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9. Socioeconomic considerations relevant to the sustainable development, use and control of genetically modified foods

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9.1. Introduction

The rapid adoption of genetically modified (GM) organisms (GMOs) in agriculture has raised several concerns regarding not only ecological but also the economic and social aspects of their effects. In this chapter, such generic concerns about GMOs are reviewed with reference to sustainable agriculture and rural development (SARD). It is suggested that current GMOs have both positive and negative effects on three indicators of the SARD, namely capital stocks, efficiency and equity. These conflicting effects depend on the socioeconomic conditions of development, use and control of GMOs, in which characteristics of a GM variety are shaped. Particularly, the influences of three problematic policy options, that is intellectual property protection, trade liberalization and biosafety implementation, are examined. Finally, intricate interactions of these policies are discussed.

There have been a variety of concerns about GMOs in agriculture, in general, apart from the issues pertinent to human health and nutrition, discussed in this special issue. These include negative impacts of GMOs on the natural environment, economic viability and maintenance of social networks in both developed and developing countries.

While the use of a number of GMOs promises to reduce the adverse effects of modern agriculture on the natural environment by reducing agricultural inputs, concerns for some hypothetical risks have also been addressed and crystallized into the Cartagena Protocol on Biosafety agreed at Montreal in 2000. In contrast to the expected economic advantages, through increased productivity, from the use of recombinant DNA technology for crop development, some critics worry about corporate control over agriculture. Although the productivity gain and labour saving may improve the living standards of rural communities, the emerging market economy in GM seeds might worsen disparities between and within communities. Overall, these controversies are emphasized by a multidimensional concept of SARD, in which the ecological, economic and social strength of future generations must be ensured no less than those of the current generation (Agenda 21: UNCED, 1992). Thus, the major issue is whether the development and use of GMOs are considered to lead to more sustainable agriculture. From another angle, the controversies may stem from different positions and interpretations by diverse stakeholders of the realities and concepts of sustainability.

Given that sustainable development is the key to these debates, the distinction between developed and developing worlds may be important because valuations of the benefits and costs for sustainability are expected to be quite different. Pinstrup-Andersen and Schiøler (2001) even argue “a position against the use of genetic modification in food and agriculture in industrialised

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countries might be perfectly compatible with its promotion in developing countries".

In the developed countries, in which modern agriculture already provides enough food and the agricultural sector accounts for only a small proportion of society, household consumers may value the quantity of food less than the quality and variety of food and the ecological impact of its production. However, in the developed world, farmers and agribusiness who are increasingly confronted with strong competition for exporting feed crops and grains because of trade liberalization, efficiency in terms of agricultural costs, including labour, may play a significant role in the economic dimension of sustainability. Traits of herbicide tolerance and insect resistance of the GM feed crops developed by multinational corporations clearly reflect the need for cost-efficiency by the industrialized agricultural sector. It can be argued that one reason for the controversy about GMOs in the developed world is the discrepancy of interests (such as in risk/benefit and ethical standards) between overseas consumers of final products and the exporting agricultural sector, which is upstream in the global food chain.

On the contrary, in developing societies, where the majority of farmers cannot afford expensive chemical inputs, yield increase rather than cost-efficiency or ecological considerations may be considered a more important aspect of sustainability. Since, in rural communities in developing countries, many in the population usually obtain food from regional markets and earn their livelihood from the agricultural sector, the discrepancies of interests between the supply and demand sides of food production may be far smaller than those in the developed world. Although the introduction of GMOs with improved productivity could be less controversial in developing countries, private corporations do not have market incentives to invest in the research and development (R&D) for improving the yield of locally consumed varieties, especially tropical crops cultivated by poor subsistence farmers.

Each society may have different values assigned to the positive and negative impacts of GMOs on sustainable development. These values in each society may reflect the social infrastructure and conditions in that society—for example, the nature of the public agricultural research system, the intellectual property right (IPR) system, food security, trade dependency, institutions for biosafety, impact on other industrial sectors, political climate, activity of non-governmental organizations (NGOs), cultural habits, and so on. Furthermore, expression of views on these issues takes place not within a country but in the global context. For example, IPR systems and biosafety measures have gradually been harmonized internationally. Globalization of industrial and public research has facilitated local research organizations to access cutting edge technologies. NGOs are also networking globally. These trends make government policies on GMOs a complicated amalgamation of the diverse interests and values of stakeholders, which may not necessarily achieve the desired outcome of sustainable development.

In this review attempts are made to give an analytical framework to illustrate how diverse socioeconomic conditions for development, use and control of GMOs cause different effects on sustainable agriculture, and hence provide the bases for determining appropriate conditions for such purposes. In other words, this review aims to disentangle economic, social and ecological aspects of generic concerns about GMOs, reviewing the literature on socioeconomic and political studies of GMOs in connection with sustainable development.

9.2. Sustainable agriculture in the socioeconomic perspective

9.2.1. Relationship between sustainable development, agriculture and food supply

Given that sustainability denotes the capacity of a system to maintain the input–output ratio at a level approximately equal to or greater than its historical average (Lynam & Herdt, 1989), sustainable development of a society does not necessarily entail sustainability of the agricultural sector of that society. Sustaining shares of different sectors may sometimes result in a stagnant rather than a dynamically evolving society. In the same way, sustainable food supply does not inevitably require maintaining or increasing agricultural production inside the boundaries of a country. Neoclassical economists might argue that trade liberalisation of agricultural products, according to the principle of comparative advantage, can afford enough traded food with a lower price and higher efficiency of production (e.g., Runge & Senauer, 2000), through which the food production on a global-scale should increase.

However, the original concept of sustainable development implies the maintenance of natural resources and the biophysical environment on which agriculture heavily depends. Conditions for agricultural sustainability should be uniquely important for a sustainable society, even if the relative contribution of the agricultural sector to gross domestic products (GDP) becomes less significant. Besides, the principle of comparative advantage, in which the production of certain goods becomes specialized, cannot be entirely relied upon. This is not only because the trading of considerable numbers of agricultural products is still protected from trade liberalization, but also because greater specialisation of agricultural products in the less diversified poorer countries may pose greater uncertainties in sustainability of natural resources, environment and food security (Dragun, 1999). Furthermore, the fact that serious food insecurity persists in many parts of the developing world, in spite of increased food production on a global scale, strongly suggests that the trade-based solution should be limited and reinforces the importance of local agriculture.

For these reasons, discussions below consider agricultural sustainability in a given local unit as one of the key preconditions for sustainable development in the whole world. The units vary from a rural community to a whole country, depending on the situation. Hence, the primary discussion on GMOs in the following sections focuses on the maintenance and improvement of diversified agricultural production, natural resource management and food supply at local level. Yet, it should be noted that an overall increase of agricultural productivity at the global level, with improved trade conditions, could also play a vital role in food security in countries with limited natural resources (for example, a small island, which is a developing state).[1]

9.2.2. Multidimensional concept of sustainable agriculture and the role of technology

At the Rio Earth Summit in 1992, the concept of SARD was specified in Chapter 14 of Agenda 21 (UNCED, 1992). The multidimensional objective of SARD involves "education initiatives, utilisation of economic incentives and development of appropriate and new technologies, thus ensuring stable supplies of nutritionally adequate food, access to those supplies by vulnerable groups, and production for markets; employment and income generation to alleviate poverty; and natural resource management and environmental protection".

A number of efforts have been made to construct frameworks to measure and estimate sustainable development.[1,2] One such framework for measuring SARD was demonstrated recently by the European Commission. It has addressed the economic, social and ecological dimensions of sustainability for maintaining a certain level of capital stocks (natural and man-made capital) and achieving efficiency and equity (European Commission, 2001). Although capital stocks include the economic and social in addition to environmental assets, efficiency predominantly relates to the economic dimension and equity relates to the social dimension. Placing emphasis on efficiency and equity may allow the changes in the economic and social functions and their stocks to be addressed dynamically. It may also allow the dilemmas between present economic viability and environmental deterioration in the future (inter-generational equity) and between sustainable agricultural policies for 'north' and 'south' (intra-generational equity) to be confronted. Based on this consideration, appropriate technologies can be evaluated by considering how the technology affects the three indicators, namely capital stocks, efficiency and equity.

Capital stocks comprise combinations of two forms of capital: N, natural resources/environmental capital, and K, man-made capital (Tisdell, 1999). The man-made capital is the produced means of further production, which includes man-made physical capital (e.g., machines, facilities), human capital (education, knowledge) and social capital (governance, institutions and cultural capital). K and N, as well as different forms of K can substitute each other from one perspective, which is called 'weak sustainability'. For example, fewer natural resources might be considered acceptable, if the lower quantity is offset by equivalent man-made capital. Assuming that the income possibilities for future generations are a function of the ratio of man-made capital to natural resource (K/N), weak sustainability advocates consider that higher K/N simply leads to larger income possibilities.

On the other hand, as 'strong sustainability' implies indispensability of certain levels of natural resources, the effect of substitution between different forms of stocks should have a limit (Pearce, 1993). In this case too, high K/N as well as low N could curtail future possibilities for human well-being. This suggests that there is an optimal K/N value and that the ratio may differ between societies. Tisdell (1999) argues that the optimal K/N value for China might be lower than for Europe, though the current K/N for China may be less than its optimum whereas that for Europe might be in the region of its optimum, given the different histories involved. Technological change has also been one of the driving forces for substituting man-made capital for natural resources. In this sense, an appropriate technology should keep K/N value close to the optimal level.

Adoption of a new technology may alter the relationship between the K/N value and future human welfare, as well as the K/N value itself, by diversifying substitutable man-made capitals. If substituting a new man-made capital stock for natural resources leads to more efficiency by, say, increased productivity per unit of land or per unit of input, the optimal K/N value might rise. Hence efficiency, the second indicator of SARD, is an important basis for maintaining natural resource stocks. Efficient agriculture involves not only using such technologies for efficient use of resources but also an efficient economic structure—for example, availability of supplies, a competitive agricultural sector and diverse income sources for farm households (European Com-

[1] FAO (2001) *The Place of Agriculture in Sustainable Development: The Way Forward on SARD* (Item 7 of the Provisional Agenda), Rome, Italy, Food and Agriculture Organization, United Nations, available [January 2003] at http://www.fao.org/DOCREP/MEETING/003/X9179e.HTM.

[2] OECD (2000) *Frameworks to Measure Sustainable Development*. An OECD Expert Workshop (Paris, France, 2–3 September, 199), Paris, Organization for Economic Cooperation and Development, available [January 2003] at http://www.belspo.be/platformisd/Nederlands/documents/oecd-expert_workshop_1999.pdf.

mission, 2001). Only if the agricultural sector is competitive and production factors are sufficiently remunerated, can the sector's production potential be sustained in the long run. Also, maintaining and creating employment opportunities may help efficient resource allocation in rural communities (Agenda 21, 14.25). Accordingly, a technology can be evaluated against efficient use of resources, viable economic structure and sufficient income generation.

Although the original definition of sustainability implies an acceptable level of inter-generational equity, sustainability of a whole society cannot be achieved without intra-generational equity. Thus, equity is a prerequisite for sustainable development, in which all members of all societies in all generations must have equal opportunities for a certain level of welfare established by society (European Commission, 2001). The sustainable use of an agricultural technology depends on its effects on equity, as an expensive technology might broaden socioeconomic disparities. In addition, ethical concerns about agricultural production methods can also be considered as a social dimension of SARD.

9.3. Is genetic manipulation in agriculture a sustainable technology?

9.3.1. Genetic manipulation in general, and GM crops in particular

Characteristics of GMOs may differ depending on the genes introduced into the parent organisms. In view of the multidimensionality of sustainable agriculture, the appropriateness of genetic manipulation of a plant also depends on a number of variables, for example the varieties into which it is introduced, the market, its added value, price and so on. Accordingly, it seems improper to ask whether these methods should lead to more sustainable agriculture or not.

In practice, however, research and development of GMOs for food have been concentrating on a few 'core crops', defined mainly by the actual or potential value of the market for seed (Lindner, 2000). These core crops include soybean, maize, canola, rice, wheat, cotton, tobacco and potato. Traits being introduced to the core crops are also concentrated into a few categories: herbicide tolerance, disease/insect resistance, tolerance to biotic and abiotic stresses, quality improvement and productivity enhancement (James, 2000; Nelson, 2001). Thus, it may be possible, to some extent, to examine how currently available and future GMOs can affect SARD based on the three sets of criteria mentioned above. It should be noted, however, that current R&D have been shaped by historical, socioeconomic and agricultural conditions, and that the examination of the effects of available GMOs on SARD will not come to any conclusions about distinctive characteristics of a particular DNA recombination. In addition, since the basis of the following analysis mainly arises from available empirical data and speculations on GMOs in industrialised countries, further careful consideration may be required for extrapolating the analysis to conditions in the developing world.

9.3.2. Capital stocks: natural resources/environmental capital

Beneficial effects on natural resources/ environmental capital stocks may include:

- amelioration of ecological damage due to the use of pesticides and herbicides by reducing their overall quantity and by replacing them with less toxic chemicals;
- avoidance of soil erosion by introducing no- or low-tillage farming in the case of herbicide tolerant (HT) GMOs; and
- possible reduction or maintenance of land use by achieving productivity gain.

An intensive survey conducted by the US Department of Agriculture (USDA) suggests an overall downward trend in pesticide use per acre, in farms adopting various GMOs from 1996 to 1998 (Heimlich *et al.*, 2000). The magnitude of the decline differs among GM crops because pesticide use generally fluctuates depending on crops, geographic areas, weather conditions, pest pressures and other factors. For example, an increase in the weight per acre of herbicide applied was observed in the case of HT maize, while it diminished by about 10% in the case of HT soybeans. In addition, there is a significant association between adoption of HT soybeans and reduced tillage or no-tillage system in the southeast, the northern plains and the corn belt of the USA (McBride & Brooks, 2000). European corn borer (ECB) infestations to maize vary greatly from year to year and across geographic sites. Adoption of *Bacillus thuringiensis* (*Bt*) maize, resistant to ECB, has been reported, at a rough estimate, to reduce by 2.5% the overall usage of four insecticides recommended for ECB, in the USA from 1995 to 1998.[3] There is a debate, however, about whether the reduction of insecticide with the use of *Bt* maize is significantly beneficial to ecosystems and human health (Obrycki, 2001; Obrycki, Losey, Taylor, & Jesse, 2001; Ortman *et al.*, 2001). In the case of *Bt* cotton, decreased use of insecticide has been observed (see Section 3.3.1).

Improved management of pests and weeds is expected to reduce yield loss. In fact, Gianessi and Carpenter (1999) calculate that for 1997 and 1998 *Bt* maize resis-

[3] Gianessi and Carpenter (1999). *Agricultural Biotechnology: Insect Control Benefit*. Washington, DC: National Center for Food and Agricultural Policy, available [January 2003] at http://www.ncfap.org/.

tant to ECB yielded 960 and 363 l, dry measure, per hectare, respectively (11.1 and 4.2 bushels per acre), more compared with non-*Bt* maize.[4] Assuming an average yield of 11240 l, dry measure, of maize per hectare (130 bushels of maize per acre; 1997/1998), these correspond to 9.0 and 3.2% of yield increase, respectively. However, the expected decline of yield loss from weeds after adopting HT soybeans, has not been so apparent (Fernandez-Cornejo & McBride, 2000). This is partly because the farms adopting them have not chosen to spray herbicides intensively, probably due to the cost-inefficiency of such a strategy (Bullock & Nitsi, 2001a). Data are also available on increased yield and decreased use of chemicals on *Bt* cotton in South Africa (see Section 3.5).

In contrast, indirect negative effects on natural resources and/or environmental capital remain speculative. Potential environmental risks include impacts on non-target organisms, selection of resistant insects and weeds and genetic flow (Batie & Ervin, 2000; Nelson & De Pinto, 2001; Stevens, 2001).

Cry proteins in *Bt* maize are toxic to *Lepidopteran* insects. An initial laboratory-based study demonstrated toxicity of *Bt* pollen to the larvae of the monarch butterfly, *Danaus plexippus* (Losey, Rayer, & Carter, 1999), and hence the possible hazardous effects of *Bt* pollen to larvae of non-target butterflies have been investigated by many researchers. It has been shown that only one type of maize pollen (Event 176 producing a high level of Cry1Ab in pollen) is potentially harmful in the field. This strain of maize represented less than 2% of total maize planted in the USA in 1999 (Hellmich *et al.*, 2001). There is some overlap between the time of pollen production (anthesis) by *Bt* maize and adjacent monarch larvae feeding in northern part of the US corn belt, but it is of short duration (Hellmich & Siegfried, 2001; Oberhauser *et al.*, 2001). The pollen deposition on milkweed leaves, which monarch larvae eat, occurs only under specific conditions depending on the distance from maize fields and the weather (Pleasants *et al.*, 2001). Thus, the US Environmental Protection Agency (EPA) has determined that there is low probability of monarch larvae encountering a toxic level of pollen from *Bt* maize (EPA, 2001). Another field study on black swallowtail, *Papilio polyxenes*, suggests that *Bt* pollen is unlikely to affect wild populations of these butterflies (Wraight, Zangerl, Carroll, & Berenbaum, 2000).

Wider concerns for risks on biodiversity have also been raised. Other species (e.g., birds, fish, arthropods) that rely on affected target pests or weeds might suffer population decline (Nelson & De Pinto, 2001), following a reduction of the population of target species; this could happen regardless of whether the reduction in target species resulted from the use of tolerant GM crops, pesticides, a natural enemy or other factors. Watkinson, Freckelton, Robinson, and Sutherland (2000) simulated the effects of HT crops on weed populations and the consequences for seed eating birds. They point out possible impacts on skylarks by reducing their food resources if farmers choose to spray herbicides intensively so as to maximise yields. Actually, farms adopting HT soybeans tend to employ modest strategies for weed control, as mentioned above, irrespective of whether their motives are to keep a threshold pest level as a pest management tactic or to maximize profit margins for higher price premium of the transgenic seeds. Thus it does not seem that there is any impact on birds. Moreover, ongoing field trials at the farm level in the UK will yield additional information on potential risks of GM crop cultivation on the environment (Gura, 2001).

Selection of resistant pests and weeds may pose more practical problems. Since exposure to *Bt* toxin can elicit *Bt*-resistant pests, and since *Bt* crops continuously express *Bt* toxin, the control of resistance development in target species has been the primary concern with widespread commercialization of *Bt* crops. In order to mitigate or slow down the emergence of resistant insects, a strategy of making refuges with non-*Bt* crops close to high-dose *Bt* varieties has been recommended by companies, and later by EPA (Nelson & De Pinto, 2001). The principle is to dilute the frequency of recessive resistant traits in the population of target insects. There is no undisputed agreement either on whether the inheritance of resistant traits is recessive (Huang, Buschman, Higgins, & McGaughey, 1999) or on adequate refuge size (Nelson & De Pinto, 2001). Nevertheless, EPA has advocated an Insect Resistance Management (IRM) program, which specifies the refuge requirement for *Bt* maize, namely a structured refuge of at least 20% non-*Bt* maize within a half mile from Cry1Ab and Cry1F *Bt* maize planted outside cotton-growing areas. The IRM plan also includes resistance monitoring and annual reporting, and a recent document from the agency states that the IRM plan will change as more scientific data become available (EPA, 2001). Monitoring over 5 years (1995–1999) indicates no significant change in European corn borer susceptibility to Cry1Ab protein. The Canadian Food Inspection Agency (CFIA) has developed similar IRM programs (Stevens, 2001). In both cases, however, there are no enforcement mechanisms for compliance with IRM. EPA collected data from several surveys on growers, and concluded that 100% compliance is not likely and 30% (or greater) non-compliance must be expected (EPA, 2001).

Gene flow, the horizontal transfer of genetic material from GMOs to the biological environment by cross-

[4] Conversion: 1 bushel = 35 litres, dry measure; 1 hectare = 2.47 acres.

pollination, has also been of concern (Chèvre, Eber, Baranger, & Renard, 1997). If HT genes move to relatively weedy plants, control of the weed may become difficult. Transfer of insecticidal genes to wild plants may make IRM complicated, as insects might develop resistance outside the field planted with GM crops. Although these concerns have been expressed, particularly in the case of rapeseed in north America, where sexually compatible weeds exist, such adverse effects on weeds and IRM in the actual agricultural environment have not been reported at this time. However, it should be noted that sexually compatible weedy relatives to GMOs could be found in the centres of the genetic origin of crops, for example wild soybean plants in East Asia, and a case by case assessment in the local setting is necessary. Moreover, in developing countries, where some centres of genetic diversity are located, agricultural diversity of crops maintained by local farmers might also be affected by gene flow from monocultures of improved varieties, including GMOs. In Mexico, where no GM maize has been grown since a 1998 moratorium by the government, DNA constructs (cauliflower mosaic virus 35S promoter) commonly utilized in GMOs have been reported in native maize landraces (Quist & Chapela, 2001). The International Maize and Wheat Improvement Centre (CIMMYT) has also screened 43 Mexican maize landraces but failed to detect any of the introduced genes and has questioned this result (see Section 3.3.4).

9.3.3. Capital stocks: man-made capital

SARD should provide a sustainable food supply, which depends on and stimulates sufficient financial (money) and physical (machines, roads, energy, communication system and other infrastructures) capital, human resources and social cohesion in rural communities. Since, among these man-made stocks, financial and physical capital mainly come from agricultural profits, and social cohesion largely depends on equity between communities, they have been examined in the following sections for efficiency and equity.

Apparently, achieving food security is one of the major objectives of sustainable development, and genetic manipulation has been expected to contribute greatly to it with less adverse impact on natural environment. Although HT and insect resistant GMOs can produce higher yields than conventional crops, by reducing loss from pests and weeds, no GMOs with inherently higher yield have been successfully developed or commercialized. This may be partly because of the technical difficulties of yield enhancement, in which multiple genes must be modified and efficacy in whole plants must be screened in field trials (McElroy, 1999). It may also be partly because current research and development have been led by private corporations in industrialized countries, where food security has been already achieved, and the technology has focused on low cost farming and value added commodities for industrialised markets rather than yield increase. As a result, 82% of GM crops were cultivated in industrialised countries in 1999 (James, 2000). Furthermore, the core crops that are genetically modified are mostly temperate commercial plants; little research has been directed to tropical 'orphan crops', that is those with very limited commercial appeal because they are grown mainly for family consumption by poor farmers in developing countries (Pinstrup-Andersen & Schiøler, 2001). In order to direct modern biotechnology towards meeting the needs of those who have insufficient food, augmentation of research activities of the public sector in developing countries and technology transfer from and co-operation with the private sector in industrialised countries are essential.

Human resources comprise the population, education, knowledge and practices in rural communities. Current GMOs developed and adopted in industrialized countries can replace human labour used in scouting the emergence of insects, spraying pesticides, ploughing to control weeds and deciding between those options. The substitution of labour-intensive processes and local knowledge by a new technology is not unique to genetic manipulation but forms part of a continuing trend of modern technology. Yet critics argue that this accelerates the reliance of farmers on purchased inputs and thus on capital-intensive R&D by multinational corporations (Kloppenberg, 1988; Busch, Lacy, Burkhardt, & Lacy, 1991). Of course farmers in the USA are themselves choosing to use GM varieties, while the old technologies are also available, largely because of the expected productivity increase through improved and convenient pest control[5] (Fernandez-Cornejo & McBride, 2000; Bullock & Nitsi, 2001b). Thus it is not true to say that commercialization of GMOs deprives farmers of self-determination (Thompson, 1997). Besides, a significant proportion of agricultural knowledge and practice in industrialized countries had already originated from companies selling seeds, agrochemicals and information.

Nevertheless, in the competitive market, farmers may have no choice but to adopt a cost-reducing innovation such as *Bt* and HT crops (Moschini, Lapan, & Sobolevsky, 2000). Such use of HT crops forces their adopters into buying a particular herbicide packaged with the crops. If adopters want to avoid technical as well as legal difficulties, they are also coerced into compliance with instructions about herbicide use, prohibition of further propagation and provision of adequate refuge in

[5] Gianessi and Carpenter (1999) *Agricultural Biotechnology: Insect Control Benefit*. Washington, DC: National Center for Food and Agricultural Policy, available [January 2003] at http://www.ncfap.org/.

the case of *Bt* crops (Bonny, 2000). These imply further industrialization of agriculture, in which quality and labour process are simultaneously controlled. Farmers in developing countries are not familiar with such industrialized management. If they do utilize GMOs, careful consideration may be needed to guarantee their self-reliance in adopting inputs and in contracts with companies, in order to ensure farmers' participation and human resource development for SARD. Furthermore, labour saving by the use of HT and insect resistant GMOs may diminish the demand for labour in the agricultural sector. This may result in unemployment or decrease income among agricultural workers in developing countries.

9.3.4. Efficiency

Efficient transformation of capital stocks into human welfare in agriculture can be evaluated by measuring productivities by economic capital, labour, land, energy and other natural resources (European Commission, 2001). Furthermore, produced goods and services must be efficiently traded and allocated to maximize their utility. This implies the necessity of a viable and competitive economic structure and individual purchasing power based on sufficient income generation.

The primary concern about the efficiency of GM technology is its profitability. A technology should make a profit primarily for its users, but also for the rest of society, so that it can prevail widely in the market economy. Profitability is also a necessary condition for income generation. Despite rather high premiums on seed prices (approximately US $15–32 per ha (US $6–13 per acre), including technology fees owing to the oligopoly (almost monopoly in some cases) in the GM seed market, adoption of GMOs has expanded rapidly. This indicates benefits from adopting GMOs but not necessarily their capital productivity. Empirical surveys and theoretical simulations, conducted mostly for examples in the USA, have suggested overall trends towards higher profits for farms adopting GMOs than for non-adopters (Fernandez-Cornejo & McBride, 2000). However, gains in the net returns vary depending on crops, regions, years, pest pressures and theoretical models, and in some cases negative trends have also been observed. Thus, it is important to elucidate what conditions affect the profitability of GM crops and how they are affected.

Although the USDA estimates the net return to the average GM adopter to be not significantly higher than that of the non-adopter (in the case of HT soybeans in 1997), the net returns vary greatly by region. The net returns were about US $99 per ha (US $40 per acre) higher in GM adopters in the US heartland (US midwest), whereas they were about US $57 per ha (about US $23 per acre) lower in the Mississippi Portal (Fernandez-Cornejo & McBride, 2000). Another survey estimated that for farms in eight midwestern states in 1997 the production costs of GM adopting farms were about US $4.9 per ha (US $2 per acre) higher than those for non-adopter farms, despite the fact that 29% of the sample achieved higher profits (> US $49 per ha (US $20 per acre); Bullock & Nitsi, 2001a). Whether a farmer can make profits by adopting HT soybeans seems to depend very much on the particular weed situation of the farm. Interestingly, Bullock and Nitsi (2001a) found that farmers growing non-HT soybeans also benefited, owing to price reductions in other herbicides as the demand shifted to glyphosate, a herbicide used with the predominant HT soybean.

Similarly, profitability of *Bt* maize adoption differs widely. Gianessi and Carpenter (1999)[6] estimated that the US maize farmers gained US $44 per ha (US $18 per acre) in income in 1997 while they lost US $2.9 per ha (US $1.81 per acre) in income in 1998 from the planting of *Bt* maize. The difference came from varying severities of ECB infestation. Farmers in the corn belt experienced extremely light infestation in 1998 and non-adopters of *Bt* maize did not lose much yield without using insecticides. In such a low infestation year, the yield protection provided by *Bt* maize hardly covered the premium of its seed price. A simulation from the average annual infestation values for ECB in Illinois from 1986 to 1998 indicated that in 10 of these 13 years *Bt* maize growers would have achieved a net positive return.[6] The breakeven yield gain from *Bt* maize was calculated to be 283 l, dry measure (or US $20.2) per hectare (3.27 bushels (or US $8.17) per acre); that is farmers adopting *Bt* maize gain positive net return if the yield loss from ECB infestation exceeds 283 litres, dry measure per ha (3.27 bushels per acre). This is lower than the average yield loss in three mid western states from 1943 to 1998 of 406 litres, dry measure per ha (4.70 bushels per acre; Bullock & Nitsi, 2001b). Therefore, *Bt* maize is profitable for a typical farmer in the year with average ECB infestation, whereas it is not profitable for all farmers every year owing to fluctuations in infestation levels and a rather high price premium for *Bt* seed. In addition, the refuge requirement also affects the profit margin of *Bt* maize, which may pose a problem of intergenerational efficiency.

Overall, from the viewpoint of profitability, it is not likely that all the farmers will ever choose to use HT soybeans or *Bt* maize. The separation of the GM and non-GM market, brought about by the consumer objections and the requirement for labelling of GM foods, may worsen the conditions for adopting GMOs. Furthermore, the expected increase in production will lead to a reduction in market price, making the profit-

[6] Gianessi and Carpenter (1999) *Agricultural Biotechnology: Insect Control Benefit*. Washington, DC: National Center for Food and Agricultural Policy, available [January 2003] at http://www.ncfap.org/.

ability of GM crops ambiguous. The drop in market prices may be amplified by the rather low elasticity in demands generally observed for agricultural products. An economic study estimates that, worldwide, complete adoption of HT soybean will bring about a 0.6% increase in soybean production and a 2.6% decrease in the price of soybeans, assuming that the yield per acre is the same as that for conventional soybeans (Moschini *et al*., 2000). If adopting HT soybean results in a 5% yield increase, it is estimated it would result in a 2.1% increase in production and a 6.1% decrease in the price, which would make adoption of HT soybean less profitable. Another simulation study using a full-adoption scenario of both HT soybean and *Bt* maize suggests more moderate changes: it is projected that, for the adoption scenario, world soybean production in 2010 would increase by 0.5% and world soybean price would decline by 0.6% compared with a non-adoption scenario. It is similarly projected that corn production would increase by 0.6% and its price would decline by 1.7% (Rosegrant, 2001).

Nevertheless, the area planted with GMOs has been expanding. The increase in area planted with GM crops between 2000 and 2001 was 19%, which is almost twice the corresponding increase between 1999 and 2000 (James, 2001). In 2001 the area planted with GM soybean was 46% of the global soybean area, increased from 36% in 2000. This continuing increase may be due not to the expected increase in income but to the convenience factor, namely the increase in productivity though changes in labour and management (Furtan & Holzman, 2001). This may allow for greater economies of size and more flexible management as the production system is simplified. The convenience factors may include reduced labour for mixing and spraying pesticide, scouting insects and weeds, ploughing for weed control and managing such options. These factors may differ greatly between farms depending on farm size, product specialization, geographical location and the skills and education of farmers, which may differentiate the attitudes of farmers to the adoption of GMOs (Fulton & Keyowski, 2000). In fact, the use of HT soybean has significantly reduced the numbers of herbicide treatments, while it has reduced, in some degree, the use of cultivators, pesticide application and scouting in some but not all the regions of the USA (McBride & Brooks, 2000). Again, in future, the requirement for risk management for possible resistant insects or weeds might reduce or offset such convenience factors.

HT and *Bt* crops can reduce the use of chemicals and tillage, leading to a decrease in energy consumption in agriculture and to the maintenance of natural resources. However these effects have been less valued, in the market, as only 2% of farmers surveyed by USDA in 1997 stated the reason they adopted HT soybean as "more environmentally friendly practices" (Fernandez-Cornejo & McBride, 2000). On the contrary, 18.4% of farmers discontinuing the use of HT soybean in Wisconsin indicated the reason as "possible environmental or safety issues," while the major reasons related to dissatisfaction with its cost and distribution (Chen & Buttel, 2000). This implies a low priority for environmental values in the agricultural market. However, scientific and public uncertainty about environmental risks of GMOs, together with a vague anxiety among consumers, seem to have offset the low valuation by the market of the beneficial effects of GMOs on the natural environment. Whether these concerns about possible environmental effects from the use of GM crops will be substantiated by future studies remains to be seen.

Adoption of GMOs has been expected to enhance the competitiveness of the agricultural and food sector of a country in the world markets. Although agribiotechnology originated and has been a strategic innovation of agrochemical corporations in industrialized countries, the regulatory frameworks and public attitudes differ between food exporting countries (the USA and Canada) and importing regions (the European Union (EU), Japan and Korea). The early adoption of and policy formation for the use of GMOs should have allowed the US producers to keep their stable competitiveness, owing to the welfare gains in the innovator's home country. However, technological spillovers through exporting GM technology to South America would diminish the welfare gain (Moschini *et al*., 2000). Differences in regulation and public responses, and the absence of commonly acceptable standards applicable to decision making worldwide have resulted in separation of the GM food market into two segments: in one GM food is accepted and in the other only non-GM food is accepted. The US competitiveness surpasses, in the short term, other exporter countries in the world market, owing to a large domestic market with no segregation of GMOs, a concentration on the food processing market and early adoption of GM crops (Kalaitzandonakes, 2000). However, the world market segmentation may lead to uncertain conditions in the long term, especially for the early adopters with large overseas markets, although not so significantly for the late adopter countries, with a small share of exports (Nielsen, Thierfelder, & Robinson, 2001).

9.3.5. Equity

This section deals with the effects of GMOs on intra-generational equity, since inter-generational equity is the definition of sustainability *per se*. The effects of GMOs on some natural resources, for example a reduction in agrochemical use and a speculative loss of biodiversity, may be equally distributed between social actors, regardless of whether they are a benefit or a risk. However, the effects on other capital stocks, particularly on man-made capital and efficiency, should be distributed among diverse stakeholders differently. The framework for evaluating equity may also vary. At least three different levels of disparity in the evaluation can be addressed: between industrialized and developing countries; between various social sectors; and between farms in different sizes and income structures.

The allocation of profits made from GMOs has been the best-studied issue among the possible effects on intra-generational equity. The first point studied is how the development and use of GMOs affect the existing wide disparities between development levels throughout the world, which make the present economic system unsustainable. Modern agricultural biotechnology, developed largely through private investment, has focused overwhelmingly on farms and markets in industrialized countries. Little private sector research has been directed to the orphan crops in developing countries in spite of the large potential benefits from biotechnology in improving productivity of such crops (James, 2000; Pinstrup-Andersen & Cohen, 2001). Although countries not planting GMOs can also enjoy significant welfare effects from decreased prices both of crops in the world market (Frisvold, Sullivan, & Raneses, 1999) and, possibly, of pesticides, through decreased demands, the effects may be distributed largely to consumers rather than to farmers who have to compete with more efficient production by GMO adopters. In this sense, small-scale farmers in developing countries may become 'orphan groups', who are left behind the technological advance.

The second point is disparities between various stakeholders, which are closely associated with the first point. The major stakeholders comprise the agribiotech companies (innovators), farmers, food manufacturers and retailers, and consumers (Van der Sluis, Diersen, & Dobbs, 2001; Babinard & Josling, 2001).

Recent work by Moschini and Lapan (1997), on the welfare effects of innovation in agricultural inputs, studied what is conventionally measured as benefits to consumers and farmers. These benefits could, in fact, be largely captured by the innovating private firms under the circumstances of the non-competitive market structure owing to IPR. Consequently, studies by Moschini, Lapan, and Sobolevsky (2000) and by Price and colleagues[7] estimated that the largest share (45 and 68% respectively) of benefits from adopting HT soybeans in the USA and South America in 1997 have been distributed to the agribiotech/seed companies. This is because of the monopolistic input markets under the strong IPR protection in the USA. Either consumers in the rest of the world (Moschini *et al.*, 2000) or US farmers,[8] followed by US consumers should have received the next largest share, ranging from 17% to 25% of the whole surplus derived from adopting HT soybean. Farmers in the rest of the world, where no adoption of HT soybeans is assumed in this simulation, may lose income. It should be noted that an earlier report by Falck-Zepeda, Traxler, and Nelson (2000), which estimated a larger farmer surplus with smaller shares for the agribiotech/seed companies and consumers, has been criticised because of its impractical assumptions.[8]

Moschini, Lapen, & Sobolevsky (2000) also suggest that diffusion of HT soybeans over the rest of the world would undermine the advantage of US farmers and allocate larger benefits to consumers and farmers outside the Americas. In particular, in the rest of the world, several developing nations—called the new agricultural countries (NACs), such as Argentina, Brazil, Thailand, and some other developing countries in the Cairns Group[8]—have increased exports of commodity crops since the 1970s (Friedmann, 1991). This has happened because of an assumption that the IPR protection in the NACs is weaker than that in the USA, allowing NAC producers to enjoy beneficial crops with a lower premium on seed prices. In fact, Argentinian farmers are mostly free from a technology fee and restrictive contracts with the agribiotech/seed companies. So, if HT soybeans are adopted in the developing countries, with weaker IPR protection, farmers there can get larger shares of benefits than producers in the USA.

However, weak IPR protection could discourage the agribiotech/seed firms from investing in research and commercialisation of GMOs in those countries. In contrast, a higher mark-up ratio in seed prices due to stronger IPR might reduce the advantages to farmers in the NACs over US producers. These estimates come from an assumption that HT soybean does not affect yields but only saves costs. If it increases soybean yield by 5%, all producers adopting HT soybean lose income because of the decreased price of the products in the world market, while consumers gain the lost share of the welfare effects (Moschini *et al.*, 2000). In principle, the distribution of welfare between producers and consumers depends on the supply and demand elasticities of the current markets for soybean and soybean products. The experience described above indicates an inelastic supply of soybeans with even more inelastic demands.

The third point—effects on disparities among producers—has also been of concern, since patented technologies developed within the private sector will become too expensive for poor farmers in developing countries (Leisinger, 1999). Indeed, data from the Agricultural Resource Management Study of USDA in 1998 indicate that the adoption rate generally increases with the size

[7] Price, Lin, and Falck-Zepeda (2001) *The distribution of benefits resulting from biotechnology adoption*. Paper presented at American Agricultural Economics Association Annual Meeting, Chicago, IL, August 5–8, 2001, available [February 2002] at http://agecon.lib.umn.edu/cgi-bin/pdf_view.pl?paperid = 2706&ftype = .pdf.

[8] Argentina, Australia, Bolivia, Brazil, Canada, Chile, Colombia, Costa Rica, Fiji, Guatemala, Indonesia, Malaysia, New Zealand, Paraguay, Philipinnes, South Africa, Thailand, Uraguay.

of operation for all GMOs commercialised in the USA. The increase was statistically significance for *Bt* maize and HT maize but not HT soybean.[9] Another survey conducted for Wisconsin farmers also demonstrated that adoption of *Bt* or HT maize or HT soybean tended to be most common among cash grain producers and among producers with large acreages of cropland. Moreover, continuing adopters from 1999 to 2000 were likely to have larger farms with a high level of annual gross sales than those who did not use GMOs. For those who stopped using GMOs in 2000, self-reported profits were subsequently lower than for the continuing adopters (Chen & Buttel, 2000). These results suggest a farm size effect on adopting GMOs in US conditions. Similarly, a simulation study on virus-resistant potato for small-scale farmers in Mexico showed that, under the present market conditions, the innovation would result in greater income disparities between large-scale and small-scale producers, despite the intended traits and varieties being more beneficial for the smallholders, as they usually use uncertified seed potatoes, which are more susceptible to potato viruses (Qaim, 2000). However, Qaim also suggested that with a targeted institutional adjustment (e.g., subsidizing the certified transgenic seed potatoes), technology access for the small-scale farmers could be improved, thus allowing smallholders to benefit from larger shares of surplus by adopting the GM potato than large-scale producers could.

Even so, for successful adjustment, further efforts may be required, including efficient public research services for small-scale farmers and local infrastructures for storage and distribution of potatoes (Massieu, Gonzalez, Chauvet, Castaneda, & Barajas, 2000).

In addition to the benefits of adopting GMOs, potential risks may distribute differently. Differing policy frameworks and capacities for biological safety (biosafety) between states may lead to dissimilar levels of vulnerability to potential risks. Perceptions of such risks differ widely depending on the political and cultural conditions of the societies, as is already seen in the controversies between the USA and Europe. Consequently, the differences in social acceptability of GMOs may also lead to unequal extension of the technology and its actual benefits and risks.

9.4. Socioeconomic conditions of development, use and control of GMOs

9.4.1. Social shaping of GMOs

As reviewed in the previous section, current and future projections of GMOs may affect the conditions of sustainable agriculture both positively and negatively. This section attempts to find linkages between such expected conflicting effects and the process of social shaping of the development and use of GMOs, in order to discuss, in the next section, adequate infrastructures for the appropriate R&D, use and control of the technology.

Recent conclusions from the study of technology have revealed intimate and interactive relationships between technology and society (Dierkes & Hoffmann, 1992; Coombs, Saviotti, & Walsh, 1992). Technology is deeply affected by the context in which it is developed, used and controlled. Every stage in the generation and implementation of a new technology involves a set of choices between different options. Social, political, cultural and organisational as well as economic and technical factors affect which options are selected. As a result, effects of a particular technological innovation also depend on such factors and the options selected.

Table 9.1 summarizes the potential effects of current GMOs on the frameworks of sustainable agriculture, discussed in the previous section, in relation to possible social contexts. The effects involve contradictory outcomes, for example 'increase in profitability' and 'decrease in profitability'. Such different outcomes depend on social contexts which shape R&D, and the use and control of GMOs (listed in right hand columns). The following sections discuss the relationships between the outcomes and the interrelated stages of social contexts.

9.4.2. Research and development of GMOs

Private firms have largely conducted the R&D of GMOs, in sharp contrast with the 'Green Revolution,' which was led by public and philanthropic research institutions. The role of public research has been marginalized because of a declining research budget in the public sector. Furthermore, the altered rules of R&D management in the public sector (particularly the Bayh-Dole Act and Offices of Technology Transfer in the USA) and the broadened scope of IPR protection for newly created organisms, developed using DNA recombination technology, have also helped the privatization of R&D in biotechnology (Parker, Castillo, & Zilberman, 2001). It is chemical and pharmaceutical multinational firms that have developed GMOs (Kenney, 1986; Kloppenberg, 1988). These firms have invested heavily in genetic manipulation since the late 1970s, with the intention of developing peptide drugs and acquiring knowledge relevant to biological processes for future pharmaceutical development. As these companies have also manufactured agrochemicals, techniques of DNA recombination have been easily transferred into their plant science divisions with little transaction costs. However, some of the pharmaceutical companies have recently demerged such agribiotech divisions, owing to

[9] Fernandez-Cornejo, Daberkow, and McBride (2001) *Decomposing the size effect on the adoption of innovations: Agribiotechnology and precision farming*. Paper presented at American Agricultural Economics Association Annual Meeting, Chicago, IL, 5–8 August, 2001, available [February 2002] at http://agecon.lib.umn.edu/cgi-bin/pdf_view.pl?paperid = 2748.

Table 9.1. Possible positive and negative effects of GMOs on agricultural sustainability and their socio-economic conditions

Frameworks of sustainability	Possible effects of GMOs	Socio-economic conditions shaping the effects of GMOs		
		R&D (innovators)	**Use (market and society)**	**Control (governments)**
Capital stocks environmental capital/natural resources	*Positive effects*			
	Decrease of pesticide residues in environment Reduced soil erosion by reduced tillage No further increase in land use	Strategies of agrochemical companies for high R&D costs and patents expiations	Competition and cost pressure in the global commodity market	Stringent regulation of agro-chemicals
	Negative effects			Strong IPR[a] for biotechnology
	Selection of resistant pests or weeds Gene flow to weeds or crops		Large-scale commodity agriculture	Lack of standardised biosafety measures
Man-made capital/human resources	*Positive effect* Increase in food supply and variety	Market-oriented R&D by private firms	Capital intensive farming	Continuing farm support policies
			Coordinated agriculture	Labelling of GMOs
	Negative effect Decrease in self-reliance of farmers	Need to manage herbicide application or refuge	Contracts between farmers with agribiotech firms	Biosafety requirements for GMOs
Efficiency	*Positive effects* Increase in productivities by labour and land	Market-oriented R&D by private firms	Capital intensive farming	Partial trade liberalisation Strong IPR in the North
	Increase in profitability by cost-saving		Segmented niche markets	
	Negative effects Decease in profitability by high seed price and fallen product price	Monopolistic innovator	Inelastic demand for food	Strong IPR in the North Abolished production adjustment
Equity	*Positive effect* Increase in competitiveness of the NAC		Use farm-saved seeds	Weak IPR in the NAC
	Negative effects Neglect of orphan crops in the South Benefit concentration on innovator Increase in disparity among farmers Socially unacceptable	Market-oriented R&D by private firms Monopolistic innovator	Non-competitive input while competitive output market Scale-, resource-, education-biased adoption	Weak IPR in the South Lack of public seed distribution Lack of standardised regulation

[a] IPR: intellectual property rights; NAC: new agricultural countries.

public controversies over GMOs or for commercial reasons.

Because the innovators have been chemical multinationals, three major consequences have resulted; these are traits of GMOs that are complementary to particular pesticides, patent-based IPR and industry concentration. First, increasing regulatory expenditures for the approval of new pesticides, together with expirations of patents that were obtained for major pesticides developed in 1970s (Hartnell, 1996) have driven the chemical companies to invest in the development of crops with traits complementing or substituting those pesticides. The regulatory environment for pesticides has been continuously strengthened, owing to public concerns about chemical pollution. Thus, R&D conditions interact with conditions for the use (market and society) and control (governments) of GMOs.

Secondly, the emergence of chemical multinationals as innovators of plant varieties has been associated with a change in the IPR systems from plant breeder's rights (PBR) to patents. This may be partly because chemical firms had protected their novel chemical substances through a patent system. In addition, DNA sequence data derived from genetic manipulation has made it easier to satisfy the requirements for a patent, that is unobviousness, novelty and industrial applicability. Patents grant stronger, but shorter, monopoly than PBR; patents do not exempt breeder's research use and farmer's privilege but, according to the 1978 UPOV (International Union for the Protection of New Varieties of Plants) treaty PBR does. Subsequent to the 1991 revision of the UPOV treaty, which limits farmer's privilege, PBR protection has become closer to that of patents. The change to patent protection has affected the market structure (discussed in Section 9.4.3, below, on use of GMOs).

Finally, accumulation of core technological assets, that is patents on genes, vectors, promoter sequences and selection makers, in the chemical multinationals has led to horizontal and vertical mergers and acquisitions in the agro-food industry complex. This happens because of economies of scale and scope (Fulton & Giannakas, 2001). Costs for R&D and regulatory approval generally become sunk costs, that is expenditures that cannot be recouped once they are incurred. This makes larger and diversified firms more profitable than smaller and uniform companies, as the proportion of sunk costs gradually decreases, in theory, with increases in the quantity (scale) and diversity (scope) of the products. In fact, Ollinger and Fernandez-Cornejo (1998) found that smaller chemical companies are more strongly affected by expenditures for research and pesticide regulation. Consequently, the pesticide industry is concentrated, with the top four firms accounting for approximately 40–50% of the world sales of pesticides from the 1970s to the 1990s. Although the seed market is less concentrated, with the top four firms having 20% of sales, the agribiotech industry, which combines the assets in the pesticide and seed industries, seems to be more concentrated than the pesticide industry. The four firm concentration ratio in the agribiotech innovation market was calculated as 79% in 1998, based on field trial data (Brennan, Pray, & Courtmanche, 2000).

Such industry concentration with larger sunk costs may cause several effects. First, it may reduce R&D activities in smaller firms. Brennan, Pray, and Courtmanche (2000) also found a relative decrease in the number of field trials by other firms compared to that by the top four firms. Secondly, it may inhibit new entries into the agribiotech market. In other words, the market is not contestable. Thirdly, it may promote mergers and acquisitions among firms. In the past 10 years, the major agribiotech companies have vigorously made linkages with companies producing biopesticides, feed and food, as well as similar agribiotech seeds. Finally, it may make GM seed prices non-competitive owing to monopolistic market power. As reviewed previously, the prices of GM are higher than estimated marginal costs in the competitive market.

From the above consideration it does not directly follow that the R&D driven by private firms necessarily leads to inappropriate consequences. Actually, if the private sector had not participated in the R&D of GMOs, the application of DNA recombination technology into agriculture would not have progressed so fast. Nevertheless, if the public research sector or other industries had played more significant roles, more appropriate GMOs for developing countries might have emerged with different crops, IPR systems other than patents might have developed and a more disseminated market structure and lower premiums for seed prices might have occurred. Given that the R&D activities and the resulting IPRs are already dominated by the concentrated private firms in industrialized countries, it will be important for the late adopter developing countries to learn how to involve public sector research in the adoption of GMOs, in order to exploit benefits from the techniques. Key issues in policy making might include promotion of private–public research linkages, an appropriate IPR system and relevant competitive economic policies.

9.4.3. Use of GMOs: input markets

At the stage where GMOs are introduced, market demands and acceptance by society mainly shape the conditions for use of the technology. Such demands and acceptance are also subject to the state of R&D and control of GMOs. HT and *Bt* crops have been developed for farms producing commercial grains, mostly for feed and vegetable oil in the competitive domestic and international markets. The USA and Brazil have been exporting approximately 33 and 26%, respectively, of soybeans from 1996 to 1999. Although the USA is the largest producer of soybeans, the net exports of soybean meal and oil from Argentina and Brazil outweigh or rival those from the USA. As for maize, 62% in Argentina and 19% in the USA have been produced for exports (Kalaitzandonakes, 2000). Thus, the growers in these countries are continuously confronted by the cost pressure from the competitive world markets under increasingly liberalized conditions for agricultural trade. The market for cost-saving GM seeds can emerge in this competitive environment. As mentioned earlier, the smaller distribution of welfare derived from GMOs to producers partly arises from the competitive market for outputs of producers with less competitive market for inputs, including GM seeds.

All markets are embedded in particular social contexts, in which suppliers, consumers and other stakeholders form a consensus on the local transactions of particular products (Bender & Westgren, 2001). Hence, adopters of GMOs have to agree with suppliers, buyers and other people on the value of products in specific social contexts, which may involve education, wealth, geographic location, risk preferences, access to credit and information, farm size, land tenure, religious belief and social networks. These factors form the social contexts of demands. Indeed, Fernandez-Cornejo and colleagues[10] identify some factors influencing the likelihood and the extent (i.e., intensity) of GMO adoption from USDA survey data. They conclude that education and farm size positively correlate with the extended adoption of *Bt* and HT maize but not with that of HT soybean. Also, the production or marketing contract is a significant determinant for the adoption of HT soybean and *Bt* maize, but not for that of HT maize. In contrast, the extent of HT soybean adoption is negatively correlated with risk preferences, marginal location and limited resources. This implies that farmers unconcerned with risks and with limited farm resources (assets and income), living outside the primary production area are less likely to adopt HT soybean. The results are largely consistent with findings by Chen and Buttel (2000) from Wisconsin farmers who adopt or stop using GMOs. Continuing adopters (used GM in 1999 and 2000) of *Bt*, HT maize and HT soybean tend to operate with higher gross sales (> US $250,000) than continuing non-adopters. Both the new adopters (used GM in 2000 but not in 1999) of *Bt* and HT maize and the disadopters (used GM in 1999) but not HT soybeans were most likely to have advanced educations. The major reasons for disadoption were dissatisfaction with costs and profitability, despite their gross sales and education levels being comparable with continuing adopters.

Although Fernandez-Cornejo and colleagues[10] maintain that HT soybean is a scale-neutral technique, it is not persuasive to generalise from the observation in the US farm situation, taking into account the smaller acres of average farms in other countries. Even in their data from the USA, the adoption of HT soybean was significantly higher among farms with 20 or more ha (50 or more acres) than among those with fewer than 20 ha, though the adoption rates were fairly stable above 20 ha. Overall, typical adopters, and probably disadopters, of GMOs in the USA are estimated to be farmers who are operating more than middle-scale (in the American standard) farms, have high income, are seeking more profitable options, and also have higher education (*Bt* and HT maize) or those who have high risk-sensitivity with enough resources in farms located inside the primary production area (HT soybean). Those farmers may have shaped and will change the demands for GM seeds, through the interaction with agribiotech/seed companies under the competitive international market for grains. Nevertheless, there are also continuing non-adopters who tend to have smaller farms with less income and fewer assets.

The mechanisms that possibly make the technology scale-biased are unknown. However, it is plausible that the convenience factors of GMOs may be less salient in smaller farms. This is because of a relatively smaller amount of labour required for scouting weeds and insects, spraying pesticide and managing those decisions in comparison with the premium of GM seed prices or combined GM/herbicide contracts, in the case of HT seeds. In addition, the uncertainty and information costs for a new technique may prevent smaller farmers from adopting them. This may also relate to the dependency on resource or education, since early adopters need to have considerable resources to absorb possible losses if the innovation is unprofitable and to have the ability to understand complex technical language (Rogers, 1995). Considering smaller farms in major developing countries (mostly less than 1 ha, except those in the NACs in South America) as well as factors such as scarce resources and poorer education, it does not seem easy to extrapolate the high uptake of GMOs in the USA to the farming conditions in developing countries. If the adoption of *Bt* or HT GM seeds in developing countries is scale-biased, or possibly in some cases resource- or education-biased, additional social institutions that can substitute or complement the insufficient conditions for adopting GM varieties may be needed to achieve the diffusion of the technology (Qaim, 2000).

9.4.4. Use of GMOs: output markets

Considering the output markets, where GM products are bought by food or feed processing companies, it is recognized that the social acceptability of the technology may indirectly influence the use of GMOs through

[10] Fernandez-Cornejo, Daberkow, and McBride, (2001) *Decomposing the size effect on the adoption of innovations: Agribiotechnology and precision farming*. Paper presented at American Agricultural Economics Association Annual Meeting, Chicago, IL, 5–8 August, 2001, available [February 2002] at http://agecon.lib.umn.edu/cgi-bin/pdf_view.pl?paperid = 2748.

the market structure of agricultural products. The so-called first-generation GMOs, with improved input traits, including *Bt* and HT grains have emerged within the existing market for commodity agriculture, since they do not affect value to processors and consumers. The key feature of the market for commodity agriculture is that massive amounts of low cost ingredients are provided to the food processing industry, within a framework of relatively coarse grades and standards (Sonka, 2001). That is, the commodity market system intentionally neglects latent differences, as the cost of doing so exceeds the benefits. Indeed, such a system has been beneficial for the processors who convert a bulk of low cost ingredients to a massive array of desirable food products for consumers. Accordingly, maize from Argentina can easily substitute for that from the USA to produce similar oil, animal feed and starch, creating competitive conditions for the international market.

GMOs have been developed for the agricultural commodity market on the assumption that products derived from GMOs and those from conventional crops are interchangeable. The fact that few of the products are consumed directly may have strengthened the postulate. Furthermore, deregulation of agriculture as implemented in the Federal Agriculture Improvement and Reform Act of 1996 (1996 Farm Act) of the USA, in which production adjustment and price support were eliminated, has facilitated the adoption of cost-efficient crops. However, consumer concerns about GM products have led food manufacturers and retailers worldwide, especially in the EU and Japan, to search for ingredients derived from non-GMOs. Hence, discrete markets for non-GM soybean and maize are emerging, while the existing commodity markets for animal feeds and food ingredients in the USA and Asia still remain open to GMOs. Many factors will affect the emerging structure of the new market for non-GM segregation. Such factors include differing scope and contamination tolerance levels in labelling policies, costs for market segmentation and identity preservation, elasticity of demands for non-GMOs, public trust in governments, and strategies of major actors in the agro-food commodity chain. The handling cost for segregation is estimated to be around 10% of the crop price at farm level (Unnevehr, Hill, & Cunningham, 2001). Given the relatively inelastic demands for non-GMOs in the EU and Japan, some producers and grain handlers with the ability to deliver non-GMOs will receive a price premium for segregating and identifying non-GMOs, as has already appeared in the case of non-GM soybeans exported from the USA to Japan.[11] Still, there is uncertainty in size, major actors and profitability of the non-GM market, mainly owing to obscurity in the state regulation systems and to the lack of an agreed international standard.

The trend to market segmentation by GMO segregation is in line with the market evolution from the existing commodity market to the coordinated market, with administrative or informational control (Sonka, 2001). In the commodity market, only one attribute of the commodity, information on prices, is transmitted between the supplier and the customer. Administrative co-ordination enables other attributes, relating to quality, to be pre-emptively transmitted, to affect decisions on production, distribution and consumption.

Historically, the administrative coordination, called 'broiler structure', was attained through vertical integration, in which a firm, usually in supply chain, took contractual control over important decisions for production in farms (Sonka, 2001). In the non-GM market with identity preservation, similar contract systems may arise. In fact, among the US soybean producers, farmers who sign contracts agreeing to follow specific production practices (e.g., to clean out the planter, flush the combine, etc.) to maintain non-GM segregation and identity preservation tend to receive higher premiums than farmers who just 'show up' with a delivery of non-GM soybeans.[12]

Identity preservation is a prerequisite to the informational coordination of the agricultural market because various identities of the products must be transmitted to narrowly defined customers with differentiated needs. This agricultural system will produce foods as 'prescription products' with differing contents and effects of ingredients that are comparable with prescription systems for pharmaceuticals (Urban, 1991). The second generation GMOs, with improved output traits, are expected to provide diverse identities for such prescription products in the narrowly segmented *niche* markets. The identity of a non-GM variety as well as a GM variety with novel output traits will be more precisely preserved under the informational coordination system (Kalaitzandonakes & Maltsbargar, 1998). In this system, not only the area and time of planting of (non-)GM seeds can be decided and monitored by 'precision farming', but also the delivery and logistics of the products can be determined and managed by the identity preserved supply chain. This will require the aid of information technology, such as computers, Geographic Information Systems, Global Positioning Systems and buyer call for delivery systems. In this sense, both non-GMOs and the second generation GMOs fit the same

[11] Bullock, Desquilbet, and Nitsi (2000). *The economics of non-GMO segregation and identity preservation*. Paper presented at American Agricultural Economics Association Annual Meeting, Tampa, FL, July 30–August 2, 2000, available [January 2003] at http://www.ace.uiuc.edu/faculty/bullock/bullock_papers.html.

[12] Bullock, Desquilbet, and Nitsi (2000) *The economics of non-GMO segregation and identity preservation*. Paper presented at American Agricultural Economics Association Annual Meeting, Tampa, FL, July 30–August 2, 2000, available [February 2002] at http://www.ace.uiuc.edu/faculty/bullock/bullock_papers.html.

coordinated market system, consisting of contracting agriculture with precision farming and differentiated *niche* markets (Zilberman, Yakin, & Heiman, 2000).

The differentiation of needs has arisen in rich countries since the achievement of food security from the food supply chain, the strategies of which have shifted from just supplying mass-produced cheap food to creating demands for a wider variety of high-quality food that has been advertised to improve consumers' diet and health. It is too naive to think that consumers differentiate their interests in food products by themselves. Rather, food manufacturers and retailers who had to compete in the saturated commodity markets have promoted the individuation of consumers, through innovating new quality choices, in order to create *niche* markets for value-added products. Consumers have been encouraged to be progressive in their buying patterns (Marsden, Flynn, & Harrison, 2000). Trade liberalisation is also considered to enhance the differentiation, since it enables out-sourcing of quality-differentiated and cost-efficient food ingredients under the condition of comparative advantage (Tisdell & Dragun, 1999). Although concern about GMOs has initially arisen from NGOs and some consumer groups, some retailers and food manufacturers have been more progressive than the majority of ordinary consumers, by announcing their plans to be GMO-free before the peak of the public controversy. Retailing and food processing firms have had to project themselves as socially progressive so as to secure the emerging *niche* markets preemptively. As a result, non-GMOs, in addition to the second generation GMOs, have emerged as value-added products for consumers, food manufacturers and retailers, in industrialised countries, who can switch over to non-GM ingredients produced in a different country with minimum transaction costs. In that sense, the controversial situation over GMOs has provided an opportunity for the food industry to find a new *niche*.

Accordingly, the emerging coordinated market for non-GMOs is unlikely to reflect the needs of consumers in developing countries. Also, with the exception of the NACs, such as Argentina and Brazil, farmers in developing countries are less likely to profit from the opportunity provided by the markets for non-GMOs. This is because they do not have enough competitive advantage, in the long term, over producers in industrialized countries armed with precision farming, which is known to be more strongly biased to farm size, resources and education levels.[13] In contrast, the first generation GMOs in the commodity market may offer better opportunities to producers in developing countries for finding profitable overseas markets. It might also cause 'broilerization' of agriculture controlled by agribiotech/seed firms, as well as agricultural specialization with loss of biodiversity, which has been characteristic of intensive farming in developed countries.

9.4.5. Control of GMOs

The introduction of GMOs into the food chain is controlled, by both governmental and international regulatory systems, at various stages: technology patenting; field-testing of the crop; animal and human consumption trials; and approval for commercial use as a crop and for human and animal consumption (Nelson, Babinard, & Josling, 2001). At any stage, decision-making for GMO regulations is the result of reconciliation and compromise between the contesting interests of stakeholders (Henson & Caswell, 1999; Babinard & Josling, 2001). The focus is on social contexts and the possible impacts that discrepancies between different regulatory policies on GMOs, especially in the USA and the EU, may have; such discrepancies may bring uncertain market conditions to farmers, manufacturers, retailers and late adopter countries.

Considering the first generation GMOs were mainly developed for the international commodity market (i.e., soybean, maize, canola) for feed, oil and processed food, it is easy to understand how the market conditions of such products and the economic interests of the farm sector could significantly affect the policy framework regulating GMOs. Not surprisingly, governmental agencies controlling food, feed, and other agricultural products in the countries exporting maize, soybean and canola, such as the USA and Canada, have developed a permissive regulatory framework on GMOs, with a product-specific, *equivalence principle*, while those in the EU, which is the largest importer of soybean, have utilized a more cautious framework, with a process-specific, *precautionary principle*[14] (Kalaitzandonakes, 2000. Although Japan, the largest importer of maize and canola, initially used a similar framework to the USA and Canada, it started, in 2001, a process-specific mandatory labelling system for foods derived from crops developed using DNA recombination technology. Under the product-specific regulatory framework, a GM product is assessed within existing frameworks for safety and nutritional fitness, as long as the product is *substantially equivalent* to the conventional one. Consequently, the Food and Drug Administration (FDA) of the USA does not require foods produced from GM crops to be specially labelled. In contrast the EU has

[13] Fernandez-Cornejo, Daberkow, and McBride (2001) *Decomposing the size effect on the adoption of innovations: Agribiotechnology and precision farming*. Paper presented at American Agricultural Economics Association Annual Meeting, Chicago IL, 5–8 August, 2001, available [February 2002] at http://agecon.lib.umn.edu/cgi-bin/pdf_view.pl?paperid = 2748.

[14] Sheldon and Josling (2002) Biotechnology regulations and the WTO. *Working Paper*, No. 02-2, International Agricultural Trade Research Consortium (IATRC), available [March 2002] at http://iatrcweb.org/Publications.htm.

not only obliged labelling of such foods since 1997 but has also introduced a *de facto* moratorium on new product approvals since 1999. Mandatory labelling for GMOs has been also implemented in agricultural exporting countries such as Australia, New Zealand, Brazil, Chile, Indonesia, and Thailand.

These conflicting regulations have caused a major dispute in international institutions such as the World Trade Organization (WTO), the Codex Alimentarius Commission (CODEX) and the Convention on Biological Diversity (CBD). For example, in the committee of the Agreement on Technical Barriers to Trade (TBT) within WTO, held in 1999, countries exporting GMOs questioned the legitimacy of the mandatory labelling system of the EU, alleging it was a discriminatory trade barrier. However, regulatory discerepancies with respect to GMOs in the international trade institutions do not imply a conflict between trade liberalization and protectionism. Rather, the situation may reflect an historical conflict between different protectionist regimes for international and domestic markets, in exporter and importer countries. Rich countries use not only trade barriers but also agricultural subsidies or other complementary programmes. Farm support policies in wealthy countries include export subsidies in the EU as well as the non-recourse marketing loan and export credit guarantee programme, which remained in the USA after the incomplete trade liberalization of the WTO regime. Indeed, the non-recourse marketing loan and fixed payments decoupled with production adjustment, employed after the 1996 Farm Act in the USA, have allowed farmers to expand their acreage of GM soybean and maize freely, despite the lower prices, and have subsequently sustained the shares of the USA in the international commodity markets. In this sense, GM grains without specific labelling can serve as a strategic tool to maintain national competitiveness under the partially liberalized condition of agricultural trade.

Although differing economic interests in agricultural trade may lead to conflicting regulations for GMOs, they do not necessarily entail precautionary measures and mandatory labelling systems. In the committee of the Agreement on Sanitary and Phytosanitary Measures (SPS) within WTO, which permits nations to restrict imports in the name of health or environmental protection, based on scientific principles, the EU has tried to widen the basis for such restrictions, by insisting that there is scientific uncertainty about the possible risks of GMOs. Finally, in 2000, this precautionary principle was incorporated into the text of the Biosafety Protocol of CBD, based on the assertion of delegates from environmental agencies rather than trade ministers of the EU and developing countries, despite strong opposition from the USA and other exporting countries (Paarlberg, 2000).

Precautionary policies on environment and health concerns in the EU and other regions have evolved from significant debates and regulatory conflicts between governments and newly formed networks of groups who oppose GM crops and food (Levidow, Carr, & Wield, 2000). In the early 1990s, there was little organized protest against GMOs in the EU member states, except in Denmark and Germany, and the potential risks of GMOs were considered as agricultural rather than as environmental and health risks. However, new networks have developed between environmental and consumer groups and organic farmers and also retailers and food processors, in response to pressure from their customers in the late 1990s. The mounting concerns of the networks have changed the framing of the issue, from intensive agricultural models, with familiar hazards, to uncertainties, with more complex cause–effect pathways, which have led government regulators and research institutions to search for new information, interpretations and solutions. For example, recent risk assessment research on gene flow from HT canola has shifted towards assessing volunteer/feral dynamics and the actual testing of backcrosses of HT canola in the field. In contrast, early research separated volunteer and feral plants, and cited familiar data with conventional crops (Levidow, 2001). Thus, scientific uncertainty associated with GMOs and the use of precautionary approaches as a solution have been socially shaped by conflicts between a wide range of stakeholders (Bender & Westgern, 2001).

For developing countries with intentions to adopt GMOs, the discrepancy in regulatory policies relating to GMOs among developed countries may create uncertain market conditions, in which the conventional commodity market and the segmented markets, including non-GMOs, co-exist with variable shares. Furthermore, conflicts in the trade agreements within WTO may also bring uncertainty to the prospect of trade liberalization. Since both sides of the conflict retain a protectionist position to some degree, the competitiveness of exporting countries will be strengthened by adopting GMOs while maintaining domestic farm support policies. This may restrict the opportunities of food-exporting, developing countries. Nevertheless, differences in GMO regulation among developed countries can offer policy options in dealing with uncertain consequences of adoption; in the negotiation of the Biosafety Protocol, most developing countries desired more cautious regulations than those of the USA.

9.5. Policy options for appropriate development, use and control of GMOs

9.5.1. Socioeconomic conditions and policy options

Possible effects of current GMOs and their relation to socioeconomic conditions, which are summarized in

Table 9.1, can provide clues as to which policy options are required to achieve sustainable agriculture. Governments can choose options in several policy areas relevant to socioeconomic conditions, such as those highlighted in Table 9.1, that influence the impact of GMOs. Paarlberg (2002) distinguishes five important areas of relevant policies: IPR, biosafety, trade, food safety and consumer choices (which might be considered as two separate areas), and public research investment. In each policy area, appropriate policy options, for example strong or weak IPR protection, should be selected to reduce or eliminate the socioeconomic conditions that lead to the negative effects for development, use and control of GMOs; while options causing positive effects should be maintained. However, the reality is not so simple.

One policy option may produce complicated multilateral effects that may influence the sustainability of agriculture both positively and negatively, as shown in Table 9.1. For example, strong IPR protection for agricultural biotechnology might result, on the one hand, in rapid and effective investments by agribiotech/seed companies to develop appropriate GM varieties for local needs, while on the other hand, it might result in monopolistic market power, by those firms, leading to expensive seed prices, which might offset the beneficial effects for farmers. Similarly, trade liberalization or stringent regulation in biosafety and labelling may bring about both positive and negative influences. This final section describes the complex relationships between some typical options, in problematic policy areas, for the development, use and control of GMOs and the possible effects of GMOs in given socioeconomic conditions.

9.5.2. Intellectual property protection

Most of the positive and negative effects of R&D come from the fact that private firms have developed the majority of GMOs. As mentioned in the previous section, the IPR system for living organisms has coevolved with privatization of agricultural research, mainly driven by agribiotech/seed companies in industrialized countries. The options in IPR for improved crops can vary widely, as follows:

- double protection with patents and PBR, which is most common in developed countries;
- PBR under the 1991 UPOV treaty, in which farmers' privilege (the right to use the harvest material as a seed source but not to sell or exchange them) is restricted;
- PBR under the 1978 UPOV treaty, which preserves farmers' privilege; or
- no IPR enforcement (Paarlberg, 2002).

The patent system or either of the PBRs can be compatible with the 'effective *sui generis* system', required in the agreement on Trade Related Aspects of Intellectual Property Rights (TRIPs) within WTO. Although members of WTO do not need to model their *sui generis* legislation on UPOV at all, it presents the only international model available on PBR. The 1978 UPOV treaty seems a preferred option for many developing countries because of its flexibility, allowing farmers to use protected varieties (Watal, 2001). The highly protective position of patent protection in the USA, in which a DNA sequence with a hypothetical function predicted by *in silico* bioinformatics (i.e., databases and computer programs) has been patented, can be contrasted with the more moderate positions in the EU and Japan. Furthermore, in response to extending IPR to plant varieties, developing countries assert farmers' rights to their traditionally cultivated 'landraces,' in which farmers' contributions are recognized in the framework of CBD. However, implementation of this seems difficult in the market economy (Mendelsohn, 2000). In addition, Appellation of Origin rights are becoming increasingly important in the *niche* markets for specialized foods that include non-GM products with identity preservation (Evenson, 2000).

In any case, it has seemed that the wider scope of IPR and stronger IPR protection, with the exception of farmers' rights, has provided stronger incentives for private firms to invest in R&D on novel genes, methods of transferring genes and improved varieties. However, an empirical study has indicated that a recent surge in patenting has not necessarily originated from strengthened patent protections (Kortum & Lerner, 1998). Also, in theory, absence or weak protection of IPR can lead to over-investment (Fama & Laffer, 1971) as well as under-investment. Private firms can recover their R&D costs in other ways. Indeed, soybean breeding companies have been indirectly appropriating rents, by charging a sufficiently high price for the parent seed, when farmers' privilege has allowed soybean growers to use saved seeds, under the relatively weak PBR protection of the USA (Lesser, 2000). Thus, there is little basis for simply expecting that stronger IPR protection alone will promote more vigorous R&D activities. Other factors, including company strategies and market conditions, may also play significant roles in motivating private R&D investment.

Even though stringent IPR protection provides an incentive for R&D investments, R&D may concentrate on inventions for which potential customers are willing to pay or by which R&D investors can acquire economic return from their investments. Thus R&D activities promoted by IPR are inherently market-oriented. In fact, private R&D in genetic manipulation for agriculture has been focused on temperate core crops, with cost-saving traits and a high premium for seed prices, owing to the size of the market and customers who can afford the higher prices. In contrast, tropical orphan crops, such as cassava, yams and sweet potatoes, are grown on relatively small areas, mainly by poor farmers; it is, therefore, difficult to attract private firms to invest in the R&D for such crops. In this case, strengthening the IPR system is not likely to change the bias of private R&D, from commodity agriculture in rich countries to that fitted for local needs in developing countries, where few farmers can pay for commercial seeds. Even the introduction of an established technology, into a well-characterized crop, in a new adopter country, must presume a relatively large market, as initial costs are estimated to range from US $2 million to US $5 million for further R&D, patenting and gaining regulatory approval (Lindner, 2000).

Nevertheless, as much of the technology for plant genetic manipulation is in the hands of private corporations, strong IPR protection would help to create 'bargaining chips,' which could be used to gain access to the technologies by non-profit research institutes. Research institutes, such as the International Agricultural Research Centres (IARC), will inevitably continue to bear a major responsibility for improving local crop varieties and distributing seeds *gratis* or with minimum costs to poor farmers in developing countries (Watal, 2001). This will also require significant levels of technological assets and human resources in the public sector. Of course NACs exporting core crops can gain higher shares of benefit owing to their weak IPR protection. This is not the case in most developing countries with poor resources, particularly the least developed countries (LDC) and net-food-importing developing countries (NFIDC). Therefore, in order to exploit the benefits from GM technologies protected by stringent IPR in industrialized countries, an effective level of IPR protection, either by patent or by PBR, is essential, together with simultaneous strengthening of public research activities.

However, there are several problems to be solved, in addition to the significant R&D investment in the public sector, if a developing country intends to successfully establish technology transfer, by implementing strong or wide IPR protections for agricultural resources and products. First, public research institutes must overcome the high costs of transactions, in multilateral negotiations, with many potential licensors, for the acquisition of protected information and materials (Wright, 2000). This involves not only methods or organisms but also numerous research tools, such as genes, vectors, promoter sequences and marker genes, which have been separately patented. In the case of provitamin A rice, for example, it is estimated that the International Rice Research Institute (IRRI) would have had to acquire 30–40 licences, from a dozen patentees, before distributing the GM rice variety to Asian developing countries (Kryder, Kowalski, & Krattiger, 2000). Although, in this particular case, exemption has been granted, general problems of proprietary claims still exist. The situation represents a typical example of the 'tragedy of anticommons,' in which an application of technology is hampered or deterred by too many proprietary claims upstream of the technology (Heller & Eisenberg, 1998). Therefore, an overly broad scope of patent protection, particularly for research tools, may have adverse effects on promoting R&D.

The second problem concerns risks associated with uncertainty about the technology to be introduced. The reduction of such risks, by gathering of information and the use of contractual forms, also constitutes a large part of the transaction costs. Consequently, establishing the freedom-to-operate (ability to experiment and commercialise products without an impermissible use of protected technology) with a GM variety may have other requirements, in addition to the cost of rent transfer to a range of patent holders. These include costs of discovering the existence and ownership of claims, evaluating the nature and suitability of the technology, and negotiating rights to use or acquire the IPR, in a uncertain market, where values are not clearly established and are constantly changing (Wright, 2000). Sometimes the negotiation fails owing to a refusal of the patentee. Nottenburg, Pardey, and Wright (2001) suggest several strategies for efficiently accessing protected technologies. The strategic options include cross licensing, patent pooling, research-only licences, market segmentation strategies, mergers or joint ventures, cost-free licenses, clearinghouse mechanisms and direct programmatic research support from the private sector, most of which entail further cooperation with the private sector as well as other public research organizations (Binenbaum, Pardey, & Wright, 2001). In any case, strengthening the capacity of public research institutes may make each option more feasible.

Third, implementation of IPR protection on plants and their genes, in developing countries, may increase the incentives of the private sector, in developed countries, to collect and preserve genetic resources *ex situ* (Evenson, 2000). This may contribute somewhat to the conservation of biodiversity on a global scale. However, it may also encourage private firms to hold genetic resources in secrecy and use them as breeding lines for IPR protected varieties. Indeed, some NGOs have alleged several cases of UPOV abuse, in which landraces have been protected as if they were new (Wright, 2000). Alternatively, genetic resources may be exchanged in an emerging 'gene market,' where the commercial value of genes may be determined between relatively small numbers of negotiating parties. Thus, important potential values of biodiversity may not only be externalized from a larger market but may also be separated from the local community and environment, which, in turn, may make people in developing countries frustrated, leading them to claim farmers' rights.

Finally, for developing countries, it is crucial to obtain domestic confidence for IPR protection. The 'north–south' diplomacy on IPR began in the 1970s, as multilateral negotiations on technology transfer, led by activist developing countries, mainly in the field of industrial products. After negotiations had failed, debt crises in the 1980s forced developing countries to embrace a model of the market economy, which shifted the balance of power, such that negotiations became more favourable to the 'north'. Meanwhile, the USA, mobilized by business organizations, such as the Pharmaceuticals Manufacturing Association (PMA) and International Intellectual Property Alliance (IIPA), began to pursue bilateral negotiations on IPR, for particular products, with each developing country, by using the section 301 intellectual property mandate in the 1984 US Trade Act (Ryan, 1998; Sell, 1998). Consequently, the USA led the second stage of diplomacy in the TRIPs within the GATT (General Agreement on Tariffs and Trade) Uruguay Round, started in 1986. Throughout the negotiation, most developing countries opposed the implementation of TRIPs. Although many developing countries have now recognized the importance of IPR for the development of competitive capabilities in agricultural research, scepticism and discontent still seem to prevail among farmers, NGOs and governmental officials.

9.5.3. Trade liberalization

Although Paarlberg (2002) discusses, particularly, trade policy toward GM crops, which may significantly reflect biosafety measures, a wider perspective should be taken in examining the socioeconomic conditions that may affect the shaping of the GMO market. For example, as was observed in the dispute in the WTO meeting at Seattle in 2000, critics of GMOs may also be critics of trade liberalization, an economic aspect of globalization, thus indicating a close relation between GMOs and global socioeconomic trends.

Continuing major issues throughout the GATT and WTO negotiations on agricultural trade liberalization have included market access, export subsidies and domestic support.[15] Duties on agricultural products still remain very high (62%, global average of maximum permitted), and export subsidies as well as export credit are also widely used by developed, exporting countries, though both have been significantly reduced. Furthermore, many countries still want exemption from cutbacks in domestic support, and use so-called green and blue box policies to meet specific domestic concerns, while exporting countries, such as the Cairns Group countries and the USA, now insist on massive cutbacks. Nevertheless, present domestic support heavily concentrates (90%) on the USA, the EU and Japan. Subsidised exports to developing countries and protection against imports from such countries persist among developed countries; this has led to dissatisfaction in developing countries. The LDCs and NFIDCs, particularly, have expressed scepticism about the beneficial effects of trade liberalization policies, whereas economists in the World Bank insist on the 'pro-poor' nature of the policies (Dollar & Kraay, 2000).

Mainstream neoclassical economists are confident that the removal of trade distortions will, in almost all situations, boost economic welfare and will, in many situations, also improve the environment, particularly if governments have in place and enforce optimal environmental policies (Anderson, 1998). Thus, the concerns of developing countries may, at least partly, result from incomplete or retarded liberalization, though environmental improvement may not be expected so confidently. If this is the case, perhaps developing countries should simply require more thorough and rapid trade liberalization, including liberalization for GM products, instead of demanding exemption. However, inadequate global and national food supplies, together with persistent food crises in sub-Saharan Africa, despite expanding supplies at the national and global level, indicate the importance of considering local and social needs. Emerging empirical analyses within mainstream economics also cast some doubt on the, largely unchallenged, assumption that increased trade liberalization has been good for growth, and hence poverty reduction (Davis, Thomas, & Amponsah, 2001). Trade liberalization can affect economic welfare both positively and negatively, depending on local and social situations, even though aggregate effects seem to be positive.

Moreover, from the perspective of economic sociology and neo-institutional economics, the market is a social and institutional construction, with actors, values, norms and institutions. As mentioned in the previous section, input trait GMOs have emerged within the global commodity market, where large-scale and resource-rich farms, with governmental support, grow commodity crops that are substantially equivalent worldwide to feed, oil and other processed foods. Here, it is the norm to see products from different regions and conditions as equivalent, and to compete mainly on price, not on particular qualities, the regions where the crop was grown and growing methods. These norms are supported by the food industry and farm support policies. Thus, input trait GMOs may well be suitable for farms producing in the global commodity market,

[15] IATRC (2001) *The Current WTO Agricultural Negotitations: Options for Progress* (Comissioned Paper No 18), St Paul, MN, International Agricultural Trade Research Consultancy, available [March 2002] at http://iatrcweb.org/.

including large-scale farms in NACs and the Cairns Group countries, but not for other farms. However, trade liberalization and deregulation of the commodity markets will create more differentiated norms and spaces for competition. These involve segmented markets for non-GMOs and output trait GMOs, as mentioned previously. Segmented markets for value-added products may impose particular norms for competition in production. As already discussed, such GMOs may not fit the situations in the LDCs and NFIDCs. Rather, Dragun (1999) points out that trade liberalization and deregulation of the less-concentrated and less-specialised market in developing countries (where a wide range of crops is grown with public, rather than privately owned resources, and distributed through diverse channels) may lead to crop specialization. This, in turn, may be accompanied by some adverse effects, such as biodiversity loss, disruption of local diet and health, and institutional breakdown.

The contingent nature of markets upon social conditions may explain the heterogeneity and diversity in trade policy proposals submitted by member countries at the WTO negotiations. For example, many developing countries have proposed reductions in export subsidies, tariffs and safeguards in developed countries, while, with the exception of the Cairns Group, they have sought to maintain tariffs and special safeguards specific to developing countries. Some countries regard food security as accessibility to food, by multiple means, including trade, whereas other countries give priority to self-sufficiency in basic food supplies. Expansion of input trait GMOs, with cheap prices in the global market, may be beneficial for urban consumers in developing countries, regardless of whether the exports of the GMOs are heavily subsidized by the governments of developed countries. However, for countries that stick to self-sufficiency such cheap GMOs from developed countries will be a threat to domestic agriculture and poor farmers. In contrast, the segmented markets for non-GMOs may present difficulties for NACs adopting GMOs. The future of the negotiations is unforeseeable, and outcomes of the different levels and scopes of liberalization at present seem very complicated.

In any case, it is unlikely that complete market access and the removal of export and domestic supports will be achieved in near future, indicating persistent co-existence of the commodity market and the value-added segmented markets, where existing exporter countries have potential comparative advantages. However, the options for developing countries may not be limited to strategies fit for the commodity market or the value-added markets, or pesticide-complementary or value-added GMOs. If significant technology transfer and innovative conditions were to be established, under adequate IPR protection, and public research were to be increased, social institutions and market conditions specific for developing countries could shape suitable GMOs for local needs. GMOs developed under self-sufficient policies and decentralized market systems might be different from those now prevailing in developed countries.

9.5.4. Biosafety and labelling

Even if IPR and trade policies were established that aimed at providing benefit from GM technologies in a developing country (irrespective of whether they were directed to domestic adoption of appropriate GMOs or to importing GM products) the government would be confronted with issues of biosafety, in terms of both the environment and labelling for consumer choice. Policy options are given in gradients between a products-specific, equivalence principle and process-specific, precautionary principle, as previously described, for risk assessment, approval, trade and labelling of GM products. The former approach tends to favour either no labelling or voluntary negative labelling, indicating that the product is GM-free, while the latter tends to lead to mandatory positive labelling.[16]

With the exception of the NACs, the Cairns Group and some NFIDCs, many developing countries are now using careful approaches to controlling GMOs, though a large proportion of them have not yet established effective legislation. In the negotiation of the Biosafety Protocol at CBD, developing countries, excluding Uruguay, Chile and Argentina (members of the so-called the Miami Group), formed the 'Like Minded Group' to insist on strict regulations for transboundary movements of GMOs, including requirements for advanced informed agreement, labelling and the superiority of the protocol to WTO agreements. In addition, among countries that have already approved some GMOs or are equipped with regulations, most governments, with the exception of the USA, Canada, Argentina and a few Southeast Asian economies, have legislated some levels of mandatory labelling[16] (Phillips & McNeill, 2000).

The socioeconomic and political backgrounds to the cautious approaches taken by developing countries seem diverse. For instance, in the Philippines, where stringent national biosafety guidelines were introduced in 1991, campaigns of national and international NGOs have influenced public attitudes against GMOs and hence, to some degree, the political decision-making process. Aerni, Phan-Huy and Rieder (2000) report a survey that showed that NGOs and scientists expressed negative and positive views, respectively, on *Bt* rice, and government officials and politicians tended to have rather ambivalent attitudes, between those of the other groups. Since government now needs the cooperation of

[16] Sheldon and Josling (2002). Biotechnology regulations and the WTO. *Working Paper*, No.02-2, International Agricultural Trade Research Consortium (IATRC), available [March 2002] at http://iatrcweb.org/Publications.htm.

NGOs for sustainable development and people's empowerment, the officials and politicians seemed to have had some sympathy with NGOs, and they assented to the statement in the questionnaire that the NGO approach (Alternative Pest Management) might be a better strategy for resource-poor farmers to ensure their own food security. It is also noted that most of the respondents worried about the effects of GM technology on sustainable agriculture but not about the effects on human health. In Mexico, however, polarization of the views between political stakeholders was less significant. Respondents were more optimistic about the sustainability of GM maize, despite their concerns about inadequate biosafety regulations. Furthermore, Mexican NGOs also seemed to play a significant role in the political decision-making process (Aerni, 2001). In addition to the influence of NGOs, foreign aid interventions may affect the legislation process, especially when the government has a weak bureaucracy. Paarlberg (2002) describes the development of the Kenyan biosafety policies as shaped under the influences of its donor countries, the Netherlands and Sweden. Of course, the biosafety policies also depend on geographical and biological conditions. Countries with a diversity of wild crops, such as Mexico, with maize, and the Southeast Asian countries, with rice, may wish to select more cautious biosafety policies.

Generally speaking, risks for human health and wildlife are of less concern than economic and agrarian problems in developing countries. This conclusion derives from the reluctance of developing countries to include environmental protection or agricultural diversity in the WTO negotiations on non-trade concerns, which food importing, developed countries have strongly asserted. In the Biosafety Protocol of CBD, socioeconomic considerations on the effects of GMO introduction are also stressed. Furthermore, it is also possible that IPR claims by foreign corporations and fear about their power of market control may motivate concerns of NGOs; for example, the robust protests by farmers' organizations observed in India may indirectly affect the politics of biosafety. It is interesting to note that although social pathways toward GMO regulations in developing countries, differ from policies, in the EU and other OECD countries, that have been determined in terms of the precautionary principle, they have led to similar consequences in biosafety and labelling policies.

However, the outcomes of the similar trend in regulations may differ, depending on the self-sufficiency of basic food supply, purchasing power, the purpose of the GM product and market conditions. In net-food-importing, developed countries, biosafety and labelling policies may bring relief for consumers and competitive opportunities for domestic farmers and retailers in the value-added *niche* markets, in addition to the existing commodity market. For example, in Japan, approximately 80% of imported maize and soybeans are processed for animal feeds and vegetable oils, without any labelling or identity preservation, while some part of the rest is processed for ingredients in foods, for which mandatory labels are required, on the basis of detectable GM contents. Thus, for food which does not need labels, manufacturers and retailers can choose to enjoy either cheap GM ingredients or the added value of GM-free ingredients with premium prices. In contrast, in a NFIDC that has neither purchasing power nor a competitive food industry, biosafety and labelling policies may undermine the food security and viability of the food manufacturing and retailing sector. This is particularly the case when a GM crop forms a significant share of the global commodity market, and the conventional crop is directly consumed rather than processed for animal feeds in that country. The policies may also inhibit the domestic adoption of GM varieties, regardless of whether they are developed by public or private organizations. Alternatively, for developing countries with sufficient basic food production, policies in the food-importing countries may present risks in dealing with uncertain market conditions, as well as opportunities for entry into a newly segmented market for non-GM products. This might encourage the development of alternative technologies to achieve economic and environmental efficiencies comparable to those of GMOs. In any event, differing biosafety and labelling policies may alter the trade flows of agricultural products, and hence reconstruct global market conditions and trade policies.

9.6. Conclusions

Effects of policy selections on shaping socioeconomic conditions for the development, use and control of GMOs appear very intricate, since an option that directs a condition in one way may affect other policy options that may direct it in another way. As shown in Fig. 9.1, the possible effects seem, at least in part, twisted. In other words, the three trends of altering policies in each stage, that is IPR protection, trade liberalization and securing biosafety and labelling, do not always coincide with each other.

Stronger IPR protection sometimes leads to a monopolistic innovator who restricts competitive production in prices. Although stringent IPR protection does not necessarily contradict the competitive market, reconciliation between monopoly and competition has long been an issue in industrialized societies. In the reverse direction, low supply elasticity in prices, under the farm support policies, may allow farmers to expand their production with premium seed, which may increase demands for improved varieties with IPR protection. Thus, the trends in IPR protection and trade liberalization may contradict each other. However, in spite of the conflict, food-exporting, developed countries have insisted on strengthening both policies in the TRIPs

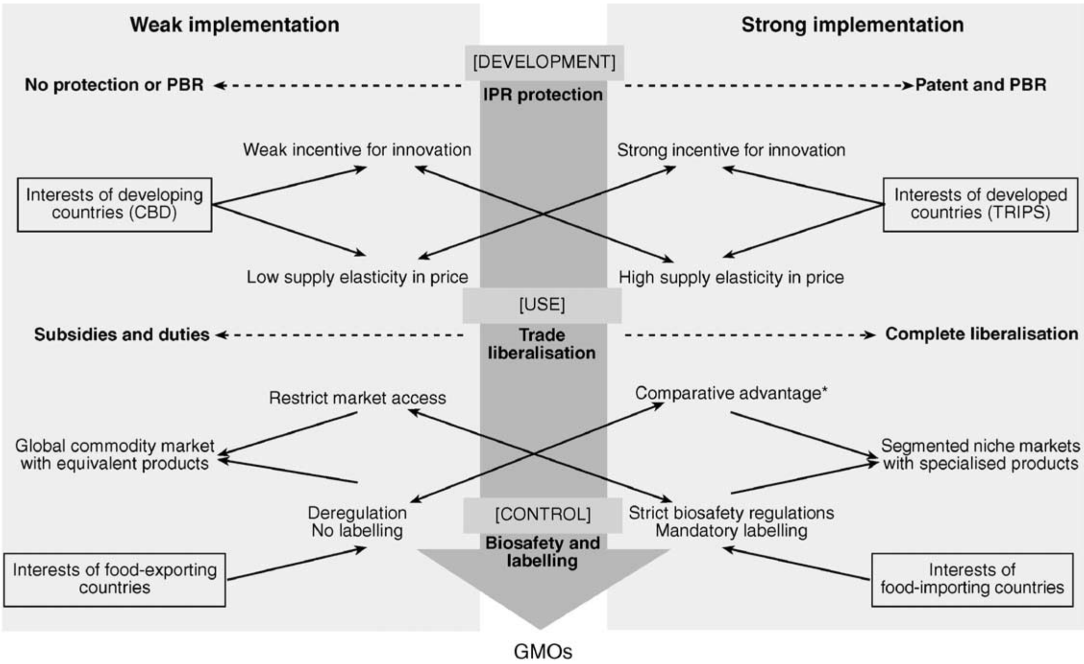

Fig. 9.1. Twisted cause–effect relationships in the policy options for shaping GMOs. → Arrows represent potential relationships; - - - - → Dotted arrows represent the scope of policy options. PBR, Plant Breeder's Rights; CBD, Convention on Diversity; TRIPS, Trade Related Aspects of Intellectual Property Rights. *The ability to produce a good at lower cost, relative to other goods, compared to another country, which leads to the specialization and expansion of its production under the trade liberalization

negotiations, whereas NFIDCs have opposed them both. This is the first twist in the cause-effect relationships. Generally speaking, the major inconsistency in developed countries resides between innovative incentive and competitive efficiency. In contrast, in developing countries, trade protectionism, despite stagnant domestic R&D under the weak IPR systems, worsens agricultural productivity and food supply.

In the second twist, trade liberalization and strict biosafety implementations with mandatory labelling contradict each other, as observed in the negotiations on the Biosafety Protocol. Nevertheless, trends in liberalization and biosafety may result in somewhat cooperative consequences. On the one hand, specialization of agricultural products, with particular values under the principle of comparative advantage in liberalized and deregulated market conditions, entails differentiation of products by a labelling system, with identity-preserved distribution, which may result in segmented *niche* markets for value-added products, including both non-GM and output trait GM crops. On the other hand, the commodity market for mass-produced grains may arise from protectionist farm support policies, which promise equalized returns, coincident with a norm that regards products derived from different regions and conditions as 'equivalent' commodities. Furthermore, strict biosafety and labelling policies may weaken the incentive of private firms to invest in R&D of GMOs for that country. Conversely, *ex situ* collection of genetic resources, induced by strong IPR, may conflict with *in situ* preservation of region specific crops by farmers' rights, as determined in CBD. In this sense, biosafety and labelling policies, at least in some cases, may conflict with IPR protection. This may represent the third twist.

Through these intricate interactions, particular characteristics of a GM variety have been and will be developed. The first generation of GMOs with input traits resulted from strong IPR protection and low supply elasticity in prices of farm products, under subsidized commodity agriculture. However, the commodity market for GMOs may have been inherently unstable because of the tension between the protectionist regime and emerging biosafety policy that has challenged the commercialization of the technology, particularly in food-importing countries. Accordingly, food-exporting countries have further promoted trade liberalization, though it may jeopardize the commodity market by cutting subsidies and introducing the principle of comparative advantage. It may also, therefore, reduce the profitability of farming with GMOs, predominantly in developed countries that have been supporting the agricultural sector and implementing stronger IPR protection. These outcomes may pose greater uncertainty in efficiency and equity of the adoption of input trait GMOs.

Subsequently, the second generation of GMOs, with value-added output traits, will emerge in conditions of strong IPR protection, high supply elasticity and strict biosafety policies. The high supply elasticity in prices, as well as emerging demands for value-added varieties with smaller markets, may make innovating firms vulnerable to uncertain market and regulatory conditions, with consequent impacts on returns from R&D investments for such GM varieties. This could accelerate the concentration of the agribiotech/seed industry. Thus, the segmented niche markets for both GMOs and non-GMOs also seem unstable.

It is not easy to forecast the future reshaping of GMOs, nor their effects SARD. Furthermore, the reality of the socioeconomic conditions that affect the shaping of GMOs is far more complicated than the simplified scheme presented herein. Even in this simplified framework, there is no single package of policy options that can establish appropriate development, use and control of GMOs. Nevertheless, the trends of IPR protection, trade liberalization and biosafety implementation seem inevitable, at least in the short term. Considering that conflicting interests and cause-effect relationships may create uncertain and unintended outcomes in the future of SARD, elucidating the origin of these contradictions may help to clarify the problems arising from these inevitable trends. Of course, some possible policies implied in the literature reviewed herein may reconcile such contradictions and contribute to diminishing the uncertain and unintended outcomes of GMOs. For example, strengthening public R&D and technology transferring organizations may help to reduce the conflict between incentives for innovation and efficiency in the competitive market. Alternatively, the standardization and reconciliation of international trade and biosafety policies may reduce uncertainty about the socioeconomic as well as ecological consequences of GMOs.

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