ACCESSING AGRICULTURAL BIOTECHNOLOGY IN EMERGING ECONOMIES

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FOREWORD

These Proceedings bring together two framework papers that were presented and discussed at the Workshop on Biotechnology in November 2002, under the auspices of the OECD Global Forum on Knowledge Economy*. The OECD Global Forum on Knowledge Economy is one of eight "Global Forums" managed by the OECD's Centre for Co-operation with non-Members. Their objective is to deepen and extend relations with non-member economies in a range of different subject areas, where global dialogue is important. This activity is part of the CCNM-AGR programme of work on emerging issues in non-member economies.

The Proceedings are divided into two parts. The first paper discusses methods to assess the impacts of modern agricultural biotechnology, and was prepared by Jose Falck-Zepeda, Joel Cohen and John Komen from the International Service for National Agricultural Research (ISNAR). The second paper focuses on designing a country and policy typology for developing countries based on their capacities in the field of agricultural biotechnology, and was prepared by Eduardo J. Trigo, Grupo CEO, Buenos Aires, Argentina. Both papers were discussed in the Workshop and were revised and updated based on the discussions and written comments received from participants.

The first paper considers analytical approaches to estimating the potential impacts of modern agricultural biotechnology on the diversified farming systems in non-OECD countries. The study provides a synthesis of current methodologies for impact assessment and outlines the more comprehensive Sustainable Livelihoods conceptual framework for evaluating biotechnology products. While conventional cost/benefit and economic welfare approaches will continue to form the foundation for assessing the impacts of modern agricultural biotechnology, the assessment of impacts at the community or household level is important in order to gauge the extent to which poor farmers in developing and emerging economies can access and benefit from these technologies. Most current crop biotechnology products focus on reducing production costs, primarily through reducing vulnerability to losses due to pests and diseases.

With the increasing emphasis on developing biotechnologies for food crops in developing countries, there is a need to develop appropriate impact assessment methods that are more inclusive. While many important lessons have been drawn from the experiences of the green revolution in developing countries, the application of modern biotechnologies in agriculture raise many new issues. For many developing countries, assessing the impacts of modern agricultural biotechnology continues to represent a formidable challenge, but is a critical step in order to provide the objective information required by policy makers in designing their national agriculture and biotechnology policies.

The second paper considers the usefulness of modern agricultural biotechnology in developing countries to help deal with the food supply challenge they are likely to confront in the coming decades. Only a limited number of countries are currently in a position to benefit from these technologies. The large more advanced countries, such as Brazil, China, India, are developing biotechnologies to specifically address their agricultural problems through publicly funded national research systems, as well as by adapting imported biotechnologies from abroad. However, many developing countries do not yet have the infrastructure to handle new biotech innovations and some even lack the capacities to fully capture the benefits from conventional agricultural technologies. In addition, many of the current biotech products that have reached the market concentrate on a narrow range of traits for temperate and sub-tropical crops, and therefore, have limited potential in most developing countries. However, there is growing evidence to suggest that research is now shifting to tropical food crops and livestock and this may create more opportunities for developing countries.

This paper outlines a proposed typology of policies and countries based on a country's capacity to innovate, adopt and utilise modern biotechnologies in agricultural production. The study emphasises the heterogeneity of developing and emerging economies with respect to their current policies on agricultural biotechnology, as well as the institutional framework to develop and monitor modern technologies. The lack of adequate human and physical infrastructure makes it difficult to access modern biotechnology, and is often compounded by the weak links between conventional agricultural research and delivery systems and biotech delivery systems. Intellectual property rights play an important role in influencing the transformation of research and knowledge into useful biotech products, as well as the sharing of the spillover effects of biotech research between the different stakeholders in the food system. In many developing countries small size and undeveloped seed markets limit the transfer of new biotechnologies, especially to poor farmers. The proposed typology sets out a useful framework in order to identify the policy, institutional and infrastructural strengths and weaknesses of developing countries and their current potential to benefit from the wide array of biotechnology products available in agriculture.

These proceedings are published under the responsibility of the Secretary-General of the OECD.

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These proceedings bring together the two core framework papers from the OECD Global Forum on Knowledge Economy: Biotechnology, held in Paris on 18-19 November 2002.

The Forum was prepared by the OECD. Michael Ryan was responsible for the design and organisation of the Forum. Thanks are extended to all those who provided papers and contributed to the success of the discussions. The papers were edited by Michael Ryan and Wayne Jones, with the assistance of Lisa Eveleigh and Stefanie Milowski, who formatted the document and prepared it for publication.

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PART I

IMPACT ASSESSMENT AND AGRICULTURAL BIOTECHNOLOGY RESEARCH METHODOLOGIES FOR DEVELOPING, EMERGING AND TRANSITION ECONOMIES

EXECUTIVE SUMMARY

Recent advances in agricultural applications of modern biotechnology show a significant potential to contribute to sustainable gains in agricultural productivity, reducing poverty and enhancing food security in developing countries. As these innovations are increasingly adopted, impact assessment becomes a critical tool for addressing potential socio-economic and environmental costs and benefits.

A key message of this report is that conventional economic impact assessment may not be broad enough to address the complex nature of a rural community in developing, emerging and transition economies (DETEs). The report introduces a Sustainable Livelihoods approach, which may provide a more appropriate framework to quantify and qualify the impact of biotechnologies in these countries. The Sustainable Livelihoods approach is a broad-based inclusive framework that facilitates and requires multi-disciplinary work to assess impact in a community. It considers the vulnerability context, as well as the policies, community portfolio of assets, institutions, and significantly; the linkages between these components.

While there are several conceptual and implementation issues that still need to be resolved regarding the specific nature of biotechnology innovations, the Sustainable Livelihoods approach can be a very valuable tool to guide research. The approach requires a change of mentality on the part of the impact assessor, development agencies and research institutions, in the sense that the community in the end guides the research. This bottom-up approach to research identification and evaluation in some cases may mean that alternative approaches, besides biotechnology, may need to be explored and researched.

Impact assessment is critical for confirming whether biotechnology has extended to small holders or farming communities beyond the reach of markets and most importantly, if these biotechnologies have accomplished the ultimate goal of improving the livelihood of communities in DETEs. Studies reviewed in this report indicate that the current wave of input reducing biotechnologies can and do provide positive benefits to producers in DETEs. The need for DETEs to develop their own capacity to assess the impact of biotechnologies is stressed.

These studies also indicate policy and infrastructure requirements needed to ensure that biotechnology will benefit rural communities such as:

- Capacity to generate, adapt, and/or negotiate access to biotechnology innovations;
- Capacity to generate good quality animal and plant germplasm where biotechnology can be used;
- Ability to identify and prioritise critical problems affecting the rural poor that may be addressed by biotechnology;
- Existence of a technology and information delivery system;
- Existence of a rational (science-based), transparent and expedient biosafety regulatory system;
- Ability of the public sector and the international agricultural research centres to negotiate and promote private-public partnerships in an environment where biotechnologies for resource poor farmers can be considered public goods.

Finally, development of a long term, systematic programme of comparative studies is recommended to ensure ongoing monitoring and analysis of the impact of existing or near-term introductions of biotechnology products in DETEs. In turn, this would provide reliable information to decision makers about the expected benefits, costs and risks of such technologies.

1. Introduction and Background

(i) Purpose and objectives

The United Nations (1999) expects that by 2030, the world's population will rise to 8.1 billion. According to FAO (2000), almost all of this population increase will occur in DETEs (Developing, Emerging and Transition Economies). These are countries that can ill-afford additional population increases that will increase food demand. Some authors (Douthwaite, 2001; Moore-Lappé *et. al*, 1998) propose that there is currently sufficient food to feed the world's population; the problem of world hunger is not of quantity, but of unequal distribution. However, even if in the short-run we resolve the issue of distribution, with a growing population the amount of food demanded will necessarily grow in the long run. The challenge is not only having to feed more people, but to do so taking into account production of food with less arable land available to agriculture, fewer non-renewable resources, less water and fewer people engaged in primary agriculture (Kishore and Shewmaker 1999; Conway 1999).

Agricultural biotechnology may contribute to solving the issues of poverty and food insecurity given the increasing constraints faced by agriculture in DETEs. However, decision makers need to have answers to critical questions in order to ensure that biotechnologies will reach and address the problems of their intended targets. The critical questions in this discussion are: What are the necessary institutional and research infrastructures to supply appropriate agricultural biotechnologies to DETEs? How can DETEs guide the development of pro-poor agricultural biotechnologies? What is the impact of biotechnology on the environment, human health or on the livelihood of the rural poor? Debate over these questions has generated very passionate exchanges of opinions and controversies in different forums.

These questions are of paramount importance given that innovators in OECD countries develop the majority of applications of modern biotechnology for market-based economies, or for commodities used in highly productive environments. The need for biotechnologies for resource poor farmers should be weighed against current technological capacity, the current trend of declining public investment in agricultural research in many DETEs, and the perception that biotechnologies have no place in poverty alleviation strategies. Indeed, part of the criticism directed against biotechnology, particularly towards genetically modified crops, is that few or no benefits accrue to poor farmers, or consumers in DETEs. Critics of biotechnology are often unable to base their opinions on sound facts, as there is very little information about the long-term costs, benefits and risks associated with using biotechnology, especially for the rural poor. Addressing these issues may help answer the questions raised above.

A limited number of studies have applied different methodologies and approaches to assessing the impact of new agricultural biotechnologies in developing countries. These studies have suggested positive impacts for small-scale farmers[1]. While the foregoing studies provide valuable insights, the evidence of biotechnology impacts is still fragmentary. New approaches, which are more comprehensive, are required to better understand the likely impacts of agricultural biotechnology products on rural livelihoods, positive or negative.

1. These studies also suggest that certain conditions are necessary if farmers are to reap maximum benefits from what the technology has to offer, such as improved management practices or improved seed distribution.

The purpose of this report is twofold. First, the report reviews and discusses findings and limitations of existing socio-economic methodological approaches to analyse the impacts of biotechnology. The main limitation of existing socio-economic methodologies is that they tend to focus on a narrow disciplinary emphasis when, in fact, impact occurs at many levels within a community, hence the need for comprehensive evaluation methodologies. Second, we introduce the comprehensive Sustainable Livelihoods (SL) conceptual framework, and suggest how this framework could be applied to measure the impacts of agricultural biotechnologies.

The SL framework utilises the concepts of vulnerability, community assets, policies and institutions, and the linkages between these factors. The SL methodology allows a better understanding of the likely impacts, positive or negative, of agricultural biotechnology products on the livelihoods of rural communities in DETEs. We expect that this report will contribute to policy discussions, within both DETEs and OECD countries, on how to evaluate the role of biotechnology in agricultural development strategies for developing countries. This will improve the ongoing debate and provide essential information to policy makers, researchers, leaders of communities and civil society.

In this report, we concentrate on social and economic impact assessments as compared to the SL methodology[2]. In the remainder of this section, we provide a working definition of biotechnology and a brief summary of the status of public sector biotechnology research in selected DETEs. The second section will discuss the relevant concepts related to benefits, costs and risks of agricultural biotechnologies in DETEs. Section three provides a review of the literature for existing socio-economic impact assessment methods as well as exploring existing cases of impact assessment drawing particularly on the experience of DETEs. In the fourth section, we introduce the Sustainable Livelihoods methodology. The SL methodology is a broad based methodology that seeks to address the existing linkages affected by the introduction and adoption of a technology in a community. Crucial issues and limitations to implementing the methodology are discussed, and ongoing impact assessment research activities that use the SL framework are reviewed. The final section draws conclusions about impact assessment methodologies and various policy issues arising from the discussion.

(ii) Biotechnology in DETEs

Definition and scope of biotechnology

This report uses the definition of biotechnology proposed by Cohen (1999). In this definition, biotechnologies are the products arising from cellular or molecular biology and the resulting techniques coming from these disciplines for improving the genetic makeup and agronomic management of crops and animals[3]. These techniques include fermentation, microbial inoculation of plants, plant cell and tissue culture, enzyme technologies, embryo transfer, protoplast fusions, hybridoma or monoclonal antibody technology and rDNA technologies. This definition allows for a focus on products arising from the research continuum between traditional and modern biotechnology. The artificial segregation between modern and traditional biotechnologies will certainly disappear, as

2. Impact assessment researchers have developed distinct methodologies for environmental, risk, environmental health, and strategic environmental assessments (IAEG, 2000). However, a review of these alternative impact methodologies falls outside the scope of this report

3. This definition is similar to the working definition of biotechnology used by OECD (OECD, 1999).

laboratories world-wide incorporate modern biotechnology techniques into their daily research operations.

Public biotechnology research in developing countries – the state of the art

As access to biotechnology tools and research increases among developing countries, biosafety regulatory, trade related and economic impact assessments will become more essential. Such studies will help to minimise the costs and risks, and to maximise the benefits of biotechnology research. Recognising the need for this information, ISNAR's Biotechnology Service began a research project regarding the use, regulatory status and constraints facing developing country *public sector* research organisations.

This study, titled 'Next Harvest', is comprised of data collected from, and with a number of public sector institutes in Asia, Africa and Latin America. This information focuses on food crops, and hence, fibre and animal transgenics are not included. ISNAR collected data for food crops to be modified, their source of germplasm, the transgenic event employed, its biological use, regulatory status and means for deployment. By collecting data in this comprehensive manner, it is possible to bring together concerns of access, use and benefit from biotechnology research; relation to breeding and varietal registration; regulatory categories and status; and, plans for dissemination to users. Data has been assembled by country, and it is now possible to derive preliminary summaries as shown below. Comprehensive summaries will be available only after all data and conclusions are verified with participating countries.

In addition to ISNAR's data, other sources of information exist as collected by the Pew Initiative on Biotechnology (2001), and by Burrill and Company (2000). These reports describe the range of temperate crops, traits and technologies being advanced by public and private research in industrialised countries. While the first tier of commercial products has primarily focused on new inputs to help farmers (herbicide, insect and disease resistance), a far broader range of products is expected from the coming wave of research (see below).

Currently, based on data from 11 countries, the following preliminary findings can be discussed:

- *The research pipeline is increasing and diversifying*. An increasing diversification of crops being transformed in industrialised country research is readily seen. This trend is also seen among developing countries. These include all basic food commodities, fruits and vegetables, tree species, papaya, and oil palm.

- *Biotechnology objectives are primarily for disease/insect resistance*. Transformation events for tropical crops are primarily concentrated on disease and insect resistance. This is the principal difference with temperate crop biotechnology, where biotechnology objectives provide a far greater range of applications, including herbicide resistance, nematode resistance, and allergenicity reduction (Pew Initiative on Biotechnology, 2001).[4] The major focus for developing country public research is insect resistance in

4. For developed countries, Burrill and Company (2000) document other applications in the research pipeline that include: (a) High-performance cooking oils: achieved by providing high levels of high oleic or low levels of linoleic acid; (b) Healthier cooking oils: reduced saturated fats; (c) Delayed ripening fruits and vegetables: superior flavor, color and texture for shipping; (d) Nutritionally enhanced foods: increased nutrients, vitamins and other nutrition related ingredients.

cereals (rice, maize, sorghum), virus resistance in vegetables, potato, papaya and resistance to Black Sigatoka fungus in banana.

- *Wide access to proprietary genes and technologies*. At present, all countries studied show various methods to access modern technologies. This can be through license or transfer agreements, international collaboration, or a number of other mechanisms. Their use in transformation and as sources for biotic resistance is very clear and growing. In most cases, the use of protected technology is being advanced, without serious concerns over intellectual property rights (IPR). In many cases the problems are sorted out beforehand or for local crops being transformed, IPR concerns are not an issue because of the lack of export or trade implications.

- *Regulatory difficulties and challenges*. Besides the focus of transgenic events, the second biggest difference in developing country biotechnology is the scarce number of regulatory approvals provided for scale up or commercial release. This is not to say that all regulatory questions have been met, or that all necessary safety data have been provided. Rather it is to say that the most severe restriction to progress in this research, at present, is due to other regulatory difficulties (Cohen and Paarlberg 2002) and costs encountered as research moves to larger field scale testing (Cohen 2001). Thus, while research is freer to advance in North America and other centres of innovation, it is often curtailed in developing countries, where, by and large, only commercial use of transformed cotton and soyabeans has been allowed.

In the regulatory status data compiled to date, discrete categories were used, ranging from laboratory, to confined scale up and ultimately, commercial release. By far, most developing country applications are at the stage of laboratory or confined release, with the exception of China. As for China, it has developed some crop events that are now in scale up testing or ready for commercial release. This also reflects the length of time needed to gain acceptance, approval and the best product from GM research. Few developing countries, besides China, can take advantage of such key investments to make their research available to farmers (Huang *et. al*, 2001, 2002).

(iii) Costs, benefits, and risks of agricultural biotechnologies in DETEs

In this section, we describe the benefits, costs, and risks of biotechnologies. Table 1 provides a sample list of possible benefits, costs and risks in order to emphasise that the main imperative for DETEs is to examine agricultural biotechnologies with the appropriate impact assessment methodologies that will be able to address the complex adoption, diffusion, and hence impact, of innovations in DETEs.

Most current developments in transgenic crops aim to increase output per unit of land or reduce production costs[5]. Alternatively, current developments seek to increase value added of final products by improving quality. These types of improvements are characteristic of the first and second wave of transgenic crops released commercially, or that are currently in the research pipeline. Biotechnologies, developed mainly for a developed country setting (*i.e.* Bt cotton or herbicide resistant soyabeans), have diffused to regions and countries with similar agro-ecological characteristics, but this path of dissemination represents an exceptional case, not a result of DETEs' policies or strategies to develop biotechnologies.

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5. Biotechnology companies in industrialized nations have developed most current biotechnologies for agricultural areas that already have high productivity levels.

Table 1. **A sample list of possible benefits, costs and risk of agricultural biotechnologies**

BENEFITS	COSTS	RISKS
Improved technologies • Unit cost reductions in production • Reductions in pesticide applications • Improved nutritional qualities • Biotic and abiotic stress resistance **Improved knowledge** • Basic research (improved efficiency of future research) • Applied techniques (improved efficiency of current research)	**"Economic"** • Technology/User fees • Additional farm management costs • Increased prices of inputs (imperfect competition setting) • Increased dependency • Trade considerations **Research costs** • Capital & Human **Safety** • Risk avoidance - Regulatory framework	**Financial risk** • Liability and indemnification - after the fact compensation of damage • Insurance value of technology fees **Human health** • Allergenicity • Toxicity • Antibiotic resistance **Environmental** • Impact on non-target organisms • Unintended expression and effects • Gene flow

From the standpoint of DETEs, perhaps a more effective strategy would be to specifically target biotechnology innovations that may increase productivity in marginal areas, where an increase in food production is needed, where crop yields are significantly lower than those obtained in developed countries, and where all other technological means have been exhausted (Herrera-Estrella 1999). Making such productivity increases possible calls for technologies that combat low productivity levels, post-harvest losses in marginal areas, control pre-harvest pests and increase yields on unfavourable soil conditions.

We envision that poor farmers and consumers in DETEs may benefit from biotechnology through the following paths:

- Benefit poor farmers directly by increasing their on-farm production. This may involve production of more food for their own consumption, increasing the output of marketed products that increase farm income, and lowering costs per unit of output;

- Improve nutritional status of the poor from increased nutritional contents of targeted crops or animals;

- Benefit small farmers and landless labourers through greater agricultural employment opportunities and higher wages within the adopting regions;

- Improve environmental efficiencies/cost reduction, coming with decreased use of chemical inputs;

- Benefit a wide range of rural poor within adopting regions through growth in the local non-farm economy;

- Increase migration opportunities for the poor to other regions and urban areas; and

- Benefit both urban and rural poor by lowering food prices.

It is important to emphasise that the paths by which biotechnology can help address the issues of poverty and food security cannot be examined in isolation from the socio-economic environment where the community exists. For example, even if biotechnologies manage to improve farm production, this may not be enough to facilitate long-term household sustainable development if households cannot sell their surplus production in functioning markets. Furthermore, if trade policies from developed countries depress food prices and reduce access to their markets, this can only mean negating potential opportunities to DETEs. The analysis framework should carefully consider the linkages with institutions and processes outside a community, in some cases outside the country or region that may affect, or even negate the possibility of benefiting from an innovation. Conventional socio-economic impact assessment methodologies may not address all (relevant) affected linkages in a community.

The National Academy of Sciences (2000) of the United States argues that in order to realise agricultural biotechnology benefits, public and private sector research institutions need to emphasise biotechnology innovations that will express the following traits:

- Pest resistance: offers benefit to farmers in need of genetic control mechanisms, where cultural practices are not effective, and where a reduction in pesticides is advantageous, leading to the need for more research to assess sustainability of resistance expressed in transgenic pest-protected plants.

- Improved yield: isolation of dwarfing genes originally used to increase yields of cereals during the green revolution has now been shown to have the same effect in other crops, with the potential to increase yield in other crops.

- Tolerance to biotic and abiotic stresses: genetic control of the rice yellow mottle virus is one example of how transgenics can accomplish resistance when conventional approaches failed to do so, illustrating the need for public funded transgenic work to extend such benefits to smallholder farming communities.

- Nutritional benefits: traditional breeding has generally not been successful in increasing nutritional elements of many plant varieties, but recent progress enhancing vitamin A content and elevated iron levels in rice shows the potential of such research for developing countries.

- Reduced environmental impact: producing crops that tolerate stressful conditions, by introducing GM traits that control root diseases, will help farmers cultivate crops where reduced tillage is essential.

The emphasis on genetic traits and research areas discussed above refers to end-products of research that poor farmers in DETEs may adopt for use. However, an important and often neglected benefit, particularly of more established biotechnologies such as tissue culture, or of newer technologies such as genomics, is that they may improve existing research processes. For example, genomics may improve the efficiency of future basic or applied research. Increases in current research efficiency allow innovating institutions to make better investment decisions, as the uncertainty associated with research output is reduced.

Integrating biotechnology with conventional technologies requires significant additional investments in research, human, and financial resources. The development of a gene construct may entail significant research resources. In addition, innovators have to comply with additional biosafety evaluation procedures that in some cases may constitute a limit to entry for smaller firms and the public sector. Public sector and smaller research institutions may not have financial or human resources to comply with required toxicological, allergenicity and animal testing required for novel products.

Biotechnology innovators recuperate the cost of development by charging technology or user fees. Producers consider technology or user fees when deciding whether to adopt (and continue using) a particular biotechnology. Producers base this assessment on biotechnology's ability to provide enough benefits to recuperate additional input costs and compensation for the risks of using the technology. For example, in the case of input enhancing technologies, particularly GMOs designed to address biotic challenges, producers have to pay for the technology up-front without knowing if they need the technology, and thus face additional financial risks beyond conventional technologies. Financial risk arises because biotic challenges are random and vary from year to year.

In addition, with growing demand for labelled products, producers who use biotechnology products may be penalised by purchasers of outputs because of potential trade considerations. This is particularly the case for nations with an active international trade with countries that restrict the sale of products of biotechnology. Increasingly, impact assessment will also need to include insurance value to the producer.

An issue which is increasingly being considered, particularly after the Starlink maize incident in the United States, is the issue of after-sale risk avoidance in the form of liability and indemnification[6]. Institutions will have to increase resources to protect themselves from this form of, after the fact, compensation for damage. All of these development costs increase the cost to the final user.

The discussion so far has concentrated on private costs, benefits and risks. However, biotechnologies also imply potential benefits, costs and risk of significant societal value. Individual producers cannot capture societal benefits, and society does not expect them to cover all of these costs and risks. Several Non-Governmental Organisations (NGOs) and researchers that oppose biotechnology have portrayed biotechnology products as harmful to the environment (Clark, 1998), to human health (Ho, 1999), and to the socio-economic status of small farmers (Shiva, 2000). These authors indicate that biotechnology has potential risks, such as allergenicity and toxicity, induce antibiotic resistance, environmental and vertical movement of genes, impact on non-target organisms and other unintended effects. These authors' arguments rely on preliminary or laboratory level research that indicate a potential risk with existing technologies. However, the "absence of evidence, does not constitute evidence of absence". It is important to point out that, although a high proportion of land in the United States and Argentina is

6. Starlink, an insect resistant variety of maize, was approved temporarily for animal use only in the United States due to concerns of potential allergenicity problems. Traces of Starlink® were found in human food for consumption. The contamination may have occurred at any point of the commercialization channel. The innovator destroyed all available seed, abandoned the development of this biotechnology and purchased back all known stocks of grain.

sown to GMO varieties, there is, as yet, no scientifically verified case of any person's health being directly affected by the technology (Kaeppler, 2000; Thompson, 2000).

Reports made by the Royal Society in the United Kingdom (2002), the European Commission (2002), and by a Workshop held at the University of California-Berkeley[7] (Altieri, 2000), indicate that, up to now, there has been no catastrophic event recorded or scientifically documented from the release of genetically modified organisms. The European Commission publication reviewed biosafety assessments of 81 projects funded by the European Commission from 1984 to 2000. This report concludes that substantial efforts have been made to assess biosafety and that greater knowledge has been accumulated about the risk characteristics of GMOs. However, the University of California-Berkeley conference report raised questions about the long-term risks and sparseness of environmental information of GMOs.

2. Methodology and findings of socio-economic assessment of the impact of biotechnology

Socio-economic impact assessment is not an end in itself, but rather a way to identify alternatives, so that scientists can enhance the benefits and minimise the costs of adoption and diffusion of innovations. Alternatively, socio-economic impact assessment can be incorporated into the decision making process to improve its quality. Socio-economic impact assessment will always be speculative and results of its estimations need to be taken with caution. Even in the case of an *ex post* analysis, there will always be parameters and other variables which are subjected to biases, either of the researcher or from the data sources, or uncertainties about the true values of the parameters being measured.

In most instances, results from a case study can only be applied to the place were the study was conducted. Socio-economic impact assessment practitioners can extrapolate results to other regions in a limited amount of cases and with extreme care. A practitioner cannot, and should not make over-generalisations as a result, from estimations. To deduce general conclusions about the impact of agricultural biotechnology, it is important to review socio-economic impact assessment studies from different regions or countries and under diverse socio-economic circumstances. This exercise may allow the identification of critical components that affect the impact of biotechnologies on communities.

This section will briefly describe the two most widely used methods of socio-economic impact assessment of technologies, the Cost/Benefit and Economic Surplus methods. In addition, we discuss some methodological shortcomings of these two methodologies. The purpose of discussing the impact methodologies here is to provide a background to better understand the discussion of empirical impact assessment studies in the next section of the report.

It is important to point out that impact assessment methodologies can be used in an *ex ante* or *ex post* setting. *Ex ante* impact assessment, refers to the analysis that estimates the potential impact of the adoption and diffusion of an innovation. Practitioners customarily perform *ex ante* analysis to evaluate competing project options and to allocate resources based on a priority setting exercise. In an *ex ante* analysis, the researcher proposes plausible values for key parameters in the model chosen.

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7. The Consultative Group on International Agricultural Research Non-Governmental Organizations Committee (CGIAR-NGO) organized this Workshop. This Workshop was co-sponsored by the Institute for Food and Development Policy (Food First) and the Center for Biological Control, University of California at Berkeley.

In contrast, *ex post* impact assessment refers to the analysis that evaluates past performance and achievements. This is an after-the-fact analysis that examines the use of inputs and seeks to provide information to policy makers. In an e*x post* analysis; the researcher collects data on key parameters from primary or secondary sources. The probability of success, adoption rates, and information about production performance are known or can be estimated from different sources.

One of the critical issues of e*x post* (and to a lesser degree *ex ante*) analysis is making the appropriate comparison between the "with" and "without" innovation scenarios. Agronomic and other life sciences experiments customarily deal with the appropriate comparison by comparing the proposed treatments with a control. In the case of economic impact studies, the control option is not possible; the next best solution is to use information available for the conventional (older) technology. The researcher can make estimations of the "without-innovation" prices and quantities using formulas derived from the system of supply and demand equations. In the economics literature, the "without innovation" scenario is known as the counter-factual scenario.

(i) Cost/Benefit and Net Present Value methods

Cost-Benefit (CB) analysis is a widely used and documented method, whose purpose is to provide consistent procedures to evaluate decisions in terms of their consequences. Often the literature distinguishes between two different sub-sets of approaches in CB analysis. The first one, the financial approach, includes examination of cash costs and benefits only. This is the procedure used by private firms and individuals to examine competing projects. The decision rule to accept a project is simply that a project is undertaken as long as benefits exceed costs. This decision rule is equivalent to positing that net benefits are greater than or equal to zero. The second, the socio-economic approach, adds the cost of alternatives (opportunity cost) and external influences on society. Alternative costs are customarily valued using "shadow prices"; prices that include all the costs incurred by society in order to supply a good in the market.

Analysts have to apply "shadow prices" rigorously in DETEs, because of market imperfections, distortions induced by the State, price and wage rigidities, unequal income distribution, and fragmentation of the capital markets. The aforementioned characteristics do not affect CB analysis exclusively; they are common to all impact assessment methodologies. However, this methodology often has to rely on other socio-economic methodologies to estimate the impact of a particular innovation on prices and other parameters in a society. This dependence on other methodologies may complicate the CB analysis tremendously and may even negate its major virtues of expediency and simplicity.

To reflect the time value of money, researchers need to discount the flow of future net benefits using the appropriate discount factor or interest rate. Thus, discounting is a procedure to estimate the present value of benefits and costs realised during the course of the project. The process of discounting assumes that money spent today is more valuable than money spent in the future, as today's money can be invested, and thus can generate income until future use. In addition, discounting assumes that most people prefer to consume now rather than later. Discounting also assumes that the future is uncertain, and that for most people it is hard to delay consumption that produces immediate gratification.

The Net Present Value is thus the sum of the discounted stream of annual net benefits. Net Present Value requires subtracting all the costs necessary to bring the project into existence. An alternative measurement is the Internal Rate of Return (IRR), which is simply the rate of interest which, when applied to discount the stream of net benefits, makes the NPV equal zero. The analyst compares the

IRR to an existing benchmark rate of interest, usually the prevailing bank-lending rate. If the IRR is greater than the benchmark rate of return, then the project is accepted.

(ii) Economic surplus

The economic surplus methodology seeks to estimate net additional benefits to the economy due to an innovation. This methodology is also known as economic welfare analysis. The economic surplus methodology is based on the principle that supply and demand for a particular good reaches an equilibrium point. Equilibrium represents a combination of prices and quantities, where at the given price the quantity demanded by individuals exactly equals the amount supplied by firms or producers[8]. Changes in the equilibrium quantity and price occur because of external shocks to the system of supply and demand functions (*i.e.* introduction of a biotechnology innovation). External shocks induce a shift in the demand or supply functions and a new equilibrium is reached. In the particular case of technology, innovation may cause a per-unit cost reduction (increase), or equivalently, more (less) output produced with the same amount of inputs.

Economic surplus is composed of consumer and producer surplus. Both producer and consumer surplus are customarily measured as changes with respect to a counterfactual case, usually no innovation available or, alternatively, usage of an older technology. Changes in consumer surplus arise through the associated price decrease due to the adoption of the innovation that causes the shift in supply, multiplied by the quantity of the good consumed. Changes in producer surplus arise from the change in net benefits associated with increased post-innovation output. Net benefits may be a result of an increase in output produce or from a decrease in the cost of production. In both cases, an output increase or cost of production decrease, the researcher measures changes net of the loss due to the price change induced by the innovation. This is a well-established methodology in the economic literature and has been shown to provide valuable contributions to impact assessment efforts.

Researchers initiate the estimation procedure of economic surplus by deciding on the type of model to use. A decision on the type of model to use, will also include decisions about the type of functions (linear vs. curvilinear) and the type of supply or demand shift (parallel or pivotal). If there is a need to have preliminary estimations, the procedures that use a parallel shift and linear functions are very useful. This decision will also have to consider whether or not there is sufficient good quality data to do an econometric study.

Impact assessment practitioners have used several estimation procedures to estimate economic surplus. The main advantage of econometric methods is the ability to test hypotheses about the parameters in the model. The econometric method requires extensive good quality data, often not available in DETEs. The mathematical programming method obviates the need for extensive data and requires extensive knowledge about the processes and production characteristics of the innovation, but it is hard to judge the robustness of the model.

The quasi-rent approach provides an expedient and useful first approach to measure economic surplus. However, the quasi-rent approach is significantly close to economic surplus only when the change in supply or demand is small, and the elasticity of supply is unitary. If the innovation departs from these narrow assumptions, quasi-rents and economic surplus will diverge. The equilibrium displacement models provide a stronger theoretical background, allow for multiple modelling possibilities of policies, and are relatively simple and expedient to use. Very little data is required and the existing

8. The economic surplus method is thus a static model because there is no mention of how equilibrium is reached.

literature provides the data. However, because the equilibrium displacement models are based in linear functions and parallel shifts, they may not be suitable for all potential problems to be confronted by the practitioner. Table 2 provides a description of the characteristics of each estimation procedure described previously.

The obvious question that arises from the previous discussion and from Table 2 is how does a researcher choose between these methodologies and estimation methods? The evaluation criteria to choose the appropriate methodology are expediency, available resources, data availability and quality, and the type of research or policy question to be answered. For example, the quasi-rent, standard surplus models, and the Equilibrium Displacement Models are very expedient, with little data required, and require relatively few resources to implement. However, the quasi-rent approach can only be thought of as a first approximation to check results from other economic surplus models. The Equilibrium Displacement Models can model policy implications readily, however, they require the modeller to have advanced knowledge of economic concepts and methods, as well as extensive knowledge of the policy implications.

Table 2. **Advantages and disadvantages of economic surplus estimation approaches**

Estimation approach	Advantages	Disadvantages
Standard models	• Very little data required • Simple models • Most data found in the literature	• May be inflexible • Linear models may not be appropriate for some production processes
Econometric	• Ability to test statistically hypotheses about parameters • Possibility of addressing some data problems	• Large amount of good quality data required
Equilibrium Displacement Models (EDM)	• Ability to model explicit economic and policy considerations • Very little data required • Data available in the literature	• Linear models may not be appropriate for some production processes
Linear programming	• Very little data required	• Extensive production (engineering) knowledge required • In most cases unable to statistically test hypotheses about parameters
Quasi-rent approaches	• Expedient • Relatively little data required	• Converges to standard models of economic surplus only when cost or yield changes are small and when the elasticity of supply is unitary

(iii) Existing cases of socio-economic impact assessment in DETEs

Assessing the socio-economic impact of technology has been the subject of several studies, conferences and discussions. However, there is a scarcity of conclusive data for biotechnology, partly because of its novelty[9]. Furthermore, it is important to point out that developed countries have done

9. Examples of biotechnology impact papers are those presented in the conferences hosted by the International Consortium on Agricultural Biotechnology Research (ICABR) conferences in Ravello, Italy.

much of the existing socio-economic impact research. In this section, we review the few existing socio-economic impact papers in DETEs. At the same time, we point out existing gaps in the knowledge continuum in DETEs.

Excellent literature reviews of existing agronomic and socio-economic studies done in developed countries can be found in Marra, Pardey and Alston (2002); Shelton, Zhao and Roush (2002); and a Working Paper of the European Commission (2002). The main conclusions from these papers is that the crops derived from biotechnology research, first released commercially, can provide significant benefits to adopting farmers, while at the same time decreasing the amount of pesticides applied or allowing substitution of less toxic active ingredients. In some cases, using biotechnology may facilitate the adoption of erosion reduction methods such as no-tillage or reduced-tillage practices. In most cases the benefits accrued to the farmer compensate the extra-cost of fees paid to the biotechnology innovators for its use.

Insect resistance

Table 3 presents a sample of selected studies that have examined the distribution of benefits and the economic impact of biotechnologies in developing countries. Most of the impact studies done in developing countries to date have concentrated on insect-resistant cotton (Bt cotton)[10.] This is in part because Bt cotton is one of the most widely diffused biotechnologies in developing countries, but also because Bt cotton is well suited for smaller scale farming. In addition, Bt cotton has the potential to decrease highly toxic pesticide levels and may have other environmental and public health implications.

Studies that document the potential impact of this technology have been conducted in China Mexico (Traxler *et. al,* 2001), and South Africa (Beyers *et. al,* 2001), (Huang *et. al,* 2002)[11]. They indicate that the adoption of Bt cotton leads to higher yields and a marked decrease in pesticide use, which may bear substantial environmental and human-health benefits. Thus, the planting of Bt cotton enhanced farmers' incomes, as the increase in yields and reduction in chemical applications outweighed higher seed costs. During the analysed planting seasons, a significant share of total benefits accrued to farmers, with smaller portions going to consumers and seed companies.

Huang, Hu, Pray, Qiao and Rozelle (2001) estimated the impact of Bt cotton in China. China approved Bt cotton for cultivation in 1998. Two competing sets of Bt cotton varieties were approved for cultivation in different provinces. Thus, the two sets of varieties are not allowed to compete with each other. The first one is a set of varieties produced by the Chinese Academy of Agricultural Sciences. The second is a set of cotton varieties produced and introduced into China by a joint venture between Monsanto Corporation and a Chinese partner. Estimations from these researchers indicate that Bt cotton in general has a significant advantage over conventional cotton. In the surveys conducted in 1999 and 2000, the authors reported that, on average, growers using Bt cotton reduced pesticide use

10. For a literature review of agronomic and socioeconomic impact assessment for insect resistant cotton, please consult Edge *et. al* (2001), and Falck-Zepeda, Traxler and Nelson (1999, 2000). For economic impact assessment of Bt cotton in the United States please see Falck-Zepeda, Traxler and Nelson (2000a, 2000b); Falck-Zepeda, Traxler and Nelson (2001).

11. These papers presented in the Consultation Biotechnology and Rural Livelihood - Enhancing the Benefits, June 25–28, 2001. A consultation organized by the International Service for National Agricultural Research, The Hague, The Netherlands. ISNAR's Briefing Paper 53 (Falck-Zepeda, Cohen, Meinzen Dick, and Komen; In Press) summarises these papers, as well as, conclusions and recommendations from the consultations.

from 55 to 16 kg of formulated product per hectare. In addition, Bt cotton adopters reduced the number of insecticide sprays per crop from 20 to 7.

In addition to a 70% pesticide reduction, the authors also noted the almost complete elimination of highly toxic organochlorine and organophosphate insecticides. Preliminary evidence in this study suggests that the use of Bt cotton resulted in a significant positive effect on farmers' health. The authors noted that 30% of farmers who used conventional cotton varieties reported health problems associated with spraying compared with only 9% who used Bt cotton. The authors concluded that the evidence is quite clear that Bt cotton reduces pesticide use and is likely to be beneficial to health and the environment.

Table 3. **A sample of case studies estimating the impact of insect resistant cotton biotechnology**

Authors	**Country conducted**	**Years of analysis**	**Estimation method**	**Results**
Huang, Hu, Pray, Qiao and Rozelle 2001	China	1999	Net returns, Econometric	MNC Bt cotton net revenue per hectare was RMBY 855. China's Bt cotton varieties average net returns were RMBY 1433. Non-Bt in the sample reported a 2229 loss per hectare.
Traxler, Godoy-Avila, Falck-Zepeda and Espinoza-Arellano 2001	Mexico	1997 1998	Economic surplus	Producers captured 10%, Innovators 90% of additional income. Producers captured 90%, Innovators 10% of additional surplus
Beyers, Ismaël, Piesse and Thirtle 2001	South Africa	1998/99 1999/00	Accounting and Econometric	In 1998 gross margins per hectare almost the same between adopters and non-adopters. In 1999, adopters had a 58% higher gross margin per hectare. For 1998, results show that adopters averaged 74% efficiency, as compared with 66% for the non-adopters. In 1999, the equivalent figures were 88% and 48%.
Falck-Zepeda, Traxler and Nelson 2000a	U.S.A.	1996	Economic surplus	U.S. Producers captured 59%, Innovators 26%, and the "rest of world" (ROW) 6% of additional benefits.
Falck-Zepeda, Traxler and Nelson 2000b	U.S.A.	1997	Economic surplus	U.S. Producers captured 42%, U.S. consumers 7%, Innovators 44%, and the ROW 6% of additional benefits

Beyers, Ismaël, Piesse and Thirtle (2001) and Ismaël, Bennet, Morse (2001), estimated the impact of the adoption of Bt cotton in Makhatini Flats in South Africa in 1998/99 and 1999/00. In 1998/99 the researchers did not find significant differences in net benefits, contrary to 1999/00, where net benefits were 58% higher for adopters of the Bt cotton technology. In their study, econometric estimations indicated that in 1998 adopters of Bt cotton were more efficient in using their resources compared to non-adopters. The difference between adopters and non-adopters was even more significant in 1999, with adopters achieving an 88% efficiency with respect to the potential production possibility. The significance of these results is the additional benefit of technology pushing adopters to a higher efficiency level compared to non-adopters. This observation magnifies the significance of information reaching producers to maximise the technology benefits.

Traxler, Godoy-Avila, Falck-Zepeda, and Espinoza Arellano (2001) examined the impact of the adoption of Bt cotton in the Comarca Lagunera region in northern Mexico in 1997 and 1998. The Mexican government gave Monsanto a provisional permit to offer Bt cotton for cultivation in 1996. The researchers used an economic surplus model, where a small open economy adopts a technology. In this model, because of the openness of the economy and the inability to affect prices, consumers in the region do not see additional surplus from the innovation, whereas the producers and innovators capture all the rents produced. Results presented in this paper indicate that in 1997 producers captured 10% of the additional rents and innovators the remaining 90%. In contrast, in 1998 producers captured 90% of additional rents and innovators the remaining 10%. Differences in infestation levels and the need to control insect populations explain mostly these inter-year differences in rent distribution.

The Traxler *et. al* paper also serves to highlight the adoption decision estimations made by producers in this area. From a producer standpoint, biotechnology has additional deployment costs compared to conventional technology. The biotechnology innovators in the private sector have charged producers in the area technology and user fees. These technology and user fees were charged in addition to those made for the equivalent conventional technology. For example, the average technology fee charged to cotton farmers for Bt cotton in northern Mexico amounted to USD 80 per hectare. This is the same technology fee charged to producers in the United States. In the region, producers plant Bt seed cotton at an average rate of 14 kilograms per hectare. To recuperate the additional cost of Bt cotton in northern Mexico, producers would have to get either reduced sprays of pesticide or an increase in lint production of USD 50.90 per hectare. At a world price of USD 1.42 per kg, this represents 35 kilograms of extra lint per hectare. Conversely, the additional cost of the Bt seed could be recuperated with a reduction of 1.3 sprays per production cycle[12].

The papers examined here highlight the importance for researchers to examine all the linkages affected by the introduction of a technology in a community. For example, the China study shows public health and environmental implications that may escape traditional socio-economic studies. What is more important is the need to examine the impact of the technology on the community as a whole. Communities in developing countries are bound to use additional measurements of wealth and security apart from monetary considerations. In addition, communities may use informal and formal institutions, as well as intangible interrelationships between different members in a community to deal with innovations.

An additional critical point is that even in the case of a country such as the United States, where innovators have very strong intellectual property protections, the innovators were unable to capture all the additional rents created by the technology. In essence, innovators have to share rents with farmers to provide incentives for the adoption and continued use of the technology. This experience, also observed in countries with less protection, indicates the need to provide sensible policies that will foster the use of the technology and, at the same time, reduce the possibility of above-competitive, monopolistic prices.

12. We estimate these figures by dividing the 14kg of seed sown per hectare by the 22kg of seed per bag; then multiply by the cost per 22kg bag of USD 80. This figure is calculated at an average cost of pesticide application of USD 37.03 per hectare.

Herbicide resistance

Pachico *et. al* (2001) presented an *ex ante* study of the potential income and employment effects of herbicide resistant cassava in Colombia. This study used the DREAM software from IFPRI to develop economic surplus estimates of the adoption of herbicide tolerant cassava compared to conventionally-bred cassava technology that uses either hand labour or mechanical cultivation and harvesting. The herbicide resistant technology raises consumer and producer surplus compared to conventionally bred cassava with either mechanical or hand labour. In an expected result, herbicide resistant cassava decreased the amount of labour required in the region analysed. In some regions in Colombia, particularly the region where the study was conducted, there are labour shortages now. Thus, a labour saving technology may be appropriate for these regions. Furthermore, in some regions in Colombia mechanical cultivation of cassava is not possible due to topography.

The impact assessment experience in developed countries with herbicide resistant products is mixed. Two papers by Duffy (2001, 2002) indicate that in 1998 and in 2000 herbicide resistant soyabeans did not offer any significant economic advantage over conventional varieties. In practical terms, this means that the potential savings in equipment depreciation, fuel, and a reduction in herbicide costs per unit of land do not offset the additional cost of the technology and user fees charged for the herbicide resistant soyabeans. The paper also indicates that the yield of herbicide tolerant soyabeans is slightly lower than for conventional soyabeans[13]. What then explains the continued adoption of herbicide resistant soyabeans in the United States and elsewhere? According to Duffy, the main considerations by producers are convenience and management simplification. Although many papers have indicated the possibility that convenience and management simplification may be significant factors explaining the adoption decision of herbicide resistant crops, very few have presented formal models to incorporate this behavioural assumption into them. Demont and Tollens (2001) discuss one of the most interesting models that incorporate convenience in the adoption process.

Virus resistance

Qaim (1999a) examines the case of virus-resistant sweet potatoes in Kenya. According to Qaim, poor small farm holders in Kenya cultivate sweet potatoes as insurance because of its hardiness in hostile growing conditions. Yields are low in Kenya compared to other regions in the world partially because of disease. The main disease affecting sweet potatoes is the sweet potato virus disease (SPVD), which is a complex system of different viruses. Average crop losses due to SPVD can be as high as 12%. A concomitant pest is the sweet potato weevil, which may increase yield losses to 20%. There is no effective treatment for the SPVD and the weevil.

A joint project between the Kenya Agricultural Research Institute (KARI) a public sector research institute and Monsanto Corporation was initiated in 1992 with mediation from the International Service for the Acquisition of Agri-biotech Applications (ISAAA). Monsanto agreed to develop the virus-resistance technology specifically for the Kenya situation, to negotiate royalty-free transfer of technology and expertise and the allowance of a royalty-free licensing agreement that would allow diffusion of transgenic sweet potatoes in Kenya and other African countries. *Ex ante* estimates from Qaim, indicates the welfare gains in Kenya due to the adoption of transgenic sweet potatoes can vary between USD 5.4 and USD 9.9 million. Of these additional rents, producers capture 74%, and consumers the rest. This is an expected outcome as producers benefit through subsistence consumption. On the other hand, poor urban consumers benefit through a reduction in prices.

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13. The yield drag of herbicide resistant soyabeans has been observed by Benbrook (2000).

Qaim's *ex ante* estimates the rate of return to research involved in the creation of transgenic sweet potatoes are around 60% return on investment. This includes research and technology transfer costs of all research institutes, but does not include the basic research done by Monsanto. This case study highlights the possibilities of public-private partnerships mediated through an honest broker, the ability to address a production problem that had no solutions with existing technology, and the potential distribution of benefits because of a publicly available technology being released in a community.

Qaim (1999b) examined the *ex ante* case of transgenic virus resistant potatoes in Mexico. This is a joint project between CINVESTAV (Centre for Research and Advanced Studies), a public research institute in Mexico, and Monsanto Corporation. In contrast to the Kenya case, transgenic potatoes in Mexico used existing technology developed for the United States market. This implied that Monsanto provided strict guidelines to use the technology in Mexico, leaving the door open for future market penetration by one of its subsidiaries.

Qaim's *ex ante* welfare analysis indicates that if current institutional arrangements of poor seed distribution channels were kept, gains would represent USD 30.3 million of which producers would capture 46% and consumers 54%. On the other hand, if the public sector provides the improved technology under improved access conditions to small holders, benefits can increase to USD 45.1 million and producers' share of total surplus increases to 51%. Qaim also disaggregates the benefits among potato producers. If the present institutional arrangement is kept, mostly large-scale producers will capture gains. In contrast, if the improved technology is provided under improved access to small holders, their ability to capture additional surplus increases substantially, even obtaining a higher percentage than large-scale producers.

(iv) Discussion of DETE data problems, biotechnology specific problems and additional factors to consider

DETE data problems

Analysis of the impact on farmers of the adoption of technologies in DETEs implies dealing with complex agro-ecological systems, often lacking access to modern marketing systems. Such farmers typically work in smallholder areas, depending on a few key commodities, livestock or aquatic resources for food consumption and sale. Many of these areas are remote, with delivery and use of modern agricultural inputs restricted. Farmers have little cash income, therefore, inputs are very difficult to obtain or purchase. From an ecological perspective, many of these areas are rich in agro-biodiversity, with some farmers working in centres of diversity for major and minor food crops. For products derived from biotechnology to impact smallholder communities, they must address the needs and agro-ecological environment of farmers and the poor, who are often beyond the reach of modern markets. The special circumstance that producers face in DETEs cause researchers to have additional data collection and methodological limitations and challenges. In this section, we will discuss such limitations and challenges.

Scott (1995) discusses specific limitations and challenges of developing country data. The most important limitation is that data are often not available or are difficult to collect. Even if data are available, reliability becomes an issue. Long series of prices and quantities supplied and demanded are often not available in DETEs. This limits the possibility of time-series econometric analysis. Differences in data collection procedures and definitions also limit the possibility of cross national and regional comparisons. We will review critical data required for most methodological approaches and then discuss ways to overcome some of the limitations encountered in DETEs.

All of the methodologies described in the previous section consider a limited set of outcomes from the adoption of an agricultural innovation, mainly because they tend to be aligned along specific disciplines. As such, economists and sociologists have a poor record of collaboration and methodological convergence. This is the same story with anthropologists and political scientists. The lack of convergence between social science practitioners and methodologies has reduced the ability to understand the complexity of communities in DETEs, but also the complexity of the impact of innovation in these communities. Economists have traditionally relied almost exclusively on quantitative methods to examine impacts. In contrast, sociologists (and other social scientists) have used mainly qualitative methodologies.

(v) Limitations to supply and diffusion of biotechnologies in DETEs

A critical question in choosing the methodological approach to measure the impact of biotechnology is whether biotechnology is different from other technologies studied in the past. If so, what is different about biotechnology? Answers to these questions will undoubtedly affect not only the design of any proposed study, but will also dominate the discussion on research and development and other policies. We propose that several issues separate biotechnology from other technologies.

- Market structure, market power, and distributional implications

Private sector companies have primarily researched, developed and marketed biotechnology products. This is a departure from the "Green Revolution" technologies of the 1950s and 1960s, such as semi-dwarf varieties of wheat, developed primarily by the public sector. Private sector exclusive ownership of current biotechnology innovations opens the possibility of private sector companies to exercise market power in the seed (and other input) markets. Economists and the public sector have traditionally been wary of increases in market concentration and the related increase in market power. Economists are often wary that monopolistic market structures being associated with above normal prices and extraction of rents from producers who buy inputs. In the specific case of seed markets, some authors (Doyle (1985); Kloppenburg, (1988) propose that seed prices are higher than normal, and that the long-term goals of enhancing germplasm and improving genetic diversity have suffered with increases in market concentration.

It is important to emphasise the connection between market power and structure and its distributional implications. In a monopolistic market structure that arises because of the innovation, the innovator may be able to exercise market power. Innovators exercise market power by having the ability to charge consumers prices above those existing in a competitive market setting. The need to provide incentives for adopting the innovation, the availability of technological substitutes, and the potential entry of potential competitors who may see abnormal profits as a sign for potential lines of business may challenge the amount charged over the competitive price by the innovator.

The models used to evaluate impacts under a monopoly, imperfectly competitive and competitive environments are different, and, most importantly, impact assessment results will differ between a competitive and a monopolistic situation. Estimates of the distribution of rents from the United States of Bt cotton from Falck-Zepeda *et. al* (2000a, 2000b, 2001) indicate that the innovators' ability to capture all rents, as predicted by some economists, is limited. The existence of other input alternatives and production possibilities particularly limits the ability of innovators to charge above competitive market prices. Studies cited in this report seem to support this conclusion. The relevance for DETEs of this finding is that the attention of policy makers should centre on providing the right incentives to the supply of appropriate technologies and worry less about potential monopolistic pricing by the private sector. This should provide some leeway in designing and implementing biotechnology policies in DETEs.

- Intellectual property issues

An expanding body of literature exists showing that, increasingly, both private firms and public institutions claim property rights in agricultural research and biotechnology. Property rights instruments include patent rights; plant variety rights; and contractual rights arising from material transfer agreements (MTAs). The strengthening and enforcement of intellectual property rights (IPRs) throughout the world have dramatically influenced the processes for research collaboration and international transfer of new technologies. While there is no conclusive evidence whether stronger IPRs enhance or impede the availability and diffusion of new technology to DETEs, it is important that research institutes carefully consider their IP management strategies and "freedom to operate" prior to embarking on new R&D projects. Given the general situation of "weak" protection of biotechnology inventions in most DETEs, problems of intellectual property infringement (of inventions protected in industrialised, but not DETEs) may generally, not be too serious. This could of course change in the future.

- Environmental and biosafety regulatory issues

There is a very significant disagreement on risk characteristics of Genetically Modified Organisms. Although there has not been one documented case, so far, of any environmental or human health damage, there are some aspects of the risk profile of GMOs that are not known, simply because the accumulated knowledge derived from the commercial-scale release of GMOs is still limited. This lack of familiarity has resulted, in a large number of countries, in stringent biosafety regulations and sluggish decision-making, thus adopting a precautionary approach to the diffusion of GMOs. It is important to point out that research can enhance familiarity with biotechnologies and contribute to informed biosafety decision making through risk assessment studies.

- Consumer acceptability

Consumers in Europe, and some consumers in the United States, and countries in Asia, have concerns about current biotechnology products. There is an increasing body of literature documenting this phenomenon; however, the important factor is that consumer groups in Europe and Japan have been very vocal about their opposition to biotechnology and have managed to exercise political pressure on governments to stop the development of biotechnology products. According to Paarlberg (2002), the consequence of this political pressure is that developing countries may have an even smaller probability of accessing biotechnologies suited to answer their problems. This is because developing countries are afraid that Europe and Japan will shun imports from countries using modern biotechnologies. Furthermore, Paarlberg argues that increased European Union regulations on labelling will further discourage the creation and diffusion of genetically modified crops in poor countries.

The discussion of impact assessment papers, as well as other crucial issues related to biotechnology suggest that certain conditions are necessary if farmers are to reap the benefits from what the technology has to offer, such as improved management practices, or improved seed distribution. As such, the following discussion will use the specific case of GMOs; however, many of the issues discussed here can be applied to other types of biotechnology. It is obvious that there are a significant number of structural and institutional constraints in DETEs that may prevent producers from accessing biotechnology products. Many of these constraints lie outside the realm of agricultural policy formulation. Issues such as education, physical infrastructure or macroeconomic policy of a particular country will certainly have an effect on the availability of biotechnology. However, our intention in this report is to point out some of the constraints and bottlenecks that may be addressed under a comprehensive biotechnology policy with the expectation that specific exogenous issues may be addressed as they arise.

A key factor that needs to be analysed is the specific DETE policy on biotechnology[14]. A second key factor is whether the gene construct (gene and the transfer technology) exists or needs to be researched and developed. DETEs may take advantage of biotechnology events created to address the needs of developed countries. The critical access issue is the ability to negotiate licenses and other technology transfer instruments to allow access to the technology. If there is no capacity to take advantage of the existing technology, either by the local public or by the private sector, multinational private firms may be granted access to markets in DETEs. The key issue then becomes the ability of multinational private firms to protect and enforce intellectual property in DETEs.

Even if the gene construct exists, the need arises to have appropriate and adapted germplasm to insert the gene construct. Breeding and agronomic innovation is as important as the gene construct. Biotechnology requires both to be successful. In some DETEs, an alternative path to acquire biotechnologies would be to increase investment in breeding and agronomic innovations with the objective to broker deals with the innovators who have developed the gene constructs. Integration between biotechnology and breeding/agronomic innovation opens the door to private-public and private-private collaborations. In both cases, appropriate instruments to protect intellectual property need to be in place.

Another key factor is the existence of functioning seed or plant material markets. The public sector in DETEs usually does not have the resources to promote and market innovations. Biotechnology events have the additional complication of having to comply with biosafety evaluation protocols and regulations. Biotechnology events demand increased flows of information and knowledge embedded in the technology. These information and knowledge flows need to reach producers in order to allow them to exploit the potential of the technology (Tripp, 2000). For example, in Bt cotton, there is the need to reserve tracts of land as refuges to reduce the possibility of insect resistance to the Bt toxin. Producers need to have access to this information coupled with knowledge of additional changes in management practices.

All of these key factors interact with each other. Consumer and policy-makers’ acceptance will determine deployment of the biotechnology construct. Biotechnology policies are the result of consumer and policy-makers’ knowledge and attitudes toward the technology. Consumer and policy-makers’ attitudes may be biased depending on the transparency and credibility of the biosafety approval process and regulatory institutions, as well as the relevance of the problems, which biotechnology intends to address.

3. Opportunities and challenges for using sustainable livelihood concepts for biotechnology impact

Information on yields and net benefits as presented in the studies reviewed previously are useful. Traditional economic impact studies are an important contribution to the debate on the impacts of biotechnology in developing countries. However, among other things, some of these studies did not explicitly try to account for the environmental and human-health effects of agricultural biotechnology, or broader aspects such as poverty alleviation and food security. In this section, we introduce the Sustainable Livelihoods Framework as an alternative and comprehensive approach to examine the actual or potential impacts of a biotechnology in a community.

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14. Paarlberg (2000) provides a framework to classify different countries into categories according to the policy environment towards biotechnology.

(i) The Sustainable Livelihoods framework[15]

The Sustainable Livelihoods conceptual framework enhances the understanding of causes of poverty and food insecurity, by analysing relationships between relevant factors at the household, community and regional levels (Figure 1). This approach explicitly requires examining the context in which people live in a rural community. By including concepts of vulnerability, assets, and empowerment, the Sustainable Livelihoods framework goes beyond conventional socio-economic measures by augmenting these with values considered important by a community, but, at the same time examining the critical path and linkages that connect these components.

15. This sub-section is based on Meinzen-Dick (2001) and Adato and Meinzen-Dick (2000).

Figure 1. **The Sustainable Livelihoods framework and the impacts of agricultural biotechnologies**

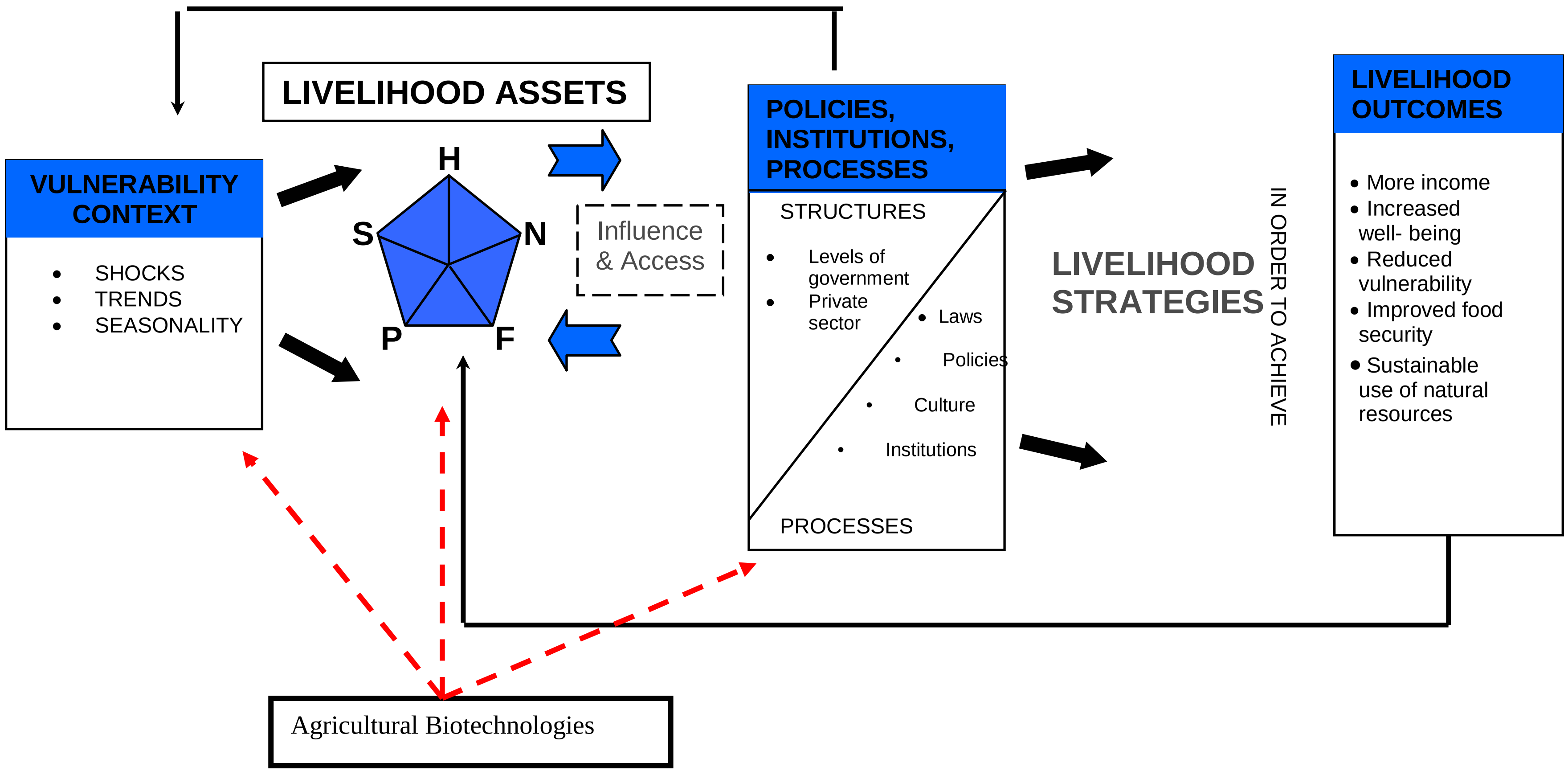

Figure 1 illustrates the Sustainable Livelihoods (SL) conceptual framework adapted from the United Kingdom Department for International Development (DFID) Sustainable Livelihoods conceptual framework. The SL framework is dynamic, recognises changes due to both external fluctuations and the results of people's actions. The starting point is the vulnerability context within which people operate. External influences such as weather and price changes affect the vulnerability context. Vulnerability refers to issues outside people's control. It is important to point out that it is not only objective "risk" that matters, but also people's subjective assessments of issues that make them vulnerable. These issues matter because both perceived and actual vulnerability can influence people's decisions and hence their livelihood strategies, and thus may affect their willingness to adopt agricultural biotechnologies. In turn, external influences may affect people's assets in a community.

The SL framework proposes that people in a community hold a portfolio of assets. This portfolio of assets is a more inclusive and complete inventory of valued items by a community other than monetary measurements as used in traditional socio-economic studies. Assets included in the portfolio are social, natural, physical, financial and human, denoted in the pentagon in Figure 1 by the letters S, N, P, F and H respectively.

Natural capital may include land, water, forests, and biodiversity. Physical capital includes community infrastructure such as transportation, roads, buildings, water supply and sanitation, energy, technology and communications. Financial capital includes savings in the form of cash or other liquid assets, credit from formal and informal sources, as well as inflows from state transfers and remittances. Human capital includes education, skills, knowledge, health, nutrition, and labour power. Social capital includes any community networks that increase trust, ability to work together, access to opportunities, and informal safety nets. The SL framework neatly separates assets into five categories; however, often assets in communities may not be clearly allocated to a particular category. For example, for some communities cattle may be a physical asset, but at the same time a financial asset serving as a reserve or collateral account for emergencies.

Policies, institutions, and processes affect how people use and have access to their assets in pursuit of different livelihood strategies. The box in Figure 1 – Policies, Institutions, Processes- refers to both formal and informal institutions and organisations that shape livelihoods by influencing access to assets, livelihood strategies, and vulnerability. Civil society including the public and private sectors, and community institutions may all be relevant to consider in the analysis. All of these institutions influence people's livelihood strategies. Assets interact with policies, institutions and processes, which in turn shape the choice of livelihood strategies.

Livelihood strategies are choices that people employ in pursuit of income, security, well being, and other productive goals. What is important about the livelihood strategies approach is that it recognises that households and even individuals may pursue multiple strategies, either sequentially or simultaneously. Livelihood outcomes encompass many types of impacts of agricultural research on poverty. Potential outcomes may include income, food security, and sustainable use of natural resources. Outcomes may be reflected in such things as strengthening the asset base, reduced vulnerability, and other aspects of well being such as health, self-esteem, and a sense of control.

The Sustainable Livelihoods framework brings in many considerations that are often not included in an impact study dealing with the impact of agricultural research. At the same time, it is often not easy to see how agricultural research and biotechnologies might fit into this framework. In Figure 1, we have indicated three ways in which the products of agricultural biotechnologies research can intervene in a community: by affecting the vulnerability context, through linkages to the asset base, or as part of the policies, institutions, and processes.

Agricultural biotechnology research can reduce vulnerability, such as when producers adopt GM insect resistant or disease resistant crops. Pest resistance makes farmers less susceptible to target pest infestations. Another example may be aluminium, salinity or drought tolerant crops. These biotechnologies reduce producers' vulnerability to crop losses. However, agricultural biotechnology can also increase vulnerability, such as when new varieties are more susceptible to crop failure due to other than target insect or disease susceptibility, or when farmers have to purchase the seed every year under conditions of cash and credit constraints. In the latter example, farmers' having cash and credit constraints is not an exclusive attribute of biotechnologies; rather these constraints will affect any technology offered to farmers. Furthermore, cash and credit constraints are a major constraint to any development effort.

Agricultural biotechnology research and technology adoption may have strong links and help modify the asset base. Additional (excess) income may help improve human capital through education or to purchase new equipment that becomes part of the physical capital. In addition, insect resistant crops may augment the population of beneficial insects above and below topsoil. Crops resistant to salinity capture excess salinity in the soil, and thus improve, or even eliminate the salinity problem. The aforementioned agricultural biotechnologies may improve the natural capital of land. This experience is not limited to the physical or natural asset base. Interesting experiences in Zimbabwe (Mnyulwa, 2001) and Colombia (Perry, 2001), have shown that participatory or action research processes can help improve significantly the biotechnology research process by strengthening the human and social capital asset base, as a consequence of knowledge generated by producer groups.

The debate on the Green Revolution provides other interesting examples of technologies modifying the asset base. Most of the debate over the Green Revolution centred on whether large land holdings (natural capital) were required to adopt the various components of the Green Revolution package, and thus take first-adopter advantage of the benefits of the technology package. In addition to the relationship between land holding scale and adoption, considerable research and policy efforts related to expanding agricultural credit (financial capital) and infrastructure (physical capital) in order to foster technology adoption.

Finally, agricultural biotechnology research can be considered as part of the policies, institutions, and processes box, as a mechanism that creates options for people to build upon various assets to pursue their livelihoods. For example, drought-tolerant varieties can allow farmers without irrigation to pursue farming with less fear of disastrous losses. Insect-resistant rice may provide further incentives (less insecticide sprayed or additional income) to adopt aquaculture technologies that allow people to increase efficiency of flooded land by adding fish for income and home consumption.

The prospect of covering all aspects of the sustainable livelihoods framework, or even all questions identified as critical for assessing the livelihood impact of agricultural research, can be overwhelming. This is a significant problem for econometric analysis, because there are many inter-related factors, which create statistical problems that require larger data sets in order to obtain meaningful results. To overcome the inherent complexity of the SL framework it is imperative to implement an integrated and interdisciplinary approach that draws upon both quantitative and qualitative data collection and analysis. In a typical Sustainable Livelihood study, the major data collection methods used include surveys, focus groups, key informant interviews, in-depth household case studies, and secondary data. Careful attention needs to be given to sampling and data collection, with links between samples wherever possible. This raises a very positive attribute of the SL methodology as it forces researchers to understand the context in which an innovation is being deployed, as well as, provides the opportunity to incorporate and provide incentives for co-operation between multiple disciplines.

(ii) Limitations and challenges

A fundamental difficulty with estimating impacts is the lack of a clear definition of concepts such as "Poverty" and "Sustainable Livelihood." For example, in a particular community, farmers may not be the "poorest of the poor" themselves, but still have a major impact on poverty. The fundamental question of what constitutes poverty and sustainable livelihood magnifies the problem of lack of information on the impact of technologies in the rural sector. This gap in knowledge increases the difficulty in identifying the direct and indirect linkages, and the costs and benefits of the introduction of a particular innovation in a community.

In our introduction to the SL methodology, we proposed three paths through which agricultural biotechnology may affect livelihoods in a community. However, the nexus between agricultural biotechnology research, technology generation and poverty alleviation still needs to be studied further. In most cases agricultural biotechnology policy has to be framed within the perspective of overall development goals and policies of a country or region. Biotechnology can then be viewed as a springboard to facilitate other activities, or as a way of providing options to people. It is important to point out that the SL framework is a way of identifying livelihood strategies and entry points from the bottom-up. If research priority setting, planning and implementation are done in this fashion, then sustainability may be achieved. A perverse situation can occur where a researcher can conduct an SL study, where there is a need to identify the "appropriate technology" from a pre-determined portfolio of technologies. The donor or the development agency willing to fund the programme pre-determines the technology portfolio. This of course, is the traditional "top down" approach to determine research priorities and intervention.

The SL framework has to be more than a good checklist, or a tool that allows communication between disciplines by providing a common language and approach to conceptualise poor rural communities. The SL framework is a concept that should and must change mindsets to broaden our understanding of poor communities. The broadening of a mindset implies posing paradigm changing questions, which may affect long established notions about development or socio-economic impact assessment.

For example, a long-held tenet in economic development in most DETEs with labour surpluses, is the imperative to promote labour using, not labour saving technologies. An example of labour saving technologies is herbicide use. However, as we have seen in the Pachico *et. al* paper, a developing country may have localised labour shortages. Alternatively, Dr. Florence Wambugu in a meeting of the American Association of Agricultural Scientists indicated eloquently that the most vulnerable groups in Africa, women and children, do most of the weeding in poor rural communities (cited by Gressel, 1996). A labour saving technology may free the most vulnerable groups in a community from backbreaking labour, thus freeing time for education and other self-improving endeavours. Alternatively, a country must make the alternate (hopefully informed) choice of maintaining the *status quo* and deny an additional opportunity for the most vulnerable groups in their society.

An important consideration is the correct identification of the counterfactual case. In many cases, the counterfactual can be no intervention at all. Yet, maintaining the "no intervention" counterfactual in all probabilities will have its own set of costs and benefits. In the examples of insect resistant Bt cotton, the "no intervention" option could be either to continue spraying with conventional insecticides, or drop cotton altogether from the household production plan.

There are operation and conceptual challenges, as well as research issues that need to be resolved as research is conducted using the SL framework to evaluate the impact of biotechnology in DETEs. These issues are the result of observations made from the initial implementation phase of the ISNAR

SL project, but also of literature reviews of existing SL projects in other areas of impact assessment. These include:

- Currently, there is limited experience and data available for research in sustainable livelihoods. In the particular case of biotechnology, most applications are still immature, hampering the ability to conduct multi-year, *ex-post* analysis.

- Coupling a Sustainable Livelihood approach with *ex ante* economic analysis will be difficult, as it will require the researcher to propose many assumptions about uncertain effects on existing community links. Still, it would be a useful approach to begin by identifying the livelihoods asset base, "vulnerable" groups in a specific community or region, and potential links affected by the introduction of a technology that will serve as a counterfactual and a benchmark with which to compare after the innovation is adopted in a community.

- The need to avoid the problem of being inundated by the massive amount of data collected and providing a defined message/lessons. Is the study replicable, and does it comply with rigorous tests of validity and reliability?

- The need to balance effort, expense and benefits, while designing an SL project.

- Ability of researchers to identify, quantify and/or qualify the line of causality from intervention to poverty alleviation and reduction of food insecurity.

- What is the relationship between adoption, the diffusion process and impact assessment?

- The institutional and regulatory context for the delivery and farm-level adoption of products from biotechnology. This is an important factor to consider, especially as regulatory hurdles may lead to delayed dissemination of transgenic products. It adds a new dimension to the analysis, thereby complicating future studies.

- The uncertainties involved in foreseeing and evaluating potential concerns regarding the environmental/biosafety aspects and public acceptance of genetically-modified food products.

- Finally, what are the implications of an SL study for present and future research strategies/processes of the CGIAR system, other International Agricultural Research Centres and National Research Organisations and Systems?

(iii) On-going and planned research initiatives/approaches

IFPRI/SPIA Sustainable Livelihoods impact assessment

The question of the impacts of agricultural research on the rural poor continues to be widely discussed in the Consultative Group on Agricultural Research (CGIAR) and other venues. For example, the paucity of information led the CGIAR to formalise impact assessment on the rural poor through the Standing Panel on Impact Assessment (SPIA). The CGIAR commissioned IFPRI to perform an impact assessment project that started in 2000. The main objective of this project is to build capacity within the different centres that comprise the CGIAR to perform impact assessment of agricultural research on the rural poor. The IFPRI/SPIA project is reviewing cases in Bangladesh, Kenya, Zimbabwe and Mexico.

This project is using the Sustainable Livelihood methodology. The rationale for using this methodology in the IFPRI/SPIA project came partially from an extensive literature review conducted in the first phase of the project, which indicated that research might impact the livelihood of the poor in rural areas under certain conditions. This literature review also showed there were many paths through which the rural poor might obtain benefits or incur costs. Some of these paths had to be included to get a complete measure of the impacts of agricultural research. The authors of the literature review, Kerr and Kolavalli, point out that "Technology's role in alleviating poverty is both indirect and partial; technology alone cannot overcome poverty, nor can continued poverty be blamed on improved technology." The approach builds upon a multi-country study of the impact of conventional agricultural research led by IFPRI on behalf of the Standing Panel on Impact Assessment (SPIA) for the CGIAR (IFPRI 2000).

ISNAR/IFPRI biotechnology and SL

ISNAR's Biotechnology Service (IBS) organised a Consultation in June 2001 to strengthen approaches for socio-economic impact analysis of biotechnology on the poor in developing countries. The Consultation examined the Sustainable Livelihoods framework as the basis for implementing impact assessments on inputs from agricultural biotechnology. At the Consultation, researcher scientists, potential institutional collaborators, representatives from CGIAR centres, and donor and development agencies examined conceptual and implementation issues surrounding the Sustainable Livelihoods framework, studied examples of recent economic impacts of biotechnology products, and helped define selection criteria to examine the impact of biotechnology on the livelihood of poor producers in developing countries. These contributions became part of the project "Biotechnology and Sustainable Livelihoods – Examining Risks and Benefits", a collaborative effort that ISNAR, IFPRI and other collaborating international and national organisations will implement. The purpose of this project is to quantify and/or qualify the actual or potential impacts of agricultural biotechnology on the livelihood of rural farmers in developing countries, to build institutional capacity in developing countries for such research and to generate first-hand information from selected study sites.

The current ISNAR project proposal suggests adopting a broader "Sustainable Livelihood" approach to study the impact of agricultural biotechnology. Broader studies and methodologies to evaluate the complete impact of biotechnology would therefore increase understanding of how a range of agricultural research affects the lives of the poor. ISNAR and IFPRI are currently seeking funds to initiate this project. A pilot case study using some of the principles of the SL framework will be initiated this year to explore the *ex ante* case of insect resistant potatoes in Colombia in collaboration with the International Potato Center (CIP) and CORPOICA, a Colombian partner. This initial pilot study will be self-financed by ISNAR, and may develop into a full-fledged SL project, if successful in obtaining external funds.

4. Summary and conclusions

Impact assessment can provide key information for decision makers in developing countries, who all too often are left to rely on risk analysis, distorted information from advocacy groups, or focus exclusively on trade consequences of the adoption of biotechnologies. Impact studies, such as the insect resistant cotton examples given in this report, offer an important source of scientific information to be used for both research and policy analysis, to guide future biotechnology interventions, and identify areas that may block or hinder expected gains from a given biotechnology.

The limited diffusion of food crop biotechnologies in DETEs is largely due to restricted regulatory and trade related issues. This is why the few existing studies using socio-economic impact assessment methodologies in DETEs have centred on Bt cotton. Bt cotton is the most widely used biotechnology crop in DETEs, apart from herbicide resistant soyabeans. The biggest challenge for impact assessment methodologies, however, will come with the evaluation of food crops. When developing countries increase the development and adoption of food crop biotechnologies, requests for high-quality impact assessments will also increase. While the Bt cotton studies examined in this report show positive impacts in terms of income and environmental benefits for cotton, what will be the impact of biotechnology-developed food crops?

The complexity and importance of food crops in DETEs is crucial to the selection of the appropriate impact assessment methodology. In anticipation of this need, ISNAR will use the Sustainable Livelihoods framework as a broader tool for conducting impact assessment. As shown in this report, the SL framework offers the benefits over other methods, in that it provides a systematic and comprehensive way to examine relevant issues in poor communities such as vulnerability, community values and assets, institutions and strategies. This unified approach helps multi-disciplinary work come to fruition as it provides a common language and methodology where disciplines converge. Furthermore, adoption of the SL framework represents a mentality (and perhaps even a paradigm) change that induces researchers and development agencies to think about livelihoods as a state of nature that needs to develop from the bottom-up, and thus allow convergence with the body of scientific knowledge and human capital that rose using the traditional top-down approach to research.

However, we should note that many of the existing studies, as well as those just beginning, rely largely on funds from international donor organisations or foundations. There is very limited capacity in the DETEs themselves to conduct this work now, China being possibly the exception. In addition, as noted in this report, most releases are taking place in non-DETEs. For this reason, in DETEs there are more challenges and opportunities to conduct *ex ante* studies, build team approaches to account for technology policy issues, as well as impact at the community or household level. The major response from the international community has been given to biotechnology research itself and biosafety. However, promoting further consideration of impact assessment, given the expectation for food crop technologies to become available, would have much merit.

One fundamental challenge will be to ensure that impact assessments truly target the poor. Obviously, this has much to do with the impact assessment methodology employed, as well as with the assessed farmer community and system adopting a biotechnology. Impact assessment will be critical for confirming, whether biotechnology has extended to small holders or farming communities beyond the reach of markets, and most importantly, if these biotechnologies have accomplished the ultimate goal of improving the livelihood of communities in DETEs. Studies reviewed in this report indicate that the current wave of input reducing biotechnologies can provide positive benefits to producers in DETEs. In the future, impact assessment will need to provide feedback to researchers and policy makers about research gaps and the need for alternatives to provide an ever-growing portfolio of approaches to address poverty alleviation in DETEs.

However, these studies also indicate a number of policies and infrastructure requirements needed to ensure that biotechnology will not only reach the poor, but that they will be directed to resource poor farmers. Such requirements will vary depending on a country’s existing capacity to produce, adapt and/or or access biotechnology innovations. Such requirements may include:

- The capacity to generate, adapt, and/or negotiate access to biotechnology innovations;
- The capacity to generate good quality animal and plant germplasm, where biotechnology can be used;
- The ability to identify and prioritise critical problems affecting the rural poor that may be addressed by biotechnology;
- The existence of a technology and information delivery system;
- The existence of a rational (science-based), transparent and expedient biosafety regulatory system; and,
- The ability of the public sector and international agricultural research centres to negotiate and promote private-public partnerships in an environment where biotechnologies for resource poor farmers can be considered public goods.

It is not only important to consider how countries will develop or obtain access to appropriate technologies, but, as part of a longer-term perspective, to build capacity to evaluate impacts. One source of this expertise is with the CGIAR commodity and policy centres, where work has been ongoing by CIMMYT, IRRI, CIP, IFPRI, ISNAR, and others. Building such collaboration will strengthen local capacity, while taking advantage of methodologies pioneered by the centres.

Policy and financing issues for DETEs governments will also need review. Biological scientists and those involved in regulation and IPR will not want to see scarce resources diverted to impact analysis. However, if we are to be prepared for the release of important GM crop products, such as rice, maize, potatoes, then we must also anticipate a role of growing importance for NARS in DETEs. How best to develop this local capacity, and convey assessment findings and implications to policy makers is now an important consideration, so that this input to decision-making and policy analysis can convey its findings in the most useful manner. Reviewing the history of impact assessment studies and their evolution as applied to the Green Revolution technologies is one starting point. In addition, a long-term, systematic programme of comparative studies should be developed to analyse the impact of existing or near-term introduction of biotechnology in DETEs in order to provide reliable information to decision makers regarding the expected benefits, costs and risks of such introductions. The complex nature of SL approaches reinforces the need to establish a long-term research effort. Moreover, the close involvement of economic, social and policy research institutes from DETEs is essential in this effort, thereby enhancing local analytical capacities to undertake such studies.

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PART II

DEVELOPING AND ACCESSING AGRICULTURAL BIOTECHNOLOGY IN EMERGING ECONOMIES: POLICY OPTIONS IN DIFFERENT COUNTRY CONTEXTS

EXECUTIVE SUMMARY

Developing and emerging economies' capacities to adopt new technological innovations to improve the performance of their agriculture varies widely. Several of the more advanced countries are developing both their own technologies, as well as importing new biotechnologies that have been developed abroad. Other countries, especially in Asia, Africa and Latin America are attempting to develop biotechnologies specifically directed to solving their agricultural problems through publicly funded national agricultural research systems. Most developing countries, however, have not yet reached this stage in the development of agricultural biotechnology due to weaknesses in their research and development systems and under-developed market infrastructure. If developing countries are to benefit from the use of modern biotechnology in agriculture then the key constraints within the research, technology development and delivery system need to be clearly identified and the appropriate policy measures taken.

Agricultural biotechnology is a useful tool at the disposal of developing countries to deal with the food supply challenges they must confront in the coming decades. However, the available evidence suggest that only a few countries are in the position to actually benefit from these technologies, despite the large amount of public and private sector investment over the last 20-30 years. This is partly a consequence of the status of the product life cycle and the products that have reached the market, which tend to be highly concentrated on a few traits of temperate and sub-tropical crops. Most countries do not have the facilities to handle the new innovations and some even lack the capacity to benefit from conventional agricultural technologies. However, there is some anecdotal evidence to suggest that research is now shifting to tropical crops and livestock and this is creating pressure to revisit the policy framework in many countries covering issues such as IPRs and technology transfer.

A key message of this report is that developing and emerging economies are extremely heterogeneous in terms of their current policies on agricultural biotechnology and many lack the institutional framework needed to develop and monitor modern technologies. A country's ability to benefit from modern technologies is influenced by several factors including; its research capacity, level of investment in research, regulatory framework, especially for biosafety and IPRs in the seed sector, and a well functioning market for biotechnology inputs and products. A typology of developing and emerging economies is proposed based on the country's ability to exploit the new technologies and a range of different policy options are outlined.

The application of biotechnology in agriculture offers a wide range of potential benefits, yet many of these benefits will not be realised unless a number of important policy issues are resolved. These issues relate to the particular characteristic of modern biotechnology and its interface with conventional agricultural research, the proprietary nature of new technologies and its affects on industry structure, biosafety and consumer acceptance considerations and the role technological inputs play in the biotechnology diffusion process. Each issue raises important policy challenges and choices as to how the country may best deal with them. The policy implications arising from the proposed country typology suggest that there is a major sparcity of information on the current situation and attitudes to new biotechnology in developing and emerging economies. While a small number of countries are forging ahead in developing specific biotechnology products and designing policies specific to their environment, the vast majority of countries will continue, for the foreseeable future, to rely on importing modern biotechnology from abroad.

1. Introduction

Advances in the biological sciences are producing quantum leaps in our knowledge about the way plants and animals grow and synthesise useful products, as well as in scientists' ability to transform them. Gene maps of major species are now in advanced stages of development, and functional genomics is also starting to yield a continuing flow of critical information about the role of genes, and markers for many of them. Another set of developments has taken place in the area of genetic engineering, greatly expanding the possibilities to handle and transform micro-organisms, plants and animals. These advances are starting to show up in the efficiency and effectiveness of research processes, through improved plant breeding methods, safer and more effective pest control strategies and plants with improved agronomic traits and nutritional characteristics. The use of plants as "factories" for the production of substances with either medicinal value or industrial use is no longer a distant possibility, but rather a situation already in the final stages of the development process. At the market level, tissue culture techniques have become standard applications in asexually propagated crops and are widely used to produce virus and disease free planting materials in many parts of the world. Transgenic varieties are being cultivated by more than 5.5 million farmers on about 50 million ha in 12 countries, and the pipeline of advanced field trials cover more than 15 crops and 40 different traits[16].

Among developing countries, the capacity to take advantage of these technological innovations to improve the performance of their agriculture vary widely. A limited number of countries are both developing their own technologies and introducing technologies that have been developed and transferred through market channels. Other countries in Africa, Asia and Latin America are attempting to develop biotechnologies directed to solving their specific agricultural problems through national agricultural research systems which are publicly-funded, but most have not yet reached this stage in their agricultural development. Limiting factors are not only linked to weaknesses in their R&D processes; in many instances some of the elements of the technology delivery system, which would ensure that these new products are eventually available to farmers, are not in place. For example, biosafety systems may not yet be functioning effectively, IPR issues may not have been resolved and seed certification, production and distribution may be problematic.

If developing countries are to introduce the emerging new biotechnologies and benefit from their potential contributions, it is important that the key constraints within the research, technology development and delivery system are identified and brought to the attention of policy makers and technology providers. The overall objective of this paper is to develop an analytical framework which will help identify and evaluate the types of policies and institutional arrangements most appropriate to facilitating the development and delivery of relevant agricultural biotechnologies in different developing countries.

This paper builds on research already underway in a number of research organisations to develop key socio-economic and institutional variables that impinge on a country's capacity, either to develop new biotechnology products through its own research, development and delivery system, and/or to access proprietary technology. These include a country's research capacity, level of investment in research, regulatory framework, particularly for biosafety and intellectual property rights (IPRs) in the seed sector. In addition, other important elements include the nature of the interaction between the public and private sectors in developing technologies generated by public sector research, and the level of private sector activity in seed production, marketing and distribution. Based on these issues a country typology regarding its capacities to exploit the new technologies is developed and the most relevant

16. (AgBios database at http://agbios.com and ISAAA, Brief N°24 – 2001 "Preview: Global Review of Commercialised Transgenic Crops, 2001").

policy options are highlighted. The paper is organised into four sections. The first section examines the policy implications and characteristics of biotechnology. The second section presents the basic concept of a typology of policy paths open to different developing countries. The third section is an application of the proposed typology, on the basis of information available from secondary sources. The fourth and final section offers some concluding comments and areas for future research.

2. Issues from a policy perspective

The application of biotechnology in the agricultural sector offers a wide range of potential benefits, yet many of these benefits may not be generated if a number of important issues are not resolved first (see Endnote 1). These issues are related to the characteristics of biotechnology and its interface with conventional agricultural research; the proprietary nature of the new technologies and how they affect industry structure and investment trends; biosafety and consumer acceptance considerations; and, the role that the technological inputs industry plays in the biotechnology diffusion process. Each of these issues raise specific challenges and policy options as to how countries may choose to deal with them.

(i) The scientific and institutional environment of the innovation process

At this stage, biotechnological approaches do not represent an alternative to conventional agricultural research technologies, but should be seen as complementary. Nevertheless, the emergence of biotechnology as a key component of agricultural innovation processes brings about a number of important changes in related science and technology institutional systems.

Conventional agricultural research institutions are what could be called "dedicated" systems (*e.g.* national institutes, specialised agricultural research centres, agricultural colleges, etc.), with a "vertical" structure, where the development of the basic knowledge and its application to technology generation is closely interrelated and usually undertaken within the same organisation. On the other hand, biotechnology development is of a "horizontal" nature. The discovery of rDNA and the principles of genetic engineering:

- evolve from close interaction among a number of the basic scientific disciplines (*e.g.* biology, genetics, biochemistry, chemistry, physiology, etc.); and,

- are applicable across a broad range of subject areas such as health, environment, manufacturing and agriculture.

Biotechnology capacity is of a generic nature and its natural institutional environment is that of the basic sciences, which usually have no operational links to the existing agricultural technology delivery systems. Once new genetic constructs are available, there is the need to backcross them into the broad germplasm basis of existing commercial varieties, and to undertake large scale field evaluations to adapt the new products to local ecological conditions and cultural practices. Farmers are unlikely to accept them, unless they are packaged in a genetic platform with acceptable production and productivity performance. But, the creation of the innovation itself (discovery of the new genes, markers, functions, etc.) does not need to be formally integrated into downstream technology development activities. These characteristics have direct implications, both in terms of the diversity of the institutional actors involved, as well as the structure of interactions between basic and applied research organisations (see Endnote 2).

A second set of issues that the policy discussion has to take into consideration is that the emergence of biotechnology brings about a noticeable displacement of the "technological space" in the direction of the private sector. While public goods have tended to dominate the traditional agricultural technology research, development policy and organisational systems for biotechnology, proprietary technologies are the norm rather than the exception. This fact is evident by the evolving structure and investment trends in the industry, as well as the increasingly more complex management requirements for R&D processes (see Endnote 3).

These institutional trends have significant implications for scientific and technology policy making. One is related to the need to create the conditions and incentives for different disciplinary capacities (*i.e*. biologists, agricultural scientists, informatic specialists, etc.) to work together. The importance of this aspect is highlighted by developments in the area of genomics. Most of the ongoing efforts span across a large number of very diverse institutions in most countries (see Endnote 4).

A second type of implication is that, in the traditional environment, public R&D policy in agriculture is largely determined by the orientation of policies towards agricultural development and direct investment (budgetary allocations) and priority setting within the public agricultural research institute, usually the cornerstone of the National Agricultural Research System (NARS). In the more diversified institutional environment of biotechnology based innovation systems, institutional funding allocations become less relevant as instruments of public policy *vis-à-vis* mechanisms aimed at promoting inter-institutional collaboration, including public-private joint ventures.

Issues of IPRs go beyond the conventional plant variety protection framework to patent legislation and its coverage of biological materials and processes, as well as issues about the countries' enforcement capacities. IPRs raise a new and distinct management challenge for existing research institutions, since they are generally not well equipped to deal with proprietary knowledge. There is not only the lack of negotiating skills, but the limitations of the administrative and bureaucratic systems they have to deal with in the acquisition and protection of IPRs. This situation puts them at a clear disadvantage with respect to private sector entities, and becomes a tangible barrier for accessing certain strategic technologies.

From a macro perspective, IPR regulations are also a critical component of the overall investment decision and not only set the stage for R&D investment in a given country, but also its capability to access technologies developed in other environments. Policies need to consider the promotion of private involvement in research and development, as well as more global issues related to the creation of an appropriate environment for foreign direct investment (FDI) and greater participation by foreign firms in domestic markets.

(ii) Investment requirements and potential spillover effects

There is increasing evidence that the costs of biotechnology research have been steadily decreasing; however, when compared to conventional agricultural research, biotechnology is still a more expensive undertaking[17]. Micro level investment data are not readily available, but, probably vary significantly from country to country depending on domestic price levels and other aspects, such as existing capacities in the biological sciences. However, an approximation of the magnitudes involved

17. The costs of gene sequencing needed for the use of molecular marker technologies is reported to be about 10% of what it was during the mid 1990s [Maredia *et al.* (1999)]. A similar trend is true for transformation technologies, which are becoming more routine and effective, as there is an increasing amount of available information coming out of on-going genomic and bioinformatics research efforts.

is possible on the basis of research estimates. For example, Maredia *et al.* (1999), working on the basis of personal communications by research managers from a small sample of developing countries (Egypt, South Africa and Indonesia), have estimated that the required capital investment for establishing a laboratory capable of handling molecular marker technologies ranges from USD 150 000 to 200 000 (not including scientific personnel training costs, which the same authors estimate are likely to double the total investment required), with annual operational costs of about USD 100 000. The costs of establishing and operating an advanced genetic transformation lab are estimated to be about double these figures.

Evidence from other sources, however, indicate investment needs of a much higher level. According to TAC (2000), the CGIAR centres require investments of at least twice these amounts for the same type of facilities [TAC (2000)], and figures are even higher if estimates are made based on the total cost involved, considering both the R&D and the regulatory costs required to put a GM product on the market. In the latter case, estimates are USD 1.5 – 4.5 million range for a "simple" trait, and between USD 5 – 15 million for a "complicated" trait [Traxler (2001)].

For many countries, this extra investment, in addition to the costs of developing and operating the necessary biosafety and IPR regulatory frameworks, could become a limiting factor in exploiting the full potential of the new technologies. This is particularly so, given the relatively long maturity time of investments *vis-à-vis* the short term perspective and instability of investment trends that characterise most of the developing world's NARSs. Moreover, the nature of the innovation process and the separation between generations of the innovations (knowledge, tools, products) and their applications in agriculture, may cause conflict in many developing countries, where institutions are weak. To reap the benefits of new technologies, it does not seem to be essential that an institution or a country for that matter, has the capacity to generate innovations within its own structures. The experience to date is that the biotechnology and plant breeding research steps for GMOs grown commercially have only occasionally taken place in the same institution and need not occur in the same country (see Endnote 5).

This situation raises a number of important policy issues. The most important one is the potential to benefit from spillover effects from technologies generated abroad. This possibility appears to offer enormous potential, but at this juncture, is concentrated on a relatively small number of temperate and subtropical crops. However, it is likely to expand as the pipeline of available innovations becomes more diverse. The available evidence shows that the products of upstream research (genomic information, genes, gene constructs, markers, transformation methodologies) are applicable across a wide range of crops and agro-ecological environments, while downstream products (genetically modified crops and varieties) are niche specific. The spillover potential and the complexity and cost of the required research decline as one moves towards downstream activities [Pingaly and Traxler (2001)]. These features provide the guiding force for the development of the global bioscience companies and open a window of opportunity for developing countries to access the new technologies as free-riders on investments made in other countries or markets. This is particularly true in the case of the private sector, if they are able to establish the institutional conditions for technological knowledge to flow.

Spillover effects have been found to be quite important in relation to conventional technologies, both in crops and in livestock. They are highly dependent on aspects such as agroecological homogeneity and some institutional variables, but are rarely taken into consideration in policy making, particularly regarding funding, and the number and size of research programmes [Byelee and Traxler (2001)]. There is no empirical evidence of spillover effects from modern biotechnology programmes. However, the way technology is diffused at present, indicates a high potential. The two most important innovations to date, herbicide tolerance and, particularly, insect resistance, have proven to "travel" quite well, as the same or closely related varieties are being successfully planted in all countries with significant GMO production. Furthermore, it is interesting to point out that benefits accruing to the recipient countries are quite important even in the presence of IPRs. In the case of Bt cotton in China and Mexico (Monsanto/Delta & Pineland originated varieties) the share of overall benefits going to farmers has been estimated at more than 85%, while industry estimates range between 12% and 14% [Pingaly and Traxler (2001)]. In the case of RR soyabeans in Argentina, the distribution of benefits is of the same order, with farmers capturing a share ranging from 82% to 86%, depending on whether seed retention is taken into consideration or not [Trigo *et al.* (2002)].

The above considerations highlight the relevance of developing investment strategies that reflect the way biotechnological innovations are being generated, as well as the country's particular characteristics. In this context, the strategic research investment question facing NARSs with limited research resources is; how to balance their efforts to develop their own capacity in basic biotechnology research, *vis-à-vis* positioning themselves for exploiting spillover benefits available from existing technologies. The answer to this question depends on, whether useful investments addressing important agricultural problems are made available, and the size of the domestic markets (which will determine the feasibility of the needed investments). At present, policy choices in this regard are highly affected by agro-ecological conditions, as the current pipeline is biased towards temperate and subtropical crop species, clearly limiting the possibilities of exploiting spill-in opportunities to those countries with compatible agro-climatic environments.

Market size issues are also very important. The existing evidence indicates that limitations in the diffusion of innovations has had a significant negative impact on the profitability of NARS investments in the case of conventional technologies and will, most probably, be more limiting with the type of investments required by biotechnology development [Byerlee and Traxler (1997)]. Policies regarding market size should focus on; increasing the diffusion area and/or lowering the costs of putting products through the regulatory process, information-sharing arrangements regarding biosafety (harmonisation of regulations all the way to cross-acceptance of risk assessments and releases), and bilateral or regional trade agreements on biotechnology inputs and products.

Finally, given the importance of private sector efforts in this area, a guiding principle for the design of investment policies should be to complement private investments, focusing on those issues which are likely to receive less attention by the private sector. At the same time, because of the growing importance of enforceable property rights, the whole issue of public goods should be carefully reviewed, since the existence of potentially enforceable property rights makes the distinction between public and private goods less clear-cut than before (see Endnote 6).

(iii) Biosafety, consumer acceptance and trade related issues

There have been concerns about the potential environmental and human health risks since the very early stages of biotechnology development[18,19]. This is not surprising, since these concerns have also affected most new technological changes.

Because of these concerns, biosafety policies and regulations have evolved *pari pasu* with the development and diffusion of the tools and products of biotechnology, to become an integral part of

18. When discussing environmental, food safety and consumer acceptance issues, we are essentially referring to genetic engineering techniques and GMOs, as the other main techniques (tissue culture, diagnostics and genetic markers) raise few serious questions dealing with biodiversity, consumer or ethical concerns.

19. For further information about biosafety issues see: http://binas.unido.org/binas/home

the R&D and investment policies in the sector. In accordance with this, many countries (mostly OECD members, but also an increasing number of developing countries) have developed biosafety regulations and risk evaluation mechanisms. These mechanisms accompany the product development process from the laboratory stage (safe handling guidelines), through the field and commercial trial stages. Finally, they monitor the performance of the new organisms once they go into commercial production in order to assure their safety for human and animal consumption (see Endnote 7).

The capacity to conduct food safety (health) evaluations is another key component of biosafety systems. Credible health evaluations are essential to secure consumer confidence in biotech products. Depending on whether the country is introducing completely novel products, or adapting products already (evaluated) released for commercialisation in other markets, two different levels of food safety evaluation capacities can be identified. The first is the capacity that applies to transgenic products such as RR soyabeans which have already been approved in another country. Approval would require the capacity to evaluate the health trials conducted in the country of first approval and to identify any relevant scientific gaps. The second is the ability to conduct the laboratory analyses needed to generate the nutritional data (nutrients, proteins, amino acids, calories, vitamins, etc.) and proximate composition: (ash, moisture content, crude protein, crude fat, crude carbohydrates), as well as the capacity to conduct evaluations of allergenicity (homology to allergens), natural toxicants (homology to toxicants), anti-nutritional effects, and protein digestibility.

In establishing the capacities to deal with these issues, policy makers and regulators face a delicate balance, as the costs of putting GMOs through the regulatory process may end up acting as a barrier to technology development. Biosafety regulations are complex and lengthy and often represent the single most time-consuming activity in the process of discovery and development of a transgenic crop variety. These problems are further expanded by a tendency to increase the number of studies so as to provide the information that many national regulatory bodies require as part of their risk evaluation processes. Many systems include a relatively high level of discretionary power, beyond the technical reports, regarding the final approval of a given product. This situation often leads to a high level of uncertainty regarding the final outcome, thus adding to the costs of product development (see Endnote 8).

The above process is of particular importance for smaller countries, as it will impinge directly on their ability to free-ride on R&D efforts by larger countries and benefit from potential spill-in benefits. This situation will also discriminate against national public research institutions and national firms, and reduces their ability to become active players in product development.

In this context, policy alternatives will depend on the specific country situation and the strength of its science and technology systems, as well as how general policies impinge on biotechnology. These range from highly precautionary regulatory systems, where every event is analysed on its own, independent of experiences and information from other countries, to “promotional” or open systems, where risk evaluations from other countries are fully accepted as part of the approval process [Paarlberg (2001)].

(iv) Consumer attitudes

Directly related to the biosafety discussion, is the issue of consumer acceptance of biotechnology products in general, and GMOs in particular, and how they affect both domestic and trade-related policies.

Existing evidence indicates that attitudes towards the use of biotechnology products vary significantly world-wide, with a number of countries reporting important segments of their population having strong reservations about the use of the new technologies in agriculture and food production[20]. In response to this situation, a number of countries, including developed and developing countries such as Canada, the European Union, Australia, New Zealand, Egypt, Kenya, South Africa, China, India, and Indonesia, have moved towards creating a restrictive policy environment, which includes the imposition of special labelling requirements. In the case of Europe, this even extends to blocking the registration of new GM varieties. In Europe, a number of food processing and retailing chains have also adopted voluntary GMO-free policies, inducing either segmented market conditions or an outright ban on GMO products from their supermarket shelves [Commission of the European Communities (2001)].

This trend is not surprising, as it is a very sensitive issue involving genetic modification and the food supply. To date, the technology has concentrated primarily on production and productivity-related traits. However, this situation may change as "second generation" products (involving quality traits and the so called "functional" foods or nutraceutic products) make their way into the market (see Endnote 9). Nevertheless, in most cases, including even those countries, where the majority of people support new technologies, there is an open debate about the use of biotechnology and the need to introduce identification labels for foods produced using GMOs.

The above situation increases both costs and infrastructure and may imply the need to undertake significant investments to develop the logistics to segregate GMOs from conventional crops and eventually, perhaps outright market access restrictions (see Endnote 11).

(v) Trade effects

There is still relatively little evidence to indicate the impact of new biotechnologies on trade flows. However, what has been happening in the corn market, and between the European Union and the United States in particular, points towards a potentially important area of commercial conflict. US corn exports to the EU [Commission of the European Communities (2001)] have been steadily falling since 1995, and the USDA thinks that this is mostly due to differences in the regulatory approaches used. Non-authorised crops cannot be introduced into the European Union and there is a significant difference in the number of GM products approved in both areas[21].

Another aspect is the enforcement of regulations. Many countries have passed labelling and IP legislation, but are not enforcing it. In some cases, the reason is the lack of political will to do so; in others, it is the lack of technical capacity to evaluate the established threshold standards. This is creating a very uncertain environment with negative effects for investments in technology development.

Policy options emerging from consumer acceptance and food labelling requirements are difficult to state in general terms, as they would vary significantly depending on the country product mix (the issue is of lesser importance for non-food crops, such as cotton) and the importance of the export trade. The international environment will also evolve as more GM crops come onto the market, forcing consumer acceptance issues to move from the opinion polls into real market tests. The actual

20. For a review of the situation in different countries, [see Davis (2000) and Shoemaker (2001)].

21. The United States has approved 11 GM corn varieties, while the European Union has only four, but a number of countries have suspended authorizations for growing, creating uncertainty in importers, since if traces of GMOs are found in a shipment it cannot be cleared for importation. (EU document).

conflicts between trading partners go all the way to the negotiating table in the respective international fora. At the same time, a number of different studies report that the market for niche foods is expected to grow, regardless of what happens to GMOs. These comprehensive trends will set a very different environment for handling GMOs from the one that we confront today. This is still an open issue and will probably remain so for quite some time to come.

(vi) The technology delivery infrastructure

Research and development capacities alone are not sufficient to exploit the potential benefits offered by biotechnology. The existence of input markets, capable of scaling up innovation and bringing them to the farm gate, constitute a necessary condition for effective technology transfer.

Most of the relevant biotechnology products are technologies of the "embodied" type, which must be packaged either in seeds or in other physical inputs, such as diagnostic kits, vaccines or yeast and other industrial inputs. Consequently, the capacity to develop prototypes and scale them up to industrial production and marketing are critical components for developing the biotechnology sector. In this context, the existence of a functioning (in terms of variety turnover) germplasm market and industry is probably the most critical sector, as it is through seeds that most of the input efficiency and product innovations are incorporated into the food and fibre production systems. The strategic importance of the seed sector can be seen from what has happened to its structure over the past ten years and the emergence of the “life sciences” industry. However, only a few countries have a seed market with a large enough turnover to support an active pipeline of biotechnology-based innovations (see Endnote 12). On the other hand, the diffusion of modern varieties, an indicator of the effectiveness of local crop improvement programmes and of the potential for sustained germplasm turnover, has been steadily improving in many countries of Asia and Latin America. This would tend to support the notion that the basis for the delivery mechanism may be in place and the need is for policies to attract investment into the commercial seed sector [Evenson and Gollin (2001)].

In other areas such as tissue culture, improved planting materials, diagnostics and veterinary products, industrial capacities are also critical. In general, these capacities are inbred in "knowledge-based" start-ups, that are actively involved in the R&D process; in some cases, through joint ventures with research institutions, and frequently having significant in-house research programmes. In many areas the boundary between research and applications/product development is not clear, as most research efforts have potentially important commercial applications. This justifies direct private investment and makes the traditional public/basic, and private/applied allocation of responsibilities in the technology development process less clearly defined. In this context, public policy and promotional instruments, in addition to research-related instruments need also to consider developments in the input industry, including investment promotion (foreign direct investment regulations, tax credits, public/private joint ventures) facilities for creating knowledge based start-ups.

In conclusion, the weakness of the private sector at this level is one of the most serious limitations for the future development of the industry. The root of this weakness does not appear to be linked to scientific capabilities, but to other restrictions affecting the creation of start-ups and private investments in R&D. The weakness of local capital markets and the absence of risk and venture capital mechanisms in most countries are clearly key factors and potential areas for future consideration (see Endnote 13).

(vii) Summary of main policy issues

Policy issues emerging from the discussion in the previous sections can be grouped into three areas:

- the creation of an enabling environment for the use of agricultural biotechnology;
- the development of local R&D capacities; and,
- the development of industrial and marketing capabilities related to biotechnology inputs and products.

Broadly speaking, the first area covers those factors affecting the decision-making process of economic agents related to the biotechnology sector; that is, the overall policy environment and factors affecting both public and private investment decision making. The second set of policies focus on research and development capacities and activities. It deals with the extent to which a given country is able to generate and transform knowledge into biotechnological tools and products. Finally, the third group, encompasses the links to the production systems and product markets, and the policies needed to make it possible for the products of the R&D processes to reach agricultural producers and consumers.

Table 1 presents a summary of the different policies in each area and a list of the main instruments for each case. The type of policies relevant for different countries varies depending on the country situation, which, in turn, will be determined by the existing scientific and technological capacities and the market situation. In essence, this means the size and degree of the country's integration into international agricultural trade and its overall attitudes towards the use of biotechnology in its agricultural development strategy. In general terms we could expect that, for countries at an early stage of development of their R&D capacities, certain types of policies, such as public-private joint ventures or risk/venture capital mechanisms would not represent relevant options. In the case of countries without an active participation in international markets, investment in the development of identity preservation systems may not constitute a high priority.

Apart from the mix of specific policies that a country needs to implement, the type of instruments to be applied would depend on the government's overall policy on biotechnology. Experiences from different countries indicate that some countries have been much more aggressive than others in their selection of specific policy instruments [Paarlberg (2001)]. Some countries have adopted what could be identified as a "promotional" or "permissive" policy approach designed to attract investments and to facilitate technology transfer and utilisation. Other countries have taken a more "precautionary" or "restrictive" approach, selecting policies and instruments that would slow down the pace of development and adoption of new technologies. Policy instruments related to investment, biosafety, and IPR regulatory systems are the areas where differences between countries are more evident.

In the next section, policy alternatives are discussed in the context of technical capacities and market dimensions. A number of different policy situations are then outlined based on different development paths countries face in exploiting the potential benefits offered by agricultural biotechnology.

3. A typology of policy options

Any strategy to develop agricultural biotechnology needs to consider actions in the three areas discussed above. The key question is: what is the optimum policy mix and type of instruments to use in its implementation? Many factors play a role in the policy development process, but two sets of considerations appear to synthesise the main dimensions affecting the policy choice. The first dimension relates to the country's scientific and technological capabilities. More specifically, this refers to the existing system of institutional, human and financial resources upon which the country can draw to develop and/or access existing knowledge and transform it into technological alternatives adapted to its prevailing production systems. The second dimension relates to the nature of market opportunities for the products of the R&D process. This largely reflects the economic potential for technological development and the capacity to support the required investments. The intersection of these two dimensions will produce a number of different ***“policy situations”***, which summarise the policy options effectively open to a country, given what could be considered as its “initial conditions” (existing scientific and technological capacities) and its economic prospects (market potential for the resulting products of the R&D process). In the following section the “capacities” dimension is discussed, with the aim of identifying a number of basic categories that reflect the different initial conditions. Then, using a simplified set of market variables, a basic typology of different ***“policy situations”*** is presented.

Table 1. **Summary of main policy areas and instruments for consideration in addressing agricultural biotechnology development**

	Policies aimed at	*Indicative instruments (non-exhaustive)*
Creating an enabling environment for the development of biotechnology	o Making explicit government support for biotech.	National Strategy Documents, biotech. action plans,
	o The promotion of direct foreign investments	Regulations for capital markets and foreign participation in input markets
	o Facilitating trade in the agricultural inputs sector	Tariffs and quarantine legislation
	o Establishment of biosafety regulatory framework	National biosafety committees, training programs, harmonisation of regulations and procedures, funding for research on biosafety related issues
	o Implementing intellectual property regulatory mechanisms	Plant breeders rights (UPOV78, UPOV91), patent laws covering biological materials and processes, trade secret protection and trademark legislation
Development of local R&D capacities	o Consolidating / improving existing agricultural research capacities, particularly in relation to crop improvement	Increased investments in exiting NARS institutions
	o Increasing public investments for R&D and human resources development in areas related to biotech	National biotechnology program
	o Improving research org. and management mechanisms to facilitate inter-institutional work (public-public as well as public-private)	Networking and project funding, human resources and personnel policies that allow scientists to move between institutions, joint venture mechanisms.
	o Promoting private sector participation & investments in R&D activities	R&D grants and subsidies, tax credits
	o Facilitating participation of domestic institutions in international R&D efforts	Availability of funds for project preparation activities.
Development of industrial and marketing system capabilities	o Consolidating / improving the organisation and functioning of input markets; in particular seed production and distribution systems	Seed registrations and quality assurance systems, joint ventures between public institutions and private seed companies, credit lines for local seed companies
	o Facilitating the creation of industrial capacities (new firms) to exploit biotech. Products and tools	Risk & venture capital mechanisms, incubators, technology parks
	o Improving logistical capacities in the agricultural marketing systems	Public investments in logistical systems, credit lines for infrastructure development at the farm and local levels
	o Developing quality identification / certification systems for agricultural inputs and products	Establishment of labelling standards, identity preservations systems, regulations for private certification services.

Sources: See Endnote 14.

(i) Scientific and technological capacities

Even though biotechnology represents a major breakthrough, biotechnology policy cannot be discussed independently from conventional technological capacities. In the short to medium-term, the most likely development path is not one of "conventional" *versus* "biotechnological" approaches, but one of convergence, where biotechnology is progressively incorporated into the R&D production function.

Moreover, the potential of the new technologies will still depend on the existing technology delivery infrastructure, although some aspects might change as we move towards a new product mix, particularly in areas such as diagnostics and livestock.

In this context, the existing capacity is the main determinant of how rapidly a given country can advance in incorporating biotechnology into agricultural R&D activities. If a country has no effective crop improvement programme, there will be little value in attempting to introduce new products or tools as they will not be incorporated into the technology options available to farmers. At the same time, given the importance of the basic disciplines in biotechnology development, it appears that the stronger the science base of the research systems, the better they will be to exploit new technological opportunities.

A country's R&D system today largely reflects past investments. It should be noted, however, that the relationship between research capacity and the size of the agricultural sector is not a linear one. Most of today's capacities in developing countries have evolved from the assumption that what was needed to improve agricultural productivity in those countries was a massive influx of agricultural technology. Since agricultural technology does not "travel well", for this to happen, local research institutions were needed. These institutions would then adapt existing knowledge to the predominant agro-ecological conditions. This view emerged from T.W. Schultz's seminal work, *Transforming Traditional Agriculture* and spurred a major expansion of capacities for agricultural research and technology development in the developing world (NARS and the IARCs). These efforts were built on existing structures and received significant support from international donors. Also, it is important to note that the underlying investment logic of these initiatives was built from a "public good" supply perspective, and evolved within the political context of the "welfare state" idea. In this context, public investments played a key role in the promotion of development activities based on criteria not related to agricultural production and productivity objectives, but to broader social issues, such as poverty reduction, human resources and general scientific developments, etc. [Piñeiro & Trigo, Byerlee & Traxler (2001), Pardey (2001)].

A consequence of these processes is that today's NARS structures and capacities represent the starting point and are the basis for a "static typology" of countries, and give an indication of their "supply side" potential to exploit biotechnology developments. From the operational point of view, we propose to use the status of the country's crop improvement programmes as a proxy for the strength of their NARS. Taking into consideration the policy issues discussed in the previous section, two additional criteria are also proposed for classifying countries from the perspective of their capacities to develop and/or use new technologies. The first is the nature of their capacities for biotechnology R&D (how advanced is the country in incorporating biotechnology based research approaches into their policies and programmes). The second criteria is related to the country's actual experience in applying these capacities in developing and marketing biotechnology products. This latter dimension is also expected to reflect the degree to which the country has advanced in the development of institutional and management frameworks needed to handle the new technologies.

Four categories can be proposed on the basis of the criteria outlined above:

a) Non selective importers of technology. This group includes countries where there is no accumulated institutional capital and technology diffusion taking place as a spontaneous process based on individual initiatives ("no-capacities").

b) Selective importers of technology. Countries in this group include (i) countries having conventional crop improvement capacities, and introduces modern varieties through importing and testing for local adaptation; (ii) countries that have taken some steps towards developing biotechnology capacities, *i.e.* have a "biotechnology development strategy", training programmes, tissue culture facilities- mostly through donor support; and (iii) countries that have both a biosafety and an IPR framework in place, but no operational experience.

c) Users of technology tools. This group includes countries that have consolidated conventional plant breeding capacities, and are able to release varieties from their own crosses on a continuous basis. These countries use biotechnology tools in their crop improvement programmes. This covers the entire spectrum of techniques from cell and tissue culture, to marker-assisted breeding and genetic transformation. Although, the latter case may be only relevant for borderline cases, probably in large markets, or in relation to crops of particular importance, such as export or plantation crops, with long-established research support systems. In this category, agricultural research institutions have good linkages to other research institutions and, in some cases, they are integrated into the same institutional framework (usually universities). For example, the country may have a general S&T policy and investment instruments for both research and technology delivery systems. Countries in this category have operational experience with the management and eventual release into the environment of GM varieties.

d) Innovators. Countries in this group have research programmes for both basic and applied research and developments of new tools, as well as products in a wide range of crops and species (*i.e.* to develop new molecular markers, to conduct genomics work and to transform specific crops). This category includes countries with a science and technology system that can undertake frontier research and product development, and provide a continuous release of products through established links with product and input sectors. They also have good linkages to advanced research institutions in the developed world, which are often reflected in joint research projects.

(ii) Policy options

Table 2 presents a list of ***"policy situations"*** using the categories of capacities discussed in the previous section, as well as the size of the potential diffusion area for the products of the R&D process in biotechnology. The shaded cells represent the initial situations or very unlikely occurrence. The arrows indicate the development paths that could be followed by active policies aimed at extending, in any given country situation, the use of biotechnology in their agricultural R&D. The emphasis is on "major" developments, where the research systems move from one capacity level to the next, *i.e.* from having the means to use molecular markers in assisting breeding efforts, to a situation where they can undertake the development of new markers, or the identifications of new genes. These developments are represented in the table by the solid line arrows. At the same time, there could be movements within the same "*capacity cell*", *i.e.* strengthening or expanding an already existing capacity, either by expanding the crop coverage, or the scale of operation with given techniques, etc.; these developments are represented by the broken line arrows and are an ongoing possibility for every case. Actually, the most common policy path was one of continuous capacity improvement, and not one of discrete "leaps" of capacities. In the following paragraphs, the main *"policy situations"* are analysed and the main options and instruments are discussed.

Table 2. **"Policy situations" for improving agricultural biotechnology use in developing countries**

Status / Country Characteristics	"Small market"[1]	"Medium-size market"[2]	"Large market"[3]
Importers of Technology (non-selective)	❶	❶	
Importers of Technology (selective/adaptation)	❷	❸	❹
Tools users			❺
Innovators			

1. Agricultural sector oriented mostly to domestic markets, no sector large enough to support a full-fledged crop improvement programme. Underdeveloped seed distribution systems.
2. Agricultural sector mostly oriented to domestic market, but with a few subsectors (usually export crops) large enough to support crop improvement programmes. An organised seed distribution system exists, with private sector participation in some crops.
3. Large and diversified agricultural sector. Seed markets are well organised with the participation of national and international private sectors.

For simplicity, options are summarised around three main situations, with the intermediate case subdivided according to the size and potential of the countries' agricultural sectors (Table 3). Given that, at present, the research and product pipeline is clearly biased toward temperate agricultural settings, the opportunities to benefit form technological spill-ins are much greater for countries with temperate agricultural conditions than for those in tropical areas. Similarly, for countries located in regions undergoing economic integration processes, market size restrictions are of lesser importance than for those that are not part of this type of political arrangement[22].

Setting the stage for using biotechnology products (❶) This situation corresponds to the lower end of the scale, and includes countries that have research institutions with weak crop improvement capacities, which are relatively isolated from agricultural input markets. The relevant cell here is the one related to "small-" and "medium-size markets". There is a low probability of a "large market" case

22. As a general rule, policies for each new case are "cumulative", as each "new" situation builds on the previous, with a growing set of issues to be confronted.

having a weak institutional situation, as an initial condition. Relevant policies within this situation are those aimed at the development of conventional plant breeding and a basic level of biosafety and IPR regulatory framework and (public and/or private) seed distribution systems.

The two limiting factors that need additional consideration for successful policy implementation at this stage are (i) the difficulty to insure a sustained level of investment in the agricultural research process; and (ii) the overall weakness of regulatory institutions and the way this impinges on the effective implementation of biosafety measures and IPRs.

Improving the efficiency and products of agricultural research, through increased use of biotechnology tools (❷small market, ❸medium-size market, and ❹large market). This situation transcends all market sizes and, probably, represents the most likely one. The basic issue here relates to the possibility of exploiting potential spill-in benefits from existing technologies and involves countries having ongoing crop improvement programmes as well as basic level biosafety and IPR frameworks, all the way up to the "tool user" capacity situation, where some biotechnology techniques and products are already in use, i.e. tissue culture labs and commercial scale facilities. At the most advanced stage, imported GMOs are backcrossed into local commercial germplasm and may already be in the field trial stage.

Policy objectives tend to evolve according to market size. In most situations the focus is on both establishing and upgrading the capabilities to exploit technologies such as molecular markers and genetic transformation and their interface with agricultural inputs and product markets. In this context, the following factors may need to be taken into consideration:

- The definition of country strategies to guide public investments;
- Mechanisms to promote private sector participation as a provider of research services, technologies and products;
- The development of organisational and management mechanisms to facilitate inter-institutional collaborations, both between public sector institutions, and in the form of public-private joint ventures;
- The institutionalisation of IPR management both at the research and product levels, including variety registration and seed quality systems;
- The strengthening of biosafety enforcement capacities and the generation of related scientific and technical information; and
- The development of systems for segregating GMOs and conventional products.

In the case of small and medium-size markets (❷ and ❸), policies will be highly sensitive to economies of scale issues and need to be focused on expanding the application of new technologies and lowering the costs of product development. Collaborative research agreements, regional biosafety and IPR facilities and GMO seed production may become relevant instruments depending on geopolitical considerations, such as the extent of regional integration or trade agreements [*e.g.* MERCOSUR, the Andean Pact, the CARICOM or the Central American Community in Latin America and the Caribbean, the Association of South Eastern Asian Nations (ASEAN) in Asia, or the Southern Africa Development Community in Africa].

Some countries with small and medium-size markets also evolve to become innovators, and, consequently, their policy strategies may also consider market variables beyond those related to agriculture, including those linked to technology export activities.

In type ❹ situations, the size of the diffusion area of the new technologies should imply no restrictions, and investments and tools should be aimed at mobilising resources, both from the public and the private sectors and exploiting possible economies of size and scope. Beyond S&T policies, those oriented to the development of an attractive investment environment in general, and the promotion of foreign direct investments in particular, are critical instruments to insure suitable conditions for the quick transfer of technologies relevant to the country's specific agro-ecological conditions.

Table 3. **Summary of objectives and tools for the main "policy situations"**

POLICY STATUS	POLICY OBJECTIVES	TOOLS
Setting the stage for using biotechnology products	- Development of conventional capacities - Establishment of a regulatory system to facilitate access to biotechnology products - Improvement of the technology delivery system	• Support for NARS applied and adaptive research in agronomy and conventional breeding (infrastructure and human resources development) • Development of operational biosafety and IPR regulatory frameworks • Design of seed legislation • promotion of the agricultural technical services industry
Improving the efficiency, and products of agricultural research, through increased use of biotechnological tools	**For countries with small and medium-size markets** - to create the environment for accessing potential spill-in benefits from existing R&D investments. **For countries with larger markets** - To build/strengthen capacities for technology exploitation in plant and animal health research. - To target transgenic research in important crops	• Support of NARS and S&T Institutions • IPR legislation (UPOV, Patents) Biosafety regulations and enforcement capacities • Funding for research projects that integrate capacities from different institutions, including those from abroad • Funding (institutional and/or project) for research in areas related to technology and biosafety evaluation • Funding for private sector R&D projects (co-financing, subsidised loans, tax credits for R&D) • Strengthening seed legislation and seed distribution systems • Mechanisms for facilitating public/private joint ventures in biotechnology related R&D projects • Promotion of risk and venture capital mechanisms • Development of quality, certification and identity preservation systems
Building capacities to develop biotechnology based innovations	- To promote and to support basic and strategic research directed at improving the efficiency and scope of technology development. - To consolidate the investment environment, including FDI, biosafety and IPRs	• Support of NARS and S&T Institutions, • Promotion of multi-institutional genome projects in key crops • Establishment of a biosafety operational framework • Development of IPR enforcement mechanisms • Design of regulations on foreign direct investment.

Building capacities to develop biotechnology-based innovations (❺) This case includes countries that have both, a large market potential and a long tradition in agricultural research, often with an already diversified S&T system, with significant capacities in basic as well as in applied biological research. Two types of policy issues are relevant in this situation. One is related to resource mobilisation and tools aimed at improving the efficiency of inter-institutional and public-private linkages, as well as private investment in R&D. The second is linked to improving the investment environment in general, and foreign direct investments in particular.

4. Applying the proposed approach to real world situations

The placing of any given country in one of the "***policy situations"*** described above, requires specific information about that particular country's S&T system, as well as information on institutional capacities, and the structure and dimensions of its agricultural sector. However, a tentative empirical application of the typology is possible on the basis of available statistical and institutional information (from secondary sources).

For the "capacities" dimension of the typology the following indicators are used:

- **Status of the crop breeding programmes.** This is assessed on the basis of an adaptation of the typology developed by Traxler and Byerlee (1995), based on the breadth and output of their capacities in wheat and rice improvement[23]. Two levels are proposed. One level (xx) corresponds to countries with breeding programmes with, at least, experience of releasing varieties from their own crosses (stages 2 and 3 in the Traxler-Byerlee classification); the second level (x) includes capacities to undertake testing of imported varieties (stage 1 in the Traxler-Byerlee classification). For countries where wheat or rice are not important crops, we use an additional indicator based on the capacities of the maize breeding programme. In these cases, countries where more than 50% of released varieties come from their own crosses are classified as (xx) and the rest as (x).

- **Level of current biotechnology capacities.** This is assessed through subjective judgement calls on the basis of existing country profiles from different sources[24]. Countries are assigned values; x, xx and xxx, depending on whether they have some incipient biotechnology capacity (usually operational plant tissue culture facilities); more diverse capacities (cover a wide range of capacities including molecular markers), and finally, the capacity to undertake basic research and develop biotechnology innovation (proteomics, genomic, methodologies, marker systems, etc.). The number of biotech related patents and number of publications in referenced sources are also used as complementary indicators of a country's strength in the biotech area. (A summary of the information used for assigning the corresponding values to the different countries is shown in Annex 1).

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23. They identify three main categories. **Stage 1** are those that do not have crossing programmes, but undertake the testing of imported varieties as the basis for identification and release of materials useful to their environments. **Stage 2** have operational crossing programmes with experience of releasing varieties from their own crosses. **Stage 3** include NARS with pre-breeding research that develop a significant amount of parent materials for their crossing programmes.

24. [ISNAR; Tzotzos and Skryabin (2000); Goeschl and Swanson (2000); Asian Development Bank (2001); Trigo *et. al.* (2002); FAO/APAARI Expert Consultation on Biotechnology in Agriculture in Asia-Pacific (2002)].

- **Experience in agricultural biotechnology markets.** This is assessed on the basis of the number of transgenic crop field trials, including the total number of trials undertaken by public research institutions (Universities and national research institutions). This is expected to highlight not only a threshold level of R&D capacities, but also the broader contour of the enabling institutional environment, including the biosafety and IPR regulatory frameworks and other incentives for technology importation and diffusion.

For the market size dimension, we propose to use the potential diffusion area for the technologies measured in terms of total arable land and permanent crop area. Countries with more than 10 million ha, according to the FAOSTAT data base, are categorised as "large market"; countries in the 3–10 million ha range constitute the "medium-size market" group; and, those under 3 million ha are "small markets". The size of the domestic seed market could also be used to complement the data on total cropped land, but its value is limited, as it is available only for a small number of countries (se Endnote 11)[25].

Tables 4 and 5 contain a classification of 63 developing and emerging economies, for which there is a minimum of comparable evidence available, in accordance with the indicators proposed above. They are grouped following the five proposed "*policy situations*". The results of this exercise confirm expectations. There is a clear-cut differentiation between a small group of countries (in "policy situation" 5) that appear to be in the process of accessing and using existing biotechnology tools and products (Argentina, South Africa, Mexico, Thailand, Indonesia, the Russian Federation) and an even smaller group of countries (China, Brazil and to a lesser extent India) already positioning themselves as full-fledged actors in the industry. For the other countries examined, agricultural biotechnology is a distant option, as they lack the basic capacities to effectively access and market the new technologies. There are some exceptions, countries that appear as small and medium-size market tool users, particularly Cuba, Egypt, Chile and the Philippines. These countries have important R&D capacities and field trial activities, both by local public institutions, and by multinational firms.

In terms of policy options, situations ❸, ❹ and ❷, is the most important to be discussed in connection with policies focusing on biotechnology issues. For the rest, policy issues are less related to biotechnology development and diffusion, than to the creation of the basic agricultural research capacities, which are needed as a "launching platform" for the new approaches and the exploitation of current potential spill-in benefits.

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25. The size of the seed market would probably constitute a better indicator of the "real" market potential, since it reflects the rate of germplasm turnover and, through this, the strength of the technology delivery system.

Table 4. **Developing and emerging economies grouped by "policy situations"**

Countries	Crop Improvement 1)	Biotech capacities: Capacity level 2)	Biotech capacities: Biotech Patents 3)	Biotech capacities: CAB/Sci+ Engineer 4)	Field trials 5): Total	Field trials 5): Univ/Natl	Market Size: Arable Land	Market Size: Internal seed market (mill U$S) 6)
Building capacities to develop biotechnology based innovations (❺)								
China	xx	xxx	159	17.7	180	111	L	3000
Brazil	xx	xxx	73	31.7	343	29	L	1200
India	xx	xxx	0	76.2	17	9	L	600
México	xx	xx	1	5.5	167	30	L	350
Argentina	xx	xx	0	2.1	321	14	L	930
South Africa	xx	xx	41	1.1	281	9	L	150
Thailand	xx	xx	1	4.8	22	4	L	24*
Russian Fed.	n.a.	xx	34	0	18	3	L	13*
Indonesia	xx	xx		1.5	8	1	L	
Improving the efficiency and products of agricultural research, through increased use of biotechnological tools (large markets) (❹)								
Pakistan	xx	xx		0			L	5*
Iran	xx	xx		0			L	
Nigeria	xx	x		0			L	120
Ethiopia	xx	x		0			L	2*
Sudan	xx	x		0			L	
Ukraine	x	x	0	0,1	16	0	L	
Improving the efficiency..................(medium markets) (❸)								
Korea Rep.	xx	xx		0			M	
Morocco	xx	xx		0			M	160
Chile	xx	xx		1,0	55	2	M	120
Colombia	xx	xx		0	7	2	M	40
Philippines	xx	xx	0	1,7	2	1,5	M	
Vietnam	x	xx		0			M	
Bulgaria	n.a.	xx	7	0,3	7	3	M	
Kenya	xx	x		0	1	1	M	100
Peru	xx	x		0,4	2		M	30
Zambia	xx	x		0	1	1	M	15
Burma	xx	x		0			M	
Siria	xx	x		0			M	
Venezuela	x	x		0			M	
Improving the efficiency ....(small markets) (❷)								
Cuba	xx	xx	0	0	20	20	S	
Egypt	xx	xx	0	3,0	40	35	S	140
Bangladesh	xx	xx		0			S	60
Zimbabwe	xx	xx	0	0	3	1	S	30
Malaysia	xx	xx		0	0		S	
Uruguay	xx	x		0	29	0	S	4,5*
Paraguay	xx	x		0	0	0	S	70
Ecuador	xx	x		0			S	12
Dominican	xx	x		0			S	7
Sri Lanka	xx	x		0			S	
Nepal	xx	x		0			S	
Ivory Coast	xx	x		0			n.a.	
Haiti	xx	x		0			S	
ibia	xx	x		0			S	
Guatemala	x	x		0,1	3	0	S	8*
Costa Rica	x	x	0	0,4	18	0	S	3*
Bolivia	x	x		0,2	8	1	S	35
Slovenia	x	n.a		0			S	30
Setting the stage for using biotechnology products (❶)								
Mozambique	x	x		0			M	
Saudi Arabia	x	n.a		0			M	18
Afganistán	x	n.a		0			M	
Algeria	x	n.a		0			M	
Uganda	x	n.a		0			M	
Lithuania	x	x	0	0,1			S	
Jordan	x	x		0	1	0	S	
Nicaragua	x	x		0	1	0	S	
El Salvador	x	x		0			S	
Honduras	x	x		0			S	
Panama	x	x		0			S	
Malawi	x	n.a		0			S	10
Angola	x	n.a		0			S	
Tanzania	x	n.a		0			S	
Belize	x	n.a		0	5	0	S	
Lesotho	x	n.a		0			S	
Túnez	x	n.a		0			n.a.	

*Values with asterisk refer to seed exports, not to the internal market
For sources of this table see annex 2

Table 5. **Summary of countries in different "policy situations"**

	Market Size		
	Small	***Medium***	***Large***
Importers of Technology (non selective)	Lithuania, Jordan, Nicaragua, El Salvador, Honduras, Panama, Malawi, Angola, Tanzania, Belize, Lesotho, Trinidad and Tobago, Jamaica ❶	Uganda, Algeria, Afghanistan, Saudi Arabia, Mozambique, Tunisia ❶	
Importers of Technology (selective)	Slovenia, Bolivia, Costa Rica, Guatemala, Lybia, Haiti, Cote d Ivoire, Nepal, Sri Lanka, Dominican Republic, Ecuador, Paraguay, Uruguay ❷	Venezuela, Syria, Burma, Zambia, Peru, Kenya ❸	Nigeria, Ethiopia, Sudan, Ukraine, Iran, Pakistan ❹
Tool users	Cuba, Malaysia, Zimbabwe, Bangladesh, Egypt	Morocco, Chile, Colombia, Philippines, Vietnam, Bulgaria, Korea	Indonesia, Russian Federation, Thailand, South Africa, Argentina, Mexico ❺
Innovators			India, Brazil, China

Source: See table 3

5. Final comments on future research needs

Agricultural biotechnology is a powerful instrument at the disposal of developing countries to deal with the food supply challenges they need to confront in the coming years. However, available evidence shows that there are still only a few countries in a position to exploit these technologies, but over the last 10-15 years a number of countries have initiated important efforts in this area. In part, this is a consequence of the status of the product development cycle and the products that have reached the markets, and is highly concentrated on a few traits of temperate and subtropical crops. Existing evidence also points to the fact that the most important restriction is the weakness of infrastructure to handle innovations in the majority of innovations. Countries that lack the basis to exploit opportunities implicit in conventional technological approaches, also extend these limitations to the new biotechnologies, particularly new transgenic developments. Even when current agro-ecological biases in the technology pipeline shift in favour of tropical crops, these limitations will continue to be a critical limiting factor. This is a policy area of high priority for emerging and developing economies.

The widespread lack of experience with handling biotechnology products, points to the importance of biosafety, IPRs and other technology transfer related policy frameworks. However, available evidence does not allow a more in-depth analysis about their implications and the nature of the issues in different countries.

The impact of economies of scale and the importance of spill-over effects also appear to be critical aspects. Existing evidence appears to indicate that the size of the required investments is a key factor for shaping strategies with respect to biotechnology in the majority of countries. Consequently, policy options on how to relax these restrictions and better exploit spill-over possibilities need to be given a high priority.

Finally, some comments about the usefulness of the proposed typology and the policy recommendations emerging from it. When looking at the results in section three, the resulting "location" of the different countries in the proposed typology appears to be quite in line with what "conventional wisdom" would lead us to expect. However, in strict terms the usefulness of the proposed typology, could only be tested on the basis of the results of policy decisions regarding biotechnology development that different countries have been making over the last two decades. Unfortunately, with the exception of a handful of countries, there is very little information about these policy patterns. Four areas should be given priority in generating information regarding alternative policy patterns.

- The first are concerns over the scope of R&D efforts in developing countries and the institutional context, public and private, in which this is taking place. This should also include an analysis of the expected products and the time horizon to market readiness.

- A second area is that of the specific sequence regarding general science and technology policies, biotechnology specific programmes, biosafety and IPR frameworks, including coverage, implementation and enforcement levels. The key research question is whether actual policy patterns follow the lines implicit in our proposed typology.

- A third area is related to economies of scale and spill-over potential. It is clear that spill-overs are playing a significant role in the present pattern of technology diffusion and for many countries, market size will be a critical restriction. However, effective policy options will not be the same for different countries and further information on the dominating links is essential in order to design the most effective strategies.

- The fourth area is associated with the technology delivery system, including linkages to conventional agricultural technology and the structure of agricultural inputs and service industries.

END NOTES

1. Specific benefits may include the following:

   - Increased productivity, thus producing more food without the need to increase the area of cultivated land, thereby reducing the pressure to expand cultivated areas to forest and marginal areas.
   - Higher crop and nutritional quality, including the enhancement of vitamin and micronutrient contents of food grains, benefiting consumers who survive on limited and poor diets and who cannot afford to buy supplementary vitamins and micronutrients.
   - Increased disease and pest resistance, thus supporting integrated pest management efforts, thereby reducing the use of toxic pesticides.
   - Higher tolerance of existing high yielding varieties to drought, flooding, salinity, heavy metals and other abiotic and biotic stresses, which can stabilise and improve the yields of crops grown in rainfed areas.
   - Higher productivity and quality of farm animals and reduced environmental impacts of the increased industrialisation of animal production.
   - Promote the development of vaccines and the diagnosis of diseases for livestock and aquaculture.
   - Greater use of non-edible food crops to produce medicinal products, fuel, alcohol, and industrial oil.

   Source: Asian Development Bank, 2001.

2. According to CABI, in the mid-1990s about 65% of all scientific publications related to intermediate biotechnologies and almost 70% of those involving modern or advanced technologies came from university researchers [Trigo (2000)]. This picture is supported by the sparse data available as to where agricultural biotechnology capacity is located in some of the developing regions. In the case of Latin America and the Caribbean (LAC), an FAO survey undertaken in the early 1990s [Villalobos (1997)] identified more than 1 000 researchers working in biotechnology related areas, the majority of them in universities, while traditional agricultural research institutions accounted for about 35%, and private firms for the remainder. More recent data, also for LAC, from an ISNAR survey, shows that the universities are the most active player in the field, with the public agricultural research institutions appearing only in the case of larger countries [ISNAR (2000)]. Earlier data for some Asian (China, India, Indonesia, Malaysia, Philippines and Thailand) and African (Egypt, Kenya and Zimbabwe) countries, from an ISNAR survey, as well as a more recent study by Tzotzos and Skryabin and the Asian Development Bank, also show a quite diverse

R&D base, with universities and specialised centres of excellence, playing an increasingly important role. [Komen and Persley (1993), Tzotzos and Skryabin (2000), Asian Development Bank (2001), and FAO-AAPARI (2002)].

3. The fact that a large proportion of final products are subject to intellectual property protection is not a new issue in the agricultural research/technological inputs sector. Intellectual property regulations have been important not only in agricultural chemicals and capital goods sectors, but also regarding genetic inputs. What is new, however, is that proprietary claims are also rapidly enveloping the tools that researchers use to develop new products. This brings about the need to revise research management systems, but more importantly, it significantly extends the possibility of protecting and recouping R&D investments. In addition, it provides an incentive for the private sector to mobilise large sums of money and invest in agro-biotechnology research and development. This latter aspect has set in motion the complex global scale merger and acquisitions process that has led to the creation of what has become known as the "life sciences complex". This complex integrates biotechnology with the agricultural chemical, seeds and food/feed sectors within the context of a small group of large multi-sector/multinational conglomerates, which control a large proportion of both the emerging products and enabling technologies. [For an extended discussion of this process see Carl E. Pray and Fuglie, K. (2001)].

The importance of this trend is also evident when analysing the structure of investments in the field. Table 1 highlights not only the magnitude of the private sector in the biotechnology sector; it represents over 50% of world wide investments, but also the size of the investment gap between public and private sectors and between developed and developing countries, in spite of a sizeable effort from bilateral and international donors.[26] The structure of investments is fully reflected in the IPR situation. Comprehensive data about how pervasive IPRs are becoming is difficult to acquire, but some anecdotal evidence point to the importance of this trend. In the case of the Bt gene, out of 388 patents of application in different crops, 345 belong to private companies and 43 are owned by public institutions; out of the 70 patents needed for the development of the vitamin-A-enhanced *Golden*Rice™, more than 40 are privately owned; in the case of the RR soybeans, all of the 11 technologies involved are originally owned by four major companies [Phillips and Dierker (2001)][27]. Furthermore, to date, all of the GMO varieties of commercial importance have been developed by private companies. Even the larger public undertakings, such as those of the US Agricultural Research Service, which has conducted more than 100 GMO field trials, or the Rockefeller Foundation's Biotechnology Rice Program, have no significant presence in the near term pipeline. To date, transgenic seeds have been delivered by the public sector only in one developing country, namely China [Pray, Courtmanche and Govindasany (2001)].

26. For an extensive review of donor programmes in agricultural biotechnology [see Horstkotte-Wesseler and Byerlee (2000)].

27. Information about technologies such as molecular markers is not available, as their patentability is very limited and firms tend to use the "industrial secret" form of IPR protection. Considering the weight of private investment in genomics and bioinformatic projects, it could be expected that the bulk of useful markers will stay out of the public domain.

Endnote Table 1. **Estimated expenditure on crop biotechnology research (in USD million)**

	Biotech R&D Expenditure (Million $ / year)	Biotech as % of Sector's R&D
Industrialised		
Private Sector Seed/Chemical Multinationals (includes some LDC R&D)	1000 – 1500	40
Public Sector	900 – 1000	16
Less Developed Countries		
Public (from own resources)	100 – 150	5 - 10
Public (from foreign aid donors)	40 – 50	Na
CGIAR Centres	25 – 50	8
Private firms	???	
World Total	2065 – 2730	

Source: Carl E. Pray, Ann Courtmanche, and Ramu Govindasamy, "The Importance of Intellectual Property Rights in the International Spread of Private Sector Agricultural Biotechnology", on the basis of Byerlee and Fischer, (2000).

4. The International Rice Genome Sequencing Project (IRGSP), although initially led by Japan, has evolved into a complex network of multinational co-operation involving Korea, China, Taiwan, India, France, the US, and Brazil (http://www.rockfound.org). Along the same lines the *Xylella fastidiosa* and the sugar cane genome projects currently underway in Brazil are a collaborative effort involving 20 different institutions from the public and private sectors [Rohter (2001)].

5. At present, nearly all GMOs grown commercially in the world are the result of genetic events produced in the United States, and with a few exceptions, based on biotechnology research performed by multinational companies[28]. In the case of Argentina, the second largest producer of GMO crops in the world, (behind the United States with close to 10 million ha of transgenic crops in the year 2001), RR soybeans are based on a Monsanto gene that has been introduced into the local commercial germplasm base, through the existing conventional variety improvement programmes. In the case of Bt cotton, the process is more straightforward, as the transformation was accomplished by Monsanto for the United States in a Delta & Pineland variety; DP33b, and the same variety was then introduced into Mexico, South Africa and Argentina.[29]

28. The exceptions are 400 ha of virus resistant papaya in Hawaii developed by Cornell University [James (2000)] and approximately 100 000 ha planted to China Academy of Agricultural Sciences' Bt cotton [Pray, *et. al*].

29. At present, work is underway to backcross the event into Argentinean varieties, originally developed by INTA, the local national agricultural research institute.

6. Given the possibility of enforcing property rights in areas that were previously in the public domain, the whole legitimacy of public subsidies to research is being challenged and is in need of revision, particularly in the context of the chronic under-funding situation prevailing for most public research institutions. On the other hand, policy making has to take into consideration the fact that if the process is left to market forces alone, there will most probably be a tendency to focus research on those areas where IPR protection is more effective, and may lead to a monopoly situation. Strong public sector research institutions can serve as effective instruments of "market regulation" to prevent monopolistic behaviour by input suppliers. By providing alternate sources of biotechnology products, or "pre-competitive" technologies, public research institutions can help make markets contestable by lowering barriers to entry to smaller firms that may not be able to afford the full cost of product development. Even in a situation where the bulk of investment and innovations come from the private sector, and will be subject to IPR protection, public sector investments will continue to be essential: (i) to develop and implement strategies to access proprietary technologies of importance for the country (joint ventures, licensing within market segmentation agreements, etc.); (ii) to assure the applications of the new technologies for a more efficient and effective provision of public goods (*i.e.* epidemiology and areas related to natural resource management and conservation); and (iii) to make it more attractive for the private sector to invest in research in areas that would not otherwise attract enough investment due to small market size or risk.

7. Every event intended for eventual commercial release is required to go through these processes, as well as undergo a safety evaluation for human and animal consumption. This process may take up to six years, depending on the complexity of the issues involved (degree of novelty of the traits, agro-ecological considerations, etc.). Although there are differences from system to system, in general, they are convergent in that: (i) they focus on the assessment of the potential health and/or environmental risks associated with the introduction of a given organism into the environment and/or the food supply; (ii) the process is based on the nature of the organism and the environment into which it is introduced, and not on the method by which it was produced; and (iii) the systems should be supported by a continuing body of new biological and ecological research oriented to the generation of basic information for the improvement of risk evaluation processes and methodologies, as well as to the monitoring of the behaviour of GMOs after their introduction into the environment. For a description of regulatory systems see http://binas.unido.org/binas/reg and for an over view of the LAC situation see Trigo *et. al*.

8. Specific evidence of the cost of this situation are not available, but some examples provide an idea of the magnitude of the problem. In Argentina, the second largest country in terms of GMO area under production in the world, evaluations went into a *de facto* moratorium from late 1999 to 2001 because of the lack of political will to proceed to give final approval to the events that had successfully completed the trials scheduled for the scientific and technical evaluation stages [Burachick and Trainor (2002)]. In Brazil and India, initially expedient systems were put in place. Later, due to lobbying from the environmental and other interests groups, they shifted towards highly precautionary approaches that have led to no commercial releases at all in Brazil and, only recently, the partial release of Bt cotton in India. These cases highlight the uncertainty of the outcome of the regulatory processes and how it is affecting product development [Paarlberg (2001)].

9. A recent study assessing the feasibility and relevance of non-GM food chains, undertaken in France, lends some support to this view. The study found that about one-third of consumers reject GM-labelled food, a further one-third would buy them if they were cheaper, and the

remainder do not care and would buy them anyway. Since the middle group has a high price-elasticity, one could assume that as market conditions evolve, the non-GM segment of the market would tend to become of lesser importance. This line of reasoning is further supported by a study by Fishhoff and Fishhoff (2002) about public opinions about biotechnology, which, based on the analysis of a number of polls in different countries, concludes that "the picture that emerges from these polls shows moderately orderly attitudes, responding in plausibly sensible ways to circumstances (*e.g.* differences in the technologies or the evaluators). These results suggest some reason for optimism that citizens will respond reasonably, should they receive relevant information, in a comprehensible form from trusted sources".

10. Under the Protocol, every signatory country is committed to undertake the actions needed to ensure the safe use of biotechnological approaches, especially when movement across international boundaries is involved. It follows as a general guideline in the preamble to the convention with the statement that "when there is a threat of significant reduction or loss of biological biodiversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimise such a threat". The "advanced previous consent" requirement is set to go into effect two years after the ratification of the Protocol, an event that is expected to take place during 2003, when fifty countries ratify the agreement.

11. Estimates of the cost implications of identity preservation systems are not readily available. At present, consumers do not seem to be prepared to validate price differentials for non-GM products, labelling and IP requirements may end up acting as a barrier to technology diffusion [Ablin y Paz (2001); Commission of the European Communities (2001); Australia New Zealand Food Standards Council (2000)]. This is particularly true for the majority of developing countries, as very few of them have the appropriate logistical infrastructure to readily implement effective identity preservation processes throughout the marketing chain. This situation may eventually prevent them from fully exploiting the productivity enhancing benefits of the new biotechnologies, thus altering their competitiveness in some areas in favour of more advanced countries with well-established logistical infrastructures.

12. Endnote Table 2. **Estimated values (USD million) of the size of commercial markets for seed and planting material for selected countries**

Country	Internal commercial market	Country	Internal commercial market	Country	Internal commercial market
USA	5700	Australia	280	Slovakia	90
China	3000	Hungary	200	Switzerland	80
Japan	2500	Denmark	200	Finland	80
CIS	2000	Sweden	200	Ireland	60
France	1370	Austria	170	Portugal	60
Brazil	1200	Turkey	170	Bangladesh	60
Germany	1000	Morocco	160	Colombia	40
Argentina	930	South Africa	150	Bolivia	35
Italy	650	Czech Republic	150	Peru	30
India	600	Greece	140	Zimbabwe	30
United Kingdom	570	Egypt	140	Slovenia	30
Canada	550	Belgium	130	Saudi Arabia	18
Poland	400	Chile	120	Zambia	15
Mexico	350	Nigeria	120	Ecuador	12
Spain	300	Kenya	100	Malawi	10
Netherlands	300	New Zealand	90	Dominican Rep.	7

The commercial world seed market is assessed at approximately USD 30 billion.

Source: International Seed Federation (FIS/ASSINEL).

13. At present, the situation throughout the developing world is that this type of infrastructure is evolving slowly, with only a handful of firms in countries such as China, India, Brazil, Mexico, Indonesia, Egypt, South Africa and Argentina. Actively involved in the development and marketing of plant and animal biotechnology products. Most of these efforts are in the simpler, more traditional areas (tissue culture and diagnostics), with only a few using molecular biology and genetic engineering as part of their core business. Quantitative information about the number of firms is very sparce, with overall numbers only for Latin America, where a sector review undertaken by ISNAR reported that; 35 firms in Argentina, 45 in Brazil, 30 in Chile and 25 in Mexico are involved in manufacturing or service activities in the biotechnology area. Other sources reported in Trigo (1999) identify a small number of firms operating in countries such as Uruguay, Colombia, Costa Rica and Venezuela. Cuba is also marketing a relatively important number of biotechnology products,

but not through commercial firms). Tzotzos and Sktyabin (2000) also report that there are several firms involved in South Africa (involved in the production of industrial enzymes, diagnostics, vaccines and plant tissue culture among other areas), Egypt (alcohol, acetic acid production, fermented food, plant tissue culture), Malaysia (mostly related to palm oil and rubber industries), and Thailand (mainly in aquaculture and the shrimp sector in particular).

14. **Table 1. Sources and explanations**

a. Author's estimates based on wheat and rice variety releases (Traxler, G. and Pingali, P.L., International Collaboration in Crop Improvement Research: Current Status and Future Prospects) and of maize variety releases obtained from own crosses (no CIMMYT). CIMMYT Maize Research Impacts Survey, 1998/99.

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ANNEX 1. Summary of existing country profiles of the stage of development of biotechnology capacities

(1)

Countries	*Institutional highlights*	*Policy highlights*			*Qualitative capacities*	*Quantitative indicators*
		Biosafety	*Intellectual Property Rights*	*Main programme*		
Biotech capacities **xxx**						
China (1) (3) (4) (5) (15)	Large number of institutions involved in biotechnology. About 5000 researchers devoted to biotechnology research.	Draft regulations, National and Provincial Biosafety Committees assigned responsibility for risk evaluatives.	Revised patent law effective as of January 1993, excludes plant and animal varieties	Rice genome, rice hybridation. Other: new high yield, high quality and stress resistance varieties.	Gene clonation. DNA recombinant. Genetic engineering. Cell and tissue culture. Transgenic plants. MAS (molecular markers assisted selection). Rice hybridation.	50% of developing countries total budget on biotechnology R&D. More than 15 crops transformed, 180 field trials, 31 GMO market approved (2000).
Brazil (1) (17) (18)	Numerous institutions involved in biotechnology, public and private. Most of funds and institutions are public. Good development of public/private co-operation mechanisms. Wide use of biotechnology on human health and agricultural sciences.	CNTBio (National Technical Commission on Biotechnology) is the agency responsible to control biotechnology, under the scope of the Ministry of S&T. CNTBio issues a technical opinion previous to any release of a GMO to the environment. Releases blocked by judiciary intervention.	1997 law recognising IPR for biotechnological processes, not for plants or animals.	Genomics: gene sequencing of bacteria and fungus. EMBRAPA conducts a big programme on plant breeding for annual tropical and sub-tropical crops. PADCT (long term National Programme for S&T development).	Genetic engineering techniques. Genetic marker techniques. Diagnostic techniques. Cell biology techniques. Microbial techniques.	343 GMO field trials. CENARGEN-EMBRAPA has developed transgenic plants and animals, also GMOs with improved nutritional qualities. Development and invests on human resources. Research invest is 70 % public vs.30% private. Wide presence of multinational private companies.

India (1) (3)	Prime co-ordinating agency DBT (Department of Biotech.). National biotechnology board. Large R&D infrastructure. 31 universities , 500 laboratories and research institutes (ICGEB)	Guidelines and institutional mechanism put into operation in 1990	No patent protection for biotechnology products. Plant variety rights under consideration	Genome sequencing of rice and arabidopsis	Mapping of rice. Wide hybridisation of rice and brassicas. Tissue culture. Genetic engineering. Transgenic plants. Embryo-transfer in cattle. Recombinant DNA	- DBT budget about 30 million a year - 17 field trials - Bt Cotton approved for commercialisation in 2001
XX						
Mexico (1) (17) (18)	CONACYT is the main government agency in co-ordinating sci. and technology activities.19 post graduate programmes in agricultural biotechnology subjects. 75 agricultural biotech. research laboratories and over 200 qualified researchers active in this field.	Official standard since 1996, but still lacks provisions for the release of GM micro-organisms.	Biotechnology products and processes and transgenic animals and plants are patentable.	Transgenic plants tolerant to stresses. Transfer apomixis to maize.	Broad genetic engineering (Transgenic plants) and tissue culture capacities.	167 GMO field trials. 35 institutions carrying out biotechnology research. Around 100 firms using biotechnologies.
Argentina (17) (18)	Public institutions and private institutions devoted to biotechnology development.	CONABIA (National Advisory Committee on Agricultural Biotechnology) proposes regulations to governmental authority. Two regulations approved: one for plant GMOs and the other for GM micro-organisms and/or its products for animal applications.	Two systems: patent legislation and the legislation on seeds and phytogenetic creations. Plants, animals and core biological reproductive procedures are not patentable.	On plants (diagnostic of phytopathogen in crops, transgenic plants, hybrids, gene identification), animal (diseases diagnosis, vaccines, embryo manipulation and transgenic animals) and food industry (food inputs, quality improvement)	Cell biology techniques. Genetic engineering techniques. Genetic marker techniques. Diagnostic techniques. Microbial techniques.	495 GMO field trials. Over 20 research units (most of them are public) and 8 private companies having biotechnology R&D department. Over 300 researchers involved in about 250 biotechnology projects. Most important GMO producer (soybeans, maize, cotton) in developing world
South Africa (1)	3 main NR Institutes (ARC, CSIR and MRC). 5 Universities with biotech related capacities. 46 private companies, 40 develop and produce ag. biotech products.	Regulation process in place and with long operational experience.	Legislation is not clear about biotech products and processes	Major investment, industrial fermentations and crops improvement (lysine fermentation at AECI)	Capacities in a wide spectrum of biotech related techniques	more than 280 field trials on 12 GMO crops
Thailand (2) (3) (12) (13)	Public organisations (2 major are NCGEB and NSTDA), promoting biotechnology research and involvement private sector.	Biosafety guidelines under development.	New patent act (1992) protects biotechnology inventions.	Development of molecular markers for rice breeding (Highlight in molecular breeding)	MAS (marker assisted selection techniques). Cell biology techniques. Genetic engineering techniques. Tissue culture. Embryo-transp. Rice and archid genome.	Public sector investments about $ 5 million a year 22 Field trials

Russian Federation (1)	1996 government approved a federal programme on technologies with 4 subsidiary programs related to biotechnology. 26 major research institutions under 5 academies of sciences. Public founds and some private founds.	Regulations since 1978, adapted in 1996.	n.a	Human genome. Pharmaceutical industry.	Strong pharmaceutical related capacities. Less in ag. related fields.	First GMO crops are in the final stage of registration. 18 Field Trials.
Indonesia (1) (2) (3) (11)	9 public institutes. 11 public universities. 5 private companies. 4 centres of excellence (2 agricultural, 1 medicine, 1 industrial). Large part of funding comes from outside sources. IUCs financed by World Bank Loan.	Guidelines being prepared by NCBs committee on biosafety.	New IPR legislation being prepared. Not yet released any transgenic material.	mostly public funding	Cell culture and tissue culture in plant and animal. Monoclonal antibodies. Enzyme technology. Genetic engineering. PCR technology. Embryo-transfer. molecular genetics.	8 crops in review, 1 released OGM for commercial production.
Pakistan (10) (8)	4 major ag. research labs and 16 other gov. laboratories, 2 private research institutes. Almost all the funds for R&D are public funds; large percentage from international donors	Biosafety Committee and National Commission on Biotechnology.	n.a.	Cotton genome project.	Research on genetic engineering in crop improvement, not yet available for field trials. Tissue culture (potato) advanced.	No field trials.
Iran (6)	Biotechnology is a priority area for the present gov. Insufficient public founds, inadequate RR.HH. 4 Major research institutes/centres and 15 laboratories.	Existing frameworks is not operative	No IPR framework. IPR protection.	DNA markers for rice selection.	Tissue culture, marker assisted selection (MAS), research on genetic engineering	1 field trial on GMO.
Korea (1) (14)	A National Institute of Agricultural Biotechnology + 12 governmental institutes. 6 R&D programs of Agricultural Biotech by Korean gov.	n.a	n.a.	Crop genome project (international rice genome sequencing project IRGSP). Chinese Cabbage genome project. Microbe genome project. Bioinformatics.	Wide R&D capacities.	GMO crops in advanced stage of development.
Morocco (1)	7 major public biotechnology research institutions. Private firms working only in certain crops. Most funding is from international donors.	n.a	n.a.	Focus on horticultural crops.	Plant tissue culture and related areas in several institutes. A few using GE and molecular markers.	n.a

Chile (1) (17) (18)	Public institutions (7) and private (2). 800 researchers working on biological sciences, mainly in universities. Around 30 private companies working on biotechnology.	No regulations regarding the release of GMO.(only for winter nursery purposes)	n.a.	No official policy for biotechnology development, although a National Plan without founds. Focus areas using biotechnology are the agricultural sector and the mining sector.	Good capacities in cell biology techniques, also has capacities in genetic engineering techniques, genetics marker techniques, diagnostics and other applications in the area of microbial techniques.	55 GMO field trials. 9 universities, 2 research institutes, 33 laboratories involved on biotechnologies. About 30 biotechnology firms, most of them are new and small.
Colombia (1) (3) (17) (18)	Governmental agency (COLCIENCIAS) implements biotech. program. Private (14) and public (7) institutions on biotech. research. Infrastructure located primarily at research centres and universities. Public founds, and also research centres linked directly to farmers' associations. Public institutions operating under the private law system.	Guidelines under consideration	Government increased coverage of patent law in 1992, now includes biotechnology products. Plant variety rights under consideration	Transgenic plants of tropical and sub-tropical crops under development.	Cell biology techniques. Genetic engineering techniques. Genetic marker techniques. Diagnostic techniques. Microbial techniques.	7 GMO field trials, almost entirely government-funded, through ICA and public universities.1993 budget about USD 2,8 million. 74 active research teams, 57 % of which is working in plant and agricultural biotech. sector.
Philippines (1) (3)	Main institutes, National Institute of Molecular Biology and Biotechnology, University of Philippines at Los Banos.	Biosafety system in place. National biosafety committee. Network of Institutional Biosafety committees	No patent protection for biotechnology products	Focus on GM banana and papaya with virus resistance.	Report capacities in gen engineering and tissue culture techniques. Diagnostics. Molecular markers.	2 GMO field trials.
Bulgaria (1)	1 National co-ordinating centre (Institute of GE). Founds from public sector (70% of the total)	Since 1996 has formal regulations. Covers only releases of higher plants and products derived thereof.	Regulations based on EU legislation.	Development of disease resistant tobacco cultivators.	Some genetic engineering capacity (transgenic crops).	7 GMO Field trials. To date no biotech products on the market.
Cuba (1)	The Biological Fund, created under the presidency of the Minister of Sci., T&Environment, identify priority R&D and production areas, and prepared a development plan including the allocation of human and material resources.	Guidelines following international criteria.	Since 1983 instruments developed.	Sugarcane hybridation. Human health inputs (recombinant proteins for medical and veterinary uses, vaccines and diagnostic media), Industry inputs, embryo manipulation. Transgenic plants.	Genetic engineering. Capacities to produce monoclonal antibodies and recombinant DNA (vaccines). Embryo manipulation. Tissue culture.	20 GMO field trials. Almost 1000 researchers with Ph.D degrees involved on biotechnology research.

Egypt (1) (3)	National strategy and research programme in modern biotechnology. AGERI (public institute), collaborates with private sector. Heavly invests. 5 major institutes and 3 private companies working on tissue culture.	Formal guidelines have been adopted and are under implementation	No patent protection for biotechnology products	Production of GMO conferring crops resistance to biotic and abiotic stresses.	Genetic engineering and tissue culture techniques.	Total government spending about USD 3 million annually. 40 Field trials
Bangladesh (16)	National network with 11 institutes (governmental and autonomous), leading by the Bangladesh Agricultural Research Centre (BARC). 3 private organisations. Recent National Institute of Biotechnology.	Biosafety guidelines in effect.	n.a.	True Potato Seed Programme, for in vitro production of disease free breeders seed production.	tissue culture (micropropagation). Recombinant DNA technology and marker assisted selection (MAS) capacities.	n.a.
Zimbabwe (1) (3)	Public institutions, major is Biotech. Research Institute (BRI). Universities are the major research institutions.	Guidelines under consideration, to date no legislation on biosafety.	To date no IPR legislation.	BRI is organised into 5 core research areas, one is Agricultural Biotechnology Research.	tissue culture, marker assisted selection (MAS), DNA recombinant and genetic engineering.	3 GMO field trials.
Malaysia (3) (7)	9 R&D organisations, 7 universities, 11 programs. Biotechnology co-operative centres (public/private), 11 developmental projects.	Guidelines being considered.	No patent protection for biotechnology products	n.a	Genetic engineering (transgenic and molecular markers) and tissue culture techniques.	n.a
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Kenya (1) (3)	National advisory committee on biotechnology and its applications (NACBAA). 6 public research institutes, major is Kenya Ag. Res.Inst. (KARI). Public and international founds.	guidelines approved.	Biotechnology inventions protected under 1989 patent law	Report from NACBAA indicating priority areas, but no specific policy.	Tissue culture, recombinant DNA, bovine genome mapping under research.	1 Field trial.

Nigeria (1)	Public organisations (universities, 16 agriculture research institutes) and others (international organisations and NGOs).	No formal legislation, proposal under consideration.	No formal legislation, proposal under consideration.	No evidence of co-ordination in biotechnology or the regulation of its practice. Scientists are working towards elaborating a policy. No special budget for biotech.	Some Tissue culture, Research on GE and molecular genetics only on international organisations.	n.a
Peru (17) (18)	CONCYTEC (public agency). Public and private institutions working on biotechnology development.	n.a	UPOV regulations No patent coverage	Except on the International Potato Centre (CIP), no modern agricultural biotechnology is being applied at research level.	Micropropagation, tissue and cell culture. Only at the CIP, genetic engineering techniques, genetic marker techniques, diagnostic techniques.	2 GMO field trials. (at international centre)
Uruguay (17) (18)	4 public institutes working in crops and livestock. Important funding from competitive funds. Several private firms.	Biosafety framework by Ministerial Resolution	n.a.	Main focus is on livestock and cereals (rice)	Good micropropagation (tissue and cell culture). Also reports capacities in other areas including genetic engineering.	29 GMO field trials.
Ecuador (17) (18)	FUNDACYT is a private, non-profit organisation to promote sci. and tech. development. It administers public funds.	No biosafety framework	No IPR framework	n.a	Cell and tissue culture. Limited capacity on biotechnology (on genetic engineering techniques, genetic marker and diagnostic techniques).	Around 200 researchers involved on agricultural research.
Paraguay (17) (18)	National Council of Science and Technology (CONACYT) is the public autonomous agency co-ordinating the operation of the national research system.	Biosafety Regulations by Ministerial Resolution	No IPR framework	n.a	Tissue culture. Limited development on biotechnologies, genetic engineering techniques, genetic marker techniques. Diagnostic techniques. Microbial techniques.	n.a
Nepal (9)	Five Year Plan with high priority on R&D of biotechnology.	No biosafety guidelines.	No IPR protection for biotech.	No specific policy for biotechnology. No investment policy.	Some Tissue culture capacities.	n.a.

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14. Suhk Chul Suh (2002). Status of Agricultural Biotechnology Research in Republic of Korea. National Institute of Agricultural Biotechnology.
15. Sun Zongxiu, Cheng Shihua and Zhai Huqu, (2002). Status of Agricultural Biotechnology in China. Presented in the FAO/APARI expert consultation meeting on the status of biotechnology in Asia and the Pacific, FAO Regional Office, Bangkok, Thailand.
16. Nurul Alam, (2002). National Perspective on Agricultural Biotechnology in Bangladesh. Presented in the FAO/APARI expert consultation meeting on the status of biotechnology in Asia and the Pacific, FAO Regional Office, Bangkok, Thailand.
17. Verástegui, Javier (2000) to IBS ISNAR. Overview of agricultural biotechnology research in Latin America and the Caribbean.
18. Implications of Developments in Agricultural Biotechnology in Latin America and the Caribbean for IDB Lending. 2001.ISNAR.

DRAFT AGENDA, LIST OF SPEAKERS AND TIMETABLE

OECD Global Forum on the Knowledge Economy:
Modern Agricultural Biotechnology in Non-Member Countries

Paris, 18-19 November 2002

This meeting of the Global Forum seeks to examine and debate the economic and policy dimensions of modern agricultural biotechnology in developing and emerging economies. First, country participants will provide an update on policy approaches to, and infrastructure for modern biotechnologies in their countries, including markets for biotechnology products, institutional arrangements, human capacity, and the interface of conventional and modern biotechnologies. The meeting will then seek to evaluate methods for assessing the impacts of modern animal and crop biotechnologies in developing and emerging economies, as well as discussing a proposed typology of countries based on their capacities for biotechnology uptake and use in agricultural production.

Modern biotechnology encompasses approaches ranging from the widely used techniques of traditional biotechnology, such as microbial fermentation, tissue culture or embryo transfer, to the more advanced techniques of genetic engineering and genomics. The success of the more complex technologies depends on several factors including greater knowledge, as well as understanding and experience of the traditional techniques. Hence, the classical methods of plant and animal breeding still underpin new techniques for the development of transgenic varieties.

Modern agricultural biotechnologies provide considerable scope for raising productivity and output and contributing to the accelerated development of the agro-food sector in most countries. The rapid changes in biotechnology have raised expectations in developing countries for feeding growing populations from a deteriorating and diminishing resource base. Many developing countries are increasing their research capacity in modern biotechnology and focusing on increasing agricultural productivity through improving pest and disease resistance, for example. Concerns are also arising in developing countries about the possible future effects of the new technologies, including the growing gap between rich and poor farmers, the growing dominance of multinationals in the market for agricultural seeds and the complex debate over intellectual property rights. In addition, there is much debate over the impacts on the environment and on resource sustainability. Policy makers in most developing and emerging economies have not, yet, taken any formal position on the opportunities and challenges associated with the adoption of modern agricultural biotechnologies.

The Workshop will bring together policy makers from OECD countries and a range of non-OECD countries, including Argentina, Brazil, Bulgaria, China, Chinese Taipei, Costa Rica, Egypt, India, Indonesia, Kenya, Philippines, Russia, South Africa, Thailand, Uganda, and Ukraine. In addition, experts from the World Bank, FAO, Business and Industry Advisory Committee to OECD (BIAC), International Federation of Agricultural Producers (IFAP), as well as academia and other applied research institutions (IFPRI) will participate in the Forum. The main aim of the Forum is to facilitate an objective and well informed debate on the economic, institutional and policy issues associated with modern biotechnologies, so as to help policy makers in developing and emerging economies in designing appropriate policy frameworks in their countries for modern agricultural biotechnologies.

Monday, 18 November

9.30-10.30 **SESSION I: Overview**

Chair: Mr. Michael Oborne (STI/OECD)

This session will inform participants of ongoing work on biotechnology, frame the main issues for the meeting and set objectives for the discussion.

10 minutes	**Opening Statement:** Mr. Herwig Schlögl, Deputy Secretary-General (OECD)
	Introductory remarks
10 minutes	Mr. Michael Oborne, Director (SGE/Advisory Unit on Multidisciplinary issues, OECD)
10 minutes	Mr. Stefan Tangermann, Director, Food, Agriculture and Fisheries (OECD).
	Discussion
10.15-10.30	***Coffee***

10.30-13.00 **SESSION II: The Current State of Modern Agricultural Biotechnology in Developing and Emerging Economies: Country Presentations**

Chair: Mr. Derek Byerlee (World Bank)

Rapporteur: Mr. Peter Kearns (ENV/OECD)

The purpose of this session is to identify and debate the key strengths and weaknesses of the agricultural research, development and delivery system in developing and emerging economies. There is a wide range of technical and policy variables that affect the development and use of new technologies many of which are country and region specific. A better understanding of the country and regional constraints to the use of modern technologies is essential in identifying appropriate technologies to enhance agricultural production.

10 minutes	Brazil
10 minutes	China
10 minutes	India
10 minutes	Costa Rica
10 minutes	South Africa
15 minutes	**Discussants:** Mr. Terry Medley (BIAC), Ms. Bhavani Pathak (USAID), Mr. Chebet Maikut (IFAP).

Plenary Discussion

13.00-15.00 ***Lunch***

15.00-18.00 **<u>SESSION III</u>: A Framework for Assessing the Economic Impacts of Modern Agricultural Biotechnology**

Chair: Mr. Colin Thirtle (Imperial College of Science, Technology & Medicine, London)

Rapporteur: Mrs. Alexandra Trzeciak-Duval (AGR/OECD)

Recent studies have applied different methodologies and approaches to assessing the economic and social impacts of new agricultural biotechnologies in developing countries. These studies have suggested that certain conditions may need to be met if farmers are to reap maximum benefits from what the technology has to offer, such as improved management practices or improved seed distribution. While existing studies provide valuable insights, new, more comprehensive approaches are required to better understand the likely impacts of agricultural biotechnology products on rural livelihoods. The purpose of this session is to review and discuss methodological approaches to analysing impacts at the household level, as well as the analysis of factors that determine the adoption and diffusion of technology at the household level.

25 minutes *"Assessing Agricultural Biotechnology in Developing and Emerging Economies, The Sustainable Livelihoods Approach"*, Mr. Jose Falck Zepeda, Mr. Joel Cohen and Mr. John Komen.

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10 minutes *"Some Implications of the Sustainable Livelihoods Approach to Assessing Agricultural Biotechnologies"*, Ms. Linda Brown (DFID).

10 minutes "*Environmental Issues in Assessing Agricultural Biotechnologies"*, Env NGO

10 minutes *"Economic Measurement Issues in Assessing Agricultural Biotechnologies"*, Ms. Linda Fulponi (AGR/OECD).

Plenary Discussion

Tuesday, 19 November 2002

10.00-13.00 **SESSION IV: Opportunities and Challenges for Modern Agricultural Biotechnology in Developing and Emerging Economies**

Chair: Mr. Josef Schmidhuber (FAO)

Rapporteur: Mr. Iain Gillespie (STI/OECD)

The purpose of this session is to discuss the agricultural and technology policies and institutional arrangements in developing and emerging economies that may influence the development and delivery of relevant biotechnologies in different agricultural situations. The key issues and constraints in research, development, delivery systems are identified and debated. The development of input and output markets and market infrastructure are also examined in some depth. Based on the analysis of available information and data a typology of developing and emerging countries is proposed.

25 minutes *"Developing and Assessing Agricultural Biotechnology in Emerging Economies"*, Mr. Eduardo Trigo
CCNM/GF/KE/BIO/(2002)6.

10 minutes *"Implications of Agricultural Biotechnology on Trade in Agricultural Products"*, Mr. Sherman Robinson (IFPRI).
CCNM/GF/KE/BIO/(2002)7

10 minutes *"Agricultural Biotechnology in Developing Economies: Industry Perspective"*, Mr. Robert B. Horsch (BIAC).

10 minutes *"Agricultural Biotechnology in Developing Economies: Consumer Perspective"*, Consumers International

Plenary Discussion

13.00-15.00 ***Lunch***

15.00-16.45 **SESSION V: Roundtable Discussion**

In this session, the three rapporteurs from the previous sessions will present a summary of the main issues discussed as well as outlining the major constraints and challenges in the developing country context. Countries will provide remarks based on their perspectives on the policy issues. Policy makers from member and non-member countries and NGOs will have the opportunity to comment on the summaries and to make any final remarks to the Forum.

Chair: Mr. Ken Ash, Deputy Director, Food, Agriculture and Fisheries (OECD)

10 minutes **Introductory remarks:** Mr. Seiichi Kondo, Deputy Secretary-General (OECD)

25 minutes Rapporteurs' reports

25 minutes Country remarks: Perspectives from member and non-member countries

55 minutes Discussion by policy makers from OECD, non-member countries and NGOs

16.45 **SESSION VI: Summary and Follow-up**

The purpose of this brief session is to inform all participants of future work planned on modern agricultural biotechnology, and to invite final comments from participants.

Chair: Mr. Stefan Tangermann, Director, Food, Agriculture and Fisheries (OECD)

10 minutes Ms. Marilyn Yakowitz (CCNM/OECD)

10 minutes Mr. Michael Ryan (AGR/OECD)

Final comments from participants

Wrap-up of the meeting by the Chair

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