planted on 1.5 million hectares.

Our conceptual analysis and data suggest that the introduction of GMSVs will not necessarily lead to a wholesale loss of biodiversity and to drastic reductions in the number of varieties grown. Actually, many local varieties are preserved in a transgenic form when the seed sector is efficient and the transaction costs of genetic modification are low. Adoption of GMSVs 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 GMSVs from abroad or to 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 GMSVs easy access to local varieties will increase the biodiversity of GMSVs.

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-service payments can subsidize farmers to continue to grow traditional varieties when a generic GMSV is replacing this local GMSV. Alternatively, some of the private costs associated with developing or introducing a local GMSV 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 for cases in which 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 the use of chemicals or classical breeding. The new capacities that have been and will be introduced by GMSVs may allow the restoration of some local GMSVs that were replaced in the past by generic GMSVs because of vulnerability to pests that now can be addressed by genetic modification. As tools of biotechnology are enhanced, GMSVs will provide vehicles for the restoration of forgotten varieties and for the enhancement of biodiversity.

4. Overcoming Access to IPRs for Developing Biotechnology in Developing Countries

Thus far, we have argued that GMSVs can be beneficial in developing countries by enhancing crop yields and reducing pesticide use. Thus GMSV introduction need not affect crop biodiversity negatively. However, there is increasing concern that a different issue, that of private ownership of IPRs, may constrain the use of scientific tools and techniques used to develop genetic technologies and thus restrict the potential benefit of biotechnology. 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 GoldenRice™ (Kryder, Kowalski, and Krattiger, 2000). 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 in which essential IPRs are controlled by the private sector. Private companies own the IPRs and, to a large extent, they control the development of mechanical and chemical agricultural technologies. Classical plant breeding was in many ways a unique category of technology in which the development of new products was controlled largely by the public sector that had 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 B*t* and RR varieties, to fulfill the regulatory requirements to register them, and to develop the 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 neither own nor 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, in many cases, have transferred them 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 the development of new commercial technologies, firms, and sometimes entire industries. Efforts over the last 25 years to formalize this process and to provide some financial returns to the universities were made within the Bayh-Dole Act of 1980 and by the establishment of Offices of Technology Transfer (OTTs) in most research universities (Graff and Zilberman, 2001). 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 their 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 the OTT was to increase the utilization of university innovations by established firms. Yet, to further enhance the commercialization of university innovations, OTTs often facilitated 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 that built 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, such as Gennetech, Amgene, and 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 such as Calgene, Agracetus, and Mycogen.

The only organizations to have established the organizational structure for access to needed IPRs to provide their scientists with the ‘freedom to operate’ for new product developments were the major seed and chemical corporations in agricultural biotechnology. The private sector, however, targets the development of biotechnology products that are profitable and inevitably under invests 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 revenue. Thus, scientists in the public sector will do much of the adaptation of agricultural technologies to the needs of developing countries. They, however, lack much of the organizational structure needed for access to IPRs and therefore would benefit from institutional arrangements that would reduce IPR transaction costs and allow them some degree of ‘freedom to operate.’

Graff and Zilberman (2001) 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:

- *Information About Property Rights*. First, scientists may be uninformed about IPR requirements for product development. If, for example, a new variety is introduced mostly for domestic consumption for a country in which the patents are not registered, there is no need to license the 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.
- *A Commonly Accessible Pool of Key IPRs*. Graff et al. (2003) 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 on the associated transaction costs of obtaining permission to use their IPRs. Furthermore, private technology developers might also attain access to the technology pool in exchange for providing agreed upon access to their technologies to other members of the pool.
- *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, 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.

Some of the functions of the intellectual property clearinghouse have been performed by several existing organizations for a while. The Center for

Application of Molecular Biology in Agriculture (CAMBIA) in Australia has developed a set of enabling biotechnologies it offers to developing countries at low or no cost. CAMBIA also has conducted several studies on the ‘freedom to operate’ using basic agricultural biotechnologies (e.g., agrobacterium) globally. The International Service for the Acquisition of Agri-biotech Applications (ISAAA) and BioDevelopments have mediated technology exchanges between multinational enterprises and African countries or organizations.

Recently, we observed the emergence of several organizations that aspire to the properties of the clearinghouse mentioned above. One example is the Public Sector Intellectual Property Resource for Agriculture (PIPRA) established by a number of major public universities (Atkinson et al. 2003). 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. While IPRs may be a constraint in developing agricultural biotechnologies for the poor in developing countries, there are emerging mechanisms that could be used to overcome that constraint and correct the distortions caused by private-sector incentives to exercise IPRs over the technology.

5. Conclusions

The commercial application of agricultural biotechnology started in North America and spread to China and South America. This article argues 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 developed a conceptual explanation on the yield effects of GMSVs and cited some evidence where GMSVs in developing countries have significant yield effects, which also contribute significantly to human welfare by reducing chemical use. We demonstrate that adoption of GMSVs might not necessarily lead to the 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. For example, the North American Free Trade Agreement’s (NAFTA) Commission on Environmental Cooperation (CEC) is reviewing GM traits in Mexican landrace corn and their implication. Some gene flow from the GMSVs is unavoidable, and there are external genetic effects whenever a new variety is introduced. However, the lack of significant evidence of severe side effects in the last several years in which large amounts of land have been planted with GMSVs is encouraging, but the challenge is to monitor the side effects of GMSVs and, more importantly, to better understand their impact on the environment. The concerns about the side effects have especially important impacts on a critical factor affecting the future of technology-consumer acceptance. The acceptance is likely to increase as the public becomes more confident about the safety of the technology, appreciates its benefits, and has trust in the regulatory process.

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 requires 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 benign environmentally than are current technologies. In addition to providing direct benefits, the adoption and success of GMOs will provide the impetus to develop alternative molecular approaches.

References

Altieri, M.A. *Genetic Engineering in Agriculture: The Myths, Environmental Risks and Alternatives*, Special Report No. 1, Food First, Oakland, California, 2001.

Ameden, H. and D. Zilberman. “Adoption of Biotechnology in Developing Countries,” Working Paper, University of California, Berkeley, California, 2003.

Atkinson, R.C., R.N. Beachy, G. Conway, F.A. Cordova, M.A. Fox, K.A. Holbrook, D.F. Klessig, R.L. McCormick, P.M. McPherson, H.R. Rawlings III, R. Rapson, L.N. Vanderhoef, J.D. Wiley, and C.E. Young. “Policy Forum: Public Sector Collaboration for Agricultural IP Management.” *Science* 301(2003):174–5.

Bayh-Doyle Act. 2004. Available at: www.pbs.org/bloodlines/themes/law.html.

Frisvold, G.B., J. Sullivan, and A. Raneses. “Genetic Improvements in Major U.S. Crops: The Size and Distribution of Benefits.” *Agricultural Economics* 28(2003):109–19.

Graff, G. and D. Zilberman. “An Intellectual Property Clearinghouse for Agricultural Biotechnology.” *Nature Biotechnology* 19 (2001):1179–80.

Graff, G.D., S.E. Cullen, K.J. Bradford, D. Zilberman, and A.B. Bennett. “The Public-Private Structure of Intellectual Property Ownership in Agricultural Biotechnology.” *Nature Biotechnology* 21(2003):989–95.

Herring, R. “Underground Seeds: The Lessons of India’s B*t* Cotton Episode for Representations of the Poor, Property Claims, and Biosafety Regimes.” Paper presented at the *Transgenics and the Poor: Science, Regulation and Development Strategy Conference*, Cornell University, Ithaca, New York, November 7–8, 2003.

Kryder, R.D., S.P. Kowalski, and A.F. Krattiger. *The Intellectual and Technical Property Components of Pro-Vitamin A Rice (GoldenRice™): A Preliminary Freedom-To-Operate Review*. ISAAA Briefs No. 20. Ithaca, New York, 2000.

Lichtenberg, E. and D. Zilberman. “The Econometrics of Damage Control: Why Specification Matters.” *American Journal of Agricultural Economics* 8(1986):262–73.

Marra, M.C., B.J. Hubbell, and G. Carlson. “Information Quality, Technology Depreciation, and B*t* Cotton Adoption in the Southeast.” *Journal of Agricultural and Resource Economics* 26(2001):158–75.

Paarlberg, R. *The Politics of Precaution: Genetically Modified Crops in Developing Countries*. New York, NY: Johns Hopkins University Press, 2001.

Pray, C.E., J. Huang, R. Hu, and S. Rozelle. “Five Years of B*t* Cotton in China—The Benefits Continue.” *The Plant Journal* 31(2002):423–30.

Qaim, M. and D. Zilberman. “Yield Effects of Genetically Modified Crops in Developing Countries.” *Science* 299 (2003):900–02.

Qaim, M., C. Yarkin, and D. Zilberman. “Impact of Biotechnology on Agro-biodiversity.” Paper presented at the *Allied Social Science Meeting*, Washington, DC, January 3, 2003.

Roy, D. “GMOs and Poverty in Gujarat: Is there a Connection?” Paper presented at the *Transgenics and the Poor: Science, Regulation and Development Strategy Conference*, Cornell University, Ithaca, New York, November 7–8, 2003.

Sunding, D. and D. Zilberman. “The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Industry,” in *Handbook of Agricultural and Resource Economics*, edited by B. Gardner and G.C. Rausser. Amsterdam: Elsevier Science, 2001: 207–61.

Thirtle, C., L. Beyers, Y. Ismaël, and J. Piesse. “Can GM-Technologies Help the Poor? The Impact of B*t* Cotton in the Makhathini Flats of KwaZulu-Natal.” *World Development* 31(2003): 717–32.

Traxler, G. and J. Falck-Zepeda. “The Distribution of Benefits from the Introduction of Transgenic Cotton Varieties.” *AgBioForum* 2(1999):94–8. Available at: http://www.agbioforum.missouri.edu.

Traxler, G., S. Godoy-Avila, J. Falck-Zepeda, and J. de J. Espinoza-Arellano. “Transgenic Cotton in Mexico: Economic and Environmental Impacts.” Paper presented at the 5th *ICABR International Conference on Biotechnology, Science and Modern Agriculture: A New Industry at the Dawn of the Century*, Ravello, Italy, June, 15–18, 2001.