THE ECONOMICS OF AGROBIO TECHNOLOGY

J. Wesseler
Social Science Department, Wageningen University, NL

Keywords: Agrobiotechnology, brown-wiener process, cost-benefit analysis, developed countries, developing countries, discounting, ex-ante technology assessment, general equilibrium model, genetically modified organisms, intellectual property rights, irreversibility, partial equilibrium model, patents, real option value, risk, risk assessment, scientific uncertainty, stochastic process, time preference, uncertainty, welfare distribution

Contents

1. Introduction
2. Important Economic Aspects of Agrobiotechnology
3. Methodological Approaches to Assess the Benefits and Costs
4. Empirical Evidence
5. Conclusions and Outlook
Glossary
Bibliography
Biographical Sketch

Summary

The development and application of agrobiotechnology has important implications for the organization of research, the economics of agriculture production, and consumer welfare. The role of public-private partnerships in research will become more important in the future and will challenge the independence of public research. The concentration among the life-science companies through mergers and acquisition has to be observed closely to avoid excessive use of monopolistic power. This will be of special concern for regulators, as they have to weigh the gains through patents against the welfare losses of restricted monopolies.

It is still uncertain if consumers will accept food products made from transgenic crops (see also– Why genetic modification arouses concern). Experiences in the US with BST-milk suggest that negative labeling may be a solution and create niche markets.

Until now, one of the major problems in the economics of agrobiotechnology is the assessment of benefits and costs and their distribution along the supply chain. The nature of the problem demands analytical methods that have only been developed recently. The incorporation of irreversibility and uncertainty allows researchers to recognize the risk associated with the release of transgenic crops into the environment at the theoretical level. Some important progress has been made recently.
1. Introduction

Agrobiotechnology challenges the political economy of agriculture in many countries. Never before has a new technology in the field of agriculture been so emotionally debated among different stakeholders. Developing countries’ scientists fear to be bypassed by the new technology, while at the same time groups of consumers, politicians and non-government organizations (NGOs), both in developed and developing countries, oppose the introduction of transgenic crops (see also - Transgenic plants), which they see as a threat to biodiversity, human health and the economy of rural communities, ultimately endangering sustainable development. Radical groups go as far as destroying research plots and laboratory equipment. Especially in Western Europe, many people have lost their confidence in modern science because of the BSE scandal, HIV-tained blood and other such incidents. Consumers are further disconcerted by the disagreement among scientists about the environmental and human health impact of transgenic crops (see also - Why genetic modification arouses concern). While some highlight the potential risks, others argue that they are negligible.

However, much of the discussion on the risks and benefits of agrobiotechnology is based on ideologies and beliefs. Scientific evidence about long-term effects is scarce, and economic analyses are at a very initial stage of providing guidance to policy makers and other stakeholders.

In the following, the economics of agrobiotechnology will be discussed, with special emphasis on the expected impact of agrobiotechnology on different levels of the research-development-application continuum. First, important economic characteristics of agrobiotechnology are presented. This is followed by a discussion of different methodologies to compare expected costs and benefits. Specific attention will be paid to a methodological approach that takes irreversibility and uncertainty into account. Section 4 discusses some empirical studies, while Section 5 presents the main conclusions and an outlook on future trends and research priorities.

2. Important Economic Aspects of Agrobiotechnology

From an economic point of view, the two most important aspects of agrobiotechnology that need to be considered relate to issues of efficiency and equity. Efficiency looks at the impact of agrobiotechnology on resource allocation and productivity within the economy, while the question of equity attempts to analyze how the benefits and costs of these new technologies will be distributed among different stakeholders. The three main stakeholder groups who are affected by or have an interest in agrobiotechnology are:

- the providers of the technology, namely universities, other public research institutions and private companies;
- the farmers as the main users of the technology; and
- the consumers as those who are confronted with the final products (figure1).

The questions regarding efficiency and equity can therefore be discussed at the level of research and development, at the production (= agricultural sector) level, and at the consumption level. In addition, national governments and international organizations as
the regulatory bodies that have the power to influence the distribution of cost and benefits of the new technology also have to be considered. Furthermore, since agrobiotechnology will not only have an impact on western agriculture and society, but also on those of developing countries, who expect large benefits from its application, the conditions under which those benefits will materialize for the benefit of developing countries are of particular interest.

![Figure 1: The main stakeholder groups in the agrobiotechnology chain](image)

**2.1 Research and Development Level**

The basic foundations of agrobiotechnology have been developed by public research institutions in developed countries. However, the introduction of patents and other Intellectual Property Rights (IPRs) for biotechnology inventions provided an incentive for private companies to invest in the technology, so that now private investments in agrobiotechnology research exceed those of the public sector manyfold. A patent puts its owner in the position of a temporary monopolist for the supply of a specific product. For as long as the patent is valid, the owner can exploit monopolistic profits (see also - Inventions, patents and morality). This situation can be justified by the high initial investments needed to generate an invention. Without intellectual property protection, the private sector would have no incentive to invest in research and less technical change would be generated.

The nature of agrobiotechnology, which relies on seeds as the carriers of the invention, has resulted in several mergers and acquisition (M&As) between biotechnology and seed companies. Biotech companies, which were able to incorporate new traits into existing germplasm, did not have the seed distribution system necessary to capture the gains from their new developments. In order to bring their products to the market, biotech companies could either enter into contracts with seed companies, or they could actively engage in this part of the development process through vertical integration, i.e. by buying into the seed distribution system through M&As with seed companies. The latter option became dominant, as specifically transaction costs could be reduced considerable through M&As. However, this situation of concentration has given rise to concerns among many critics of agrobiotechnology as they see the market power of multi-national biotech-cum-seed companies as becoming overly strong.

The growing involvement of private companies in agrobiotechnology research has given rise to many new forms of public-private partnerships. These partnerships have changed the research sector in the US, especially with respect to the land-grant universities. The role of public research is put into question as the share of privately
financed research projects at public research institutions increases. On the one hand, public research institutions need partnerships with private companies to access the protected germplasm, molecular tools and processes of these companies, but also to commercialize their own research findings for the public benefit. On the other hand, the independence of public research and the character of public research as a public good is threatened by too much private sector involvement. Most notable in this respect is the contract between the U.C. Berkeley’s College of Natural Resources and the life-science company Novartis, in which Novartis made an initial commitment of US$ 25 Mio. to fund research and obtained the right to negotiate licenses on the research results. The structure of such emerging public/private partnerships is also important for the development of agrobiotechnology for developing countries where private investment in agricultural research remains negligible. Many life-science companies hold property rights on genetic material of world food crops like rice or corn. This limits the research possibilities of public institutions, including the international agriculture research centers. Partnerships between the private sector and national and international research centers have been discussed to improve the research potential of the centers.

2.2 Agriculture Sector Level

There are three important aspects that have to be considered when analyzing investments in agrobiotechnology at the farm level. First, investments in agrobiotechnology are done under temporal uncertainty, second they are to a certain degree irreversible, and third they can be postponed into the future. While the first aspect concerns mostly the farmers’ decision to use a transgenic variety, the latter two aspects become important at the level of society in the decision on whether or not to release a transgenic variety for public use.

Temporal uncertainty exists since future prices, yields, and costs of the new products are unknown. The price of genetically engineered crops may increase or decrease compared to “conventional” varieties for a number of reasons such as consumer reactions or government regulations. For example, the relative price of GM-varieties may decrease if consumers are willing to pay a premium for GMO-free products. On the other hand, the relative price may also increase if an increasing number of consumers believe that GMO products have a higher value than non-GMO products, for example because of higher nutritional value. On the production side, the relative variable costs may increase or decrease depending on prices for the different inputs needed as well as differences in production technology. For example, the culture of herbicide-tolerant plants (see also - Crop protection through pest resistance genes) may reduce the number of herbicide applications and hence reduce the variable costs for oil. Furthermore, the relative changes in yield are unknown. All three, product prices, variable costs, and yields, contribute to the farmers’ uncertainty about the relative changes in future gross margins. In addition, regulations regarding the development, release and use of agrobiotechnology products may change over time. As additional information on the environmental impact of GMOs becomes available, regulating agencies will start to implement guidelines for their use, which may add additional costs to the producer, processor or developer.

Irreversibility exists as a release of genetically modified organisms may have a negative
impact on the environment (see also - Potential effects on biodiversity). There are long-
term risks related to the widespread use of transgenic crops. For example, gene flow in
plants can enable domesticated plants to become pernicious weeds, or it can enhance the
fitness of wild plants, which might turn out to be serious weeds, thus shifting the
ecological balance in a natural plant community (see also - Biotechnology and agro-
biodiversity). New viruses could develop from virus-containing transgenic crops. Plant-
produced insecticides might have harmful effects on unintended targets. While some of
these scenarios are highly unlikely, little is known about the overall impact that
transgenic crops can have on biodiversity, ecosystem balance and the environment in
long run.

The decision to release transgenic crops into the environment can be postponed.
Government bodies who decide about releasing GMOs have the option to delay the
decision and to ask the applicant to provide additional information to reduce the
decision-related uncertainty.

All three, uncertainty, irreversibility and the option to delay the decision have an impact
on the decision rule for releasing GMOs into the environment, as will be shown below.

2.3 Consumer Level

Uncertainties on the impact of agrobiotechnology abound at the consumer level as well.
The first generation of transgenic crops, which focused on herbicide tolerance and pest
resistance as the dominant traits, does not provide any significant benefits for the
consumer. Product prices will not decrease until the share of primary products in the
total costs of consumer goods is very low. Currently, the share of wheat in the costs for
bread is below 10 percent, the other costs are accounted for by processing, transport,
and packaging. Therefore, it is understandable that consumers are reluctant to buy
products containing transgenic crops, more so as they do not have any direct positive
impact on health but, on the contrary, are perceived as being risky to consume. The
second generation of transgenic crops is expected to provide more direct benefits to
consumers, for example through improved nutritional contents of the crops. It still has
to be shown if consumers in developed countries will accept this as a benefit, since they
already have alternatives for a balanced nutrition. Most of the benefits from the second
generation of transgenic crops at the consumer level are expected to be realized in
developing countries (see also – GMO-Technology and Malnutrition), where problems
of malnutrition can be addressed through products such as Vitamin A- enhanced
transgenic rice.

3. Methodological Approaches to Assess the Benefits and Costs of
Agrobiotechnology

Several studies have tried to assess the benefits and costs of agrobiotechnology. These
studies have used different approaches to model benefits and costs. In general, the
methodologies used can be grouped into deterministic and stochastic models. The latter
ones are commonly used for ex-ante assessments while the deterministic models tend to
be used for ex-post analyses.
3.1 Deterministic Models

Deterministic models can be divided into general equilibrium models and partial equilibrium models.

General equilibrium models have the advantage of taking the whole economy into account. On the other hand, they can become extremely complex and many details are lost along the way. While they are often used for theoretical purposes, empirical applications are less common. Also, incorporating issues of uncertainty and irreversibility in such models is still a problem that has not yet been totally resolved at the theoretical level. More common are deterministic partial equilibrium models. They have the advantage of providing room for details. So far, most of the empirical applications to agrobiotechnology have used models of this type for ex-post analyses. Some authors have also used them for ex-ante assessments.

In general, partial equilibrium models attempt to identify the supply and demand functions for the products in question and to calculate the discounted sum of the changes in producer and consumer surplus due to an intervention (such as the introduction of a new product or a new production technology). This allows the researcher to identify the welfare changes and their distribution among the different stakeholders. For an ex-ante assessment, the main problem in developing such a model consists of identifying the appropriate discount rate, since the results are sensitive to small changes in the discount rate. The main advantage of partial equilibrium models is that the methods are very well developed. Their main problem is the fact that sensitivity analysis cannot consider uncertainty about several parameters simultaneously and also ignores possible correlations among them. Furthermore, in most cases it is assumed that the stakeholders have risk-neutral preferences, which is a simplification that might lead to false results. Also, the issue of irreversibility is often not included in the models.

3.2 Stochastic Models

Stochastic models are used for the ex-ante assessment of new technologies. They can, as the name implies, consider the stochastic nature of the problem. They can be grouped into models with stationary and non-stationary variables, according to the properties of the stochastic variables.

3.2.1 Models with Stationary Stochastic Variables

These models are probably the most common type of models used for the ex-ante assessment of new technologies in agriculture. Their main advantage is that they are easily constructed and solved. Using random distributions of stochastic variables and deriving the cumulative probability function of the annuity by Monte-Carlo simulation allows the researcher to include uncertainties about parameter values. Different scenarios can be compared by using the criterion of stochastic dominance. This approach, illustrated in Figure 2, is appropriate for cases in which the option to delay the investment doesn't exist. Still, the problem of identifying the appropriate discount rate and the risk preference remain. Assuming risk aversion and either eliciting the individual rate of time preference or approximating the rate of time preference by using
indicators like interest rates on capital markets can solve most problems.

Figure 2: Ex-ante Risk Assessment using Monte-Carlo Simulation

### 3.2.2 Models with Non-Stationary Stochastic Variables

In general, however, an ex-ante assessment of the costs and benefits of a new product of agrobiotechnology should take into account that the release of a GMO can be delayed
until more information on its risks becomes available. The real option approach allows analysts to explicitly consider and value the possibility of delaying a decision. The real option to release GMOs into the environment is in analogy to call options on stocks in financial market. If the real option is exercised (i.e., the GMO is released into the environment), the agriculture sector receives the discounted sum of benefits from GMOs, equivalent to a stock on the stock exchange. Equivalent to the exercise price of a call option are the irreversible costs of releasing GMOs into the environment. The irreversible costs have to be seen as the external costs of releasing GMOs. The comparison between a call option, a real option on investments, and on the decision to release GMOs into the environment is illustrated in Figure 3.

A simple numerical example will be used to illustrate the approach:

A company has developed a herbicide-tolerant crop. The immediate increase in gross margin, $\pi_0$, through the introduction of the new variety is about US$ 1 Mio. For the next year, $t_1$, it is expected that the additional gross margin will change. Two situations are possible. Either the additional gross margin, $\pi_{1H}$, will increase to US$ 1.5Mio., if more farmers adopt the technology and other factors are also in favor of the technology or, if the factors are less favorable, the additional gross margin, $\pi_{1L}$, decreases to US$ 0.5Mio. To keep it simple, the additional gross margin remains the same from $t_1$ onwards. The probabilities of both scenarios (favorable/non-favorable) are assumed to be the same, $p=1-q=0.5$.

Further, it will be assumed that the gross margins are independent of the development of the economy and the riskless rate of return of 10 percent can be used as the discount rate. The release of the new transgenic crop into the environment is assumed to have a negative impact on biodiversity. A contingent valuation study shall have revealed that the negative impact will be in the order of US$ 8 Mio. There are no additional costs and benefits that have to be considered. In this case the net-present-value of the immediate release (NPV$_I$) of the transgenic crop into the environment would provide the following solution:

$$\text{NPV}_I = -I + \pi_0 + \frac{(p \cdot \pi_{1H})}{r} + \frac{((1-p) \cdot \pi_{1L})}{r} = -8 + 1 + 7.5 + 2.5 = 3.0$$ (1)
The NPV$_I$ of equation 1 is positive and hence, under the traditional cost-benefit approach, the new variety should be released into the environment. However, this evaluation did not consider the possibility of delaying the release into the environment until more information becomes available on factors that may have an impact on the result. If the release was postponed by one year and it is assumed that the new state will be known with certainty, it is obvious that the transgenic crops should not be planted if the additional gross margin decreases to US$ 0.5Mio. On the other hand, if the other state occurs, the NPV$_I$ will be the following:

\[
\text{NPV}_D = 0.5 \left( \frac{1}{1+r} + \sum_{t=1}^{\infty} \frac{\pi_{t+1}}{(1+r)^t} \right) = \frac{4.25}{1.1} = 3.86
\]  

The result of equation 2 shows that in the case of delaying the decision, a higher NPV would be achieved, $\text{NPV}_D > \text{NPV}_I$, and hence this strategy should be adopted. Ignoring the option to delay the release into the environment would result in a sub-optimal decision under this scenario.

Now, $V$ will be defined as the discounted sum of $\pi$:

\[
V = \sum_{t=0}^{\infty} \frac{\pi_t}{(1+r_t)}
\]  

$V$ shall be called the additional net-benefits of a specific GMO compared to the alternative non-GMO. Note that $V$ does not include the irreversible costs. It will be further assumed that the decision to release GMOs into the environment can be made at any point from now into the future and that $V$ changes continuously as the net-benefits change continuously, for example because of commodity and factor price changes. Under the assumption that $V$ follows a geometric brown-wiener stochastic process and the irreversible costs are known with certainty, it can be shown that additional net-benefits $V$ from GMOs have to be at least:

\[
V^* = \frac{\beta}{\beta - 1} \cdot 1, \text{ with } \beta = \frac{1}{2} - \frac{r - \delta}{\sigma^2} + \left[ \frac{r - \delta}{\sigma^2} - \frac{1}{2} \right]^2 + \frac{2r}{\sigma^2}, \text{ and } \beta > 1,
\]  

where $\delta$ is the difference between the discount rate and the trend variable of the brown-wiener process and $\sigma$ the variance of the net-benefits. $V^*$ is the so-called hurdle rate. This is the factor by which the additional net-benefits have to be above the irreversible costs to make the release of GMOs desirable from an economic point of view. Figure 4 illustrates the difference between including and ignoring the option to delay the release into the environment. The linear line shows the traditional decision-making criteria, where the $NPV = V - I > 0$ turns positive at the point where $V > I$. The non-linear line
includes the option to delay the decision. As long as the non-linear function is above the linear one, it is optimal to wait. Only if the net-benefits are equal or above $V^*$ is it optimal to immediately release GMOs.

\[ E[V_0] = \frac{\lambda \cdot dGM \cdot L}{\mu}. \quad (6) \]

In the EU, cotton, maize, potatoes, rape, soybeans, and sugar beet are grown on almost 15.5 percent of the arable land or almost 12 Mio. ha (FAO 2000). Assuming adoption rates of 25 percent, 50 percent, and 100 percent and an increase in the gross margin per ha of about 25Euro, 50Euro and 100Euro and a risk-free discount rate of 8 percent results in the values shown in Table 1. The range of the benefits under these scenarios for the EU would be between almost 907 and 14507 Mio. Euro. If they are divided by the hurdle rate $V^*$, the maximal tolerable irreversible costs can be obtained and be used as benchmark values. If reasonable parameter values are used, the hurdle rate $V^*$ will be between 1.2 and 2, depending on the stochastic process, and hence, the maximal tolerable irreversible costs will be in the range of 454 Mio. Euro and 12089 Mio. Euro.
<table>
<thead>
<tr>
<th>Country</th>
<th>Arable land (’000 ha)</th>
<th>Pot. TG crops* (’000 ha)</th>
<th>%</th>
<th>Increase 25 Euro/ha Adoption (%)</th>
<th>Increase 50 Euro/ha Adoption (%)</th>
<th>Increase 100 Euro/ha Adoption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>EU (15)</td>
<td>75818</td>
<td>11606</td>
<td>15.31</td>
<td>3626.75</td>
<td>1813.38</td>
<td>906.69</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7253.50</td>
<td>3626.75</td>
<td>1813.38</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14507.00</td>
<td>7253.50</td>
<td>3626.75</td>
</tr>
<tr>
<td>Austria</td>
<td>1397</td>
<td>333</td>
<td>23.87</td>
<td>104.21</td>
<td>52.10</td>
<td>26.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>208.42</td>
<td>104.21</td>
<td>52.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>416.84</td>
<td>208.42</td>
<td>104.21</td>
</tr>
<tr>
<td>Belgium-Luxembourg</td>
<td>768</td>
<td>166</td>
<td>21.58</td>
<td>51.78</td>
<td>25.89</td>
<td>12.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>103.56</td>
<td>51.78</td>
<td>25.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>207.12</td>
<td>103.56</td>
<td>51.78</td>
</tr>
<tr>
<td>Denmark</td>
<td>2365</td>
<td>212</td>
<td>8.96</td>
<td>66.25</td>
<td>33.13</td>
<td>16.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>132.50</td>
<td>66.25</td>
<td>33.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>265.00</td>
<td>132.50</td>
<td>66.25</td>
</tr>
<tr>
<td>Finland</td>
<td>2126</td>
<td>129</td>
<td>6.05</td>
<td>40.22</td>
<td>20.11</td>
<td>10.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80.44</td>
<td>40.22</td>
<td>20.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>160.88</td>
<td>80.44</td>
<td>40.22</td>
</tr>
<tr>
<td>France</td>
<td>18305</td>
<td>3576</td>
<td>19.54</td>
<td>1117.50</td>
<td>558.75</td>
<td>279.38</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2235.00</td>
<td>1117.50</td>
<td>558.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4470.00</td>
<td>2235.00</td>
<td>1117.50</td>
</tr>
<tr>
<td>Germany</td>
<td>11832</td>
<td>2092</td>
<td>17.68</td>
<td>653.69</td>
<td>326.84</td>
<td>163.42</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1307.38</td>
<td>653.69</td>
<td>326.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2614.75</td>
<td>1307.38</td>
<td>653.69</td>
</tr>
<tr>
<td>Greece</td>
<td>2823</td>
<td>716</td>
<td>25.37</td>
<td>223.82</td>
<td>111.91</td>
<td>55.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>447.63</td>
<td>223.82</td>
<td>111.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>895.26</td>
<td>447.63</td>
<td>223.82</td>
</tr>
<tr>
<td>Ireland</td>
<td>1343</td>
<td>55</td>
<td>4.09</td>
<td>17.16</td>
<td>8.58</td>
<td>4.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>34.31</td>
<td>17.16</td>
<td>8.58</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>68.63</td>
<td>34.31</td>
<td>17.16</td>
</tr>
<tr>
<td>Italy</td>
<td>8283</td>
<td>1788</td>
<td>21.59</td>
<td>558.89</td>
<td>279.44</td>
<td>139.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1117.77</td>
<td>558.89</td>
<td>279.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2235.54</td>
<td>1117.77</td>
<td>558.89</td>
</tr>
<tr>
<td>Netherlands</td>
<td>900</td>
<td>303</td>
<td>33.67</td>
<td>94.69</td>
<td>47.34</td>
<td>23.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>189.38</td>
<td>94.69</td>
<td>47.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>378.75</td>
<td>189.38</td>
<td>94.69</td>
</tr>
<tr>
<td>Portugal</td>
<td>2153</td>
<td>271</td>
<td>12.57</td>
<td>84.56</td>
<td>42.28</td>
<td>21.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>169.12</td>
<td>84.56</td>
<td>42.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>338.23</td>
<td>169.12</td>
<td>84.56</td>
</tr>
<tr>
<td>Spain</td>
<td>14344</td>
<td>972</td>
<td>6.77</td>
<td>303.69</td>
<td>151.84</td>
<td>75.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>607.38</td>
<td>303.69</td>
<td>151.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1214.75</td>
<td>607.38</td>
<td>303.69</td>
</tr>
<tr>
<td>Sweden</td>
<td>2799</td>
<td>158</td>
<td>5.65</td>
<td>49.41</td>
<td>24.70</td>
<td>12.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>98.81</td>
<td>49.41</td>
<td>24.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>197.63</td>
<td>98.81</td>
<td>49.41</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>6380</td>
<td>835</td>
<td>13.09</td>
<td>260.91</td>
<td>130.45</td>
<td>65.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>521.81</td>
<td>260.91</td>
<td>130.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1043.63</td>
<td>521.81</td>
<td>260.91</td>
</tr>
</tbody>
</table>

*Area harvested in the EU in 1997 (Cotton, Maize, Potatoes, Rape, Soybean, and Sugar Beet.)
Source: FAO 2000 and own calculations.

Table 1: Potential benefits from transgenic crops under different changes in gross margins/ha and rates of adoption (Mio. Euro)
From a scientific point of view, it cannot be proven that one stochastic process should be preferred over the other. Until now, there exists scientific uncertainty. Reasonable arguments can be found for using a geometric brownian process. This process, which has been described as representing an optimistic view, reflects a strong belief in scientific progress. Problems will not be ignored, but the belief is that they can be solved through further scientific progress. The use of an Ornstein-Uhlenbeck process models a rather pessimistic view about the benefits from transgenic crops. There are potential benefits but they will diminish over time.

The results of modeling these views can be summarized as shown in figure 5. There are four areas of concern: Area I and IV, where both approaches provide the same results, either supporting or rejecting an immediate release, and area II and III, where the results are contradicting. The results further indicate that there are areas of potential conflicts. It is possible that, depending on the scientific belief system, scientists can arrive at different conclusions about the release of transgenic crops, while none can claim to be right.

4. Empirical Evidence

4.1 Costs and Benefits of Agrobiotechnology

Most empirical studies on the costs and benefits of agrobiotechnology have been conducted in the United States, where agrobiotechnology has been most widely applied until now. There has been a rapid adoption of transgenic corn, cotton, rapeseeds, and
soybeans since the mid-1990s. This indicates that farmers are expecting additional benefits from the new varieties, which are either herbicide-tolerant or pest-resistant. Studies confirm that on average the gross margin per area from transgenic crops is at least as high and sometimes higher than those from non-transgenic crops. However, there seems to be a regional difference in the distribution of benefits, which can be explained by regional factors like infestation level and climatic conditions. The empirical studies also indicate that the amount of pesticides may decrease, but only in specific regions and specific years, depending on the same factors as mentioned before. In some regions, pesticide use has actually increased. So far, the available data are not sufficient to provide significant information on whether first generation transgenic crops will provide net–benefits for farmers. This ex-post question can only be answered sufficiently after some years of transgenic crops planted.

There are only a few studies on the ex-ante assessment of agrobiotechnology. They are partial equilibrium models and do not include uncertainty and irreversibility and therefore the results have to be interpreted with caution. Nevertheless, they show that agrobiotechnology has a high potential especially for developing country agriculture. This, of course, does not provide a justification for intensive public investment in agrobiotechnology for developing countries if the main objective is to combat poverty. Poverty is a multi-dimensional problem, which needs to be approached through several strategies (see also - Gender aspects of biodiversity and conservation). In order to secure the sustainability of investments in agrobiotechnology, they should be undertaken as much as possible by the private sector, as the private sector allocates resources more efficiently than the public sector. Nevertheless, the public sector plays an important role for private sector investments in agrobiotechnology for developing countries. Rules and regulations, like patent laws and market reforms have to be identified and implemented that increase the incentive for private sector investments.

4.2 Distribution of Benefits and Costs

The potential net-benefits agrobiotechnology promises to society should not be discussed without having a closer look at the distribution of those net-benefits. Again, if the economy is divided into the three groups of researchers, farmers, and consumers, which group will be the main beneficiary? Empirical studies on the distribution of net-benefits from Bt-cotton showed that farmers were the group receiving the highest share from the overall net-benefits, followed by the agrobiotechnology industry and the consumers (see also - Farmers and Plant Genetic Resources). As Bt- cotton belongs to the first generation of agrobiotechnology, it can be expected that the net-benefits at the consumer level will increase with the introduction of second-generation agrobiotechnology products. The distribution of benefits also has an international dimension. As most of agrobiotechnology is currently applied in Northern America, producers and consumers in this region will be the main beneficiaries. However, other regions of the world will benefit as well, depending on their current agriculture production structure. As the prices for agricultural transgenic commodities will most likely decrease, those countries that are net-importers of those crops will benefit, specifically the EU and Japan and other developed countries. Among the developing countries, China will most likely be the main beneficiary (see also - Biotechnology in rural areas). Developing countries who are net exporters of agriculture products are
expected to be the loser. Also, the producer surplus of net-food producing farmers in developing countries is expected to decrease as well, while the surplus of consumers in urban areas is expected to increase. The total net benefits at the national level of developing countries will hence depend on the urban-rural population ratio and the level of net-food production.

5. Conclusions and Outlook

The development and application of agrobiotechnology has important implications for the organization of research, the economics of agriculture production, and consumer welfare. The role of public-private partnerships in research will become more important in the future and will challenge the independence of public research. The concentration among the life-science companies through mergers and acquisition has to be observed closely to avoid excessive use of monopolistic power. This will be of special concern for regulators, as they have to weigh the gains through patents against the welfare losses of restricted monopolies.

It is still uncertain if consumers will accept food products made from transgenic crops. Experiences in the US with BST-milk suggest that negative labeling may be a solution and create niche markets.

Until now, one of the major problems in the economics of agrobiotechnology is the assessment of benefits and costs at the farm level. The nature of the problem demands analytical methods that have only been developed recently. The incorporation of irreversibility and uncertainty allows researchers to recognize the risk associated with the release of transgenic crops into the environment at the theoretical level. The application of those models depends on the availability of empirical data. One major problem is the implication of regulations on benefits and costs and their distribution along the supply chain. Further research in this direction will improve the quality of the assessment.

Glossary

agrobiotechnology: area of biotechnology involving application to agriculture.
biotechnology: any technique that uses living organisms or parts thereof to make or modify a product or improve plants, animals, or microorganisms for specific uses.
genetically-modified organism (GMO): organism that has been modified using recombinant DNA technology.
genetic engineering: application of recombinant DNA technology.
recombinant DNA technology: molecular technique that allows to transfer genetic information between organisms of the same or different species, e.g. from animals to plants.
Relative change in gross margin: ratio of gross margin of transgenic and non-transgenic crops.
transgenic crops: crops modified by recombinant DNA technology.
transgene: gene transferred by recombinant DNA technology.
Bibliography


Wesseler, Justus (ed.) (2005): Environmental Costs and Benefits of Transgenic Crops. Dordrecht, NL: Springer Press. [Provides an overview about the important issues for assessing benefits and costs of transgenic crops from the natural as well as social science point of view].


Biographical Sketch

**J. Wesseler** has received a PhD from the University of Göttingen, Germany in Agricultural and Environmental Resource Economics in 1996. His main field of research is decision making under uncertainty and irreversibility using the real option approach applied to impact assessment and cost-benefit analysis of new agriculture technologies, natural resource management systems and rural development projects. Since 1998 he has been working as a consultant providing expertise to the Food and Agriculture Organization of the United Nations (FAO), the German Association for Technical Cooperation (GTZ), and the German Bank for Reconstruction (KfW). His international assignments include work in countries like Azerbaidschan, Brazil, India, Kenya, Malawi, Paraguay, and the Philippines.