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Crop Biotechnology in Developing Countries:

A Conceptual Framework for Ex Ante Economic Analyses

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Contents

Abstract

It is now widely acknowledged that biotechnology will have significant implications for development. While biotechnology's potential for low income economies is still the subject of controversy, this paper argues that it is precisely in these countries that food and agriculture related biotechnology could efficiently contribute to the achievement of development objectives. To date, however, biotechnological advances have been realized predominantly in industrialized countries. Policy-makers in developing countries and in development organizations are challenged to select appropriate strategies for optimally harnessing the potentials of biotechnology for the poor. Policy-oriented information on likely economic impacts of biotechnologies becomes the key parameter for guidance in program formulation, but little has been available thus far. Hitherto approaches of technology assessment proved rather inappropriate for providing such information for particular decisions. This paper presents a conceptual framework for ex ante economic studies in developing countries – a framework within which the efficiency and equity implications of specific technologies can be analyzed quantitatively. Technological impacts also depend on institutional arrangements and on political support systems, dynamics that are explicitly taken into account by the proposed scenario approach. The findings of such analyses can thus provide assistance in decision-making at various phases of the technology path.

Kurzfassung

Inzwischen gibt es einen breiten Konsens darüber, daß moderne Biotechnologie einen entscheidenden Einfluß auf die weltweite wirtschaftliche Entwicklung haben wird. Das Potential für Entwicklungsländer wird kontrovers diskutiert. Es wird zwar vermutet, daß die Technologie insbesondere im Ernährungs- und Agrarsektor in diesen Ländern einen wichtigen Entwicklungsbeitrag zur Steigerung der Produktivität leisten könnte. Bisher konzentrieren sich biotechnologische Fortschritte jedoch überwiegend auf industrialisierte Länder. Es ist eine Herausforderung der Entwicklungspolitik, diese Technologieentwicklung dahingehend zu beeinflussen, daß deren Potential auch besonders für die Armen nutzbar wird. Zeitgerechte Information über mögliche ökonomische Auswirkungen von Biotechnologie in Entwicklungsländern wird zur Schlüsselvariable im Prozeß einer angemessenen Politikformulierung. Traditionelle Ansätze der Technikfolgenabschätzung erwiesen sich als ungeeignet, solche Informationen bereitzustellen. Im vorliegenden Paper wird ein konzeptioneller Rahmen für ex ante Fallstudien vorgestellt, innerhalb dessen sich potentielle Effizienz- und Verteilungswirkungen biotechnologischer Innovationen quantitativ untersuchen lassen. Mit Hilfe eines Szenarioansatzes kann der wechselseitigen Dynamik zwischen technologischer und gesellschaftlicher Entwicklung explizit Rechnung getragen werden. Die Ergebnisse solcher Studien können die politische Entscheidungsfindung auf verschiedenen Ebenen unterstützen.

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Introduction

There is widespread agreement that modern biotechnology will considerably affect worldwide agricultural development, but its potential for low income economies continues to be the subject of controversy. The technology could bring forth sustainable productivity increases and thus make a major contribution to solving food-related problems while promoting environmentally friendly production patterns (FAO, 1995). Critiques, however, reveal a conviction that biotechnology is inappropriate for developing countries. Biotechnological products, they argue, not only fail to meet the needs of the poor, but will reinforce national and international imbalances in power (Tappeser, 1997). Development experience has shown that the impact of a technology on society is a complex interaction of the features of the technology on the one hand and of the environment in which it is embedded on the other. Both aspects are to a great extent the outcome of man-made decisions at different levels. What developing countries need is intelligent policy-making that seeks to optimize positive welfare and distributional effects of the technology while minimizing costs and negative externalities. For this task, timely and policy-oriented information on technology implications constitutes the key parameter. In the case of biotechnology, however, such information is lacking and the nature of the technology suggests that simple extrapolation of past experience with other technologies might be inappropriate. Thus, decisions have to be based more or less on intuition, which is most unsatisfactory, given their often far-reaching consequences. Public perception of new technologies and traditional practice of technology assessment focus predominantly on technology-inherent risks without sufficiently considering potential benefits within a dynamic setting (Mohr, 1997). Such biased, negative prognoses are unsuitable as guidelines for rational decision-making. Moreover, technology assessment studies (e.g. TAB, 1995) generally employ qualitative techniques only, with the result that the decision-maker’s subjective judgment remains the dominant force in the making of specific decisions. We argue that economic theory offers suitable tools for a comprehensive and quantitative evaluation of technology. This paper presents a framework within which the potential costs – including negative outcomes – and benefits of specific biotechnologies can be analyzed within a developing country setting. Although the methodological concept itself is not new, it does present rather novel ex ante tailoring to the specific information needs involved in formulating biotechnology policy for developing countries.

2 Background

Biotechnology is defined by the Office of Technology Assessment of the United States Congress as “any technique that uses living organisms, or substances from those organisms, to make or modify a product, to improve plants or animals, or to develop microorganisms for specific uses” (OTA, 1989). In the present article, this broad view is narrowed to the use of modern biotechnology in crop breeding (see e.g. Wolpers, 1996). Often, the most advanced techniques (viz. genetic engineering) have been criticized as inappropriate for poor farmers in developing countries (TAB, 1995; Lange, 1997). Here, however, it is argued that it is precisely these techniques that hold the greatest promise of contributing to the realization of high-priority policy objectives in developing countries.

With modern biotechnology, genetic resources can be harnessed much more efficiently, and breeding objectives can be attained at an accelerated pace. Against the background of rapid demographic and economic growth in developing countries, of natural resources becoming increasingly scarce, and of diminishing rates of growth in agricultural productivity using conventional technologies, it becomes obvious how important such promising new technologies are for future food security. Unlike Green Revolution technologies, biotechnology is not merely focused on increasing yields of important cereals, but also has production-stabilizing and input-reducing effects and can be applied to any crop species. Furthermore, the use of biotechnologically developed varieties is not confined to favorable or irrigated locations. On the contrary, crops with resistance to biotic and abiotic stress factors could be tailored specifically to benefit farmers in marginal agro-ecological areas. A major advantage of biotechnology with respect to scale effects is the fact that the innovation is incorporated in the seed – a traditional, divisible and reproducible farm input – and does not presuppose the adoption of complementary technology components, such as irrigation or the use of agro-chemicals. Biotechnologies also fit very well, therefore, into small-holder farming systems, where their application could induce equitable and sustainable agricultural development. Without sound international and national technology policy, however, there is the risk that the potential benefits of biotechnology will bypass developing countries, and particularly so with respect to the small farm sector.

2.1 Agricultural Biotechnology: Situation and Prospects

Although traditional forms of biotechnology have always been instrumental in agricultural history, only in the last 20 years has the enormous progress in molecular biology made it possible to apply modern biotechnology to plant breeding. The transfer of specific genes from other organisms to plants started by the mid-eighties, and the first commercial release of a transgenic crop variety took place in China in 1992. To date, around 60 genetically modified varieties have been commercially released in more than ten different countries. Significant areas of transgenic crops are being grown in nine countries, four of which, interestingly, are low or middle income economies. The rapid progress recently made in modern biotechnology and its adoption in agriculture is illustrated by the increase in the areas being cultivated with transgenic crops during the last three years, which is shown in Table 1. From 1996 to 1997, the areas cultivated with transgenics increased by a factor of 4.6, and they again more than doubled until 1998.

Table 1: Total area cultivated with transgenic crops, by country (1996-1998)

	1996		1997		1998	
Country	**Millions of hectares**	**Percent of world total**	**Millions of hectares**	**Percent of world total**	**Millions of hectares**	**Percent of world total**
Argentina	0.1	4	1.4	11	4.3	15
Australia	<0.1	1	0.1	<1	0.1	<1
Canada	0.1	4	1.3	10	2.8	10
China	1.1	39	1.8	14	n.a.	n.a.
France	0.0	0	0.0	0	<0.1	<1
Mexico	<0.1	1	<0.1	<1	0.1	<1
South Africa	0.0	0	0.0	0	<0.1	<1
Spain	0.0	0	0.0	0	<0.1	<1
USA	1.5	51	8.1	64	20.5	74
Total	**2.8**	**100**	**12.8**	**100**	**27.8**	**100**

n.a. means not available.

Note: Due to the unavailability of reliable data, China is excluded for 1998.

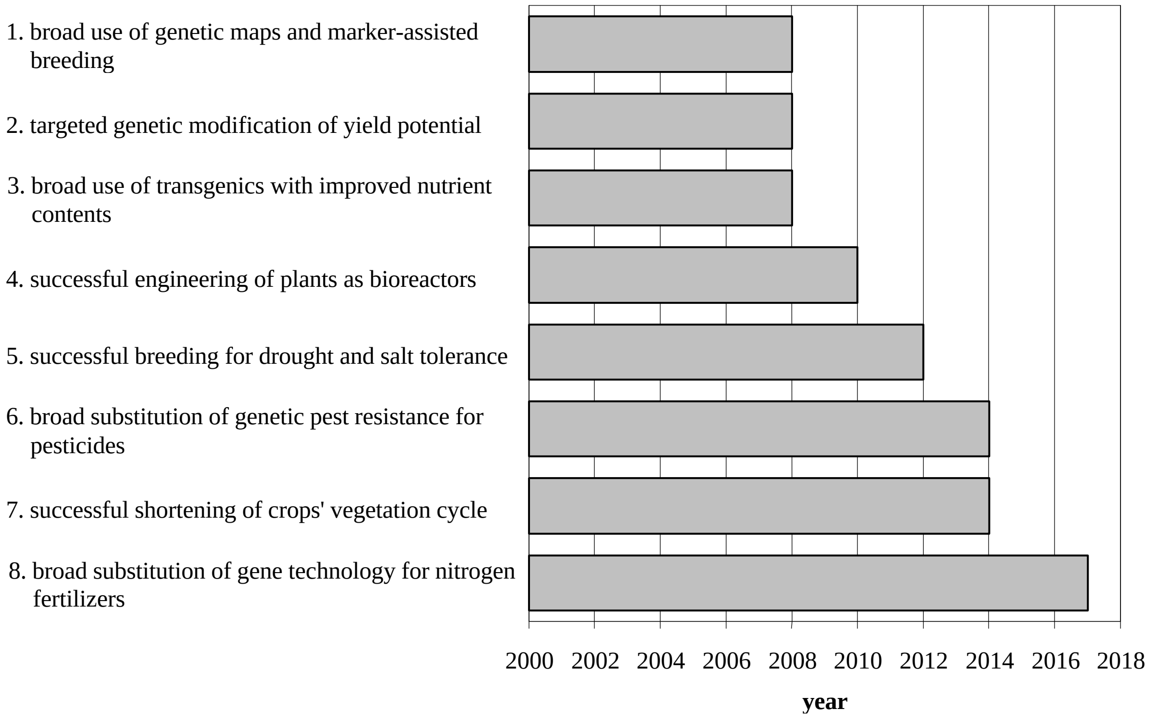
Source: James (1997; 1998).

The lion’s share of the world’s total area under cultivation with transgenic crops is in the USA. In 1997, China and Argentina ranked second and third, respectively, and all developing countries together accounted for some 25 percent of the global total (for 1998, the exact ranking is unknown because of the lack of data for China). These figures are somewhat misleading, however, as regards the biotechnological research standard of developing countries in general. Apart from China, the transgenic crop varieties under cultivation in developing countries are not domestically created technologies but the products of large transnational enterprises. With few exceptions, developing countries are still far from attaining biotechnological standards comparable to those of many industrialized countries. Developing countries’ research investments in agricultural biotechnology are estimated to make up less than two percent of the worldwide total. While the lack of technological and institutional capacities are the main constraints on wider adoption of biotechnology in developing countries, the lack of acceptance among (food) consumers is the major determinant for the observable hesitation in some industrialized countries. This is also the reason why no remarkable transgenic areas were recorded in any European country until 1998.

Even though transgenic field trials have already been conducted with more than 50 crop species, the list of products released for commercial growing is still confined to only 10 species (cf. Qaim, 1997). Many important food grains like wheat and rice and typical subsistence tuber crops like cassava or sweetpotato are still missing from this list. As regards modified genetic characteristics, some 38 percent of commercialized transgenic crop products involve herbicide-tolerant plants, 35 percent have enhanced resistance to biotic stresses (insects and viruses), while the remainder incorporate modified quality traits of various kinds (James, 1997; James and Krattiger, 1996). All of the characteristics successfully modified thus far are monogenic, i.e. are encoded by only a single gene. However, experts are optimistic that the next 10 to 15 years will see scientific breakthroughs in the engineering of polygenic traits, as well.

A recent Delphi Survey carried out in Germany regarding expected technological developments in various sectors revealed the assumptions that modern biotechnology will not only significantly influence breeding techniques, but will also have considerable impact on agricultural production patterns over the medium term (ISI, 1998). Some of the Delphi Study results relating to the use of biotechnology in agriculture are summarized in Figure 1.

Figure 1: Experts' assumptions regarding time frames for the realization of technological hypotheses



Note: This graph is based on median results obtained in the second (final) round of the Delphi Survey. It should be mentioned that 19 percent of the participating experts believe that hypothesis 8 will never be realized, and 14 percent have the same view regarding hypothesis 6. In regard to the other hypotheses, the percentage of experts holding this view was negligible.

Source: Based on data from ISI (1998).

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2.2 Why Economic Evaluation?

Although it could be shown in the previous section that biotechnological research is progressing very rapidly in general, it must not be overlooked that cutting-edge efforts are predominated by private firms in industrialized countries. Many technologies are therefore of proprietary nature. What technologies are suitable to be imported by a specific developing country? It is unlikely that such imported technologies will cover all of the country's most pressing agricultural needs. Besides, developing countries may well wish to reduce the extent of their technological dependence on industrialized countries. In what directions and how far, therefore, should a country engage in its own biotechnological research? Another consideration is the institutional setting within the country, as it may be necessary to alleviate institutional bottlenecks in order to reap the full potentials of biotechnology. Policy-makers in developing countries face the challenge of selecting appropriate national strategies. Thus far, these countries either have no biotechnology programs at all or have programs suffering from a lack of clear priorities (Komen and Persley, 1993; Cohen, 1994; Brenner, 1996). Biotechnology-program decisions also have to be made at the international level. Numerous public initiatives are conducting research on aspects of agricultural biotechnology that have been neglected by the private sector or facilitating technology transfer from North to South (for an overview of organizations see IBS, 1994). Given the increasing scarcity of public financial resources, all decisions at the different levels should be made contingent upon economic criteria. Economic impacts are largely unknown, however, and it is likely that biotechnology has significantly different economic effects than historical cases of technological development. The same holds true for potential social implications. According to the aforementioned Delphi Survey (ISI, 1998), most experts believe that the externalities of biotechnology will consist first and foremost of a social dimension. The more discontinuous the technological change, the greater are uncertainties in the decision-making process. Comprehensive and in-depth ex ante analyses are needed to guide program formulation.

2.3 The State of the Art in the Economics of Biotechnology

That agricultural biotechnology has significant economic implications is widely appreciated. Thus far, however, economists have been rather hesitant to enter this field of research, and there is consequently little economic information available at present. Ex ante statements regarding biotechnology in developing countries have hitherto often been based on ex post experiences within the Green Revolution. Owing to the differences between biotechnologies on the one hand and Green Revolution technologies on the other, however, there is reason to expect that they will also differ in impact. Moreover, most of the economic studies conducted to date have been relatively general and merely yielded qualitative conclusions (e.g. Da Silva et al., 1992; Franzen et al., 1995). Such qualitative studies are important for first impressions. Taking their conclusions as bases for making specific decisions, however, entails the drawback of continuing to rely heavily upon the intuition and subjective values of the decision-makers

(Burnquist, 1995). The literature offers only a few quantitative ex ante studies on biotechnology, most of which center on the impact of bovine somatropin on the U.S. dairy industry or of porcine somatropin on the pork industry (e.g. Zepeda et al., 1991; Marion and Wills 1990; Lemieux and Wohlgenant, 1989). Gotsch (1997) developed a model for anticipating the impact of biotechnological progress on perennial crops. While these are very fruitful approaches, they need certain modifications in order to be suitable for tackling relevant questions and practical issues in developing countries.

There are several reasons why economic research has tended to neglect the area of biotechnological change and its potential impacts (Fishel, 1987; Havlicek, 1990; Chan-Halbrendt, 1996):

- Since the bulk of biotechnological research is done in the private sector, the relevant data are not publicly available. Public biotechnology programs, in turn, must make do with limited resources and consequently give little emphasis to socioeconomic research in order not to detract funds from natural science research, the realm of “real” innovation production. Research managers in this field are themselves predominantly natural scientists.
- Economists appear to have difficulties communicating with biological scientists and vice versa. A multidisciplinary approach is a crucial prerequisite for sound ex ante studies, however, as needed data are not yet observable and exist at best in the perception of cutting-edge natural scientists.
- While economists have a long tradition of working with behavioral assumptions, they prefer to work with ‘hard’ ex post data rather than with the ‘soft’ data involved in ex ante technology assumptions.
- Agricultural economists have to bridge the gap between the large amount of policy-oriented economic information required and the small amount of information presently available.

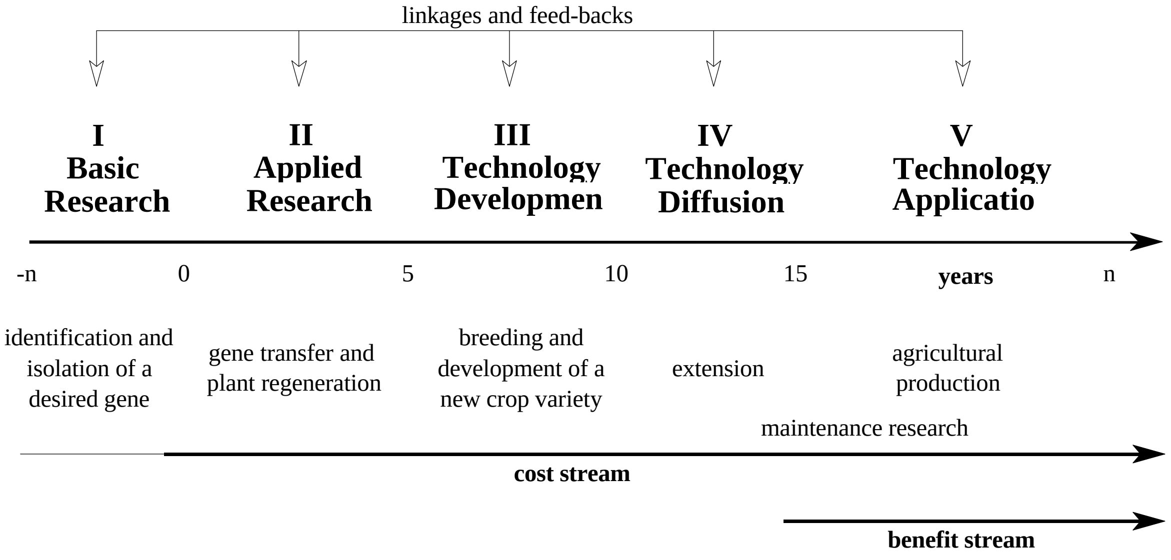
3 An Ex Ante Conceptual Framework for Specific Studies

Biotechnology embraces a large selection of different techniques for a diverse range of purposes. Aggregate studies on biotechnology generally lack the close focus needed to answer particular questions within the design of policies and programs. It is therefore necessary to conduct country-specific and product-specific studies within an analytical framework.

3.1 Technology Path

The general concept for evaluating the economic aspects of certain technologies attempts to juxtapose all costs against benefits along the technology path. This is visualized by Figure 2. The path – here subdivided into five stages – is often neither unidirectional nor straightforward, but characterized by interdependent linkages and feed-back loops between the stages.

Figure 2: Costs and benefits along the technology path of a transgenic crop variety



The path shown is for a transgenic crop variety. The general stages apply to other biotechnologies, say tissue-cultured crops, as well. Moreover, it must not be forgotten that biotechnology – as an extension of the breeding tool box – will not in all cases generate tangible outputs that differ from conventionally bred crop varieties. One important role of biotechnology, for instance, is to be seen in its accelerating traditional R&D (e.g. through molecular marker-assisted breeding) and making the same target products available earlier.

By explicitly considering the factor time, the proposed framework can take such economic impacts of biotechnology into account, as well.

The above example of a time profile is not unrealistic, but of course will have to be assessed individually for each technology. Among many other factors, the regulatory mechanisms of a country (e.g. biosafety) have considerable influence on the lengths of R&D periods. In Figure 2, year zero is the beginning of the applied research stage. This should be understood not as an argument that the analysis should neglect the field of basic research, but that in many cases it will be hard to allocate costs incurred for basic research to specific final products. Furthermore, the basic research for a technology is often conducted outside the study country. In such a case, it is not the direct cost of the basic research that matters to the study country, but the cost it has to bear in conjunction with the technology transfer. The cost stream continues until the end of the analysis. It might be argued that no further cost accrues after the new variety has entered the application phase, but some further applied research will still be necessary to maintain the variety's production potential (e.g. maintenance of breeding lines). In addition, it is conceivable that external environmental costs could arise at this stage.

Direct benefits through increased productivities occur only during the phase of technology application and the marketing of agricultural commodities (here from year twelve onwards).[1] The end of the benefit stream is reached when the technology becomes obsolete (e.g. through the evolution of pests capable of overcoming the resistance mechanism) or when it is superceded by other products. Owing to discounting, there is no point in continuing the analysis for more than 25 or 30 years.

3.2 Uncertainty in Ex Ante Analysis

As indicated earlier, the proposed studies are to be conducted on an ex ante basis, i.e. on the basis of certain assumptions and predictions. Working on assumptions regarding the future entails a great deal of uncertainty. In the face of uncertainty, decisions are often made with the help of probability-distribution functions or by simply attributing probabilities to various possible future scenarios (Anderson et al., 1977). The decision-making criterion is then the expected utility or an average value weighted according to the decision-maker's risk preference. This is an appropriate approach for the treatment of exogenous chance events. In our context, however, it would imply that nothing can be done to influence the outcome. Technology assessment studies are often implicitly founded on such a notion of technological determinism, i.e. presume a unidirectional causality from technology to a static society (Brooks, 1992). Yet technological impacts are functions of institutional arrangements and social support systems. We

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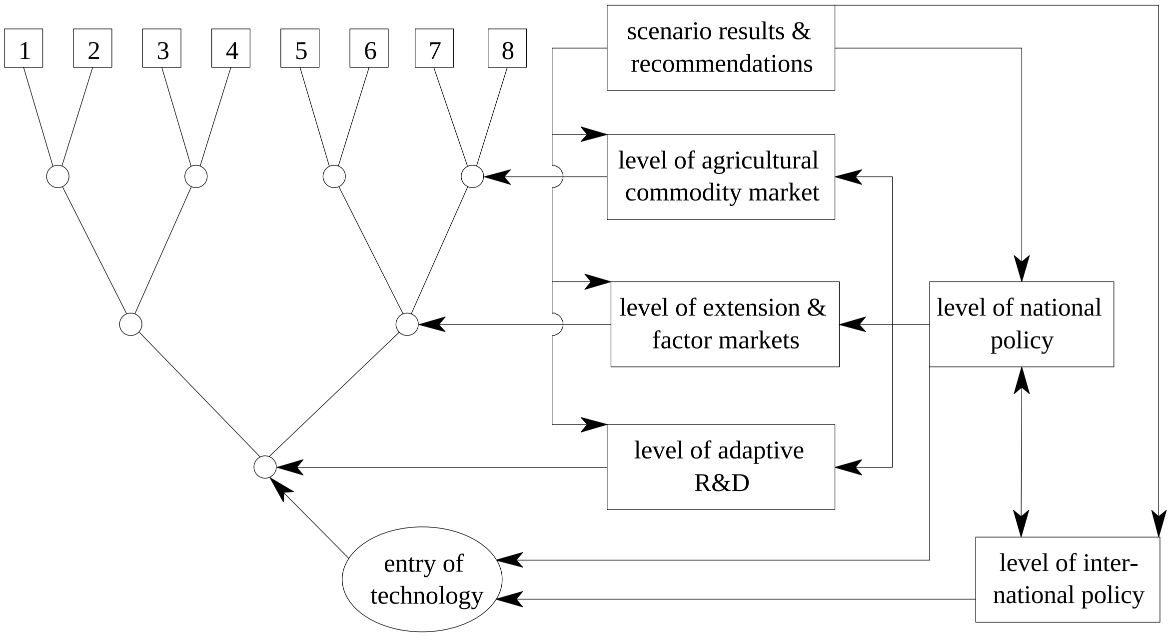
[1] Indigenous R&D offers indirect benefit potentials in the form of human-capital formation and institution building, which could facilitate future biotechnological developments going far beyond the initial R&D efforts. In terms of dynamic comparative advantages, the importance of these indirect benefits may even exceed the immediate economic impacts of the technology; nonetheless, their quantification within specific studies entails severe difficulties.

argue that technology evaluation aimed at providing policy-oriented information must explicitly take these dynamics into account. This can be done by identifying key assumptions and taking them as a basis for juxtaposing a number of different future scenarios. The selection of scenarios should include alternatives that show the effects resulting under different institutional conditions and how the latter should be modified to optimize net benefits.[2] This would make it possible to identify constraints in the technology path and make appropriate adjustment decisions. This procedure of backward induction is shown by the conceptual framework depicted in Figure 3.

The little circles on the left-hand side of the Figure denote points at which it is necessary to make assumptions about the future in regard to controlled (man-made decisions) and uncontrolled (chance) parameters. The analyst is challenged to elicit unbiased information from experts and stake-holders at the different levels indicated by the rectangles. Of course, the number of assumptions that have to be made may be much greater than the number of circles shown. It is therefore necessary to determine the commensurate number of future scenarios in each case. The arrows in the Figure indicate the pattern of influence between the different levels.

Figure 3: Conceptual framework for ex ante analyses of technology



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[2] Often, the stability of results with respect to key assumptions is tested by means of sensitivity analysis. However, sensitivity analysis is a ceteris paribus approach implying that individual parameters are independent. It does not sufficiently reflect that conditions at various levels hinge on each other.

3.3 Levels of Analysis and Information Gathering

In the framework, there are three levels (R&D, factor markets, commodity markets) at which processes directly influence the events in the technology path. These levels are described in the following with respect to the technology analysis (for an overview, see also Table 2 below). The procedure for gathering information at the different levels can be compared to a Delphi Survey focusing on the specific technology development. Of course, statements by individuals may be subjective due to personal incentive structures and/or a lack of farsightedness. In order to elicit objective information, therefore, it is necessary to survey a broad group of stake-holders from different backgrounds and different disciplines (e.g. Mills and Karanja, 1997). The information obtained needs to be cross-checked and supplemented with information available from secondary sources on the various relevant aspects and then translated into usable economic data. The three levels of analysis are influenced by the level of overall national policy, which in turn cannot be seen as independent from international arrangements. Even though the different levels can often not be distinguished that clearly in reality, they are described separately here for the purposes of analysis.

Level of Adaptive R&D

In this example, the analysis starts at the point when the technology enters the phase of adaptive research. The international influence on technology entry indicates that initial research was conducted by foreign public or private institutes and that the basic technology is transferred to the country of interest. The transfer involves negotiations between the international and the national level (e.g. on intellectual property rights). Once the basic technology becomes available, there are decisions to be made at the level of further domestic research and development to the final technology product. The more detailed the contractual arrangements of the technology transfer are, the fewer will be the degrees of freedom remaining for adaptive national R&D. Data collection involves intensive discussions both with representatives of organizations involved in the transfer process and with staff members of participating research institutes. Independent researchers not directly associated with the project should be surveyed, as well, in order to improve the reliability of data. A realistic time frame must be defined for the entire technology path, which will also require information from the other levels of analysis. On the cost side, it is necessary to collect annual data on direct R&D expenditure for past research related to the project and forecast expenditure for efforts yet to come in this connection, including also maintenance research that will be necessary after the product has been released. Costs of human capacity formation and institution building – including regulatory mechanisms in biosafety, food-safety and intellectual property rights – must not be forgotten (cf. von Braun and Virchow, 1996). Furthermore, aspects of technology-inherent risks should be discussed at this level.

To assess the benefit potentials, expected technology-induced yield or quality effects must be elicited from experts. If the R&D process has already reached a stage where the biotechnologically-derived varieties are being tested under field conditions, comparing the performance of these varieties with that of conventional ones can help to quantify the net gains in yield or quality offered by the technology. If, on the other hand, the technology is still in an earlier phase of development, other sources of information have to be considered. For estimating the yield implications of pest-resistance mechanisms, for instance, data on the regional importance of the individual pests (e.g. yield and quality losses) would be an important starting point. Since not all resistance mechanisms confer absolute immunity, however, the technology may only reduce these losses to a certain degree. Moreover, it is necessary to analyze how the performance of the technology holds up as the seeds are repeatedly reproduced by farmers themselves. And lastly, it should not be forgotten that the effects may change over time, also due to the possibility of pests overcoming the resistance mechanism.

Level of Extension and Factor Markets

The level of extension and factor markets embraces the whole spectrum between the laboratory gate and the farm. Here, apart from regarding dissemination costs, crucial assumptions have to be made regarding two issues: first, the potential technology-induced reduction in the per-unit cost of production (or value increase) for the considered crop, and second, the technology-adoption profile. The collection of data from selected farming systems is an aid in anticipating the reduction in per-unit cost. This can be done by juxtaposing crop enterprise budgets as they are at present without the technology and – combined with the information from the R&D level – as they might be using the new technology. The profitability of the technology from the farmers’ point of view is surely the most important factor in adoption decisions. The complexity of understanding and handling a new technology and its divisibility are important characteristics determining the suitability of an innovation in relation to farm size. For biotechnologies being integrated in the seed, scale neutrality should be expected in this context. Replacing varieties is always associated with risk for farmers, however, because little is known about the characteristics of the new variety and about requirements to adjust traditional cropping practices. This can lead to delayed adoption particularly by resource-poor agricultural producers, whose capacity to take risk is much lower than that of wealthier farmers. An important advantage of genetically engineered crops – in contrast to traditional crossbreeding – is that new genes can often be introduced into the genomes of already established cultivars, substantially reducing the producers’ uncertainty about the performance of the new varieties. However, adoption rates also depend on farmers’ access to the technology and to other required factors in production (e.g. rural credit) and extension. A thorough analysis of institutional arrangements on rural factor and input markets will be necessary. Evidence from the Green Revolution indicates that factor market constraints were often not identified prior to the introduction of new high yielding varieties (Marks and Papps, 1992). Hypothetical modifications to the existing institutional framework – with consequential effects on technology adoption rates – could demonstrate the efficiency and equity impacts of institutional adjustments.

Level of Agricultural Commodity Markets

Detailed data on farming systems, including information on the capacity of outlets, are again required for the level of agricultural commodity markets. Based on the assumptions made regarding productivity increases (reductions in per-unit cost) and adoption rates, market effects have to be examined. For tradable commodities, this also involves the international trade position of the country. Not only the agricultural producers, but also food consumers must be considered as potential beneficiaries of the new technology. If it is likely that the technology entails heavy commodity substitution in production or consumption, the analysis must be extended to include markets other than that for the crop under consideration. Furthermore, it is necessary to analyze whether there is divergence between private and societal costs and benefits. For instance, the domain of national price policy is of paramount importance. While from the private perspective of producers and consumers domestic incentive prices are the reference, from a societal point of view it will be necessary to adjust prices for interior distortions in order to reflect the opportunity cost for the country as a whole. Other causes of divergence include environmental externalities, for instance technology-inherent risks. Table 2 summarizes the different levels of analysis and the information required.

Table 2: Levels of analysis and required information

Level	Sources of information	Information required
Level of adaptive R&D	• Representatives of organizations involved in technology transfer • Representatives of national R&D institutes • Independent experts • Secondary sources	• Realistic time frame for the whole technology path • Potential technology-induced effects on yield or quality • Cost of the transfer and R&D • Technology-inherent risks
Level of extension and factor markets	• Farmers • Extension officers • Representatives of factor market institutions • Secondary sources	• Potential technology-induced reduction in per-unit cost • Institutional information • Technology adoption profile • Cost of technology dissemination
Level of agricultural commodity markets	• Secondary sources • Representatives of commodity market institutions • Farmers • Food consumers	• Commodity market data, incl. price policies and marketing channels • Demographic and economic background information • Data on external effects

4 Methodological Considerations

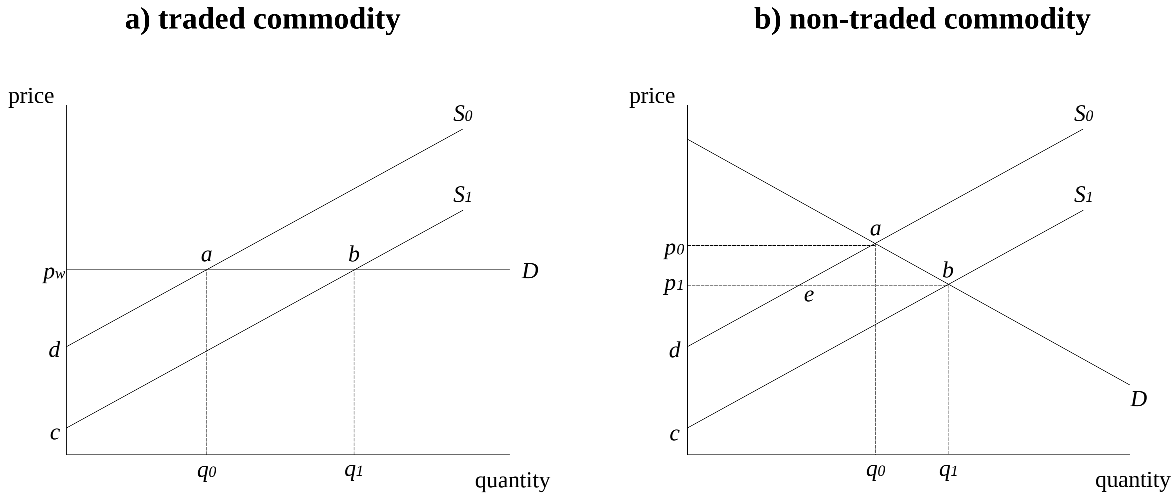
After the conceptual framework has been presented, the question arises as to what economic measures would be appropriate for use in ex ante cost-benefit analyses of biotechnologies. Alston et al. (1995) present various approaches for quantitatively evaluating agricultural technology and in each case weigh the advantages against the shortcomings. For empirical analyses of this kind, they recommend the use of commodity-market-oriented economic surplus models. There is ample evidence, however, that technological progress in agriculture has far-reaching positive ramifications for development beyond the farm sector that may be almost as important as its direct effects within the agricultural sector (e.g. Hazell and Ramasamy, 1991). In order to quantify such economy-wide effects, it would be necessary to employ multisectoral or general equilibrium models. However, there are two main obstacles that limit the merits of such models for the intended analyses of specific biotechnologies with a microeconomic focus. First, in the proposed long-term ex ante approach, it would be very difficult to realistically anticipate all the dynamic intersectoral linkages in the economy over the whole period. Second, with regard to data requirements and model size, the multisectoral perspective can be adopted only at the cost of disaggregation within the agricultural sector itself. While it is imperative to recognize that biotechnological progress has economy-wide effects, we propose the use of partial equilibrium models, aspects of which are discussed in the following. Uncertainty associated with ex ante analyses has been discussed previously and will not be taken up explicitly again in this chapter.

4.1 Basic Market Equilibrium Displacement Model

Technical change through new biotechnologically developed crop varieties reduces the unit cost of producing the agricultural commodity and thus induces a downward shift in the supply curve. This is demonstrated for a small economy in Figure , where S_0 and S_1 are the annual domestic supply curves without and with introduction of the new technology, respectively.

Graph (a) shows the situation for a traded commodity in an open economy, where the domestic price is equivalent to the world market price (p_w). In this partial equilibrium framework, the annual gain in producer surplus induced by the technology is represented by area *abcd*. Owing to the perfectly elastic demand curve (D) for a traded commodity in an open economy, domestic consumers neither gain nor lose anything as a direct consequence of technical change in agricultural production.

Figure 4: Small-economy market models with biotechnological change



Often, it is unrealistic to assume that the demand curve is perfectly elastic. If there are policy barriers to international trade, high transaction costs, or if the developing country is a large economy in the terminology of trade (particularly relevant for tropical cash crops), domestic producers face a downward-sloping demand curve. Resulting effects are conceptually shown by the market model for a non-traded commodity in graph (b) of Figure 4. Here, because of the price reduction, annual consumer surplus increases by area p_0abp_1. Producer surplus changes by *ebcd* minus p_0aep_1. Whether this represents a net gain or a loss for producers depends on the price elasticities of supply and demand. The society as a whole realizes an annual increase in economic surplus of area *abcd*. Which of the market constellations (a or b) is appropriate, must be decided from case to case. If there is poor spatial market integration within the country, it may be necessary to model regional markets separately.

In studies on technical change, functional forms for supply and demand have generally been specified as linear curves due to data limitations and the ease of handling them algebraically (Alston et al., 1995). Apart from technology-specific data, information on equilibrium prices and quantities and on own-price elasticities of supply and demand suffice to calculate surplus measures in linear models. Errors occurring because of functional misspecification appear negligible in comparison to other sources of inaccuracy in ex ante analyses. When extensive cross-commodity effects must be expected and corresponding cross-price elasticities are available, the partial equilibrium model should be extended to arrive at a multimarket model. The costs mentioned in section 0 have to be subtracted from the total economic surplus within a commensurate time frame in order to derive meaningful measures like the Net Present Value (NPV) or the Internal Rate of Return (IRR) of the technology project.

4.2 Shifts in Supply and Demand Curves

Supply Curve

The percentage downward shift (K) in the industry supply curve resulting from the introduction of the new crop variety is one of the key parameters for calculating the change in total economic surplus. The shift factor K in year t is derived as $K_t = C_t \cdot A_t$, where C_t is the technology's potential reduction in per-unit cost in year t, and A_t is the technology adoption rate in the same year. Whether K varies (pivotal shift) or is constant (parallel shift) along the curve has been the subject of controversy in the literature without there being any clear, theory-based justification for either alternative (Norton and Davis, 1981). The national supply curve is an aggregation of the individual farms' supply curves, and a pivotal shift would imply that marginal, high-cost producers would realize a different percentage technological change than do more efficient producers. The nature of the shift should be determined on the basis of empirical findings. Primary data that has already been collected can be used to compare the production efficiencies of different farmer groups, for which divergent profiles of the variable K must be expected.

Cost-benefit analysis is based not on a before/after, but a with/without project conceptualization. It is therefore necessary to examine whether the supply curve would shift if the technology were not introduced during the period under consideration. If national research in general is to be analyzed, it may be reasonable to presume zero technological progress and thus a constant supply curve as the reference (e.g. varietal obsolescence is compensated by more efficient deployment of production factors and research spill-ins). If, on the other hand, only one specific new technology is to be analyzed, this point will require closer consideration. It is likely that some kind of technological progress would occur in the reference scenario even without implementation of the biotechnology project (own conventional research and research spill-ins). This phenomenon can be modeled by extrapolating the historical growth trend of the total factor productivity in the 'without project' alternative. However, rather than being mutually exclusive, old and new technologies go hand in hand in a complementary manner, and traditional progress will not cease when the project is implemented. It may be realistic to assume that a new, biotechnologically developed crop variety incorporates an initial productivity lead over traditional varieties, which can be perpetuated in relative terms throughout the time frame. It may therefore be simplified, but not unreasonable to model a constant commodity-supply curve as the 'without project' benchmark.

Demand Curve

As was the case with the supply curve, it is necessary to determine whether the demand curve is likely to shift during the ex ante project period. There are two broad aspects that could give rise to changes in the overall demand pattern.

- First, shifts in the demand curve induced by the technology itself (endogenous shift in the 'with-technology' alternative). This is particularly relevant for technologies that tend to modify product quality rather than primarily affecting the quantities produced. Quality improvements can be modeled as upward shifts in the demand curve (Unnevehr, 1986; Lemieux and Wohlgenant, 1989). They have relevance for analyses in developing countries because biotechnology, for instance, promises to bring forth crops of improved nutritive value (e.g. Graham and Welch, 1996). It is questionable, however, whether this phenomenon will make poor consumers willing to pay more, which could create enough private incentive for agricultural producers to adopt the technology. Otherwise, quality improvement is a positive external effect and should be fostered by subsidizing technology application to achieve the societal optimum. A rough and incomplete impression of the divergence between private and societal marginal net benefits of crops with improved nutrients could be gained by assessing a related cost-reduction potential in the country's health sector.

- Second, there might be an exogenous shift in demand during the period under consideration due to population and per capita income growth (Norton et al., 1987). This aspect appears particularly important for non-traded commodities in developing countries. Hence, data on domestic demographic and economic projections and income elasticities of demand will be required to make a sound analysis of the impact of a technology on local crops.

4.3 Market Distortions and Environmental Externalities

Possible market distortions include tariffs, subsidies, quotas, inappropriate exchange rates and other policies affecting agricultural factor and commodity markets. These distortions are too diverse to be discussed in greater detail here, but must be taken into account whenever attention is being focused on the economic (as opposed to the financial) considerations of a country and whenever distributional aspects are to be analyzed explicitly. It is suggested that studies on biotechnological impacts should include a careful examination of the determinants of price formation in relevant markets. Suitable modeling approaches are presented in Alston et al. (1995).

Environmental externalities are particularly relevant for biotechnology. On the one hand, positive effects can be expected, e.g. decreased deployment of chemical pesticides thanks to crop resistance to biotic stress factors; reduced uncontrolled expansion into ecologically fragile areas due to increased productivities per unit area. On the other hand, there are technology-inherent risks that in the event of a negative outcome would have to be interpreted as social costs. These include potential vertical and horizontal transfers of genes foreign to the particular environment and the danger of a further loss of biodiversity. Environmental risks may be greater in developing countries, where many domesticated crop species had their genetic origin and where biosafety regulations are often inappropriate (von Braun and Virchow, 1997). Moreover, food safety issues and potential risks for human health need to be considered. Realistic quantification of these external costs remains a challenging task for economists and is contingent upon sound risk analyses by natural scientists.

4.4 Distributional Aspects

Generally, introducing new agricultural technologies is not per se an efficient instrument for improving income distribution within a country (Scobie and Posada, 1978). Nonetheless, it is instructive to analyze the distributional consequences of biotechnological progress in order at least to avoid being counterproductive in regard to equity objectives. Moreover, it is advisable to include distributional aspects in ex ante analyses in order to identify levers in the institutional arrangements for enhancing poor people’s participation in technology benefits. For this purpose, the society must be disaggregated into meaningful groups of stake-holders.

Distribution Between Producers and Consumers

The first obvious and important disaggregation is between agricultural producers and consumers. Food consumers have often been neglected as the main beneficiaries of technological progress in studies on the impact of the Green Revolution (Hazell and Ramasamy, 1991). Producer and consumer gains were already discussed in section 0. In many developing countries, however, the division between producers and consumers is not that clear because commodities – especially staple foods – are often produced partly for home consumption. A critical question is whether official production statistics cover home-consumed quantities because referring merely to the marketed amount of a semi-subsistence crop could crucially underestimate total net benefits of the technology. If production statistics refer only to the quantities marketed, household consumption surveys could be used to make appropriate adjustments. Moreover, home consumption affects the distribution of gains between producers and consumers. To complement the market demand curve, Hayami and Herdt (1977) introduced a demand curve for producers’ home consumption, presuming that home consumption is totally price inelastic.

Thus, total net benefits are the same as without subsistence, only that part of the consumer surplus remains with producers. The assumption of a vertical demand function for home consumption may be questioned but the price responsiveness of home consumption has in fact frequently proved to be quite low (Norton et al., 1987) and more detailed elasticity estimates on subsistence consumption are usually not available.

Distribution Among Producers

Critiques of the Green Revolution often argue that new technologies tend to favor the better-off farmers and bypass the poor, thus emphasizing existing inequalities. By the end of the 1970s, methodologies for capturing equity implications among agricultural producers had been developed and incorporated in technology evaluation analyses (e.g. Hayami and Herdt, 1977; Scobie and Posada, 1978). The general approach foresees a disaggregation of the overall supply curve into meaningful groups of farmers (small or large, farmers in different agro-ecological regions, different income levels, etc.). The selection of appropriate groups and the degree of disaggregation should be adjusted to conform with the stated project objectives. A precondition for analyzing distributional implications is that the following data be available for each constituent producer group: potential reductions in per-unit cost, adoption rates, elasticities of supply, and production shares.

Distribution Among Consumers

Changes in consumer surplus occur only if there are price or quality changes associated with the introduction of the new technology. With detailed knowledge of individual consumption patterns – such as for the producer side – it is possible to disaggregate the overall demand curve into consumer-income strata (Pinstrup-Andersen et al., 1976). A less sophisticated, albeit for our purpose probably adequate approach is to divide total gain in consumer surplus by quantity proportions consumed by the constituent consumer groups (Scobie and Posada, 1978). Relative, technology-induced changes in income distribution among consumers can also be assessed by examining the share of household income spent on the commodity under analysis by each of the different groups. In general, it may be assumed that staple-food-related technologies tend to improve income distribution among consumers, whereas technologies designed for higher-value crops may have the opposite effect.

5 Incorporating Results in the Decision-Making Process

The results of the analyses are sets of scenarios that show the discounted economic and social effects that could be brought about by the assumptions made at the various levels described in chapter 3. On the basis of these scenarios, it is possible to identify critical shortcomings in the arrangements and make recommendations for adjustments. In order for such results to contribute to the decision-making process, it is important that they be presented in a clear manner that is understandable also for non-economists. Ideally, the information obtained would guide program formulation at all the different levels, as shown in the conceptual framework in Figure 3. The example described is an analysis prior to adaptive research and adoption, meaning that decisions and resource allocations have already been made at the level of basic research. Research managers might wish to consult results of pre-basic-research analyses before making decisions on resource allocations. The conceptual framework is suitable for this kind of study, too. In pre-basic-research studies, however, the degree of uncertainty unquestionably increases substantially, and the possibility of complete project failure must be accounted for more explicitly. In the post-basic-research example elaborated here, findings cannot guide basic research for the particular project, but can aid decision-making regarding the directions to be taken by future research. In addition to their relevance for specific technology projects, country-specific studies yield results that are useful both for other countries with similar framework conditions and for setting priorities in international biotechnology programs. Analyzing proprietary technologies developed in industrialized countries within developing country settings would generate important information for private enterprises regarding the export market potential of their innovations. In sum, it may be said that enhancing knowledge of the socioeconomic implications of biotechnology will help to shift the research paradigm from its present supply-driven approach to a more demand-driven one. Only then will biotechnology be able to make an effective contribution to reducing poverty in developing countries.

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