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potential for use in developing countries

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foreword

The impetus for undertaking this work was to provide an economic perspective on the ongoing debate into the adoption of advances in biotechnology. With the pace at which the technology is advancing and the potentially revolutionary impacts that its spread could engender, objective assessments of the likely socioeconomic and environmental consequences of GM biotechnologies have become imperative.

In this report, various biotechnology adoption regimes and trade scenarios are modeled using ABARE's global trade and environment model, which demonstrates that the largest gains from adoption occur in some of the poorer regions of the world.

While food security issues of socioeconomic instability and poor distributional infrastructure need to be addressed, it is shown in the report that biotechnology offers the prospect of a more secure food supply in developing countries through improved yields, improved suitability for local conditions and improved nutrition. The potential for higher crop yields for a given area of land also shows considerable promise for the preservation of natural ecosystems, with less of the natural environment needing to be cleared for food production.

In the 21st century, food security remains a matter of great concern for much of the world's population – and gene modification technologies have the potential to provide great benefits. This not to say that the potential risks from biotechnology should be ignored. Rather, scientific risk assessments coupled with economic assessments of the benefits and costs of all biotechnology applications are crucial.

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ABARE colleagues John Hogan, Graham Love and Troy Podbury reviewed the report, as part of the internal peer review system, and provided valuable comments. Neil Andrews provided insightful information on trends in support policies, particularly in the European Union.

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summary

Despite major advances in agriculture and strong growth in food production in the latter part of the twentieth century, hunger and famine are still common in many parts of the developing world. A combination of factors such as political instability and poor distributional infrastructure, together with a prevalence of subsistence farming and consequent low levels of farm incomes, have substantially impeded production and distribution of food commodities. Given that world population is forecast to grow from 6.1 billion in 2000 to around 9.3 billion people by 2050 — or by around 54 per cent in total — and that virtually all of the increase is forecast to occur in developing countries, the issue of household food security is again becoming an issue of concern.

While efforts to improve household food security in developing countries must necessarily address problems of extreme poverty, political instability, poor infrastructure and global trade issues, gene modification technologies show considerable potential to raise agricultural productivity for a given area of land. Genetic modification is the process of transferring some element of genetic code from one organism to another by the introduction of a vector, typically a virus or bacteria, or by other techniques for inserting foreign DNA, in such a way that it functions in the receiving species and is passed on from one generation to the next. This is done in order to provide that organism with new and useful characteristics.

The application of biotechnology techniques within the agricultural sector can potentially improve food security by raising crop tolerance to adverse weather and soil conditions; by enhancing the adaptability of crops to different climates; and by improving yields, pest resistance and nutrition, particularly of staple food crops. Over the past decade, the application of biotechnology to the problems in world agriculture has yielded significant productivity gains to producers. With advancements in GM technologies, and as market acceptance and availability of GM products increases, these benefits are expected to increase.

Economic assessment of biotechnology innovations

Whether the advent of biotechnology and its applications in various aspects of human activities is beneficial is a subject of an ongoing

vigorous debate between opponents and proponents of the technology. The major potential benefits include increases in productivity through a combination of lower production costs and higher yields. Besides generating higher economic growth, this will increase world food security and help prevent environmental damage from converting natural ecosystems into arable lands. The potential risks of biotechnology, in addition to the direct costs of investment and production, can be broadly categorised as: risks to the environment and the economics of food production (potential for development of resistant organisms and weeds, and potential loss of biodiversity) and risks to human health, mainly through potential impacts on food safety.

There is no doubt that modern biotechnology, like any new technology, has its associated benefits and risks. Objective assessment of the benefits and costs of individual applications of biotechnology is necessary in determining whether or not an application is beneficial. In attempting to analyse the benefits and risks, a framework for analysis, acknowledging that there are valid potential benefits and valid risk concerns from biotechnology applications, becomes necessary.

Objective analyses, using established scientific and economic techniques are important for benefit–cost assessment of biotechnology applications. Therefore, scientific assessments of risks to food safety and to the environment of biotechnology products need to be carried out on a case by case basis. Data on risk could then be used in conducting economic analyses of benefits and costs, to determine the socioeconomic feasibility of implementing biotechnology innovations.

Generally, there is a considerable degree of uncertainty in both the outcomes and the length of time before any returns to investment in research and development in biotechnology could be realised. The expected costs of capital investment in the technology could therefore be quite large. Investment will only take place if expected benefits exceed expected costs, at a given rate of return.

Moreover, the adoption of biotechnology may have considerable socioeconomic and environmental impacts other than direct benefits and costs to private producers. Exclusion of these from the decision making process would prevent socially preferable levels of investment from being realised.

To encourage research and development, and to influence the outcomes arising from such investments, governments use certain mechanisms and economic instruments. Most prominent among these, for recovering investment costs, is the protection of intellectual property rights through patent laws. Another policy approach for better allocating resources would be through suitable economic instruments, which include regimes of charges and subsidies on the activities generating external costs and benefits, respectively.

Relative impacts in developing and developed countries

Biotechnology applications in agricultural production could generate significantly different impacts in developed and developing countries, reflecting variations in production systems between the two groups of countries. Differences in input use, management practices and scale of operations are the main features underpinning the disparity between the two production systems.

The extensive use of Green Revolution technologies over the past four decades has resulted in agricultural production expanding in developed countries, largely because yields have increased significantly. Considerable increases in crop yields have also been realised over time in middle income developing countries. In low income developing countries, where the application of material inputs is quite low and agricultural operations are mostly carried out manually, yields have remained well below levels realised elsewhere.

As a consequence, gains in productivity from the introduction of transgenic varieties with improved agronomic traits are expected to be much greater in developing countries, particularly the low income countries. In most cases, however, data from field trials in developing countries themselves are not yet available for quantifying the agronomic benefits that could accrue from adopting transgenic crops. It may therefore be misleading to generalise and apply results obtained from experience elsewhere to estimate potential benefits to developing countries.

The adoption of transgenic crops, such as herbicide tolerant varieties, could also provide significant savings in farmers' labor and time as most of the agricultural operations in developing countries are carried out manually. This would enable farmers to diversify production or engage in other income generating activities. Beneficial health impacts of transgenic crops could also be significantly greater in developing countries, particularly to farmers where manual application of chemical inputs is the norm and safety measures are generally poor.

Developing countries could realise these benefits through a number of ways. They could acquire the technology by investing in research and development to develop ‘home grown’ innovations, obtaining biotechnology products through market transactions or both. Presently, however, there are barriers to investment in biotechnology research and development in the majority of developing countries.

Global investment and impediments to uptake in developing countries

The global area under transgenic crops has risen dramatically, from 1.7 million hectares in 1996 to 58.7 million in 2002. In 2002, four countries — the United States, Argentina, Canada and China — grew 99 per cent of global GM crops, with the United States accounting for about two-thirds of the total area. In contrast, the European Union grew virtually no commercial transgenic crops over the period.

To date, investment in biotechnology has been mainly undertaken by the private sector in developed countries, particularly in north America. The concentration of expenditure on biotechnology in the private sector is associated with intellectual property protection of emerging technologies, which allows the private sector to recoup the often high costs associated with developing new products. Initially, the crops that have been targeted for genetic modifications have mainly been those extensively grown in developed countries. More recently, significant research effort has been devoted to developing transgenic rice. There has been little research on dryland food crops commonly used in least developed countries such as sorghum, millet and cassava.

By contrast, and despite expected higher benefit–cost ratios from the technology, only few developing countries, such as Argentina, have had high uptake rates of GM crops, with uptake typically concentrated in crops that are exported to developed country markets. Few others (mainly China and India) have started exploring their own national research capability in biotechnology.

In the vast majority of developing countries, both investment in biotechnology research and development and the transfer to farmers of transgenic crops already being marketed have been generally low. These low rates reflect poorly functioning financial and economic markets, and political factors. They also reflect a lack of transparent regulatory capacity necessary in dealing with risks associated with biotechnology as well as in addressing the issues of property rights development and protection that are essential to promoting innovative research. This is particularly important because of the high cost of undertaking the initial research and development in biotechnology.

Overall, the major factor determining a developed country's adoption of GM technology is the attitude of governments and the public toward this technology. Although existing (and potential) EU trade barriers may have affected attitudes toward GM foods in some of developing countries, barriers to investment in and rapid diffusion of the technology are mostly attributable to insufficient technical and regulatory capacity.

Regulatory policies and trade

As GM technologies are very recent and fast developing, most governments are trying to keep pace by developing regulatory policies that reflect consumer demands and preferences affecting GM agricultural products. Almost all developed countries require products derived from GM sources to be assessed both for their safety as foods and for their environmental impacts. However, there are considerable differences in the approaches taken by different countries. In the United States, analysis and approval mechanisms for GM foods have been subsumed into existing regulations governing the release of new foods, plants and pesticides, whereas in the European Union, regulation of GM products requires considerable separate scrutiny. Countries worldwide are in different stages of policy development, with the majority of the developing countries still in the infant stage.

Developments in domestic and trade policies for GM products are likely to be an important factor in determining volumes and values of trade flows, and ultimately levels of investment and rates of diffusion of the technology. Conservative attitudes toward GM products in western Europe may continue to induce increasingly restrictive production and trade policies, with worldwide ramifications for research and development, rates of diffusion and consequently for the potential benefits of the technology, particularly in developing countries.

Given the tradeoffs between consumption benefits from GM products and potentially higher export revenue from non-GM products, exporting countries may therefore have to choose one of three possible policy actions. They could either adopt the technology, continue to produce only non-GM products to preserve the ability to export to the European Union or follow a market segregation policy — that is, producing non-GM products for the EU market and GM products for the domestic and other export markets. The course of action followed would depend importantly on the magnitudes of potential gains in domestic consumption, the change in export earnings (both with and without adoption) and the costs of segregation and labeling.

The extent of the benefits to be realised from the introduction of biotechnology in primary food production would importantly depend on developments in domestic support policies of major producing and trading developed countries. By largely insulating domestic producer prices from world price effects and increasing domestic production and supplies on the world market, high levels of support in developed countries, particularly the European Union and the United States, could substantially erode potential benefits from GM technologies.

Income impacts of adoption and trade policies

The economic effects in different regions of the world of adoption and trade policies for agricultural biotechnology are estimated under three different scenarios. Scenario simulations were carried out using ABARE's global trade and environment model. Economic impacts are measured for fourteen regions, with each region falling in one of three income groups (low, medium and high income).

Model scenarios and assumptions

The three scenarios simulated are:

Scenario 1 — All regions adopt GM technology;

Scenario 2 — All regions, except the European Union, adopt GM technology and the European Union institutes a ban on imports of GM products;

Scenario 3 — All regions, except the European Union and poorer developing countries, adopt GM technology and the European Union institutes a ban on imports of GM products.

In the scenarios analysed, biotechnology uptake and diffusion is considered to occur over a ten year period, 2006–15. Adoption of biotechnology is assumed to result in a uniform increase in productivity in all affected crop industries of 10 per cent over the period in high and middle income countries and 20 per cent for low income countries. The crops considered to be directly affected by biotechnology are: rice, grains, oilseeds, and fruit and vegetables.

In all scenarios, potential impacts of agricultural biotechnology on welfare were estimated as deviations from expected welfare under a reference case scenario without biotechnology adoption. Only direct impacts on costs and prices are considered in this study. Indirect impacts of introducing GM technology that could be significant — such as the net impact of biotechnology on human health and the environment — are not captured in the estimated results.

Main results of the model

A general conclusion to be drawn from the results of this analysis is that agricultural biotechnology could generate substantial economic gains in regions where it is introduced. The results suggest that, with full adoption of GM technology, aggregate income for all regions, measured by gross national product (GNP), is estimated to rise by US$210 billion a year, by the end of the period. With restrictive EU production and trade policies for GM products in the second scenario and, added to that, reduction in the scope of adoption by low income developing countries in the third scenario, gains in global welfare are estimated to be lower — US$167 billion and US$134 billion respectively.

Among different country groups, potential gains in GNP from the uptake of biotechnology are highest for developing countries, ranging between 2.1 per cent for low income regions and 0.5 per cent for middle income regions. These gains arise because the benefits to consumers through reduced prices for agricultural products are accentuated by the large share of food in total expenditure in these regions. Moreover, productivity gains for low income developing countries have been assumed to be above the world average in agriculture. As a result, crop production costs are projected to fall by more than prices received by producers, leading to increased margins for farmers and enabling low income developing countries to compete more effectively on global markets.

In comparison, increases in high income countries are estimated to be under 0.2 per cent of gross national product. Of these countries, the least changes in welfare from biotechnology adoption are estimated to occur in high income traditional exporting regions of north America and Australia – New Zealand where incomes are estimated to be largely maintained at the base case levels. Lower benefits for these regions reflect declines in terms of trade as developing countries increase their relative agricultural competitiveness. Besides relatively smaller consumption gains, the chief source of benefits in these regions arise from efficiency gains in related industries.

However, the results also indicate that even if the introduction of the technology may not lead to significant increases in economic benefits for these agricultural exporting regions, it would nevertheless be necessary to do so in order to avoid the substantial losses that could result from not adopting the new technologies while the rest of the world is implementing them. According to the model, for example, Australia and New Zealand might realise little or no welfare gain under these scenarios of GM technology adoption, but welfare could decline by US$1.1–1.4 billion a year if GM technologies were not adopted in these countries.

The impacts of increases in productivity on incomes in regions adopting biotechnology far outweigh the negative effects of restrictive policies on trade in GM food products instituted in another region, as shown by simulated restrictions in the European Union. In contrast, the welfare loss in the European Union from bans on the production of and trade in GM products could be substantial, with its gross national product estimated to be about US$13 billion a year less than under the reference case. By comparison, it is estimated that gross national product in the European Union would increase by about $21 billion a year on the reference case if it adopted the GM technologies.

introduction

The problem – feeding the world's increasing population

Despite major advances in agriculture and strong growth in food production in the latter part of the twentieth century, hunger and famine are still common in many parts of the developing world. A combination of factors such as military conflicts leading to the displacement of people, together with poor distributional infrastructure to maintain food supply lines, have resulted in considerable disruption to production and substantial wastage of food.

Further, the practice of subsistence farming in marginal lands where farms are typically small and crops reliant on often highly variable rainfall can result in food production in these regions being more prone to natural disasters such as droughts and other adverse weather events. Subsidised production in many developed countries distorts markets by increasing agricultural exports and forcing down world prices. This can increase developing world food imports and result in dependence on subsidised western production at the expense of local production and domestic economic growth, with long run negative impacts on food security.

These problems are not insurmountable. Indeed, world food production at present is sufficient to meet per person calorie requirements recommended by the World Health Organisation, but it would be inappropriate to suggest that developing countries do not need to aim to increase food production because existing major producers can increase production to meet the growing demand in developing countries. Investment in improved handling and storage facilities would do much to reduce wastage and spoilage; and trade reforms could also increase production opportunities and incomes in developing countries. Freeman et al. (2000) estimated a potential gain to developing countries of US$14 billion by 2010 from a 50 per cent reduction in agricultural support levels.

Nevertheless, with the world's population expected to rise strongly over the next fifty years — and with nearly all of the population growth to be centred in developing countries, there is a real prospect that the developing world may suffer from increasingly unstable food supply. In particular, the extreme poverty of many people in developing countries and the poor productivity of subsistence farming strongly contribute to low food security and periodic famine. In addition, if incomes in these countries grew, demand for improved diets high in protein could also rise, leading in turn to increased demand for feedgrains. Kalaitzandonakes (1999) indicates that income growth in developing countries quickly translates into demand for animal protein such as fish, poultry and red meat, enterprises that are feed grain intensive, and results in further increases in demand for agricultural products.

World population growth centred on developing countries

Over the next fifty years the world's population is forecast to grow by 54 per cent, from 6.1 billion in 2000 to around 9.3 billion people by 2050 (see box 1). All of the increase in population is forecast to occur in developing countries, with population in developed countries forecast to decline slightly over this period (United Nations 2001). The growth in population is projected to occur mainly in and around the tropics. The tropical belt is the world's principal reservoir of biodiversity, harboring up to 80 per cent of global genetic resources (Avery 2002).

As much of the developing world's most fertile land is already being cultivated, increased population pressure is expected to lead to the clearance and cultivation of more marginal lands with typically less fertile soils and/or located in lower rainfall regions. This would result in lower and more variable returns from agriculture and contribute to lower levels of food security in these countries. In addition, the consequent decline in the amount of land available for the natural environment would lead to further losses of biodiversity in these regions. Goklany (2000) estimated that between 1980 and 1995 developing countries lost 190 million hectares of forest mainly because the increase in food demand exceeded increases in agricultural productivity in these countries.

With increasing population pressure in developing countries it becomes paramount to find ways of increasing productivity on existing agricultural lands if food security is to improve and environmental damage is to be minimised. Advances in agricultural biotechnology are widely considered to have a key role in fulfilling these objectives.

The term 'biotechnology' covers a wide spectrum of technology applications, ranging from simple processes such as fermentation to highly sophisticated modern technologies such as genetic engineering. Whether the advent of biotechnology and its applications in various aspects of human activities is beneficial is a subject of ongoing vigorous debate between opponents and proponents of the technology.

Box 1: World population forecasts

According to the UN Population Division's *World Population Prospects: The 2000 Revision*, the world's population grew from 2.5 billion in 1950 to 6.1 billion in 2000 and is currently growing at an annual rate of 1.2 per cent or 77 million a year. The total world population is expected to grow at a slower rate in coming years but is forecast to be around 9.3 billion in 2050 under a medium growth scenario, compared with 10.9 billion under a high growth scenario and 7.9 billion under a low growth scenario (United Nations 2001).

Populations in the more developed countries are forecast to change little over the next fifty years from current numbers of nearly 1.2 billion people, with fertility rates expected to remain at or below the replacement rate. In less developed countries, however, population is expected to rise from 4.9 billion in 2000 to 8.1 billion in 2050 (using the medium growth scenario) despite an assumed fall in fertility levels.

Population growth is expected to be most rapid in the world's 48 least developed countries, where population (growing at slightly more than 2 per cent a year) is expected to almost triple from 658 million to 1.8 billion over the period 2000–50.

No doubt modern biotechnology, like any new technology, has its associated benefits and potential risks. Objective assessment of the benefits and costs of individual applications of biotechnology is necessary in determining whether or not an application is beneficial. This report deals with issues relating mainly to the use of biotechnology in the production of food crops, with particular reference to the benefits of biotechnology in developing countries. Estimates of the potential benefits in developing countries, measured in terms of increases in gross national product, from the use of agricultural biotechnology are also provided.

developments in agricultural technology

Classical crop breeding and its limitations

Agriculture began around ten to twelve thousand years ago, when hunter–gatherer groups, faced with periodic shortages of game and other staples, began to capture and domesticate wild animals and cultivate edible plants. Over succeeding generations, the nutritional qualities of various plants and animals were stabilised and improved. Continued cross breeding and selection, conducted mainly by farmers for desirable traits (so-called classical breeding) in plants and animals, have resulted in slow improvement in domestic species. From the nineteenth century, farmer driven improvement of crops gave way to a more systematic process of hybridisation and selection, as the profession of plant breeding emerged. This occurred without the benefit of genetic science but, despite this, crop varieties that were developed showed marked improvements in yields and disease resistance (Lemaux 2000).

In the twentieth century, the science of genetics began to influence crop breeding, first with knowledge of single gene inheritance and later with the understanding that numerous genes controlled quantitative traits, with each gene having a small effect. Lemaux (2000) indicates that despite crop breeders' recognition of the importance of genetic inheritance, a lack of gene manipulation technology meant that crop breeding in the twentieth century remained largely a process of trial and error. However, while these hybridisation and selection techniques resulted in wider varietal diversity in some of the world's major cereal crops, the task of introducing desirable traits through crossbreeding remained cumbersome and time consuming.

Although major genetic improvements have been made through hybridisation and selection techniques, there have been problems associated with the transfer of undesirable traits (particularly from wild varieties) along with the sought after traits, as it is not possible to transfer single genes through sexual hybridisation. However, the transfer of unwanted genes can be reduced by the use of gene mapping technologies (for example, using restriction fragment length polymorphism and bacterial artificial chromosome libraries). These technologies have allowed classical crop breeders to be more selective in incorporating certain segments of chromosomes into progeny (Lemaux 2000).

Despite these advances, classical hybridisation and selection techniques (sexual transfer of genes) remain limited by the fact that donors of new genetic material must be sexually compatible with the recipient species. Classical hybridisation and selection techniques are therefore limited to the breeding of close relatives of the crop, typically other domesticated hybrids of the same species and/or wild landraces, and do not allow the transfer of useful genes between nonrelated species as a means of acquiring desirable characteristics.

End of the Green Revolution – implications

Beginning in the 1960s, advances in classical crop breeding and farm management techniques resulted in massive growth in cereal crop production, and came to be known as the 'Green Revolution'. The Green Revolution was driven by a need to increase land productivity in areas with growing land scarcity and/or high cost land. Increased production was also achieved through a considerable amount of investment in agricultural research and infrastructure development, particularly in irrigation.

A feature of the Green Revolution was the relatively free exchange of plant resources and the unrestricted movement of genetic material. Local varieties and wild relatives from various countries were sent to the world's gene banks and international crop breeding programs. In return, improved varieties were provided to national breeding programs. After appropriate testing, varieties were released to farmers or selected traits incorporated into breeding programs (Rerkasem 1999).

Pingali and Heisey (1999) indicated that yield growth in the post Green Revolution period has been sustained by increased use of inputs (especially in Asia) and that, more recently, productivity growth has relied on increased efficiency of input use. However, Pingali and Heisey argued that growth in productivity in developing countries is slowing, giving the example of a recent smaller increase in productivity for two of the three primary cereals, rice and wheat. They attributed the slowing down of growth in productivity to three factors: degradation of the resource base due to intensive cultivation, declining infrastructure and research investments, and the increasing opportunity cost of labor.

Conway and Toenniessen (1999) suggested two factors as the cause of smaller gains in productivity on commercial farms: first, farm productivity on the best lands is now approaching yields achieved on experimental stations, leaving little room for productivity growth, and, second, that the cumulative effects of environmental degradation — partly driven by agriculture itself — are also contributing to lower productivity gains. They also indicated that the gains in food production growth from the Green Revolution appear to have reached a ceiling and concluded that, in a world where population and food needs continue to rise, the adoption of newer technologies such as genetic modification is an avenue for maintaining productivity growth.

The use of biotechnology in agriculture is not the only option available for improving productivity growth. Pingali and Heisey (1999) have said that while in the most intensively cultivated areas resource base limitations may be leading to slackening productivity growth, in many developing countries yield frontiers can still be shifted through improvements in the way fertilisers, pesticides and labor are used. However, for gains to be achieved, investments in agricultural research and education need to be maintained or increased.

Gene modification biotechnologies

Genetic modification is the process of transferring some element of genetic code from one organism to another organism in such a way that it functions in the receiving species and is passed on from one generation to the next. This is done in order to provide that organism with new and useful characteristics (Cunningham 1999).

Genetic material that supports desired characteristics may be sourced from virtually any species. In plants, genetic modification is commonly conducted by the introduction of a vector, typically a virus or bacteria, that can introduce new DNA to the plant genome (the set of chromosomes, containing all of the plant’s genes and associated DNA). Other methods of gene transfer technologies include: electroporation, where an electric current opens pores in cell membranes allowing insertion of foreign DNA; microparticle bombardment, where cell nuclei are penetrated by particles laden with new genetic material; and microinjection, where genetic material is directly injected into target cells (Lemaux 2000; Cunningham 1999).

These gene modification technologies show considerable potential to enhance human health and well being. They offer the ability to produce crops with novel characteristics such as higher yields, drought and salinity tolerance, pest and herbicide resistance, improved nutrition and even vaccines for many illnesses. The technology is a potentially powerful tool in helping to alleviate hunger and malnutrition in developing countries. However, the practice of gene modification of food crops is controversial, and the subject of considerable debate.

case for and against using biotechnology

Major arguments in favor of using biotechnology

Over the past decade, application of biotechnology to the problems of world agriculture has yielded significant productivity gains to producers. With advancements in GM technologies, and as market acceptance and availability of GM products increases, these benefits are expected to increase. The majority of 'first generation' transgenic crops have been developed to carry genes resistant to insects or herbicides. The insect resistant genes, or Bt genes (from the naturally occurring *Bacillus thuringiensis* micro-organism), produce a toxin that kills insects feeding on the GM crop, but is harmless to humans and animals.

The major potential benefits from the current generation of transgenic crops include increases in productivity from a combination of lower production costs and higher yields. Herbicide tolerant and insect resistant crops may lower chemical use in agricultural production. Results from a number of studies (reported in US Department of Agriculture 2001) show significant increases in the net returns to US farmers growing these crops. Depending on the crop variety and location, the increases in returns stemmed from combinations of reductions in the use of chemical inputs and farm fuel and, in many instances, increases in yield. Other factors were also found to contribute to higher returns, such as the ability of farmers to grow herbicide tolerant soybean and corn in alternate rows or in rotation. Balanced against these cost savings, growers have usually faced higher seed costs, with the need to purchase new seed each season.

Reductions in the use of chemicals in agriculture also have favorable impacts on human health and the environment. Roush (2002), for example, highlighted these impacts in the cotton industry in China, where there was an average of around 1000 reported insecticide poisonings and 400 deaths a year in conventional cotton growing areas. The adoption of Bt cotton resulted in an 80 per cent reduction in pesticide use in some regions. He also reported that 22 per cent of farm workers on conventional cotton farms in China had previously suffered from headaches, nausea, skin pain or digestive problems. This figure was reduced to 5 per cent for regions that adopted Bt cotton. Increased adoption of transgenic cotton in China is expected to lead to further improvements in mortality rates and health for cotton farm workers, particularly in newly adopting regions.

Genetically modified crops are expected to have positive effects on food safety, with lower chemical use in pest resistant crops resulting in lower incidents of chemical contamination of food production, particularly for fresh fruit and vegetables. Lower pesticide use is also expected to result in less chemical contamination of local water resources, and will benefit both human health and the local environment.

Reductions in chemical applications also benefit the environment in other ways. By reducing the need for conventional tillage necessary for weed control, herbicide tolerant GM crops could be grown with minimum or no tillage. This would result in reductions in farm fuel consumption. Besides lower costs to farmers, reductions in fuel use would generate environmental benefits in terms of reductions in greenhouse gas emissions. A study in Canada (Brethour et al. 2002) shows that by using a soybean variety tolerant to the herbicide glycophosate, farmers can reduce fossil fuel use, reduce greenhouse gas emissions, reduce applications of pesticides and reduce soil erosion. Strong environmental benefits also accrue from reduced exposure of nontarget species to indiscriminate eradication through high rates of pesticide application.

In areas where there is widespread use of Bt and herbicide resistant crops, growers of non-GM crops have benefited as suppliers of herbicides and insecticides have reduced the prices of these chemicals as chemical companies push to maintain sales of these products (McGloughlin 1999).

Succeeding generations of transgenic products (sometimes known as ‘second generation’ transgenic crops) are intended to improve productivity by increasing tolerance to other stresses such as frost, drought and salinity; by influencing rates of growth and maturity in plants and animals; and by introducing various quality improvements in products, such as modifications to increase oil or protein content, to make them more attractive to consumers (US Department of Agriculture 2001).

In addition, research is progressing to genetically modify some crops to produce varieties with high value industrial properties and pharmaceutical qualities, such as incorporating vaccines for many common illnesses (‘third generation’ transgenic crops). For many poor communities in developing countries, it may be easier and cheaper to grow foods with medicinal properties than it is to pay for medicines that may be inaccessible because of high cost, poor supply lines or a lack of suitable storage facilities (Arakawa 1998).

Of particular relevance to problems of hunger and malnutrition in developing countries is the potential for biotechnology to increase the nutritional value of food. Gene technology can enable the production of new crop varieties that produce essential vitamins and trace elements. This is especially important in regions where access to food is limited and balanced diets are difficult to achieve. An example of this is the development of ‘golden rice’, a crop that has been genetically modified to produce vitamin A, which is necessary to reduce the incidence of blindness (due to vitamin A deficiency) in children for whom rice makes up a disproportionate part of the diet. Among genetically modified food animals, the development of significantly faster growing fish species (particularly salmon) could potentially increase food supplies at low cost. Farming of these genetically modified fish would also have health benefits, derived from higher consumption of omega 3 fatty acids, which have demonstrated strong benefits in reducing cardiac and other health problems (Kris-Etherton, Harris and Appel 2002).

Productivity increases afforded by biotechnology could make it possible to achieve the dual purpose of meeting current and future food demands for rapidly growing populations, particularly in developing countries, while reducing the need to encroach on lands supporting natural ecosystems. The rate of growth in productivity is crucial in determining whether it would be necessary to bring new lands into agricultural production to meet expected demand for food. Goklany (1999) shows that if the average annual increase in land productivity were just 1 per cent, the world would need to convert over 300 million hectares of new land into agricultural production by 2050. In contrast, a 1.5 per cent a year increase in productivity could double output on existing cropland over the next fifty years, without the need for additional conversion of natural ecosystems.

Major arguments against using biotechnology

In addition to the direct costs of investment and production, the potential risks of biotechnology can be broadly categorised as: risks to the environment and economics of food production (potential for development of resistant organisms and weeds and potential loss of biodiversity) and risks to human health, mainly through potential impacts on food safety. For a summary of the often raised concerns see Altieri and Rosset (1999).

Altieri and Rosset (1999) and others have argued that the transmission of genetic material from GMOs could have adverse effects on the environment as well as on crop production. On the environmental risk, one of the major concerns is the possible transmission of transgenes to the wild relatives of the GM crop through crossbreeding. Of particular concern is the potential development of 'superweeds' as a result of wild plants acquiring the genes that are responsible for herbicide resistance over time. This could result in these species outcompeting wild species and causing a reduction in biodiversity. Also, control of these 'superweeds' would come at a higher cost to the farmer and might have a negative impact on farm productivity.

The evolution of herbicide tolerant weeds through gene flow is not a problem that is exclusive to GM crops; gene flow from conventionally bred crops to wild species is already occurring. The presence of strains of rye grass that are resistant to the common herbicide glycophosate in Australia has been detected in areas where no GM crops have been grown (Glover 2002). For proper evaluations of the environmental risks from gene flow, this factor needs to be taken into account.

It was recently reported that GM transgenes may have been assimilated into wild landraces of maize (teosinte). These wild landraces are the origin of modern maize varieties in Mexico, the centre of genetic diversity for these landraces (Quist and Chapela 2001), so threatening the biodiversity of the species. Subsequently, other scientists have challenged the methodology used in that study (Prakash 2002). Being an open pollinated species, biologically diverse gene flow is natural and expected. As the International Maize and Wheat Improvement Center (CIMMYT) has said, current knowledge and theory in maize genetics suggest that there should be little impact on genetic diversity when a single gene is introduced into the genetic background of an established variety. Most genes in maize are independent, meaning that they will diffuse independently through a population rather than remain linked to other genes in the population. If a gene confers a selective advantage, it will increase and spread through the population (CIMMYT 2002).

There are also concerns that pesticide resistant crops could have negative effects on nontarget insect species. For example, there have been claims that, in north America, windblown pollen from Bt corn fields landing on surrounding vegetation could kill the larvae of Monarch butterflies feeding on milkweed (Losey, Rayor and Carter 1999). However, being relatively heavy, corn pollens do not disperse widely and the possible impact of Bt crops on nontarget species is generally recognised as being far less than the impact of conventional area spraying of pesticides that can affect a wider spectrum of insects. Based on a two year study, Sears et al. (2001) concluded that the impact of Bt corn pollen on Monarch butterfly populations is negligible.

Another environmental risk relates to animal species that have been modified to show novel or enhanced qualities. Following the recent development of a faster growing GM salmon for aquaculture farming, it is argued that the escape of such a fish to open waters might have a drastic effect on wild salmon populations. (A genetic 'promoter' from other fish — flounder or ocean trout — is used to make the fish's growth hormones flow all year long instead of for only a season at a time. The result is a fish that reaches full size a year or so before its genetically unchanged cousins. The fish do not grow any larger in the long run, and could potentially save producers money by reaching the market a year earlier.) Although the company currently involved in breeding the fish says that only sterile fish will be used for aquaculture production and so would be incapable of breeding in the wild, some critics have claimed that this cannot be guaranteed. They have also argued that the salmon's faster growth rate would result in greater predation on other fish species, upsetting the natural balance (University of Minnesota 2002).

Altieri and Rosset (1999) also raised the concern that genetic biotechnology could have adverse effects on human and animal health or result in potentially harmful migration of transgenes. A potential exists that genetic modification of foods for human consumption could lead to the development of allergens and toxins in the modified products. Regulatory authorities are generally aware of such concerns and this is seen by most authorities as a major reason for requiring stringent testing to be undertaken prior to genetically modified foods being approved for release.

Need for objective assessment of benefits and risks of biotechnology

In attempting to analyse the benefits and risks associated with the application of biotechnology to the problem of food security, a framework for analysis becomes necessary. Young (quoted in Van der Sluis, Dierson and Dobbs 2001) developed a set of principles to ensure objectivity in the arguments and, as a result, advance the debate on the effect of such new technologies.

The first principle is that both proponents and opponents of biotechnology have the common goal of responsible use of biotechnology. Without acknowledgment of this fundamental factor, there can be only limited progress in achieving a constructive dialogue among people and groups with differing stances on the issue of the application of biotechnology.

The second principle is that there are valid potential benefits from biotechnology and valid concerns about the potential impact of biotechnology. Acknowledgment of both the benefits and risks of biotechnology improves the transparency of discussion and allows for interested individuals and groups to make informed choices.

The third principle is that evaluation of biotechnology and its applications should be based on existing scientific principles. A scientific analysis must be comprehensive and evaluate the entire system, rather than focusing on details that tend to obstruct discussion on the issue.

The fourth principle is that both proponents and opponents of biotechnologies should refrain from exaggeration and sensationalism in discussing the benefits and risks of the technology. Neither benefits nor risks should be overstated. Rather, both risks and benefits should be objectively scrutinised.

For example, benefits attributed to ‘golden rice’ are conditional on other factors. First, for beta-carotene — a precursor to vitamin A — to be active, it must be split by an enzyme. Second, both beta-carotene and vitamin A are soluble in fat only. Therefore, a diet containing a sufficient amount of fat is necessary for ‘golden rice’ varieties to be effective in eliminating vitamin A deficiency (Van der Sluis et al. 2001). The overall benefits from golden rice could be overstated if these factors were not taken into account when assessing the benefit from reducing deficiencies in vitamin A.

Similarly, it must be recognised that environmental risks could differ widely between different environments. In order for gene transmission to take place between different species, there must be sexually compatible wild relatives of that particular GM crop in the region. In many countries the major staple crops are exotic plants that either have few wild relatives or reproduce asexually. For example, the majority of rural populations in poor tropical regions depend in their diet on root crops, such as cassava and taro, the productivity of which could be increased through biotechnology with virtually no risk to the environment in the form of gene flow.

In addition, the likelihood that transgenes responsible for herbicide resistance would remain stable in a weed population in the absence of continued herbicide selection pressure is considered to be minimal. A recent Australian study (quoted in Glover 2002) compared the persistence of GM insect resistant cotton with non-GM cotton and found no significant fitness advantage conferred by the transgene. It should also be recognised that gene flow between related species is a natural ongoing process. Further, the evolution of herbicide tolerant weeds through gene flow is not a problem that is exclusive to GM crops, but gene flow from conventionally bred crops to wild species is already occurring.

When considering human health and food safety concerns it is necessary to conduct rigorous scientific assessments to ensure the safety of new products. Testing so far has shown that genes and their associated proteins do not change character when inserted into a different species (McHughen 2000). If a gene produces an allergenic protein in one species, it will likely do so in a new species. Similarly, if a gene is nonallergenic in one species, it is not likely to become allergenic when transferred into another. Nevertheless, governments in most developed countries have introduced through legislation strict regulatory procedures that must be followed for comprehensive testing of genetically modified products before they are approved for release.

In broad terms, prudential oversighting and testing of GM technology must be carried out to identify issues related to the growth, consumption and release of GMOs into the environment, so that informed decisions can be made about the risks in advance of any potential release. Risks from biotechnology need to be assessed against those from other production technologies, such as risks to nontarget insects from biotechnology versus risks from higher pesticide applications in traditional varieties. Clearly, for a given level of returns, GM technologies that posed greater risks to human or animal health and/or have the potential for greater environmental damage than alternative technologies would be unlikely to be offered for regulatory assessment or gain government approval for commercial release.

economic assessment of biotechnology innovations

Without objective analyses using established scientific and economic techniques it would be difficult to judge whether the benefits of a biotechnology application exceeded its associated risks. Therefore, scientific assessments of potential risks to food safety and to the environment of biotechnology products need to be carried out on a case by case basis. Data on risk assessments could then be used in conducting economic analyses of benefits and costs to determine the socioeconomic feasibility of implementing biotechnology innovations.

External impacts and private versus public decisions

As discussed earlier, some applications of biotechnology may have socioeconomic and environmental impacts in addition to the direct benefits and costs to private producers. Moreover, there is a considerable degree of uncertainty about both the outcomes and the length of time before any returns to investment in research and development in biotechnology can be realised. The expected costs of capital investment in the technology could therefore be quite large. Private investment in a particular form of biotechnology development will only take place if expected private benefits exceed the private expected costs, at a given rate of return. However, because public and private costs and benefits may differ, the pattern of private investment in biotechnology may not be the optimal from a social perspective — for example, where there is a large number of diffuse beneficiaries.

Differences in public and private net benefits can emerge if market mechanisms are not sufficiently well developed to allow all those affected by an investment to transmit their demands to investors through the market price system. In such cases governments may have a role to implement policies that facilitate more efficient market operations. The key point in these cases is that the benefit of government intervention must exceed the cost of that intervention.

Government role

To encourage research and development and to influence the outcomes arising from such investments, governments use certain mechanisms and economic instruments. A properly defined, assigned and secure system of property rights, where a free market in resource entitlement and use is created, is one mechanism for ensuring the more efficient use of resources. Mechanisms for recovering investment costs through the protection of intellectual property rights include patents, plant breeders' rights and other sui generis systems. Well defined intellectual property rights reduce transaction costs associated with negotiation and enforcement of contracts (Fulton and Giannakas 2001). In turn, this encourages investment in and speeds up the diffusion of biotechnology both locally and globally.

Another policy approach sometimes considered when dealing with externalities is direct government intervention through suitable economic instruments — these include regimes of charges and subsidies on the activities that generate external costs and benefits respectively. The premise is that a complete internalisation of external costs and benefits through these policy measures would send new price signals to induce investors to make market based decisions that maximise both their profit and the welfare of society.

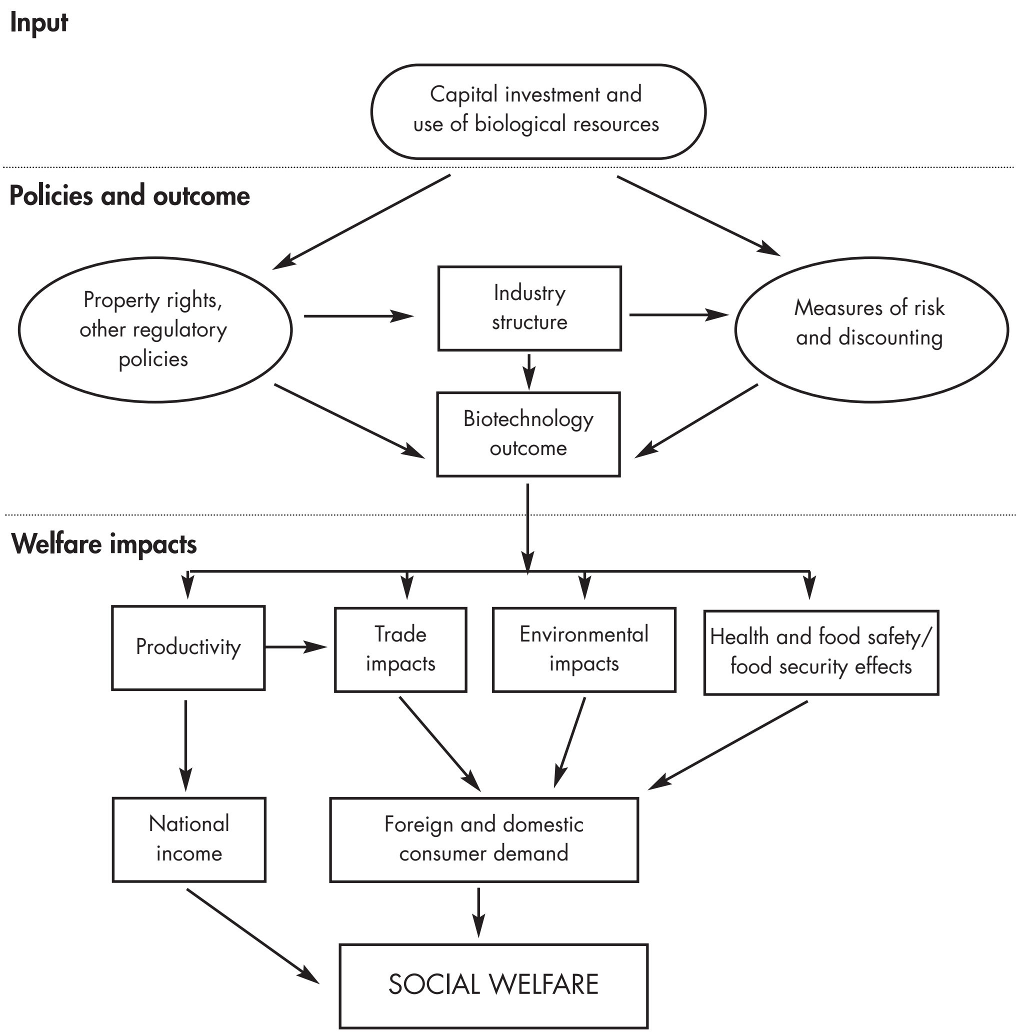
For a number of reasons, however, it is very difficult in practical terms to obtain economically superior outcomes through direct government interventions. First, in the majority of cases where externalities exist, perceived benefits and costs have nonmonetary values that are difficult to express in monetary units. This makes it difficult, in many instances, to estimate the net impact, which is crucial in guiding intervention decisions. Second, although an economic activity may potentially generate net external impacts of estimable size and direction, it is quite possible that the cost of regulation outweighs potential benefits of eliminating these impacts. Clearly, for such economic activities, one would opt for a policy of no intervention. Nevertheless, many countries have chosen to regulate GM crops.

Framework for assessment

Benefit–cost analysis provides a sound economic framework for systemic socioeconomic assessment of biotechnology innovations (figure A). To achieve a level of investment that is socially optimal, mechanisms to enable private investors to undertake comprehensive assessments of future benefits and risks (private and external) of biotechnology applications need to be in place. In determining expected costs, it is the relative rather than absolute risk that is relevant in economic analyses. It is important to compare the risks of biotechnology with the risks of competing technologies — for example, pesticide application versus Bt crops, or growing a GM crop with higher productivity versus clearing additional land for production of conventional varieties.

A suitable rate of discount to approximate society's preference through time would need to be applied to the future stream of net benefits to obtain its present value. The present value of estimated net benefits would determine whether investment should be encouraged (positive net benefit) or discouraged (negative net benefit). The size of the present net benefit of external effects dictates to what extent should investment be encouraged/discouraged in order to achieve socially preferred levels of resource commitment to this activity.

A Socioeconomic impacts of biotechnology



encouraging the use of agricultural biotechnology in developing countries

Relative impacts in developing and developed countries

Biotechnology applications in agricultural production could generate significantly different impacts in different societies. As production environments vary between localities, the benefits generated by gene modifications targeting the agronomic traits of field crops are also expected to differ. Nowhere are differences in production systems more pronounced than those between production systems in developed and developing countries. Differences in input use, management practices and scale of operation are the main features underpinning the disparity between the two production systems.

Over the past four decades, agricultural production has been expanding in developed countries, largely through significant increases in yields. Abundant use of chemical inputs and highly mechanised agricultural operations have enabled commercial production on a large scale and pushed yields close to maximum attainable limits. (Ismael, Bennett and Morse 2002). Considerable increases in yield have also been realised in many middle income developing countries over the past forty years, particularly for major grains such as rice and wheat. In comparison, agricultural production in low income developing countries has mainly come from smallholder subsistence production, where application of material inputs is quite low, reflecting their high cost relative to income levels, and agricultural operations, like weeding, are mostly carried out manually. Yields have remained well below those realised elsewhere, leaving large margins for potential increases with relatively smaller effort (Qaim and Zilberman 2003).

As a consequence, gains in productivity from the introduction of transgenic varieties with improved agronomic traits are expected to be much greater in low income developing countries. While the impact of current transgenic crops on yields in developed countries is generally considered to be insignificant, the introduction of Bt cotton in South Africa is estimated to have increased the yield achieved by adopters by an average of 46 per cent over nonadopters (Ismael, Bennett and Morse 2002). It is also reported that the introduction of transgenic rice in Asia could result in increases in production of 15–25 per cent over the next decade (Nielsen and Anderson 2001). Yield increases in food crops would greatly enhance the capacity of developing countries to reduce food insecurity.

Direct consumer and producer benefits flowing from increases in productivity could be estimated fairly easily, given availability of data from the relevant production system. In most cases, however, data from field trials in developing countries themselves are not yet available for quantifying the agronomic benefits that could accrue from adopting transgenic crops. It could therefore be misleading to generalise and apply results obtained from experience elsewhere in the world to estimate potential benefits to developing countries.

The adoption of transgenic crops, such as herbicide tolerant varieties, could also provide significant savings in farmers' labor, enabling them to diversify production or engage in other income generating activities. However, labor displacement may not be beneficial in regions where there are large numbers of landless workers with little prospect of employment elsewhere. In addition, the beneficial health impacts of transgenic crops could be significantly greater in developing countries than in developed countries, particularly to farmers where manual application of chemical inputs is the norm and safety measures are generally poor or lacking (Roush 2002).

Contrary to the case for the benefits, the impacts of the risks from biotechnology on different societies are likely to be much less variable. The higher benefits of agricultural biotechnology use in developing compared with developed countries, coupled with the similarity in the risks faced by the two groups of countries, indicate that the benefit–cost ratio of technology adoption could be considerably higher in the former group of countries.

Developing countries could realise these benefits in a number of ways. They could acquire the technology by investing in research and development to develop 'home grown' innovations, obtaining biotechnology products through market transactions or both. Presently, however, a combination of factors impedes the rapid introduction and diffusion of the technology in these countries.

Global investment and impediments to uptake in developing countries

The global area under transgenic crops has risen dramatically, from 1.7 million hectares in 1996 to 58.7 million hectares in 2002. In 2002, four countries grew 99 per cent of global GM crops: the United States, which grew 39.0 million hectares (66 per cent of the world total), Argentina 13.5 million hectares (23 per cent), Canada 3.5 million hectares (6 per cent) and China 2.1 million hectares (4 per cent) (James 2002). These estimates may well understate the actual area of GM crops. Although it is illegal to grow GM crops in Brazil, many Brazilian farmers already grow them, using seed smuggled in from Argentina. It has been estimated that up to 30 per cent of Brazil's soybean crop, or over 4 million hectares, is produced from GM seed (Gobbi 2000). In contrast, the European Union — despite having strong public and private life-science capabilities — grew little commercial transgenic crops over the period.

To date, investment in biotechnology has been mainly undertaken by the private sector in the developed countries, particularly in north America. The concentration of expenditure on biotechnology in the private sector is associated with intellectual property protection of emerging technologies (McCalla and Brown 2000). Intellectual property protection allows the private sector to recoup the often high costs associated with developing new products. Research has concentrated on three crops — cotton, hybrid maize and soybeans — and some speciality crops with commercial value. Oehmke (2002) investigated public sector and private sector research orientations in transgenic biotechnology races in the United States. He found that public universities seem to engage in research and development for smaller markets in which multinational firms have little interest. Generally, the crops that have been targeted for genetic modifications are those extensively grown in developed countries. More recently, however, significant research effort has been devoted to developing transgenic rice varieties. There has been little research on food crops commonly used in developing countries in Africa, such as sorghum, millet and cassava.

By contrast, and despite expected higher benefit–cost ratios from the technology, only few developing countries, such as Argentina, have high uptake rates for GM crops. Typically the uptake is concentrated in crops that are exported to developed country markets. Few other developing countries have started exploring their own national research capability in biotechnology. Countries that have, like China and India, are targeting benefits through implementation of biotechnology in their farm sectors (Kalaitzandonakes 1999). China in particular is developing a very large biotechnology capacity, second only to that in north America (Huang et al. 2002). The GM crops in trials include rice, wheat, cotton, tomatoes, potatoes and peanuts.

In the vast majority of developing countries, both investment in biotechnology research and development and the extent of transfers to farmers of transgenic crops already being marketed have been generally low or lacking. Low investment is largely a reflection of severely limited economic and technical capabilities. These limitations are symptoms of ill functioning financial and economic markets and political institutions. There is also a lack of transparent regulatory capacity necessary to deal with the risks associated with biotechnology as well as to address the issues of property rights development and protection that are essential to promoting innovative research. Tzotzos (1999) suggests that biotechnology regulation in developing countries has been introduced mainly in response to trade considerations, without any notion of promoting domestic industries.

A key reason why investment in biotechnology is not widespread in developing countries is the high cost of undertaking the initial research and development and the lack of adequate mechanisms for cost recovery. The cost of developing a new transgenic plant commercially has been compared with the estimated cost of over US$150 million to develop a new plant protection chemical (Richer 2000). The Green Revolution of the 1960s and 1970s took place in mainly public sector research institutions in an era when there was relatively open access to genetic resources. In contrast, the biotechnology revolution is being led largely by a relatively small number of life science companies operating at a global scale. This could slow the rate of private investment in developing countries, particularly in poorer countries where capital markets are not sufficiently developed to allow for full potential benefits from biotechnology applications to be realised.

All these factors combine to lower relative expenditure on and discourage both local and foreign private investment in agricultural biotechnology in the developing world. Reflecting this, agricultural biotechnology research in developing countries is largely undertaken by the public sector.

In summary, the major factor determining a developed country's adoption of GM technology is the attitude of governments and the public toward this technology, as demonstrated in the contrast between the United States and the European Union in sowing GM crops. In developing countries, barriers to adoption relate to developing countries being able to gain access to financial and technical assistance for the required investment in GM technology.

Role of sociopolitical infrastructure in farmer uptake of GM technology

Consumer attitudes can have a considerable bearing on the rate of uptake of GM technology, with consumer acceptance varying widely between consumers from different regions and education levels. Hoban (1996) showed that education is a major factor in consumer attitudes to GM foods, with a strong positive correlation between education and consumer acceptance. The study, conducted in the United States, showed that more highly educated consumers not only had higher acceptance of GM foods but that they actively sought out new products on the basis of improvements in taste and nutrition. Conversely, much of the resistance toward GM products came from people who did not understand the technology or the reasons for using it.

More recently Hoban (2001) has compared the results of surveys of consumer support for four applications of biotechnology undertaken in both the United States (in 1998 and 2000) and Europe (1996 and 1999). The results are shown in table 1. Support for biotechnology is generally greater in the United States than in Europe, with support increasing in the United States between 1998 and 2000, but decreasing in Europe between 1996 and 1999.

What is interesting is that consumers in both the United States and Europe consider that agricultural biotechnology tends to be less acceptable than is medical biotechnology. People are likely to trust the advice of their doctors without question but, as Hoban (2001) notes, when it comes to making choices about foods they feel qualified to make their own decisions and are more risk averse.

Other factors also play a role in consumer attitudes toward GM foods. In the European Union, the recent BSE (bovine spongiform encephalopathy or 'mad cow' disease) crisis damaged

1 Consumer support for applications of biotechnology

	United States		Europe	
	1998	2000	1996	1999
	%	%	%	%
Human genetic screening	70	84	75	63
New human medicines	80	79	71	57
Insect protected crops	66	71	58	42
Improved foods	58	60	44	31

European confidence in food safety (US Department of Agriculture 2001). In the United Kingdom, initial reports of a link between beef consumption and variant Creuzfeld-Jacob Disease (vCJD) were met with strong government denials. These denials continued against a background of mounting evidence showing that consumption of infected beef products was indeed linked to vCJD in humans. The BSE crisis resulted in considerable damage to consumer confidence in government regulatory agencies and agribusiness groups.

This lack of confidence has extended to include a particularly negative view of GM foods and the companies that create and market these products. These negative views are further promoted by some environmental activist groups, and have been assisted by the ongoing efforts by the European Union to maintain trade barriers against agricultural imports. The overall result is that consumers in the European Union have been exposed to a significant amount of information against the use of GM technology, while uptake of GM products in the European Union has remained relatively low.

Developing countries have had little access to GM resources. This lack of access together with existing (and potential) EU trade barriers have affected attitudes toward GM foods in developing countries, particularly in poor southern African countries. In August 2002, despite a severe food shortage in the region, the governments of Zambia and Zimbabwe initially rejected food aid containing GM corn from the United States on the basis that such food was perceived to be a danger to human health. It is reported that President Mwanawasa of Zambia even went so far as to describe GM maize as ‘poison’, while many people in the region continued to starve (BBC News, World Edition, September 2002).

While some governments in famine affected regions in Africa have since allowed GM food aid into their countries — Zimbabwe, Mozambique and Malawi — this has only been possible with the milling of GM grain to ensure that no GM crops could be grown from such aid. This is largely because some of these countries (notably Zimbabwe) are potential grain exporters to markets in the European Union. Maintaining a GM free status is seen as a way of protecting a grain exporting country’s market share, despite the clear advantages that GM crops offer to both farmers and the hungry at home.

In spite of this uncertainty, a survey of developing countries in 1999 revealed that many developing countries felt that the application of biotechnology advances could help their country meet the major challenges of feeding expanding populations while their land base and water resources faced growing pressures. In addition, the growth of bioscience based industries would help alleviate poverty by stimulating an associated growth in employment (Persley 2000). In turn, an improved economic environment and higher income levels will induce investment in other agricultural technologies, such as application of fertilisers and agricultural mechanisation, further enhancing agricultural production and its contribution to overall economic growth.

Need for a sound regulatory system

For developing countries to pursue biotechnological opportunities it is crucial that they have effective regulatory systems in place at national and institutional levels compatible with international best practice, and trained personnel to establish and manage these systems.

Developing countries face a variety of policy choices that will determine the uptake and the spread of agricultural biotechnologies in their country. The spread of GM crops in developing countries will depend not only on the availability of suitable technologies, but also on the willingness of authorities in developing countries to grant permission to plant GM crops. This in turn will depend on external pressures and influences faced by the regulators on any known risks to human health and safety and to the environment from GM crops.

Paarlberg (2000) has graded the policy choices open to developing countries in terms of whether they will promote or prevent the use of the new technology. Policies have been ranked from 'promotional' (policies that accelerate the spread of GM crops and foods), to 'permissive' (policies that are neutral toward the new technology), to 'precautionary' (policies that tend to slow the spread of GM crops and foods), and 'preventive' (policies that tend to block or ban the spread of new technologies).

The key regulatory areas as identified by Paarlberg (2000) are:

- Intellectual property rights. Developing countries are likely to have to recognise some of the intellectual property right claims of the private companies developing GM crops if they wish to expand the uptake of GM crops into their farming systems.

  The application in a developing country of a full patent protection policy as occurs in the United States would enhance the spread of GM crops as private companies would be more likely to invest in such countries. At the other extreme, the absence of any intellectual property rights policy would tend to discourage private sector investment.

- Biosafety. Countries must decide on how they manage the introduction of new plant varieties, particularly the level of testing and screening undertaken prior to the release of such varieties. The release of GM crops and foods would be hindered as the degree of testing and screening required was increased. A promotional policy would involve little or no testing while a preventive policy would ban GM crops on the basis of potential damage to related species and varieties.

- Trade. The trade policy that a country adopts can be influenced by the degree of consumer and importer acceptance of GM crops in international markets. For instance, countries that rely heavily on exporting commodities to Europe or Japan may steer away from encouraging investment in biotechnology advancement for these commodities. A promotional trade policy would not discourage the import and production of GM crops.

- Food safety and consumer choice. The degree of specific food labeling for and segregation of foods containing GM ingredients can determine the acceptance of GM foods in local markets. Policies could range from no specific labeling or segregation to a complete ban on the sale of GM foods. However, in many developing countries the lack of adequate refrigeration, unclean water and other infrastructure failures may be considered as more serious health hazards than any possible hazards associated with GM foods.

- Public research investment. Economic benefits have generally flowed to developing countries in the form of higher farm productivity as a result of public investment in agricultural research. Developing countries generally face a shortage of funds and limited donor funding to finance investment in biotechnology applications. Biotechnology research can be expensive, and researchers and investors must choose the crops and the level of research that give the highest returns. Options for government range from fully funding biotechnology research to leaving such research to the private sector. Byerlee and Fischer (2002) propose public–private partnerships, where complementarities between the two sectors can be fully exploited through specialisation and market segmentation, as a way to improve research and development in biotechnology in developing countries.

Intellectual property rights

Given that a major proportion of development in agricultural biotechnology is undertaken by the private sector, a key reason why there is limited investment in developing countries is the lack of a regulatory system governing the protection of intellectual property rights.

The term 'intellectual property rights' is a broad term used to cover patents, trademarks, plant breeders' rights and copyright. The critical issue in terms of agricultural biotechnology is the application of patents, although copyrights are becoming more important, as the databases that hold information about plant genes can be copyrighted. The principal public policy rationale for intellectual property rights is that they provide direct socially beneficial incentives to innovate and they facilitate further innovation by requiring public disclosure of the patented technology (Pardey, Wright and Nottenburg 2001).

A patent grants the owner of an invention monopoly rights to use the invention for a period of up to twenty years in the country where the patent is granted. The patent allows the owner to exclude others from using the invention commercially in that country. As a result, owners have a limited period in which to recoup the costs that they incurred in developing the invention. The owner is, however, required to publish details of their invention, so that other parties are able to use the invention in research that may, in turn, lead to other innovations.

Regulatory systems governing intellectual property rights vary throughout the world. The United States, Japan and Australia have the most comprehensive systems allowing for the patenting of plant varieties (Commission on Intellectual Property Rights 2002). Other developed countries and a growing number of developing countries have a form of plant variety rights legislation in place. Under patent legislation, the patent holder has the right to exert control over the use of patented material by limiting the rights of farmers to sell or sow seed that they have grown, or other breeders to use seed (or patented intermediate technologies) for further research and breeding purposes. Under plant variety rights schemes, farmers are generally allowed to keep seed for sowing or sale among other farmers and plant breeders are permitted to use protected species as a source of new varieties.

To ensure some degree of uniformity in the coverage of regulatory systems, the Agreement on Trade Related Aspects of Intellectual Property Rights, generally known as TRIPs, came into force in 1995. The agreement applies to all members of the WTO and lays down minimum, rather than optimum, levels of protection.

One of the principles of TRIPs is that national laws should provide patent protection to inventions, without discrimination as to the field of technology concerned (article 27.1). However, in response to national sensitivities about the patenting of plants and animals, WTO members agreed to include an optional exception to this principle. Article 27.3(b) of TRIPs provides that WTO members may exclude from patentability ‘plants and animals and other micro-organisms, and essentially biological processes for the production of plants and animals other than non-biological and micro-biological processes’. A review of this article was mandated for 1999, and is currently under way in the TRIPs Council (DFAT 2002).

When these revisions are implemented, TRIPs will strengthen intellectual property rights around the world. Developing countries have been granted some leeway and are permitted a transitional period until 2005 to bring their intellectual property laws into compliance with the minimum standards laid down in TRIPs.

Developing countries as a group feel disadvantaged by the agreement. Much of the world’s germplasm for the major crops produced around the world has been sourced from developing countries. Over a long period of time local farmers and plant breeders have bred crop varieties adapted to particular climatic conditions and have developed markets for their products. Generally, developing countries have not implemented IPR legislation to provide protection for such varieties. However, life science companies are able to obtain samples of these varieties. The company could then genetically modify the variety, keeping all of the desirable qualities of the variety and patent a new variety (Kerr, Hobbs and Yampoin 1999).

Nevertheless, the provisions of TRIPs when taken in conjunction with the 1993 Convention on Biological Diversity (CBD) do offer protection to developing countries, although it can be costly and time consuming to obtain protection and compensation available under the CBD. The CBD allows countries to establish sovereign national rights over biological resources found within a country, and commits member countries to conserve them, develop them in a sustainable manner and share in the benefits that may arise from any third party use of the resource. In providing access to the resources to third parties, countries are able to negotiate access and benefit sharing agreements (Gollin 2001).

Regulatory policies and trade

Testing procedures for GM products

As gene modification technologies are very recent and fast developing, most governments are trying to keep pace by developing regulatory policies that reflect consumer demands and preferences for GM products. Countries worldwide are in different stages of policy development, with the majority of the developing countries still in an early stage. Lack of farmer and consumer education and appropriate government regulation has also contributed to a very low or nonexistent uptake of GM technology in most developing countries.

In China, however, the rate of uptake of GM technology has been quite strong. Nevertheless, the Chinese government is developing regulations that require all imported GM products to be so labeled. The new approval system requires producers of GM products to request inclusion on an ‘approved foods’ list before their products can be sold or brought into China. The new system was originally scheduled to take effect on 1 July 2002 but has been extended through to September 2003. Under the new health ministry rules, anyone wishing to import GM foods into China must submit an application to include samples of packaging, labeling and technical documents evaluating edibility and nutrition quality. The application must also include a verification report on safety and nutrition from a ministry accredited testing agency. Safety certificates are also required from the country of origin showing that the product has been approved for production and use in that country.

The delays in finalising the new regulations have slowed the import of soybeans into China from the United States. Concerns have been expressed that China may be delaying finalising the regulations on the imports of GM products as a trade barrier to protect the domestic soybean industry. Soybeans are in oversupply in the main producing regions, but soybean imports into China (largely from the United States) have increased sharply in recent years, largely reflecting the higher oil content of imported seed.

Almost all developed countries require products derived from GM sources to be assessed both for their safety as foods and for their environmental impacts. However, there are considerable differences in the approaches taken by different countries. In the European Union, regulation of GM products requires considerable scrutiny and involves separate regulations for different classes of GM product. Commercial releases, field tests and food safety aspects of GM crops are regulated by member state governments with input, if members disagree, from the EU's Scientific Committee and European Commission. Relevant EU regulatory processes have been specifically designed for GM products, with each GM crop undergoing rigorous testing and analysis, regardless of similarity to existing varieties (US Department of Agriculture 2001).

In the United States, analysis and approval mechanisms for GM foods have been subsumed into existing regulations governing the release of new foods, plants and pesticides. US regulatory authorities operate under the assumption that the fact that a plant has been genetically modified is less important than the specific effects of the modification.

The US Food and Drug Administration (FDA) regulates food applications of GM crops and relies on existing laws that hold food manufacturers responsible for food safety. The FDA considers a GM crop safe if it is substantially the same as its non-GM equivalent and the genetic modification does not cause the crop to produce a substance that is new, or used in a way that produces larger amounts of a substance than is regarded as safe in food (Food and Drug Administration 2001). Should genetic modification produce a new substance that is not an approved food additive, or increased amounts of toxins or allergens, the safety of the GM product as a food must be proven. Where GM plants that have been engineered for pest resistance (that is, produce a substance toxic to pest insects) or herbicide tolerance, the US Environmental Protection Agency (EPA) determines how much of these substances may be present in food (US Department of Agriculture 2001).

Comprehensive summaries of regulatory arrangements for GMOs and GM products in the major importing and exporting countries are given in Foster et al. (2003). Regulations in five OECD members and eleven developing countries are outlined in that study.

Trade issues

Developments in domestic and trade policies for GM products are likely to be an important factor in determining volumes and values of trade flows and ultimately levels of investment and rates of diffusion of the technology. Conservative attitudes toward GM products in western Europe may continue to induce increasingly restrictive production and trade policies. These policies could thus have worldwide ramifications for research and development, rates of diffusion and consequently potential benefits of the technology, particularly in developing countries. Looked at with an EU focus, some of these impacts include:

- Restrictions on production of GM products in the European Union would directly lower the aggregate levels of investment in biotechnology research and development and reduce the flow-on benefits to poorer countries. However, this impact could be moderated by many European biotechnology firms transfering their R&D efforts elsewhere.
- Internal restrictions on production followed by restrictions or a ban on imports of GM products into the European Union would result in higher supplies of products on the world market, forcing down the price of these products. As a result, revenue from export sales of GM product would decline, causing further reductions in investment.
- As EU policies could have a significant impact on trade flows and prices of GM products, uptake and production decisions in other producing countries are likely to be made partly in response to expectations of the most likely trade policy option that the European Union might implement.
- Once the European Union places production and trade restrictions on transgenic products, it is unlikely that they would be willing to provide technical and other assistance needed by developing countries to develop their local biotechnology industries. However, this would provide additional opportunities for other providers of technical and research services in this field, such as Australia and north America.

Besides these overall impacts, the effects of EU policies on different groups of developing countries could be quite different, depending on whether a country is largely an importer of the affected commodities, an exporter or equally engaging in both activities. While predominantly importing countries could benefit considerably through lower prices and increased consumption, exporters, particularly those with most of their exports destined to the European Union, may need to consider an optimal strategy to maximise benefits. Given potential disparities in revenue from GM and non-GM exports under a ban, it is possible that differentiated markets could develop for the two products. Provided products could be segregated, exporters would have the option of producing for either market.

Exporting countries will therefore have to choose one of three possible policy actions. They could either adopt the technology; continue to produce only non-GM products to preserve the ability to export to the European Union; or follow a market segregation policy — that is, producing non-GM products for the EU market and GM products for the domestic and other export markets. The course of action followed would depend importantly on the magnitudes of potential gains in domestic consumption, the change in export earnings (both with and without adoption) and the costs of segregation and labeling.

Segregation

Segregation of products into certifiable non-GM and GM products, whether required by importing governments or in response to consumer demand, will only be achieved at additional costs to crop production. The extent of these costs depends largely on the crop type, the volume of production to be tested and the threshold of accepted contamination levels — that is, the percentage of GM content in non-GM commodities. Costs are expected to increase exponentially as tolerance levels are reduced (Stone, Matysek and Dolling 2002). GM crops, particularly those without altered quality traits, can be difficult to detect because they are only minutely different from conventional varieties. Their identification may require costly testing or comprehensive documentation throughout the supply chain (Foster 2001).

For some crops, such as cross-pollinating crops, segregation would need to be considered from the planting stage. This involves the establishment of separation distances between GM and conventional varieties of the crop. At the transport, handing and storage stage, segregation costs are mainly those associated with separate transport and storage facilities and the need for cleaning between uses for GM and non-GM crops. Consequently, there could be significant losses in the economies of scale as a result of segregation.

Canvassing the available literature on the likely costs of segregation, Foster (2001) pointed out that it is generally suggested that, for a mixed production system of GM and non-GM grain, identifying and certifying non-GM status adds 5–15 per cent to the cost of grain delivery. A study by Leading Dog Consulting (cited in Stone et al. 2002) estimated that, under present technology and segregation / identity preservation systems, costs in Australia could rise by about 10–15 per cent through the supply chain.

However, segregation costs could vary significantly among different countries, depending on the level and suitability of already existing infrastructure. For example, developed countries such as Australia and the United States have substantial infrastructure for segregation already in place. By contrast, most developing counties would need to undertake major new investment if they were to succeed in implementing segregation schemes.

Whether producers segregate or not will ultimately depend on their ability to recover the additional cost of segregation through price premiums for non-GM crops. Segregation would not be viable if premiums did not cover its costs. There is some evidence that premiums have been paid for non-GM crops. For example, it is reported that, in 2000, a fifth of elevators in the United States were paying premiums for non-GM crops ranging between 5 and 15 per cent higher than GM corn prices (Foster 2001). The author concludes that the nature of premiums and discounts suggests that markets are still in a price discovery phase. Producers and traders are trying to establish whether consumers are willing to pay sufficient premiums for certified non-GM products. However, Foster (2003) found little evidence for payments of such price premiums. Ultimately, the price relativities between GM and non-GM commodities would be the main determinant of the production and trade volume of each group — that is, the higher the relative price of a group the more would be its production and trade at the expense of the other.

Trade agreements and labeling

A factor that may influence developments in regulatory and trade policies of individual governments and consequently worldwide investment and trade in biotechnology is the current and prospective international agreements on these issues.

Disputes over trade issues in these products could arise owing to an apparent conflict between the World Trade Organisation (WTO) agreements — particularly the Agreement on the Application of Sanitary and Phytosanitary (SPS) Measures — and the Convention on Biodiversity over the regulation of the international movement of germplasm and GM foods (Pinstrup-Andersen 1999).

The Cartagena Protocol on Biosafety, which came into force in September 2003, is a multilateral agreement that aims to regulate the transborder movement of living genetically modified organisms that may adversely affect the biodiversity of the importing country. As a consequence, it has trade implications. Importantly, the European Union sees the protocol as an alternative to the disciplines imposed by the WTO through the science based SPS agreement and TRIPS. The SPS agreement is directed at eliminating nontariff trade barriers imposed under the guise of food safety or plant and animal health protection (WTO 1995). Under this agreement, a member country can determine its acceptable level of protection against health risks to plants, animals, humans or other environmental hazards and institute SPS measures to achieve this level. However, the measures must be based on a sound scientific assessment process; be no more trade restrictive than necessary to achieve the desired level of protection; and be nondiscriminatory, particularly between products that pose similar levels of risk. In contrast, risk assessments are not explicitly required in the protocol.

At present, the two systems are running in parallel and inconsistencies in application are likely to arise. WTO members exporting GM products are likely to invoke the relevant articles of the SPS agreement that put pressure on banning countries to allow market access for these products. Future disputes on GM products trade could arise along the lines of the dispute between the European Union and the United States over the European Union banning imports of US beef from hormone-fed cattle (Nielsen and Anderson 2000). The WTO ruled against the legitimacy of the ban because of the European Union's failure to provide scientific evidence of associated risks, as required under the SPS agreement. For example, at the request of the United States, Canada and Argentina on 29 August 2003 a panel was established to investigate the inconsistency of the EU approvals process for GMO products with the SPS and other trade agreements. A number of countries including Australia reserved their third party rights. The panel composition process is under way between the principal parties to the dispute.

One of the main concerns in the development of regulatory policy for biotechnology in agriculture is the issue of labeling. The primary function of labeling is to provide consumers with information necessary for making choices in line with their preferences and willingness to pay. There is an ongoing controversy on whether labeling of GM food should be obligatory through government regulations or whether governments should leave it to be voluntarily undertaken by biotechnology industries in response to buyers' demand. Hence the differences in policy approaches toward labeling in different countries.

The issue of labeling and its implications for trade in GM products has not yet been covered in detail in international agreements. The Cartagena Protocol on Biosafety did not include a decision on labeling but stated that exporters may merely state that a shipment 'may contain' living modified organisms (Secretariat of the Convention on Biological Diversity 2000). If the issue of labeling is not settled through international negotiations, it is also likely to be a source of future disputes within the WTO forum.

income impacts of adoption and trade policies

The aim in this chapter is to illustrate the effects that the rate of adoption of and trade policies governing agricultural biotechnology have on economic welfare in different regions of the world. To gauge these effects, three different scenarios were hypothesised and simulated. The simulations were carried out using ABARE's global trade and environment model (GTEM), an empirical general equilibrium model of the global economy and environment. Economic impacts are measured in terms of changes in gross national product (GNP).

Scenarios and assumptions

The three alternative scenarios simulated in this analysis are:

Scenario 1 – Adoption of GM crops in all regions of the world. This scenario assumes that current levels of uncertainty and apprehension over GM products are significantly reduced with the availability of more information.

Scenario 2 – Adoption of GM crops in all regions except the European Union, with there being a ban on imports of GM products into the European Union. In this scenario, the European Union is assumed to be successful in placing trade restrictions on imports of living GM products in accordance with the provisions of the Biosafety Protocol.

Scenario 3 – Adoption of GM crops in all regions except the European Union and low income developing countries, with there being a ban on imports of GM products into the European Union. Poor developing countries are assumed not to be able to implement biotechnology innovations in this scenario given the state of their economies and infrastructure and the costs of developing the technology.

Countries were aggregated into fourteen regional groups, loosely based on geographic location and average income. Each group falls within one of three income categories — high income, medium income and low income (box 2).

In the scenarios analysed, biotechnology uptake and diffusion are considered to occur over a period of ten years, 2006–15. Most of the empirical studies into the farm level impacts of GM crops have been undertaken in the United States. The results show wide variations in returns depending on location, type of technology and the crop variety. From field trials in Tennessee, Robert et al. (1998) estimated net returns from herbicide tolerant soybeans to be 13 per cent higher than the second most profitable system. Using econometric modeling,

Box 2: Regional grouping in the model simulations

Africa

Middle income (adopting in all scenarios)
Algeria, Egypt, Morocco, Libya, South Africa

Low income (not adopting in scenario 3)
Botswana, Lesotho, Namibia, Swaziland, Angola, Malawi, Mozambique, Zambia, Zimbabwe, Mauritius, Madagascar, Mauritania, Mayotte, Mali, Benin, Burundi, Burkina Faso, Liberia, Rwanda, Tanzania, Kenya, Uganda, Congo, Somalia, Djibouti, Eritrea, Ethiopia, Sudan, Central African Republic, Chad, Cameroon, Comoros, Cape Verde, Ivory Coast, Guinea, Guinea-Bissau, Equatorial Guinea, Ghana, Senegal, Nigeria, Niger, Sao Tome and Principe, Seychelles, Sierra Leone, Togo

Asia

High income (adopting in all scenarios)
Chinese Taipei, Hong Kong, Singapore, Japan

Middle income (adopting in all scenarios)
South Korea, Indonesia, Malaysia, Philippines, Thailand, India, China

Low income (not adopting in scenario 3)
Bangladesh, Pakistan, Sri Lanka, Viet Nam, Rest of south Asia

Middle East (adopting in all scenarios)
Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen

North America

Canada, United States (adopting in all scenarios)

South America

Middle income agricultural exporters (adopting in all scenarios)
Argentina, Brazil, Chile, Uruguay, Mexico

Other South America (not adopting in scenario 3)
Columbia, Venezuela, Bolivia, Ecuador, Guyana, Paraguay, Surinam, Central America & Caribbean

Oceania

Australia, New Zealand (adopting in all scenarios)

Europe

Western Europe (not adopting in scenario 2 and 3)
Austria, Belgium, Denmark, Finland, France, Germany, United Kingdom, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, Switzerland, Rest of European Free Trade Area

Other Europe (adopting in all scenarios)
Hungary, Poland, Newly Independent States, Turkey, Rest of Central European Associates

Rest of World (ROW) (not adopting in scenario 3)

Afghanistan, Albania, Andorra, Bermuda, Bosnia-Herzegovina, Brunei, Cambodia, Croatia, Cyprus, Gibraltar, Greenland, Guadeloupe, Lao, Macau, Macedonia, Malta, Marshall Islands, Monaco, Mongolia, Myanmar, North Korea, San Marino, Serbia and Montenegro, Pacific Islands, Papua New Guinea

Fernandez-Cornejo and McBride (2000) found that returns from herbicide tolerant soybeans varied between regions, with mean net returns for all regions estimated to increase by about 14 per cent over non-GM varieties. Marra et al. (1998) estimated that the net returns from using glyphosphate tolerant soybeans were about US$6 an acre, or around 3.5 per cent higher than those for traditional varieties, while they estimated net gains from Bt corn to be US$3–16 an acre, mainly owing to a 4–8 per cent boost in yields. Felloni et al. (2002) indicated that although increases in yields of more than 15 per cent have been observed for Bt corn in China, these are only obtainable under experimental conditions. In commercial cultivation, yield increases are more like 5–10 per cent. Following the approach used by Graham, Schneider and Brown (2001), the adoption of biotechnology is assumed to result in a uniform increase in productivity in all affected crop industries of 10 per cent above levels that would have been derived from current applications of technology over the period, in high and middle income countries — or an average of 1 per cent a year.

The increase in productivity for low income countries is assumed to be double that for high and middle income countries in this analysis. The assumption of a higher rate of productivity growth in low income developing countries reflects the potentially greater gains that these countries are expected to obtain from growing GM crops, as canvassed earlier. This assumption reflects a range of estimates of the productivity benefits expected from GM crops. The selected crops considered in this analysis to be directly affected by biotechnology are rice, grains, oilseeds and fruit and vegetables.

In all scenarios, potential impacts of agricultural biotechnology on welfare were estimated as deviations from expected welfare under a reference case scenario where it was assumed that there was no further adoption of biotechnology. The assumed annual average rates of change in GDP over the estimation period for this reference case or 'business as usual' scenario (due to factors other than biotechnology) are shown in table 2.

The assumed growth rates listed in table 2 are based on recent historical trends for each region. However, there is a degree of uncertainty about whether the assumed rates of growth could be achieved in some regions. For instance, the political and consequent economic instability currently being observed, particularly in low income countries such as in Africa, could considerably hamper economic growth over the estimation period.

Consumer demand is assumed to be unaffected by the introduction of genetically modified products — that is, there is no product differentiation between GM and non-GM products in the model and, where traded, the two product types are considered to receive the same price.

2 Assumed annual average GDP growth rates, 2006–15, reference case

	%
Low income regions	
Asia	4.7
Africa	3.5
South America	2.5
Middle income regions	
Asia	6.4
Africa	3.4
South America	3.4
Eastern Europe	3.6
Middle East	3.6
High income regions	
Japan	0.6
Other Asia	3.8
Australia and New Zealand	3.5
North America	3.4
Western Europe	2.3

Where trade bans are simulated, the ban on GM products is considered to apply only to primary commodities. Therefore, in the model simulations, it is assumed that a country produces and exports either GM or non-GM crops, but not both — that is, the possibility of being able to segregate GM and non-GM crops has not been considered, and imports of both GM and non-GM primary commodities from adopting regions into the banning region have not been allowed. If in the future, countries were to engage in production and trade of both GM and non-GM products under a suitable segregation and labeling regime, results from this analysis could overstate the potential impacts of the outlined EU policies on production and trade in GM commodities.

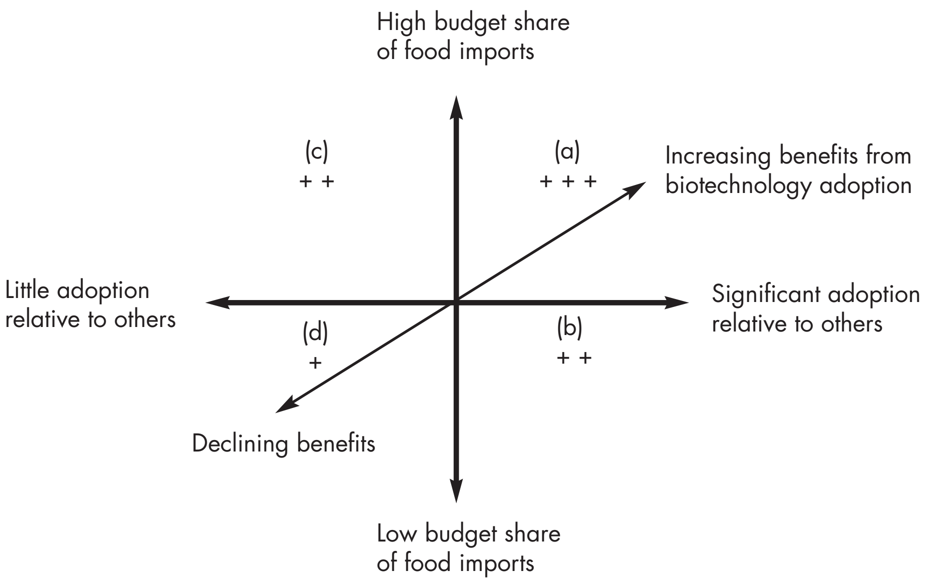
Impacts of GM introduction and sources of economic change

The global adoption of GM technologies in agricultural production is likely to result in significant productivity gains worldwide. Increases in yields and/or decreases in input use would translate into reductions in per unit costs, leading to higher levels of production. Higher world supplies would, in turn, put downward pressure on world prices as well as on farm gate and consumer prices of these commodities. Depending on the relative changes in these variables, impacts on different economic sectors and regions would vary.

Generally, economic gains are expected to be higher in countries where imports of primary food commodities initially constitute a relatively larger share of the budget. Owing to significant declines in world prices, these countries would benefit from cheaper imports even if they did not adopt the technology themselves. If they adopt GM technologies, however, considerable additional benefits could accrue. Besides taking advantage of lower production costs to increase domestic supply, they would be able to partly replace imports, thus saving foreign exchange for use in other more beneficial activities. In contrast, regions with lower shares of food imports in the budget and/or lower rates of adoption of GM technologies in crop production are expected to realise relatively lower benefits. These relationships are depicted in figure B.

- Quadrant (a) in the diagram contains countries significantly adopting biotechnology and where initial budget shares of food imports are high. Gains are highest in this quadrant (represented by three '+') signs.
- Quadrants (b) and (c) contain countries with a significant rate of adoption but a low budget share of food imports or those with low rates of adoption but a high budget share of food imports respectively. The opposing effects of these two factors combine to result in lower expected economic gains in countries within these two quadrants (represented by two '+'signs).
- Quadrant (d) contains countries where the least gains are expected to occur (represented by a single '+' sign). The potential benefit is small in these countries because of a combination of lower budget shares of food imports and a low rate of adoption of biotechnology relative to other countries.

B Four sectors of likely variations in benefits from biotechnology



Production prices and consumption impacts

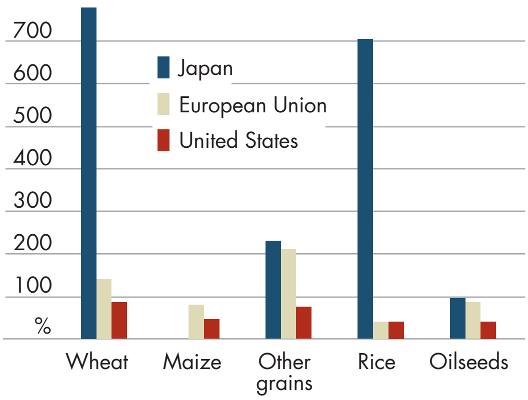
Two distinctly different impacts on farmers could result following an uptake of agricultural biotechnology. Farmers for whom the percentage reductions in per unit costs of production are greater than corresponding declines in prices stand to gain from adopting the new technologies. The resulting higher price–cost ratio (and thus higher profit margin) will cause production to expand despite lower prices, compared with the preadoption levels.

In contrast, farmers whose cost reductions are not large enough to compensate for price declines for GM commodities will face a lower price–cost ratio or smaller profit margins, with consequent cutbacks in production. In particular, farming in countries where there is no uptake of GM technologies will be less profitable owing to a reduction in world prices, without the benefit of any reduction in costs or improvement in yields.

Consumers in all regions should benefit from the declines in commodity prices resulting from the adoption of the new technologies. The magnitude of consumption gains would depend largely on two main factors: the degree of consumption response to price falls (elasticity of demand) and the initial level of consumption. The higher the response to a price change and the greater the level of consumption, the larger would be the consumption gains.

Economic gains would also accrue to producers in other agricultural and processing industries where GM commodities are used as major inputs in production. For example, there could be potential declines in feed costs for livestock industries and in the cost of the primary input for the bakery industry. There will also be flow-on effects in major sectors other than agriculture. For example, where profit margins in agriculture are expected to rise, resources will be channeled from other economic sectors into the agricultural sector. These developments assume that producers' and consumers' decisions are made in a competitive market guided by world prices.

C **Support levels in large developed countries, 1999** nominal rate of assistance



However, the extent to which these adjustments may occur depends largely on developments in the agricultural support policies of major producers, importers and/or exporters of primary food commodities and the extent to which these policies allow transmission of world price effects into domestic markets. With the exception of Australia and New Zealand, the major producing and trading developed countries provide significant amounts of support to their domestic cropping industries against international competition. Levels of assistance given to the cropping industries in Japan, the European Union and the United States are shown in figure C.

A clear example where domestic support policies cause distortions in agricultural markets is manifest in the effects of producer support under the EU Common Agricultural Policy (CAP). Since the introduction of the CAP, support to grain producers has been effected through various mechanisms. Cereal prices have been maintained above comparable world prices through a combination of administratively set support prices, barriers to import entry, provision of export subsidies and government buy-ins to prevent domestic price falling below the set level (Andrews and Nelson 2001).

Since the introduction of 'Agenda 2000' reforms, the European Union has shifted the emphasis of support away from intervention price to direct support, through successive reductions in support prices. The intention is to align consumer prices with world prices for wheat, coarse grains and rice (there is no intervention price for oilseeds). This goal has largely been achieved for wheat and coarse grains where EU internal prices are currently close to world price levels. Announced reforms for rice are also expected to bring its support prices in line with world price. As a result, it is expected that the impact of intervention prices as a support instrument will have substantially diminished, compared to other forms of protection such as direct support, export subsidies, import tariffs and quotas. Assuming that adjustments in EU intervention prices will continue in the future, EU internal prices are allowed to vary with changes in world prices in this analysis.

US farm support policies are revised every few years and introduced as a new farm bill. In the 1996 farm bill, some changes were introduced in the way that support was delivered to farmers. A set of 'production flexibility contract' payments, that do not vary with production or prices, was drawn for each year to 2002. These payments were considered to be minimally distorting or 'decoupled'. This has important implications for the US trade obligations to restrict support because, under the WTO, decoupled payments are exempt from any restriction. The government also lowered the levels of the internal floor prices. It was argued that farmers would base production decisions on world prices or on floor prices when world prices were low.

Further changes in support were introduced in the 2002 farm bill. ABARE (2001) indicated that the 2002 farm bill introduced even more damaging support structures by reintroducing many of the most market distorting elements of pre-1996 forms of protection but without reinstating parallel acreage reduction programs.

Current high levels of support in the European Union and the United States slow domestic agricultural adjustment in these countries and force more adjustment on producers elsewhere. This means that price signals to induce efficient regimes of production and trade are not reflected back to producers. For example, aggregate benefits from the introduction of GM technologies under freer trade protocols could be substantially higher that those obtained in this analysis. Anderson and Nielson (2002) estimated the welfare effects of biotechnology adoption in selected regions with and without agricultural protection policies in western Europe. With different scenarios of EU trade policies for GM products, their results showed that removing protection in western Europe would more than double world welfare gains. Under a scenario where the European Union was assumed to ban GM imports, removal of EU protection policies was estimated to result in a sixfold increase in world welfare gain.

The estimated baseline or reference case scenario in this analysis incorporates current distortions in the world market, with it being assumed that these distortions are maintained throughout the estimation period. Results from other scenarios measure deviations from the reference case under alternative regimes of adoption of GM technologies and trade in GM products. As stated above, EU internal prices are allowed to vary with changes in world prices in this analysis. However, if this turned out not to be the case and support prices were maintained above world price levels, the EU domestic market would be protected from changes in world prices. Where protection insulates the domestic market from changes in world prices, potential benefits to domestic consumers and other exporters from falls in world prices as a result of technological innovations, such as biotechnology, could be considerably lower than would have been achieved with fully flexible prices in the European Union. Likely welfare impacts of this eventuality, where all countries (including the European Union) adopt GM technology but the European Union controls its internal prices so as to eliminate imports, are examined in one of the scenarios.

Results and discussion

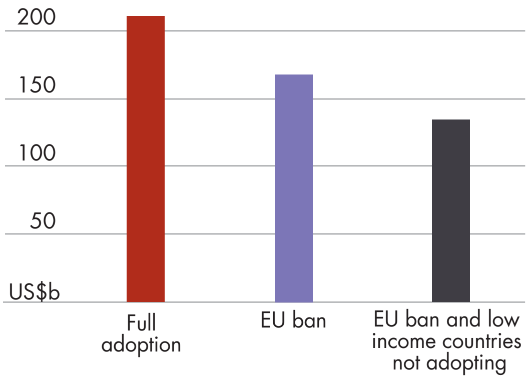
Aggregate impacts

The global benefits from adopting agricultural biotechnology are estimated to be largest under the full adoption scenario. In comparison with the reference case, the aggregate annual increase in gross national product (GNP) for all regions is estimated to be US$210.3 billion a year by the end of the period in 2015.

Gains in global welfare decline progressively in the remaining two scenarios — an EU ban and an EU ban coupled with no adoption by low income countries — with the gains in aggregate gross national product declining to US$167.6 billion and US$134.2 billion respectively.

The falls in aggregate gross national product reflect the impacts of possible decreases in the adoption of the new technologies and/or the restrictions on production and trade polices that could arise if the European Union instituted bans on GM products (figure D).

D Change in aggregate GNP, by scenario, 2015 relative to the reference case

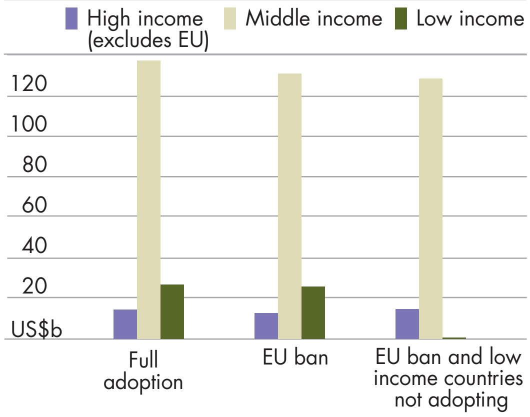


Differential impacts among income groups and regions

Welfare gains vary for the different country groups. The largest percentage increases in GNP from the introduction of GM technology are expected to occur in developing countries, with GNP increasing in the full adoption scenario by 2.1 per cent for low income regions and 0.5 per cent for middle income regions. Increases in high income countries are estimated to be under 0.2 per cent of GNP. (Note that in the following discussions on the remaining two scenarios, the high income group excludes the European Union, which is reported separately).

E Increase in aggregate GNP, by scenario and income region, 2015

relative to the reference case



Welfare impacts in dollar terms for broad groupings of countries are represented by the estimated change in gross national product relative to the reference case in each scenario (figure E). The magnitude of the gains by the 'middle income' group of countries reflects that this group contains two countries, China and India, that contain around two-thirds of the world's population.

Impacts on the welfare in individual regions of agricultural biotechnology are presented in table 3 and discussed in the following section for different scenarios of adoption and trade policies.

Likely impacts of EU support prices

It must be noted, however, that the reported gains in regional and global welfare from biotechnology adoption were based on the assumption that EU internal prices, which are presently at around world price levels, would drop freely with world prices following the introduction of biotechnology. Under this assumption, and with the European Union adopting GM technologies, the declines in EU prices are estimated to be about 15 per cent for wheat, coarse grains and oilseeds; 13 per cent for fruit and vegetables; and 7 per cent for rice.

Besides benefits to exporting countries, EU price declines could result in large benefits from significant increases in domestic consumption and a more efficient use of resources in the European Union — with total EU gain estimated at US$21 billion, or about 0.2 per cent of GNP (table 3).

Contrary to this, if EU internal prices were constrained from matching the fall in the world prices, both global benefits and benefits to the European Union from a scenario of full adoption of GM technologies would be lower. The higher the EU prices were kept above world prices the lower would be the economic gain from the technology, particularly in the European Union. The smallest gain from full adoption of GM crops is expected to occur if EU internal prices were controlled at levels that prohibit import from entry. In this case, benefits to the European Union would mainly accrue from reductions in per unit costs of production. Any realised gains in consumption through trade would be derived from trade in GM oilseeds only where there are no price interventions for this commodity.

To determine the impact of insulating EU domestic prices from world prices, a scenario of full adoption of biotechnology, where the European Union is also adopting but not allowing imports (except for oilseeds) has been simulated. In other words, it is considered that the European Union will support prices only to the point where imports are eliminated. Because of cost reductions resulting from the introduction of biotechnology, internal prices are again estimated to fall but not to the extent estimated in the original scenario. The results indicate that global economic benefit could fall by over US$10.6 billion, or about 5 per cent

3 Changes in regions' incomes and terms of trade, by 2015
relative to the reference case

	Full adoption		EU production and import ban		EU ban and low income countries not adopting	
	GNP	Terms of trade	GNP	Terms of trade	GNP	Terms of trade
	%	%	%	%	%	%
Low income regions						
Asia	3.3	0.5	3.3	0.6	0.3	1.0
Africa	2.4	–0.8	2.3	–0.9	–0.1	–0.2
South America	1.1	–0.6	1.0	–0.8	0.0	0.0
Middle income regions						
Asia	1.4	0.3	1.4	0.3	1.4	0.3
Africa	1.1	1.2	0.9	0.9	0.9	0.7
South America	0.6	–1.1	0.5	–1.3	0.5	–1.2
Eastern Europe	0.5	0.1	0.4	–0.1	0.4	–0.1
Middle East	0.9	1.8	0.8	1.6	0.6	1.2
High income regions						
Japan	0.2	0.6	0.2	0.6	0.2	0.6
Other Asia	0.3	0.3	0.3	0.3	0.3	0.3
Australia and New Zealand	0.0	–1.1	0.0	–1.1	0.0	–1.0
North America	0.0	–0.8	0.0	–0.8	0.0	–0.8
European Union	0.2	0.1	–0.1	0.2	–0.1	0.1

below that estimated under the assumption of fully flexible EU prices and open trade. Of this, the decline in welfare for the European Union is estimated at US$7.3 billion, or about 35 per lower than under the flexible prices and trade scenario. The estimated decline in welfare for the rest of the world is significantly smaller compared with that in the European Union, because declines in export revenues from the loss of the EU market and consequent slight declines in world prices are largely offset by higher consumption benefits.

Regional impacts under the different scenarios

Full adoption

In the full adoption scenario, where the aggregate gains are largest, low and middle income regions are major beneficiaries (table 3). This occurs, first, because reduced prices for agricultural products deliver benefits to consumers that are accentuated because of the large share of food in total expenditure in these regions. Second, low income developing countries have been assumed to achieve productivity gains above the world average in agriculture. As a result, costs in low income developing countries are projected to fall by more than prices in the full adoption scenario, leading to increased margins for farmers. Thus, low income developing countries are able to compete more effectively on global markets.

Even under the assumption of identical improvements in productivity for low and middle income regions (10 per cent), simulation results showed that low income regions benefited more than middle income regions. Low income countries benefit more than middle income countries not only because of the assumption of higher productivity improvements, but also because of the greater relative importance of agriculture in the economies of low income countries. Sources of gain for the different groups of countries are presented in table 4.

4 Sources of impacts of biotechnology on changes in incomes Full adoption scenario

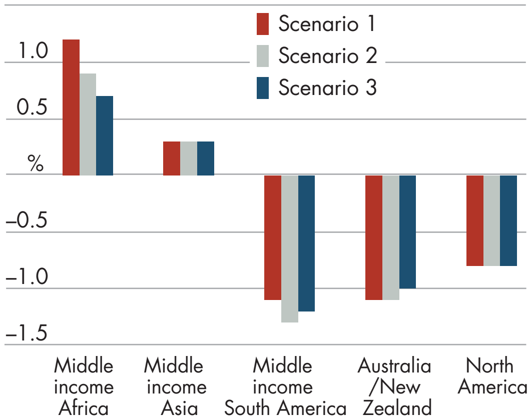
Group	Production vs price	Other sectors' income	Consumption	Net impact
European Union	Negative	Positive	Medium	Medium gain
Other high income	Negative	Positive	Medium	Medium gain
Middle income	Positive	Negative	Strong	Strong gain
Low income	Positive	Negative	Strong	Strong gain

5 Changes in volumes of grain and oilseeds exports from traditional exporters to selected regions Full adoption scenario Percentage change from the reference case in 2015

	Exporting region					
	Australia and New Zealand			North America		
	Wheat	Coarse grains	Oilseeds	Wheat	Coarse grains	Oilseeds
	%	%	%	%	%	%
Importing region						
European Union	–	–	–	31	14	10
Japan	5	–7	6	1	3	1
Middle East	14	27	21	11	7	3
Middle income Africa	21	23	14	16	6	3

In comparison, the high income groups including the European Union are estimated to realise relatively moderate gains, except for north America and Australia–New Zealand regions where incomes are estimated to remain unaffected. For high income mostly importing countries, the gains largely reflect lower prices and increased consumption of GM products.

F **Terms of trade effects, 2015**
Full adoption scenario



For high income exporters the estimated outcome is mainly caused by terms of trade effects (figure F) and the ability of many adopting countries to partially substitute domestic production for imports. Exports from north America and Australia and New Zealand to different importing regions are estimated to vary — decreasing to some regions and increasing to others. For example, Australian exports to agricultural commodity markets in middle income countries in north Africa and the Middle East are estimated to rise appreciably to meet increased domestic demand in these regions (table 5). This rise is estimated to be offset by declines in exports to other markets, particularly in middle and low income Asia, reflecting increased competitiveness and self reliance in these regions. Potential loss in revenue of traditional exporters would be partially offset through increased domestic demand for these commodities and lower production costs in related industries, such as livestock and other food processing industries.

EU ban

In the scenario where the European Union does not adopt GM technologies and bans imports of GM products from adopting countries, the gains to most countries are reduced. This highlights the global implications of EU domestic policies on the adoption of GM technologies. The relative impacts among countries depend on the extent of their trade exposure to the European Union. In particular, low and middle income countries — some of which more than doubled their base exports to the European Union under the full adoption scenario — incur significant losses in this scenario relative to the scenario with full adoption. Despite these reductions, however, there are significant net gains relative to the reference case in all regions except the European Union (table 6).

6 **Sources of impacts of biotechnology on changes in incomes**
EU ban scenario

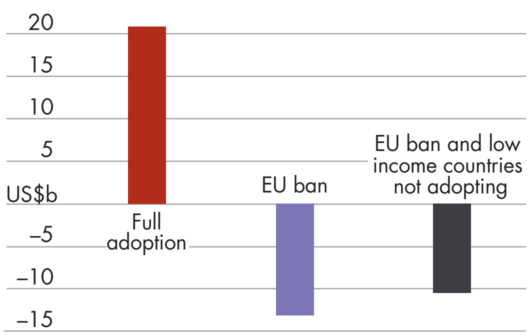
Region	Production vs price	Other sectors' income	Consumption	Net impact
European Union	Positive	Negative	Negative	Large loss
Other high income	Negative	Positive	Medium	Medium gain
Middle income	Positive	Negative	Strong	Strong gain
Low income	Positive	Negative	Strong	Strong gain

7 Changes in volumes of grain and oilseeds exports from traditional exporters to selected regions EU ban scenario Percentage change from the reference case in 2015.

	Exporting region					
	Australia and New Zealand			North America		
	Wheat %	Coarse grains %	Oilseeds %	Wheat %	Coarse grains %	Oilseeds %
Importing region						
European Union	–100	–100	–100	–100	–100	–100
Japan	2	–11	–2	3	4	3
Middle East	18	41	14	21	25	8
Middle income Africa	31	31	10	32	19	10

There are also significant consequences in north America owing mainly to the reduction in oilseeds export, mostly from the assumed EU ban on the import of GM products. In comparison, the EU ban is estimated to have little impact on income for the Australia and New Zealand region, reflecting the region's low volumes of export to the European Union. In addition, Australia is estimated to be able to further increase its grain exports to Africa and the Middle East (table 7) relative to exports in the full adoption scenario.

G Changes in GNP in the European Union, 2015 relative to the reference case



The major loser under an EU ban is the European Union itself, with its gross national product estimated to be about US$13 billion below the reference case by the end of the period (figure G). This estimate assumes that EU consumers would not be willing to pay more for non-GM crops. However, with the current consumer attitude toward GM products in Europe, this estimate may be overstating the magnitude of the loss in welfare. In order to reflect the true loss in welfare, the estimated loss would need to be discounted by the value of premiums that consumers would be willing to pay for non-GM products.

EU ban and low income countries not adopting

Under the previous scenario, the estimated reductions in benefits for low income countries reflect an assumed EU ban on imports (table 3). In this scenario, where these countries are now able to gain access to the EU markets but only with non-GM products, the loss in income is solely a result of these countries not adopting GM technologies. Production cost savings are not achieved and the prices that farmers receive are lower. It is clearly apparent that the impact of not adopting the technologies — where low income countries lose most of the benefits realised with full adoption — far outweighs the losses resulting from the restrictive trade policies of the European Union. Huang et al. (2002) reached a similar conclusion. Analysing the impacts of biotechnology adoption in China, they found that most of the gains

8 Sources of impacts of biotechnology on changes in incomes
EU ban and no adoption in low income countries scenario

Region	Production vs price	Other sectors' income	Consumption	Net impact
European Union	Negative	Negative	Negative	Medium loss
Other high income	Negative	Positive	Medium	Strong gain
Middle income	Positive	Negative	Strong	Strong gain
Low income	Negative	Negligible	Strong	Small gain

to the Chinese economy occur because of gains inside China, with trade restrictions imposed by other countries having minimal impact.

However, even in this scenario, there remain some sources of gain for low income countries owing to reduced world prices for agricultural products that result from increased agricultural productivity in adopting regions, leading in turn to high consumption benefits in nonadopting low income countries (table 8).

Additionally, the nonadopting low income countries become more competitive on EU markets owing to the assumed EU ban on imports from adopting countries — that is, these countries would be able to export non-GM products to the European Union at EU domestic prices while being able to import GM products from high and middle income regions at the lower world prices. Also, the economic losses that the European Union could potentially incur under an import ban would be moderated (as apparent in figure G) because of the possibility of importing non-GM products from low income countries.

With low income countries not adopting GM technologies, other regions — particularly traditional exporters such as north America and Oceania — may realise levels of benefit similar to (north America) or greater than (Oceania) those realised under full adoption scenario (table 3). This is because farmers in these regions face less competition on agricultural markets from low income producers.

EU not adopting but not banning GM imports

For each of the two scenarios representing restrictive EU policies — EU bans on production and imports of GM products and EU bans and low income countries not adopting — a variant scenario was also estimated where the European Union restricts the production of GM commodities but allows market access of GM commodities. Under both variations the European Union is estimated to gain from allowing trade with adopting regions.

Compared with the estimated losses to the European Union of US$13.1 billion and US$10.5 billion under the two scenarios, allowing GM imports into the European Union is estimated to generate net gains of US$5.7 billion and US$4.9 billion under the respective variant scenarios. The gains would largely be attributable to higher domestic demand, a reflection of cheaper imports. There would also be efficiency gains realised by shifting resources from crop production to other activities.

The results also indicate that, compared with a full adoption of agricultural biotechnology, an import ban on GM crops could have a greater contribution to the EU economic losses than a ban on production. The benefits forgone by not allowing the production of and trade in GM commodities would be cut by more than a half if the European Union banned production but allowed imports of GM products.

For example, in the EU ban scenario, the estimated forgone benefits to the European Union by not allowing the production and trade of GM commodities is estimated to be US$34 billion [20.8 – (–13.1)]. With imports of GM products allowed but production still banned, the benefits forgone are estimated to decline to US$15 billion [20.8 – 5.7]. Effectively, by banning imports of GM products from adopting countries, the European Union must rely on more expensive sources to meet its food demands, generating a loss to consumers and to the economy generally.

Impacts of adoption versus nonadoption for high income exporters

The high income traditional exporting regions of north America and Australia–New Zealand experience no change in economic welfare in all scenarios (table 3). As mentioned earlier, this reflects declines in terms of trade for these regions as developing countries increase their relative agricultural competitiveness.

Anderson and Nielsen (2002) and Stone et al. (2001) arrived at similar results for Australia and New Zealand when analysing the effects of the adoption of GM grains and oilseeds in selected world regions. In contrast, welfare in the European Union is estimated to increase considerably when it is assumed to adopt the technology (full adoption scenario), but could decline significantly if the European Union did not adopt GM technology. This highlights that the importance of technology adoption lies not only in increasing welfare of a region or country per se but more importantly in preventing potentially substantial losses from not adopting the technology (box 3).

Box 3: Australian welfare with and without biotechnology introduction

With biotechnology in crop production adopted widely around the world but not in Australia, Australian welfare could substantially decline owing to the large erosion of Australia's competitiveness in agricultural markets. To illustrate this point, the model was simulated to generate potential changes in welfare for the Australia–New Zealand region under the specified three scenarios if it did not adopt GM technology. The results from the model simulations are presented below.

	Full adoption	EU ban	EU ban and low income countries not adopting
	US$m/yr	US$m/yr	US$m/yr
Australia and New Zealand			
– adopting GM	–251	–255	6
– not adopting GM (flexible EU prices)	–1 623	–1 372	–1 222
– not adopting GM (controlled EU prices)	—1 730	–1 372	–1 222

It is apparent that the greater the number of regions adopting the technology, the higher is the estimated welfare losses for the Australia–New Zealand region. The loss is greatest under the full adoption scenario where all other countries except Australia and New Zealand adopt GM technologies. As more regions joined Australia and New Zealand in not adopting (first the European Union and then low income countries), the intensity of competition facing Australia and New Zealand would be partially alleviated, resulting in progressively lower economic losses. In addition, with the European Union banning GM imports in the second and third scenarios, the Australia–New Zealand region would be in a position to reduce its losses by supplying the EU market with non-GM products at higher prices.

- Reflecting the exclusion of other suppliers, such as north and south America and subsaharan Africa from the EU market because of their use of GM technology, EU prices for the selected commodities are estimated to rise.
- With Australia–New Zealand being the only region that could access the EU market and in response to the rising EU prices, Australian production of non-GM is estimated to be largely destined for export to the European Union.
- In order to meet domestic demand, Australia is estimated to significantly increase imports of these commodities from adopting countries, at prices much lower that it receives for exports. This means that other sectors that use GM products as input in production could still derive benefits through reductions in production cost.

Under these scenarios of GM technology adoption, the combined economic welfare in Australia and New Zealand might not improve to any large degree with the introduction of the technology. However, under all scenarios, the economic losses as a result of not adopting the technology would be substantially greater than any losses that might occur with GM production.

Also, if the european union insulates its domestic prices from import competition while adopting GM technologies, economic losses to the Australia–New Zealand region are estimated to increase to US$1730 million.

conclusions

While efforts to improve food security in developing countries must necessarily address problems of extreme poverty, political instability, poor infrastructure and global trade issues, gene modification technologies show considerable potential to raise agricultural productivity for a given area of land. The application of biotechnology techniques within the agriculture sector can potentially improve food security by making crops more tolerant to adverse weather and soil conditions, by adapting crops to different climates and by improving yields, pest resistance and nutrition. Genetically modified crops are expected to be of particular benefit to subsistence farmers and the poor in developing countries.

With populations in developing countries expected to increase strongly to 2050, food production must also increase if people in those countries are to avoid potentially high insecurity in food supply. However, to avoid potentially serious environmental damage — if increased production were to be achieved through the conversion of natural ecosystems into arable lands — it will be essential to increase productivity on existing agricultural land in these regions. In a world of rising population, biotechnology shows considerable potential to contribute to both food security and environmental sustainability in developing countries.

In modeling the global effects of biotechnology, results from GTEM simulations of various scenarios for technology adoption and openness of trade policy show that all regions would benefit substantially from the application of GM technologies. However, contributions to economic growth from different sources, such as changes in production, consumption and trade, are estimated to vary between regions.

Among different country groups, potential gains from the uptake of biotechnology are highest for developing countries, particularly those in the low income regions. These gains arise because benefits to consumers through reduced prices for agricultural products are accentuated by the large share of food in total expenditure in these regions. Moreover, productivity gains for low income developing countries have been assumed to be above the world average in agriculture. As a result, crop production costs are projected to fall by more than prices received by producers, leading to increased margins for farmers and enabling low income developing countries to compete more effectively on global markets.

The smallest increases in welfare from biotechnology adoption are estimated to occur in the high income groups of countries — particularly the high income traditional exporting regions of north America and Australia–New Zealand. This reflects a fall in their terms of trade as developing countries increase their relative agricultural competitiveness. Besides relatively smaller consumption gains, the chief source of benefits in the high income regions arise from efficiency gains in related industries. Taking the Australia–New Zealand region as an example, the results indicate that even if the introduction of the technology did not result in significant increases in economic benefits, it would nevertheless be necessary just to avoid the losses that could result from not adopting the new technologies while the rest of the world was rapidly implementing them.

The effects of EU restrictive policies on trade in GM food products on other regions' incomes are generally negative but the impacts differ among regions depending on each region's volume of trade with the European Union. However, under the model, all regions are better off adopting the technology regardless of the potential loss of market access to the European Union. In contrast, the welfare loss in the European Union from bans on production of and trade in GM product could be substantial.

Like any new technology, however, biotechnology has its potential risks. Food safety and environmental risk assessments need to be carried out on a strict scientific basis. Economic analyses of benefits and costs are necessary to determine the socioeconomic feasibility of implementing specific biotechnology applications.

Despite the seemingly high potential benefits for developing countries, there are significant barriers to biotechnology uptake and investment. This is mainly a reflection of inadequate technical, institutional and regulatory capacity in many developing countries. Proactive government policies to encourage research and development in biotechnology — particularly through publicly funded research, or through public–private research partnerships — are therefore important in optimising the level of investment in biotechnology.

Consumer surveys have demonstrated that consumer acceptance increases with the level of education and awareness of the technology and its potential impacts. It would, therefore, be expected that better informed consumer decisions would favor increased uptake of biotechnology and its products.

references

ABARE 2001, *Rising US Agricultural Support: Avoiding a Common Agricultural Policy of the United States and Europe?* ABARE Current Issues, 01.7, Canberra, October.

Anderson, K. and Nielsen, C. 2002, *Economic Effects of Agricultural Biotechnology Research in the Presence of Price-Distorting Policies*, Discussion Paper no. 0232, Centre for International Economic Studies, University of Adelaide, November.

Andrews, N. and Nelson, R. 2001, 'Agenda 2000: the European Union's reform package for grains', *Australian Commodities*, vol. 8, no. 2, pp. 317–30.

Altieri, M.A. and Rosset, P. 1999, 'Ten reasons why biotechnology will not ensure food security, protect the environment and reduce poverty in the developing world', *AgBioForum*, vol. 2, nos 3–4, pp. 155–62 (www.agbioforum.org).

Arakawa, T. 1998, 'Efficacy of a food plant-based oral cholera toxin B subunit vaccine', *Nature Biotech*, vol. 16, pp. 292–7.

Avery, D.T. 2002, *Agriculture and Livestock Production to Sustain the Environment*, Centre for Global Food Issues, Hudson Institute, Indianapolis.

Brethour, C., Mussell, A., Mayer, H. and Martin, L. 2002, *Agronomic, Economic and Environmental Impacts of the Commercial Cultivation of Glyphosate Tolerant Soybeans in Ontario*, Final Draft, George Morris Centre, Guelph, Ontario.

Byerlee, D. and Fischer, K. 2002, 'Accessing modern science: policy and institutional options for agricultural biotechnology in developing countries', *World Development*, Elsevier Science Ltd, vol. 30, no. 4, pp. 931–48,

CIMMYT 2002, *Transgenic Maize in Mexico: Facts and Future Research Needs – A Statement on the Discovery of Transgenic Maize in Mexican Farm Fields*, International Maize and Wheat Improvement Centre, Mexico, May (www.cymmt.org).

Commission on Intellectual Property Rights 2002, *Integrating Intellectual Property Rights and Development Policy*, Report of the Commission on Intellectual Property Rights, London.

Conway, G. and Toenniessen, G. 1999, 'Feeding the world in the 21st century', *Nature*, vol. 402, C55.

Cunningham, E.P. 1999, *Recent Developments in Biotechnology as They Relate to Animal Genetic Resources for Food and Agriculture*, FAO Background Study Paper no. 10, Rome, April.

DFAT (Department of Foreign Affairs and Trade) 2002, *TRIPs – the Article 27.3(b) Review*, Canberra (www.dfat.gov.au/ip/biotech.html).

Kris-Etherton, P.M., Harris, W.S. and Appel, L.J. 2002, 'Fish consumption, fish oil, Omega-3 fatty acids, and cardiovascular disease', *Circulation*, American Heart Association, Hagerstown, Maryland, vol. 106, no. 21, pp. 2747–57.

Felloni, F., Gilbert, J., Wahl, T.and Wandschneider, P. 2000, 'Trade policy, biotechnology and grain self-sufficiency in China', Agricultural Economics, Amesterdam, vol. 28, no. 3, pp. 173–86.

Fernandez-Cornejo, J. and McBride, W. 2003, *Genetically Engineered Crops for Pest Management in US Agriculture: Farm-Level Effects*, Economic Research Service, US Department of Agriculture, Washington DC, April.

Food and Drug Administration 2001, 'Draft guidance for industry: voluntary labeling indicating whether foods have or have not been developed using biotechnology', *Federal Register/ Notices*, vol. 66, no. 12, pp. 4839–42.

Foster, M. 2001, Genetically *Modified Grains: Market Implications for Australian Growers*, ABARE Research Report 01.10, Canberra.

—— 2003, *GM Canola: What are its Economics under Australian Conditions?* Australian Grains Industry 2003, ABARE, Canberra.

——, Berry, P. and Hogan, J. 2003, *Market Access Issues for GM Products: Implications for Australia*, ABARE *e*Report 03.13 to the Department of Agriculture, Fisheries and Forestry, Australia, Canberra, July.

Freeman, F., Mélanie, J., Roberts, I., Vanzetti, D., Tielu, A. and Beutre, B. 2000, *The Impact of Agricultural Trade Liberalisation on Developing Countries*, ABARE Research Report 2000.6, Canberra.

Fulton, M. and Giannakas, K. 2001, 'Agricultural biotechnology and industry structure', *AgBioForum*, vol. 4, no. 2, pp. 137–51 (www.agbioforum.org).

Glover, J. 2002, *Gene Flow Study: Implications for GM Crop Release in Australia*, Bureau of Rural Sciences, Canberra.

Gobbi, P. 2000, 'Brazil's hot debateover genetically modified foods', *Science Wire*, 13 November (www.exploratorium.edu/theworld/gm/brazil.html).

Goklany, I.M. 2000, *Applying the Precautionary Principle to Genetically Modified Crops*, Weidenbaum Center Working Paper no. 157, Washington University, St Louis.

Gollin, M.A. 1999, 'Meeting global food needs: the environmental trade-offs between increasing land conversion and land productivity', *Technology*, vol. 6, pp. 107–30.

—— 2001, 'Biopmacy: the legal prespective', February (www.actionbioscience.org/biodiversity/gollin.html).

Graham, B., Schneider, K. and Brown, S. 2001, *Australia's Trading Future: A Medium Term Perspective*, ABARE Report to the Department of Foreign Affairs and Trade, Canberra, October.

Hoban, T.J. 1996, 'Trends in consumer attitudes about biotechnology', *Journal of Food Distribution Research*, 27 February, vol. 27, no. 1, pp. 1–10.

—— 2001, American consumers: awareness and acceptance of biotechnology, Paper presented at the National Agricultural Biotechnology Council Winter/Spring Council Meeting, Washington DC, March.

Huang, J., Hu, R., van Meijl, H. and van Tongeren, F. 2002, Biotechnology boost to crop productivity in China and its impact on global trade, *e*Paper presented at the Fifth Annual Conference on Global Economic Analysis, the Hague, the Netherlands, 5–7 June.

Ismael, Y., Bennett, R. and Morse, S. 2002, 'Benefits from Bt cotton use by smallholder farmers in South Africa', *AgBioForum*, vol. 5, no. 1, pp. 1–5 (www.agbioforum.org).

James, C. 2002, *Global Review of Commercialized Transgenic Crops: 2001*, ISAAA Briefs no. 27, Preview, International Service for Acquisition of Agric-Biotech Applications, Ithaca, New York.

Kalaitzandonakes, N.G. 1999, 'Agrobiotechnology in the developing world', *AgBioForum*, vol. 2, nos 3–4, pp. 147–9 (www.agbioforum.org).

Kerr, W.A., Hobbs, J.E. and Yampoin, R. 1999, 'Intellectual property protection, biotechnology and developing countries: will TRIPs be effective?', *AgBioForum*, vol. 2, nos 3–4, pp. 203–11 (www.agbioforum.org).

Lemaux, P.G. 2000, Advances in technology for cereal breeding, Presentation at the Seed Biotechnology Symposium at University of California, Davis, 29 August (ucbiotech.org/resources/biotech/talks/crops/advances.html).

Losey, J.E., Rayor, L.S. and Carter, M.E. 1999, 'Transgenic pollen harms monarch larvae', *Nature*, vol. 399, p. 214.

Marra, M., Carlson, G. and Hubbell, B. 1998, *Economic Impacts of the First Crop Biotechnologies*, North Carolina State University, Raleigh (www.ag-econ.ncsu.edu/faculty/marra/firstcrop/img001.gif).

McCalla, A.F. and Brown, L.R. 2000, 'Feeding the developing world in the next millennium: a question of science?', in G.J. Persley and M.M. Lantin (eds), *Agricultural Biotechnology and the Poor*, Proceedings of an International Conference, Washington DC, 21–22 October, pp. 32–6.

McGloughlin, M. 1999, 'Ten reasons why biotechnology will be important to the developing world', *AgBioForum*, vol. 2, nos 3–4, pp. 163–74 (www.agbioforum.org).

McHughen, A. 2000, *Biotechnology and Food*, American Council on Science and Health, New York.

Nielsen, C. and Anderson, K. 2000, GMOs *Trade Policy and Welfare in Rich and Poor Countries*, Policy Discussion Paper no. 0021, Centre for International Economic Studies, University of Adelaide.

Oehmke, J.F. 2002, 'Biotechnology R&D races, industry structure, and public and private sector research orientation', *AgBioForum*, vol. 4, no. 2, pp. 105–14 (www.agbioforum.org).

Paarlberg, R.L. 2000, *Governing the GM Crop Revolution: Policy Choices for Developing Countries*, Food, Agriculture, and the Environment Discussion Paper 33, International Food Policy Research Institute, Washington DC.

Pardey, P.G., Wright, B.D. and Nottenburg, C. 2001, 'Are intellectual property rights stifling agricultural biotechnology in developing countries?' in INFPRI 2000-01 *Annual Report*, International Food Policy Research Institute, Washington DC.

Persley, G.J. 2000, 'Agricultural biotechnology and the poor: promethean science', in G.J. Persley and M.M. Lantin (eds), *Agricultural Biotechnology and the Poor*, Proceedings of an International Conference, Washington DC, 21–22 October.

Pingali, P.L. and Heisey, P.W. 1999, *Cereal Crop Productivity in Developing Countries*, CIMMYT Economics Paper 99-03, Mexico.

Pinstrup-Andersen, P. 1999, 'Agricultural biotechnology, trade, and the developing countries', *AgBioForum*, vol. 2, nos 3–4, pp. 215–17 (www.agbioforum.org).

Prakash, C.S. 2002, *Mexican Maize Not Under Threat*, Agbioworld Foundation, Tuskegee Institute, Alabama (www.agbioworld.org).

Qaim, M and Zilberman, D. 2003, 'Yield effects of genetically modified crops in developing countries', *Science*, vol. 299, February (www.sciencemag.org).

Quist, D. and Chapela, I. 2001, ‘Transgenic DNA introgressed into traditional maize landraces in Oaxaca, Mexico’, *Nature*, London, vol. 414, pp. 541–3.

Rerkasem, B. 1999, ‘Intellectual property rights and agricultural plant genetic resource’, *TDRI Quarterly Review*, Bangkok, vol. 14, no. 2, pp. 7–11.

Richer, D.L. 2000, ‘Intellectual property protection: who needs it’, in G.J. Persley and M.M. Lantin (eds), *Agricultural Biotechnology and the Poor*, Proceedings of an International Conference, Washington DC, 21–22 October.

Roberts, R.K., Pendergrass, R. and Hayes, R.M. 1998, Farm-level economic analysis of Roundup Ready™ soybeans, Paper presented at the Southern Agricultural Economics Association Meeting, Little Rock, Arkansas, 1–4 February.

Roush, R.T. 2002, ‘GMOs in food production – the perceptions and the reality’, *Animal Production Australia*, vol. 24, pp. 512–17.

Sears, M., Hellmich, R., Stanley-Horn, D., Oberhauser, K., Pleasants, J., Mattila, H., Siegfried, B. and Dively, G. 2001, ‘Impact of Bt corn pollen on monarch butterfly populations: a risk assessment’, *Proceeding of the National Academy of Sciences*, University of Illinois, Urbana, vol. 98, pp. 11937–42.

Secretariat of the Convention on Biological Diversity 2000, *Cartagena Protocol on Biosafety to the Convention on Biological Diversity: Text and Annexes*, Montreal.

Stone, S., Matysek, A. and Dolling, A. 2002, *Modelling Possible Impacts of GM Crops on Australian Trad*e, Productivity Commission Staff Paper, Melbourne, October.

Tzotzos, G. 1999, ‘Regulation of biotechnology in LDCs: implications for technology development and transfer’, *AgBioForum*, vol. 2, nos 3–4, pp. 212–14 (www.agbioforum.org).

United Nations 2001, *World Population Prospects: The 2000 Revision: Highlights* – Draft, ESA/P/WP.165, Population Division, New York.

University of Minnesota 2002, Kiosk Online, Minnesota (www1.umn.edu/urelate/kiosk/12.00text/salmon).

US Department of Agriculture 2001, *Economic Issues in Biotechnology*, Economic Research Service, Agriculture Information Bulletin no. 762, Washington DC.

Van der Sluis, E., Dierson, M. and Dobbs, T. 2001, *Selected Economic Implications and Policy Aspects of Agricultural Biotechnology*, South Dakota State University Economics Staff Paper no. 2001–6, South Dakota, October.