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Economics, Ecology and GMOs: Sustainability, Precaution and Related Issues

by

Clem Tisdell

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Economics, Ecology and GMOs: Sustainability, Precaution and Related Issues

ABSTRACT

Ecological, evolutionary and economic issues involved in introducing genetically modified organisms (GMOs), mainly in agriculture, are discussed. The ecological and evolutionary impacts identified hamper (economic) valuation of GMOs and their biosafety regulation and creates difficulties for planning for sustainable development. Assessment of the desirability of releasing GMOs is difficult because of lack of communal agreement about the risks involved, about how much precaution should be exercised given collective risks, and disagreement on the appropriate social criterion to apply. Changes in legal liability are not always economic and cannot eliminate the social conflict generated by GMOs. The economics of developing and marketing GMOs is explored, assuming the type of intellectual property rights in GMOs in the United States. It is found that the economics of developing and marketing GMOs favours large enterprises as primary suppliers. In marketing GMOs, sales to larger-sized commercial farms rather than smaller-sized ones are preferred. GMOs preferred for development are those designed to satisfy large agricultural markets, mostly located in higher income countries. The patenting of GMOs, co-evolution, various social conflicts in the use of GMOs and legal liability for damages caused by GMOs are discussed both from a socioeconomic and biosafety point of view.

Keywords: Biodiversity; biosafety; genetically modified organisms; GMOs; intellectual property rights; market structure, sustainable development.

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1. Introduction

Decisions about the development and introduction of genetically modified organisms (GMOs) usually have to be made in circumstances where their economic and ecological consequences are very uncertain. Furthermore, these decisions must be made in a holistic context requiring simultaneous consideration of economic, ecological, social, political and other factors. Both the uncertainty and the wide range of factors that need to be taken into account in assessing the consequences of the introduction of GMOs for sustainable development make sustainable development planning challenging in this case.

The development of genetically modified organisms has generated both high expectations about their ability to increase economic production and help reduce economic scarcity as well as dire predictions about how they might reduce biodiversity, add to health risks and in the long-term, threaten economic sustainability. Furthermore, strong opposing views exist in the literature about the environmental benefits and costs of GMOs. Proponents emphasize the benefits of decreased pesticide use whereas opponents argue that these benefits do not materialize in many cases (Zhao, et al., 2011) and that when they do, they may not be sustained. For genetically engineered herbicide-resistant crops, reduced tillage is also seen as an environmental advantage. However, assessment of the economic costs and benefits of the development and sustainable use of GMOs is complex as is the evaluation of their ecological consequences (Xue and Tisdell, 2000; 2002).

A useful summary of the potential **positive** impacts of biotechnologies on economic development is given by Just, Alston and Zilberman (2006, pp. 710-712) who also express concern about the level of regulation costs borne by private firms in developing such technologies and in having them approved; a view which contrasts markedly with that of Batie and Ervin (2001). Furthermore, Quaim, Pray and

Zilberman (2008) provide a positive assessment of the economics of Bt production (including its use in China), but Zhao et al. (2011) suggest that these economic benefits are grossly overstated in China's case. These examples indicate that experts disagree in their assessments of the benefits of GMOs. Nevertheless, it is clear that GMOs vary in their ability to reduce economic scarcity and in their environmental and sustainability consequences. Individual cases need to be assessed. This view accords with that of Wolfenbarger and Phifer (2000) who state "Neither the risks nor the benefits of GEOs [genetically engineered organisms] are certain or universal. Both may vary spatially and temporarily on a case-by-case basis." Furthermore, even in the case of those GMOs which reduce scarcity, their scarcity-reducing benefits may diminish with the increased frequency of their use.

The use of GMOs inevitably results in ecological changes which usually have consequences for economic sustainability. It is argued in this chapter that the use of GMOs is likely to result, in the long run, in a decline in pre-existing biodiversity. Furthermore, some of the desired attributes of particular GMOs may be eroded in due course by the operation of ecological and evolutionary forces. Hence, their use can result in unsustainable economic development. The economics of developing and marketing GMOs (and this also has important implications for sustainable development planning) is also analysed in this chapter. It is claimed that when this is left to the private sector, the development of GMOs is heavily influenced by the nature of the economics of property rights in them. Economic factors favour the development and marketing of GMOs by **large** enterprises. Consequently, a few firms gain market power which may also result in political power. Furthermore, economic considerations favour the development of GMOs to satisfy the requirements of large-scale commercial farms and those farms are the prime (initial) markets for GMOs. Several other socioeconomic factors are important when considering the development and use of GMOs. These include the building of patent walls, lack of co-evolution and related safety issues, provisions concerning legal liability and social conflicts about the use of GMOs. All of these factors have sustainability implications.

The coverage of the analysis in this chapter proceeds as follows: Firstly, ecological sustainability issues raised by the introduction of agricultural GMOs are discussed. These include long-term biodiversity change caused by the use of GMOs, the ecological erosion of the fitness of GMOs with the passage of time, trade-offs of attributes of organisms as a result of genetic manipulation and long-term changes in interspecies competition, for example, cases in which one pest is controlled as a result of genetic modification of a plant but this is countered by the increased occurrence of another pest. All these factors have consequences for the sustainability of agricultural production when a new agricultural GMO is adopted and therefore are consequential for the sustainability of economic development. The second subject considered in this chapter is the consequences for decision-making of risk and uncertainty about the preference of new agricultural GMOs. That raises questions about how to rationally make decisions about whether a new GMO should be allowed to be used, about how much caution should be exercised in this regard, the appropriate social criteria to adopt in such situations and whether or not laws governing liability can be sufficient to deal with possible damages caused by the use of GMOs.

The third relevant subject for analysis is economics of developing and marketing GMOS. It is argued that economic structures that tend to evolve in industries supplying GMOs lead to 'lop-sided' development and result in business strategies that may undermine the sustainability of development and politically compromise the planning of sustainable development. In fact, there is shown to be a danger of less sustainable use of GMOs in developing countries than in high income ones. Fourth, before concluding some other socioeconomic issues affecting the development and use of GMOs are considered. These include patent walls, lack of co-evolution, social conflicts and knowledge imperfections amongst the users of GMOs and these all have consequences sustainable development involving the use of GMOs. Economic ecological and social considerations are all important in considering the scope for GMOs to contribute to sustainable development.

2. Ecological Issues

Initially, the introduction of a GMO adds to the extent of global biodiversity because some time is needed for economic and ecological change to occur. However, the initial situation is not an equilibrium one. The continuing use of the GMO is likely to change the ecological balance with the passage of time and may eventually reduce the extent of genetic diversity and/or change its composition. The change in biodiversity may come about as a result of a variety of processes. Note that because biological diversity is very heterogeneous, attempts to measure its extent by a single index are problematic, as has been pointed out by Scholes and Biggs (2005). Assigning economic or other values to its composition can be even more controversial. Nevertheless, as observed by Andow and Zwahlen (2006, p.207), there is a risk of transgenic plants resulting in the "loss of biological diversity, namely variability among living organisms including the ecological complexes of which they are part; this variability includes diversity within species, between species and of ecosystems". It is worth considering some of the possible genetic changes that may come about as a result of the introduction of a GMO.

2.1 Processes of long-term biodiversity change

Wolfenbarger and Phifer (2000) argue that the consequences of introduction of a new GMO into an ecosystem can be likened to the introduction of non-native species to a part of the world where it has not previously been present. It may or may not become invasive, and forecasts of its impact prior to its introduction can be very unreliable. They point out that "not every risk associated with the release of new organisms, including transgenics, can be identified, much less considered". Wolfenbarger and Phifer (2000) identify several of these ecological risks as do Andow and Zwahlen (2006). These potential risks are complex and diverse and only a partial indication of them is possible here.

Genetic flows involving GMOs can alter the set of extant biodiversity as the result of evolutionary processes that add new types of organisms to the set of living things and eliminate others. For example, cross breeding of non-GMOs with a GMO may eventually eliminate some other varieties or strains of living organisms because the cross breeds become dominant. Furthermore, some GMOs may escape into the wild and in some instances, may outcompete and eliminate competitive organisms**.** However, this could be a rare event because many agricultural GMOs are only able to survive under artificially managed environmental conditions. Nevertheless, it is possible (Wolfenbarger and Phifer, 2000), and Andow and Zwahlen (2006, p.208) point out that several new transgenic plant species (for instance, those with increased stress tolerance) are more likely to become feral and hybridize with wild relatives than are existing agricultural transgenic plants, such as variants of maize. They state: “As some of these newly transgenic species are already invasive in parts of their geographic range, there is a risk that these species could become more invasive, invade new habitats and cause a loss in biodiversity and ecosystem functions” (Andow and Zwahlen, 2006, p.208).

An important indirect [economic] route by which GMOs can lead to a loss in genetic diversity is if they provide an economic incentive for the extension or intensification of agriculture, aquaculture or silviculture. Extensions of these land uses are likely to reduce the size and variety of habitats available to other species and reduce biodiversity in the wild. Intensification can also reduce the availability of diverse micro-habitats and reduce the presence of the varied species inhabiting these. The likelihood of these effects increases with a rise in the commercial economic success of a GMO and the more elastic is the demand for the produce of the GMO.

Nevertheless, as pointed out by one reviewer, the opposite view exists (expressed, for example, by Just, Alston, et al., 2006, p.711), namely that the development and widespread use of GMOs in agriculture will reduce the extension of agriculture globally and result in its intensification in a more environmentally friendly way than at present. However, this view seems to be too optimistic. Although the introduction of agricultural GMOs may raise yields on existing land used for agriculture, this does not ensure that the amount of land used globally for agriculture falls, other things being held constant. This outcome depends on the demand for agricultural produce being relatively inelastic. Also much depends on the type of GMOs developed. Those GMOs that, for example, show greater stress tolerance can result in agricultural intensification on marginal agricultural land, for instance, the replacement of grazing by cropping and consequently the acceleration of wild biodiversity loss. As for the use of GMOs resulting in agricultural practices (such as reduced use of pesticides and minimum tillage) that are more environmentally friendly than existing ones, it is probably dangerous to generalize about this. For instance, in some cases pesticide use has not fallen because secondary pests have increased. This has been reported for Bt cotton in China (Zhao, et al., 2011).

Apart from possibly accelerating loss of wild biodiversity, a commercially successful GMO may displace similar traditional varieties of organisms in agriculture, aquaculture or silviculture due to economic or commercial selection (Tisdell, 2003b). Consequently, a loss of previously human modified or developed genetic stock is likely to occur. Thus, in the long-term, the sustained use of GMOs can reduce both pre-existing biodiversity in the wild as well as the previously available stock of human modified genetic material. The conceptual issues involved are worth some attention. Let us focus on the stock of genetic material.

The stock of genetic material is just one component of biodiversity but it is an important component. The successful introduction of a GMO is hypothesised, as a rule, to eventually reduce the prior stock of genetic material. Initially, this introduction has no impact on this prior stock because economic, evolutionary and ecological processes take time to have an effect. The hypothesised impact on the genetic stock of the introduction and diffusion of the use of GMO can be envisaged by considering Figure 1. There the set L plus R represents the set of genetic material prior to the introduction of a successful GMO. However, after sufficient time has elapsed from the date of introduction of the successful use of a new GMO, the set of genetic material may correspond to set R plus set A. The set L of prior genetic material is lost, the set R is retained and a set A, is added. The set A consists of the genetic material in the GMO plus changes in other genetic material induced by the adoption of the GMOs for example, possible new genetic combinations as a result of transgene flows. The relative size of the sets may vary but it is hypothesised that none of these are empty.

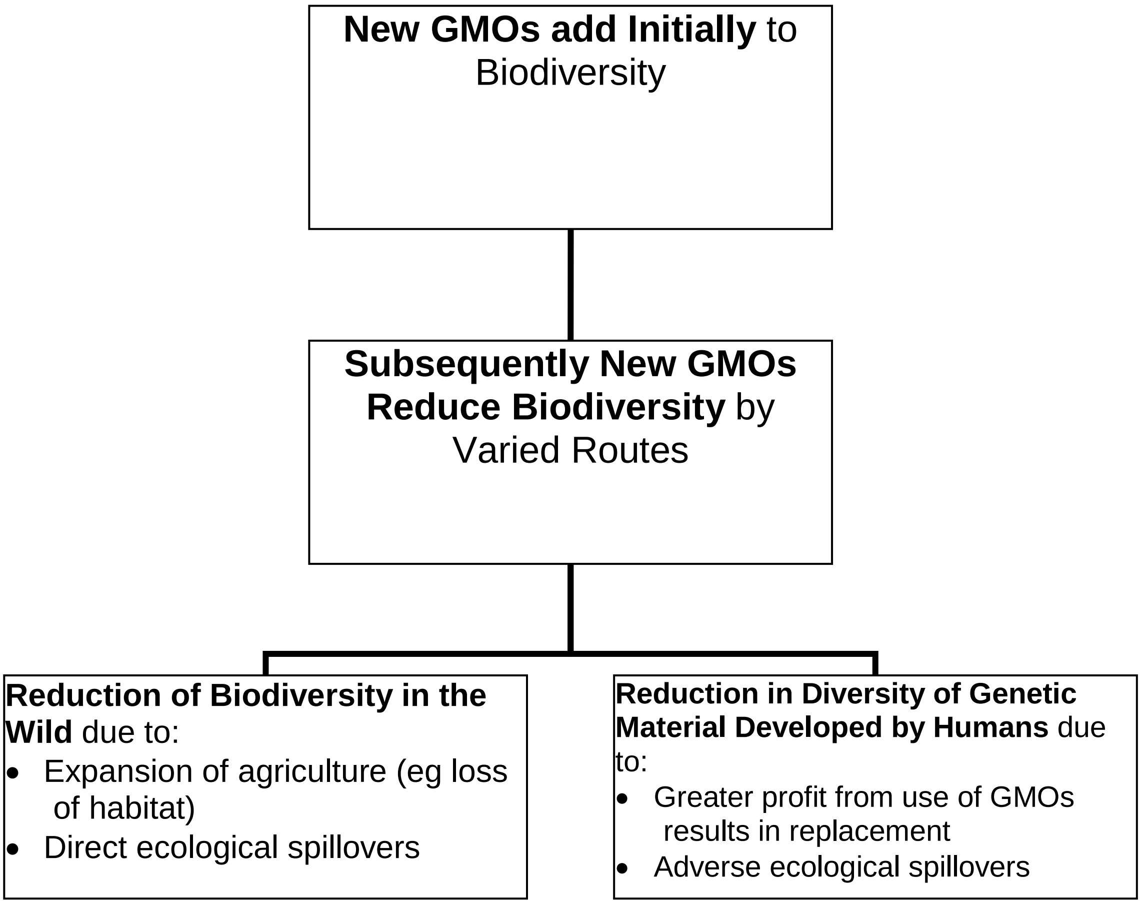

Figure 1: Hypothetical types of potential changes in the stock of genetic material once a GMO has been successfully adopted for a sufficient period of time. The pattern has similarities with biodiversity change likely to occur when a non-native species is introduced to a new region.

The stock of genetic material may also be divided into that existing in the wild and that contained in organisms cultured by humankind. These categories may partially overlap, but not all organisms cultured by humans are able to exist in the wild because processes of selection by humans result in many of these organisms being only able to persist in human managed environments. If human-selected organisms are lost, they may be irreplaceable or they might only be replaced after incurring considerable cost and after a very long period of time. These might be called 'human heritage organisms'.

The suggested likely pattern of biodiversity change as the result of a new agricultural GMO can be summarised as follows:

(1) Initially (for a short period of time) the new GMO adds to biodiversity because of its limited time in the environment and its limited spatial presence. This assumes that the new GMO adds to the available combinations of genetic material.
(2) Subsequently (after the passage of sufficient time), the new GMO can be expected to reduce **prior** biodiversity.
(3) It may reduce the set of prior genetic material in the wild as well as that in human 'developed' genetic material (heritage biodiversity) contained in organisms cultured by humans.
(4) Loss of pre-existing genetic material in the wild may occur (a) because agricultural land use is extended or intensified resulting in loss of habitat utilized by wild organisms and (b) as a result of gene flows from GMOs and or competition from GMOs with wild organisms. Additions to this genetic material could also occur in the long term.
(5) Human 'developed' genetic material may be lost (a) because it is more profitable to culture GMOs rather than non-GMOs and (b) gene flows from GMOs or ecological competition from them may result in the disappearance of some human developed organisms.

There may also be other pathways by which GMOs alter the set of prior genetic material and reduce this set.

Some contrary views are also found in the literature. For example, Just, Alston and Zilberman (2006, p. 711) state that new transgenic varieties increase yields and may reduce farmland use thereby helping to preserve wild biodiversity. Quaim, Yarkin and Zilberman (2005) argue that the use of genetically modified varieties of crops might increase crop diversity although they do not completely dismiss the view that traditional local varieties could be replaced by a small number of genetically modified ones.

Note that the pattern of biodiversity change illustrated in Figure 1 has no implications about whether overall biodiversity increases or decreases in the long run following the introduction of a GMO. It merely implies a change in the set of the elements of biodiversity – these changes may be desirable or undesirable.

2.2 Evolution, erosion of attributes such as pest resistance, secondary pests, induced evolution of other organisms

The quality of some desired attributes of GMOs may be diminished in the long run by evolutionary processes. For example, in the long run, an insect pest (as a result of natural selection) could develop increased resistance to Bt modified crops (see Andow and Zwahlen, 2006, pp. 203-206). Another possibility is that pests not affected to any great extent by Bt (or another genetic modification) may eventually increase their populations and adversely affect the benefits otherwise obtained from these modifications of plants (Zhao, et al., 2011). Ecological evolution and change may also occur in natural organisms to take advantage of new niches opened up by the presence of genetically modified organisms.

2.3 Genetic modification can involve trade-off between attributes

In genetically modifying an organism in order to increase its fitness for a particular purpose, there is a risk that other relevant traits will be weakened and become negative. The overall fitness of the organism may even decline. This view is similar to that of Marion Dawkins (1986) which she expresses in a different context. These trade-offs are not always anticipated by scientists. For example, Liu (2009) has reported that exudates from Bt cotton roots in China increase the susceptibility of some varieties of that cotton to cotton blast, a fungal disease. The incidence of this disease has increased and is causing a substantial decline in cotton yields in China. This trait of Bt cotton was not predicted by scientists.

A Chinese scientist (Lu, 2009) has also reported that China has genetically modified some species of poplar trees to reduce their lignin content. Their lowered lignin content reduces the cost of processing these trees for paper production. But the lower lignin content makes the trees more prone to damage by wind and increases their susceptibility to some pests. Furthermore, it has been found the development of Bt poplars to control attacks by one species of beetle has made them more vulnerable to attack by another species of beetle (Lu, 2009). Thus, there is evidence that the development of organisms by genetic engineering to improve one or more attributes of an organism often does so at the expense of other desirable attributes.

Some of the trade-offs resulting from genetic modification appear to be predictable but others are uncertain and can come as a surprise. When such a trade-off is unavoidable, there is an associated economic problem in the case of commercially utilised organisms, namely to ensure that the engineered genetic combination gives the greatest net economic benefit in relation to the attainable set of genetic combinations. However, making this optimal economic decision is complicated by the presence of uncertainty. Consequently, there is difficulty in predicting accurately the possible trade-off of the relevant attributes. Furthermore, social decision-making under risk and uncertainty is complex because of heterogeneous attitudes to risk-taking in society. Furthermore, the sustainability of the attributes of the GMO needs to be considered because as a result of evolutionary, ecological and other factors, the desired attributes of a GMO may be eroded with the passage of time. These dynamic considerations further complicate the economics of genetic manipulation and add to uncertainty. A simple economic conceptualisation of the economic trade-off problem involved in genetic engineering and associated issues is given in Tisdell (2009b, pp. 344-348).

2.4 Changes in interspecies competition as a possible negative consequence of GMOs

Two mechanisms have been mentioned that can result in the fitness of GMOs being undermined. These are the erosion of desirable attributes with the passage of time and the need to trade-off traits. Another factor that can reduce the economic suitability of GMOs is that their presence may improve the competitiveness of competing species some of which may be regarded as pests. The case of Bt poplars has already been mentioned. Another case involves herbicide-resistant GM rice developed experimentally in China. It has been found that it is prone to cross-fertilise with wild rice which is regarded as a weed in rice crops (Lu and Fu, 2009). Because there is less rural labour available for weeding by hand in China due to the rural-to-urban migration drift, the increased resistance of GM wild rice to herbicide could become a serious economic problem if herbicide-resistant GM rice becomes available for commercial use.

2.5 Selective breeding is less risky than genetic engineering

Note the above-mentioned evolutionary and ecological changes can also occur when a new variety of organism is introduced by selective breeding, that is the natural ecological disturbances mentioned can occur plus those induced by economic change (Tisdell, 2003b; Wolfenbarger and Phifer, 2000). However, it is usually believed that such changes will be smaller and slower when selective breeding is adopted for genetic development than is potentially possible when new GMOs are introduced. Hence, the ecological risks and uncertainties associated with the introduction of GMOs are normally considered much higher than is the use of selective breeding. For example, Wolfenbarger and Phifer (2000) state in their conclusions: "Traditional breeding is limited by the available genetic variability in the target organism on its relatives. The great potential, as well as risk, of genetic engineering is that it removes those limits, providing a greater range of possibilities for transforming desired phenotypes into organisms". It might be noted that the introduction of hybrids that are unable to reproduce themselves pose a smaller ecological risk than GMOs that can reproduce. However, the introduction of these hybrids can lead to the extension of agricultural land-use and its intensification and thereby, indirectly reduce biodiversity.

3. Risks, Uncertainty and Decisions About Introducing Agricultural GMOs

Rational decisions about the development and use of GMOs are complicated by the fact that their biological and ecological consequences are usually subject to considerable uncertainty. In turn, this adds to the difficulty of estimating their social and economic impacts accurately; a difficulty that is compounded by the fact that their environmental impacts are not confined to the adopter of a GMO. Environmental spillovers or externalities from the use of GMOs create hazards (risk of losses) for non-users as has been well documented (Batie, 2003; Batie and Ervin, 2001; Ervin, et al., 2003). Consequently, all these factors have resulted in considerable discussion of optimal procedures for the introduction of GMOs and their regulation (see, for example, Just, Alston, et al., 2006). Questions debated include the following:

- To what extent and how should precaution be exercised before allowing a GMO to be used?
- In turn, this necessitates a decision about the appropriate social criterion to use in making this decision.
- To what extent should legal liability be used to improve the social desirability of choices about the development and use of GMOs?

Only brief comments on these aspects are required because of their extensive coverage in the relevant literature.

3.1 Exercising caution

Views differ about how much caution (care) should be exercised before a new agricultural GMO is released and about the nature of restrictions that should be put on its use. For example, Zilberman (2006) suggests that nature and extent of the precautions legally required in the United States before a new GMO can be released are excessive from an economic point of view, whereas others such as Batie and Ervin (2001) and Batie (2003) and Ervin et al. (2003) argue that greater precaution should be exercised in the regulation of biotechnology in the United States. Ervin et al. (2003, p.8) state: "A rebalancing of US regulation to focus more on controlling type II errors appears prudent given the small amount of science to inform biosafety regulation". According to these authors, biosafety regulation in the US gives too much weight to type I errors, that is the likelihood of rejecting the hypothesis that a new GMO has no serious adverse environmental consequences, when it in fact does have these consequences. A type II error involves the opposite mistake.

A useful way to think about the problem is to consider how much information should be collected about the possible environmental consequences of a GMO before it is released. The process of collecting existing information (by experimentation and so on) involves an extra cost and this has to be weighed against the extra benefits obtained. Baumol and Quandt (1964) contend that from an economic perspective the collection of information should only proceed to the point where the extra cost of its provision equals its extra expected benefit. However, a problem is that the extra expected benefit from extra search is often very uncertain, especially in the case of new GMOs. Thus, it is not clear in advance how much search is a desirable precaution.

Furthermore, not everyone will be interested only in **expected** benefits, that is benefit on average. Many will be concerned about the range of possibilities, including the worst potential outcome from the adoption of a GMO. Attitudes to risk-bearing will need to be taken into account and within society, these are heterogeneous.

It has been suggested that the precautionary principle could be usefully applied in decision-making about the introduction of GMOs. However, there are many different interpretations of this principle, some of these are problematic (Tisdell, 2010). Moreover they are mostly not very specific. Nevertheless, as a rule, other things being held constant, it is rational to take greater care (exercise more precaution) in making decisions about the release of GMOs when the changes set in train are irreversible or can only be reversed at a substantial cost (see, for example, Tisdell, 1970). However, it might happen sometimes that the introduction of a GMO create no irreversible environmental change, for example, if it is withdrawn sufficiently quickly after its initial introduction. Individual cases need to be assessed. However sight should not be lost of the fact that unfavourable changes in biodiversity from the introduction of GMOs can have serious adverse economic consequences for future generations (Tisdell, 2011a).

3.2 The appropriate social criterion

The adoption of new GMOs is likely to result in some members of society gaining and others losing: losing for example, as a result of adverse environmental spillovers. Zilberman (2006) suggests that this is likely in most cases where technological change occurs. Where economic changes bring gains to some members of society and losses to others, some economists suggest that the potential Paretian improvement (Kaldor-Hicks) criterion should be adopted to decide if the change is socially advantageous. The change is judged to be socially advantageous if the gainers could compensate the losers and be better off than before the change. Posner (1971) has advocated use of this principle as a guide to just laws (Tisdell, 2011b)

However, this criterion ignores income distribution. Furthermore, in the case of GMOs, it is not always clear in advance of their introduction and use (and it may be so for a considerable period of time after their release) whether the gains of some are sufficient to more than compensate the losers. Because of the uncertainties about the performance of GMOs, the introduction of some may cause a net social loss to society. What criterion should society adopt when this is possible? This is unresolved.

3.3 Legal liability

One way in which society may try to cope with the uncertainties associated with the development and use of GMOs is to make their developers and users legally liable for the adverse consequences of their introduction. The question then arises of whether that liability should be strict or should only apply if there is inadequate exercise of a duty of care (Tisdell, 1983). If strict liability applies, it will make for greater caution on the part of the developers and users of GMOs. But if the burden of proof is on the plaintiffs, it may be difficult and costly to succeed in bringing a case (even a class action) for damages. If liability is not strict but relies on the exercise of the duty of care, the extent to which a duty of care has been exercised is open to debate. Thus legal liability alone seems insufficient to protect society against all damages that might be inflicted by the use of a potentially damaging GMO. Furthermore, the maximum compensation that can be paid by those responsible for torts is limited by the amount of their available assets. These may fall well short of the amount of compensation required and in some instances, monetary payment to victims may be deemed insufficient to compensate them for damages.

4. Economics of Developing and Marketing GMOs

4.1 General influences of economic factors on the nature of development and marketing of GMOs

In addition to the ecological risks faced by nature and society at large, high costs and considerable business risks are involved in developing GMOs. Therefore, when their development is left to private enterprise, only large firms usually engage in this activity. Furthermore, if businesses are to have an economic incentive to develop new GMOs, then they must be assured of intellectual property rights. Patents are used in many countries for this purpose.

However, it is important to note that patent laws and regulations covering the granting of patents in relation to GMOs are not the same in all countries. For example, in China, patents are granted on the techniques for producing specific GMOs but not on the products produced as a result of the availability of those techniques (Greenpeace China and Third World Network, 2008). For example, a patent would be granted in China on techniques to produce a Bt modified plant but not in seed which transmits this genetic trait. However, in the United States both techniques for producing genetically modified organisms and the products produced as a result of applying these techniques are protected by patent law. The economic analysis of GMOs that follows is based on the assumption of strong and extensive patent laws of the type adopted in the United States.

Patents grant a monopoly to the patentee to use the patented invention for a specific number of years. During this period, the inventor has a monopoly in the use of the invention, in this case a new GMO. A business that has a patent for a GMO may, therefore, engage in monopoly–pricing of its use. This is not socially ideal (Tisdell and Hartley, 2008, pp. 36-37, Ch. 8). However, it is necessary for the inventor to be sufficiently rewarded for his/her inventiveness. Otherwise, there is no private economic incentive to engage in R& D effort. This is particularly important bearing in mind that not all research efforts are successful in developing an economically viable new product. Furthermore, the patent is only for a limited period of time and there is no guarantee that some other firm will not develop a commercially superior competitive GMO within this period. This will limit the profit possibilities available to the original patentee.

In addition, the level of the monopoly price of say GM seed will be influenced by the price of competitive traditional seed and by farmers' net profits when using this seed (Tisdell, 2005, p.221). This constrains the price which the owner of GM seed will find it profitable to charge. In some instances, however, the GMO-monopolist may deliberately charge a low price initially for the use of its GMO to encourage its adoption and eliminate the use of competing traditional organisms. This predatory behaviour can eliminate competing traditional varieties of a crop and can be a prelude to higher monopoly prices for the GMO (Tisdell, 2005, p.222).

The legal costs of protecting patented GMOs against infringements of rights can be high. Once again, this tends to favour large firms as developers of GMOs, as does the high cost of obtaining approval for their release.

The establishment of legal property rights in new GMOs is only part of the economics of developing and marketing them. The transaction costs of marketing some GMOs (for example GM seed) are high because considerable effort is required to ensure that the buyers do not re-use or sell any GM seed they produce without permission. This adds to the cost of drawing up contracts with clients, there are costs incurred by sellers in monitoring the use of GMOs by buyers to ensure compliance with agreements, and there may be considerable legal costs if breach of contract occurs. Similar costs do not arise in the case of hybrids.

These transaction costs favour the marketing of GMOs by large companies. They also favour their sale to larger-sized agricultural and related enterprises because market transaction costs per unit of the GMO sold tends to decline with the value of sales to an individual production unit.

Taking into account potential economic gains and transaction costs, there is an economic incentive to develop GMOs that are likely to be adopted by large-scale commercial farming enterprises, particularly in higher income countries. Furthermore, organisms (for example, crops) for which there is a large volume of demand are likely to the favoured, other things equal. Private businesses have little incentive (at least, initially) to develop GMOs to suit farming involving small-scale units or semi-subsistence. Therefore, crops which are important in LDCs (but not in higher income countries) are unlikely to be initially targeted by private enterprises for the development of GMOs unless they are plantation crops, possibly involving foreign investment. Figure 2 provides an overview of predicted patterns of development of GMOs by private enterprises when economic considerations are taken into account.

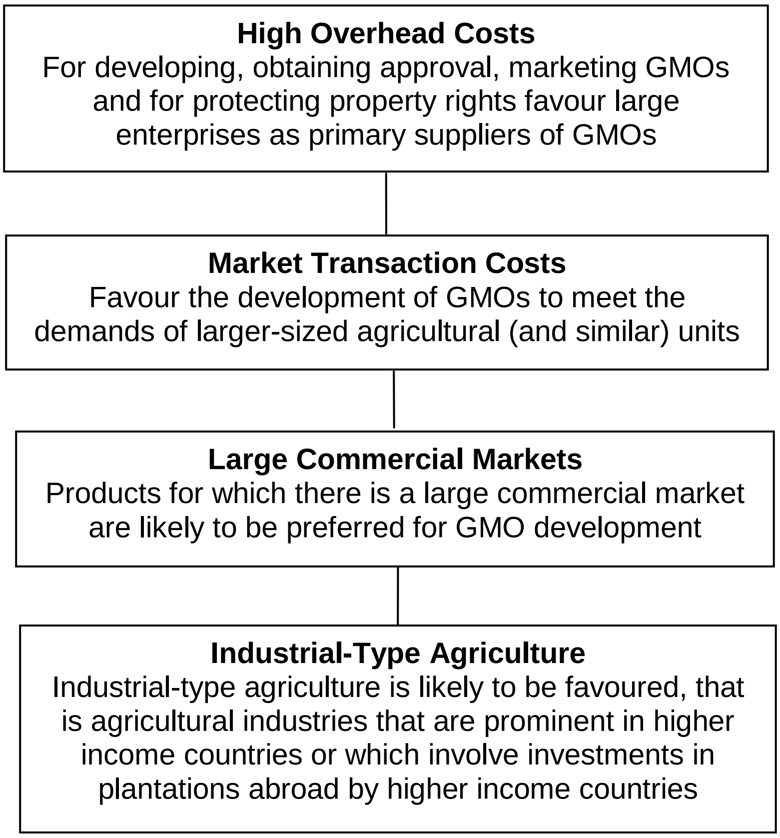

Figure 2: A chart showing predicted 'biased' patterns of development of GMOs by private enterprises due to economic considerations.

The view that the type of biases indicated in Figure 2 exist in the development and use of GMOs has been previously expressed by Batie and Ervin (2001). They state: "Theory and empirical evidence suggest that there are significant incentives for private firms to discount and neglect certain environmental impacts and develop products to meet mainly the needs of those able and willing to pay". They argue that the development of GMOs is largely 'technology push' driven and that private firms in undertaking this development are unlikely to promote the social good because of missing markets (market failures). Although the developers of GMOs have to market and push their sales to would-be users who have no previous knowledge or experience with them, the economic incentives for their development is basically driven by (latent) private demand for their use and depends on prospective private economic returns, as is clear from the theory outlined below. Therefore, if Batie and Envin's view is that advances in biotechnology are basically supply-driven, it does not seem to be correct.

Observe that while new GMOs are more likely to be developed in higher income countries (such as the USA) for the use of their farmers than in lower income countries, diffusion to less developed countries occurs. The economic theory of price discrimination suggests that a firm with a global monopoly in a GMO is likely to charge a lower price to users in markets where demand is lower and more elastic (developing countries?) than in markets where demand is higher and more inelastic (higher income countries). In addition, fewer precautionary measures may be required in the use of the GMO in a less developed country than in higher income countries. This adds to the commercial attractiveness of GMO markets in developing countries in the beginning but is likely to accelerate the erosion of their economic value with the passage of time. The issues involved are worthy of study.

The possibility of biases in the development of biotechnology has already been noted in the relevant economic literature. For example, Just, Zilberman and Alston (2006, p.7) argue that large-crop, large-country bias exists in the development of GMOs. They state (p.7) that "the reason is that biotech firms require a large potential market to justify the large overhead costs of regulatory compliance in addition to research and development (Alston, 2004; Bradford, et al., 2006)"

However, the strength of this bias is likely to weaken with the passage of time. With the passing of time, development of GMOs for smaller markets can become profitable. This is because much of the knowledge obtained in initially creating genetically modified agricultural organisms (e.g. crops) of a particular type can often be transferred to different organisms and markets. The extra cost of the research and development required to do this (for instance, insert the Bt gene construct into a new type of crop) is reduced as a result of learning-by-doing, which of course, takes time.

4.2 Support from economic theory for the above propositions

Support for several of the propositions summarised in Figure 2 about likely patterns of development and use of GMOs is provided by the application of basic economic theory. In order to show this, assume that the GM product is GM seed and consider the proposition that, other things being equal, the economic incentive to develop such seed is greater the larger is the expected size of the market for it. For simplicity, assume that the successful development of the GM seed will establish a monopoly for it.

In Figure 3, line BD_1 represents the demand for the GM seed if the market is small and the line D_2D_2 represents the demand for it if its market is larger. The average operating cost of supplying the GM seed once it has been developed is assumed to be a constant OA and therefore, line AC represents the average variable cost of its supply. The line BMR is the marginal revenue line corresponding to the demand relationship BD_1. Hence, when demand is at level BD_1, the maximum operating profit of the producer of patented GM seed is equivalent to the area of rectangle $AFJP_1$. There is a mark-up on average operating costs for each unit of seed sold of AP_1. If this margin is retained when the demand for the seed is much higher at D_2D_2, operating profit increases substantially. It rises by an amount equal to the area of rectangle FGHJ, that is by an amount equivalent to $(X_2 - X_1)(P_1 - A)$. Therefore, the economic advantages of a larger-sized market are apparent.

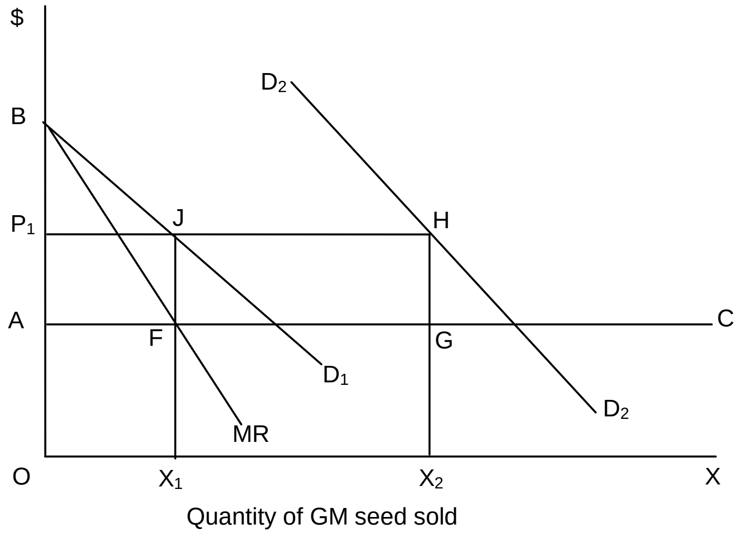

Figure 3 An illustration of the proposition that the larger is the size of the expected market for a GMO, the greater is the profitability of developing it, other things held constant.

Observe also that if there are high overhead costs to be recovered (for example, the costs of the R&D invested in the creation of the GMO), this will also favour markets of larger size. When overhead costs are taken into account, the average total cost of supplying a new type of GM seed might be as indicated by the declining curve marked RST in Figure 4. Line BD_1 represents the demand for the GM seed if the market is relatively small and D_2D_2 represents demand if the market is larger. Because of the overhead costs involved, the development of GM seed for the smaller-sized market is unprofitable but it is profitable for the larger-sized market, other things being equal.

The presence of high overhead costs (and patents) with significant barriers to entry into the agricultural biotechnology industry fosters market concentration. High overhead costs include the costs of obtaining approval for the release and use of new GMOs. An additional ‘overhead’ cost in many countries (such as the United States) is the cost of political lobbying and engaging in publicity campaigns to counter opposition by some public interest groups (environmentalists, some types of consumers) to the release of GMOs. Heisey and Schimmelpfennig (2006, p. 421) found that in the United States “for large agricultural biotechnology firms, there is a rough positive relationship between firms’ R & D or net sales and the amounts they devote to the lobbying and campaign contributions”. These costs can reduce the private economic attractiveness of investment in the development of GMOs in high income countries.

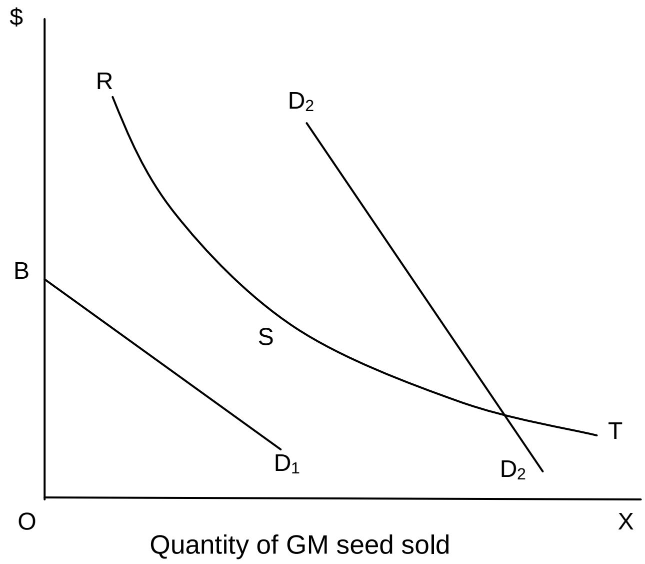

Figure 4: An illustration of the proposition that when overhead costs are large (as they are likely to be for the development and marketing of GM seed) the development of a GMO to satisfy smaller-sized markets is unlikely to be profitable.

When the demand for using an organism is relatively inelastic, this can increase the profitability of developing a GMO, other things being held constant. The more inelastic is the demand for a resource, the higher is the monopoly price that can be secured by monopolist from it and the greater are the profits from its supply, other things being equal. This is illustrated in Figure 5. If demand for GM seed corresponds in this diagram to BD_1, then making the same assumptions as previously made for Figure 3, the patentee's monopoly price is P_1 and his/her profit is equal to the area of rectangle $AFJP_1$. Should, however, the demand curve for the GM seed be steeper, as for example indicated by the line D_2D_2, the profit-maximizing monopoly price will be higher. In the case illustrated it is P_2. Consequently, operating profit from selling the GMO rises by an amount equivalent to the area of rectangle P_1JKP_2. The steeper or more inelastic the demand curve, the greater is the monopoly profit. Hence, if the size of the market for GM seed is large and the demand for it is relatively inelastic, this provides a strong economic incentive for the development of GM seed.

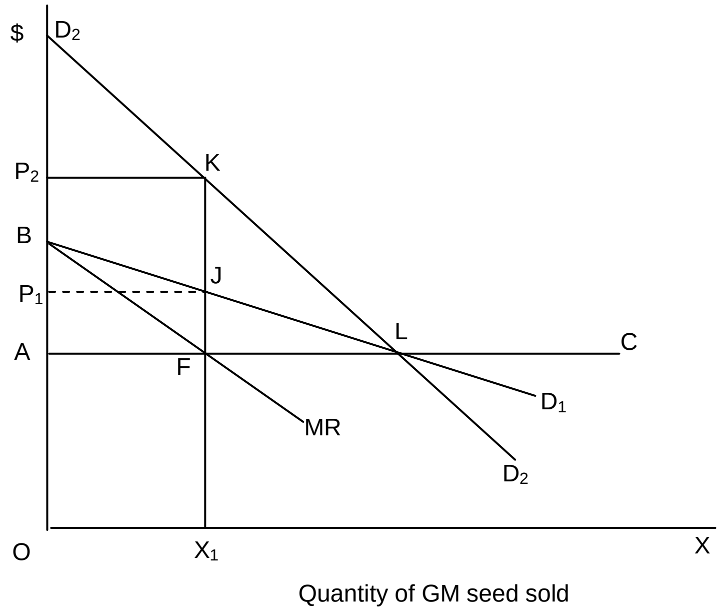

Figure 5: An illustration of the proposition that other things held equal, the profitability of developing a new GMO is greater the more inelastic is the predicted demand for it.

Note that in Figure 5, the marginal revenue line (not shown) corresponding to D_2D_2 passes through point F as does that for BD_1. This is because in the linear case, the decline in the marginal revenue line occurs at twice the rate of the decline of the average revenue line (equals the demand relationship) which implies that the distance of the average revenue line form the vertical axis is twice that of the marginal revenue line. Because the two demand lines are equal at L, the corresponding marginal revenue lines must also intersect at F, and the distance AF = FL. Observe also that if the demand curves shown were for two separate markets, the monopolist would find it profitable to engage in price discrimination. It would be most profitable to charge a low price, P_1, in one market and a high price of P_2 in the other market where demand is more inelastic. This suggests the price charged for GM seed is likely to be higher in a high income country than in one with lower income. Of course, the reason for doing this has little or nothing to do with the pursuit of social justice but is motivated by profit maximisation.

It was argued above that sellers of GMOs are likely to find it more profitable to sell to large-scale farms than smaller ones. This is based on the view the average transaction costs involve in sales are likely to fall as the quantity sold to any production unit rises.

This is illustrated by Figure 6. In Figure 6, line AFC represents the average production cost of the supplier of GM seed and curve HJK represents the average total cost of supplying GM seed to a farming unit. The difference between line AFC and curve HJK represents the level of average marketing transaction costs involved in selling GM seed to a farm. Suppose that the seller of GM seed sells it at P_1 per unit. Then it is unprofitable to sell GM seed to farms that wish to buy less than x_1 of it. For those farms wanting to buy more than x_1 of seed, the profit of the seller rises with the amount sold to a farm. Hence, the hypothesis stated above that developers of GMOs favour developing these for industries in which large commercial farms exist is supported.

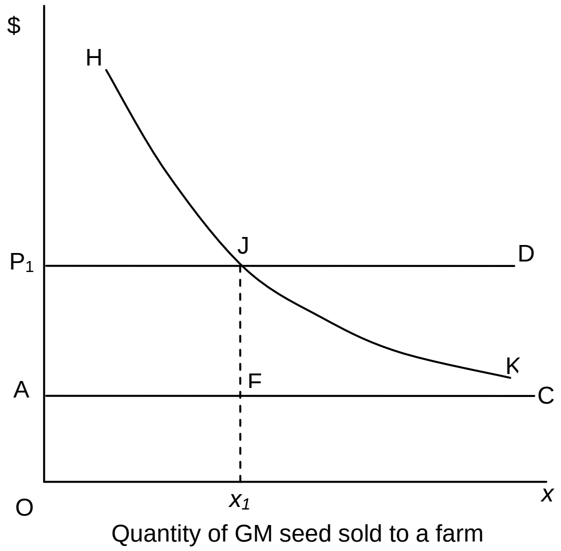

Figure 6: An illustration of the proposition that developers of GM seed are likely to find it more profitable to sell it to large commercial farms than small farms. In the case illustrated, it is unprofitable for the seller to sell to a farm which buys less than x_1 of seed.

If marketing transaction costs of the supplier of GM seed includes monitoring costs of their use incurred either voluntarily in pursuit of their own self-interest or as a result of legal obligations (checking on the presence of refuges, barriers to pollen drift), the level of these costs may vary by the types of economy in which GM seed is released. These costs might, for example be lower in developing countries in which case smaller agricultural producers might be accessed particularly if patent-holder's use of agents to distribute GM seed in developing countries involves reduced market transaction costs. In fact, large corporations involved in the sale and development of GMO crops (such as Syngenta and Monsanto) prefer to license the production and commercialisation of their technology in developing countries to a local company. Furthermore, less demanding biosafety rules (and or less ability to enforce rules) for farm use of GM seed in developing countries will tend to initially raise the demand by their farmers for GM seed, including those on smaller-sized farms. However, as a result of accelerated environmental deterioration (e.g. faster erosion of the value of the genetic composition of the GMO), this demand may not be sustained for a long period of time.

5. Other Socioeconomic Factors Relevant to the Introduction of GMOs

5.1 Patent walls

Use of the patent system by creators of new GMOs can be used in special cases to create patent walls. This involves the use of a range of unilateral patents which make it difficult for others to make progress in developing new GMOs without infringing on the rights of existing patents. This creates barriers to the entry of potential competitors to existing suppliers of GMOs, reduces market competition and favours market concentration. In turn, this can slow technological progress (see, for example, Tisdell, 1999) .

Furthermore, some LDCs believe that such a situation is likely to be unfair to them since they are likely to be restricted in their future options of developing GMOs by the existence of patented GMOs, many of which are based on the modification of genetic material originally obtained from them e.g. soya beans (Xue, et al., 2004). A further bone of contention is that in many cases, no compensation is paid to our LDC for use of the original genetic material used the presence of which was essential for the creation of the GMO. The issue of whether compensation should be paid for the use of such material is, however, complex from an economic point of view. From a global development and economic welfare point of view it can be argued that payment for the use of extant genetic material of this type is only justified in special circumstances

(Tisdell, 2009a) The matter is complicated for example, by the fact that some LDC make extensive use of genetic material derived from other LDCs (for instance, tomatoes and potatoes) and they also use genetic material that has come from countries that are now higher income countries, for example some types of maize from the United States.

5.2 Lack of co-evolution

GMOs are usually developed in experimental conditions divorced from local conditions. Whereas most other methods of genetic change involve slow and gradual changes in genetic material, creation of GMOs can result in rapid and large shifts in the composition of genetic material. Therefore, the creation of GMOs is considered to be relatively hazardous. Change may not be gradualistic, scope for learning by trial-and-error may be reduced and the potential for irreversible consequences are seen as heightening the risk of releasing GMOs. Hence, there are considerable concerns about biosafety risks associated with the introduction of GMOs.

A further potential problem is the lack of social and ecological co-evolution which can arise when new GMOs are released. Some writers, such as Norgaard (1994) regard lack of co-evolution to be undesirable. In the past, the social practices of many local communities evolved in step with changes in their agricultural and other productive practices, thus balance and social harmony existed between local communities and changes in production methods. In modern times, however, this harmony is destroyed by rapid changes in production methods and in types of production (Tisdell, 2003a, Ch. 19). The result in increasing stress for individuals and social dislocation. The introduction of GMOs potentially adds to this lack of co-evolution. Lack of co-evolution seems to be symptomatic of modern economic systems.

Social changes and variations in productive forces are interdependent, as observed by Marx (1930). The social desirability of such changes is always difficult to evaluate. For example, are the social changes that occur desirable or undesirable? If they are undesirable, does the increase in the availability of economic commodities as a result of the introduction of new techniques, e.g. GMOs, more than compensate for the undesirability of the social changes that are generated? Scientific answers to such questions based on positivism are not available but consideration of these questions should not be avoided even though they are beyond the scope of economics when it is defined narrowly.

5.3 Social conflicts about the use of GMOs, and knowledge imperfections

The use of GMOs frequently creates social conflict. For example, some social groups are fearful of their possible biological consequences, including their possible long-term impacts or health. Some buyers of produce wish to avoid products, particularly food products, that contain GMOs. This can result in some GM products selling at a reduced price compared to similar non-GMO products. This contributes in part to the occurrence of conflicts between growers of non-GMO crops and those cultivating GM crops.

Two problems can occur:

(1) cross pollination may occur between some GM and non-GM crops and

(2) if it is unclear to buyers what produce is based on GMOs and which is not, they may become suspicious of crops for which both GM and non-CM varieties exist and reduce their demand for these crops.

There is a problem of asymmetric information between sellers and buyers in this case (Akerlof, 1970; Varian, 2006, Ch. 37). In this case, sellers know the nature of the product but consumers are unable to determine this just from inspection of the product. Consequently, there is scope for fraud by sellers. In extreme cases, this leads to the collapse of the whole market and in many cases results in reduced demand for some types of the marketed product. For example, in the case being considered here, it could result in the demand for produce which is claimed to be GM-free declining. Certification schemes can, however, help to reduce the problem and laws may be strengthened to require accurate disclosure of the nature of the goods being traded, that is whether they are GM-free or not.

A related problem is that many farmers have little or no knowledge about GMOs. Zhao et al. (2011, p. 994-995) reported on the basis of their survey in China that "farmers have virtually no knowledge about Bt cotton and genetic engineering. A low level of understanding implies that farmers have virtually no means to interpret possible agricultural production problems that they might encounter in the field."

In order to reduce the problem of possible cross pollination of GM crops and non-GM crops, they may be located in areas that are spatially well separated. For some crops which depend on drifts of pollen in the wind for pollination, border hedges may be required to lower the likelihood of pollen-drift. But as one reviewer stressed, this does not give complete protection. Furthermore, it is pertinent to note the following in relation to GMOs: "Currently, insect resistance management advises a strategy that combines a high-dose exposure to toxin interspersed with planting refuges, areas without the transgenic crop, to minimize the spread of resistance of a population. Evidence indicates that a properly implemented refuge strategy can slow the rate of existence evolution but does not prevent it." (Wolfenbarger and Phifer, 2000)

Batie and Ervin (2001) argue that in the context of GMO introduction and use, major reasons for social conflict and failures to make wise social choices are missing information and missing market. It is certainly true that these factors can add to social conflict. However, even with perfect information and perfect markets, social conflict is still likely to occur when new biotechnologies are introduced because as a rule there are gainers and losers in society (Just, Zilberman, et al., 2006, p.4).

Legal liability for the use of GMOs is an issue. For example, to what extent should developers of GMOs be liable for any environmental damages caused by their use? To what extent should farmers who use GMOs be responsible for any environmental damages caused by their use?

The socially appropriate extent of legal liability is difficult to determine. Strict liability for damages caused by a GMO will reduce economic incentives to develop and use them. The consequence could be loss of substantial economic benefits. Questions requiring consideration include how wide ranging should legal liability for damages be, should it be capped, should a developer be absolved from legal liability if the government approves a GMO for use and to what extent should liability be reduced by the fact that its developer acts with care (see Tisdell, 1993, Ch. 5). It seems that as the level of income in countries rises that their preferences tend to shift from limited legal liability for possible damages caused by new products towards strict liability.

The conferral of legal rights is one thing and enforcing them is another. Costs and other difficulties are involved in enforcing laws or taking advantage of the law. The costs sometimes exceed the expected benefits of legal action and actions are frequently uncertain. Legal solutions frequently entail high transaction costs.

The question of the adequacy of proof and the one of burden of proof on parties affects the economics of pursuing legal action. If for example, a non-GMO crop is "contaminated" by a GM crop, it may be difficult to prove which farm(s) using GMs is (are) responsible. In Germany, this has resulted in laws being passed which make all growers of related GM crops in the locality legally responsible to contribute collectively to compensation. This means that the plaintiff does not have to identify the particular farm(s) that was (were) the sources of the "contamination".

The stage at which it is socially optimal to release a GMO after the development and testing of it is difficult to determine. This is because even after considerable testing, some environmental impacts may be uncertain. Further delay may reduce those uncertainties but if the economic benefits from using the GMO seem to be substantial, delay involves considerable opportunity costs. It is usually too costly to wait for the release of a new economically promising GMO until virtually no doubts remain about its environmental impacts. Community standards and expectations have to be taken into account in deciding on the appropriate time at which to release a new GMO.

6. Concluding Comments

Planning for sustainable development is complex when this development depends on the introduction of new techniques having uncertain and potentially irreversible effects as is the case for some new biotechnologies, particularly those relying on new

GMOs. As shown in this chapter, ecological, economic and social factors associated with the adoption of GMOs all have to be taken into account in assessing the prospects for the sustainable use of GMOs and whether they are likely to permanently increase economic production and human welfare. Social agreement is lacking about what rules should be adopted in allowing the adoption of GMOs and particularly about how much and what type of precaution should be taking before permitting the use of GMOs. It may, indeed, not be possible to achieve social unanimity about this. Nevertheless, consideration of the economic, ecological and social effects identified in this chapter as resulting from the introduction of GMOs should enable more informed decisions to be made about their impacts on sustainable development. This should assist policy-makers in planning the role that GMOs should ply in their plans for sustainable development. Policy-makers need to be aware that the introduction of GMOs do not provide a miraculous means to achieve sustainable development and may even in some areas, threaten its achievement.

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