Transgenic Virus Resistant Potatoes in Mexico:

Potential Socioeconomic Implications of North-South Biotechnology Transfer

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Executive Summary

Despite the rapid international development of biotechnology, we still lack knowledge and information about how low- and middle-income countries can best access this promising technology. Nor are the socioeconomic repercussions of applying biotechnology in these countries' agricultural sectors well understood. This study seeks to fill in some of the gaps in our knowledge by analyzing a biotechnology transfer project that provided proprietary recombinant potato technology to Mexico.

In 1991, the government of Mexico and the private US corporation Monsanto entered into a North-South biotechnology transfer agreement in which Monsanto agreed to donate non-conventional virus resistance technology for potatoes. ISAAA developed and brokered the agreement, and the Rockefeller Foundation provided funding for the project. Two public Mexican research institutes, CINVESTAV and INIFAP, carried out product development and adapted the technology to local potato varieties. In 1993, the first transgenic potato field trials in Mexico took place. The release of three transformed varieties (Alpha, Norteña and the red variety Rosita) with resistance to the potato viruses PVX and PVY is expected in 1999. After seed multiplication by national seed producers, farmers' technology adoption could start from the year 2000 onwards, under optimistic assumptions. In addition, a new project phase began in 1997, when Monsanto donated technology that confers resistance to PLRV, an economically more important virus in Mexico than PVX or PVY, but for which non-conventional resistance had not previously been available. The release to seed growers for multiplication of Norteña and Rosita varieties resistant to all three viruses is scheduled for 2001. The use, however, of the PLRV technology in Alpha—the country's most popular and widely used potato variety—is prohibited in the current licensing agreement. Since none of these technologies have yet reached farmers' fields, the socioeconomic effects of these innovations are quantitatively analyzed within an *ex ante* framework by means of an equilibrium displacement model of the Mexican potato market.

The most pressing phytosanitary problem in Mexican potato production does not have biotechnological nor conventional solutions. Virus resistance nevertheless is the priority need for which proven technologies are available. The limited use of pathogen-free seed material—only 23 percent of the land devoted to growing potatoes is cultivated with certified seeds—leads to virus-induced yield losses that are much higher than in countries with better developed potato seed industries. Genetic resistance is therefore likely to considerably increase potato yields, even without additional inputs. On average, the potential net yield gain of the transgenic varieties is projected to be 5 percent with resistance to PVX and PVY only, with an increase to 22 percent when resistance to PLRV is added. These productivity increases will raise income levels for Mexican potato farmers and will also benefit domestic consumers, who will pay lower prices as long as the international potato trade remains limited. In a closed potato economy, consumers would capture about half of the total economic benefits created by these biotechnology applications. Increased international potato trade—a possible outcome of the NAFTA trade agreement—would slightly reduce the overall advantage of the technology, though with an increased benefit share for domestic producers.

This study includes an analysis of hypothetical scenarios in which the Alpha variety also possesses resistance to PLRV. The results show that if Monsanto were to donate PLRV resistance for the Alpha variety, then the project's Internal Rate of Return (IRR) would increase from 50 to 64 percent, and, even more impressively, the aggregate benefits of the biotechnology transfer could triple. The additional cost of including this resistance would be low because of Mexico's previous experience in related technology development. Furthermore, because Alpha is not widely grown in countries other than Mexico, Monsanto's own commercial interest in transforming the variety would not be more than moderate.

New agricultural technologies are often criticized for fostering inequality among farmers. The potential effects of the distribution of recombinant potato technology, therefore, are explicitly considered in this study in terms of different farm sizes. On average, potato farms in Mexico are larger than those devoted to more basic food crops. In addition, potato production is predominantly for commercial purposes—production for household consumption is negligible. Still, there are striking differences between different potato farm types. In the northern parts of the country, large potato production units with advanced technological standards predominate, while in the central and southern parts of Mexico there are more small, resource-poor farms. The smaller the farm, the fewer the purchases of certified, clean seed material. Most of the smaller producers use farm-saved seeds or buy tubers destined for the fresh market from larger producers. The repeated vegetative

reproduction of potato seeds leads to a constant virus buildup in the stock, so that virus-induced yield losses—and thus agronomic technology potentials—are highest in smaller farming systems. So, while PVX-PVY-PLRV resistant varieties decrease per unit production costs on large farms by 13 percent, small-scale producers' costs are even cut by 32 percent. These significant benefits would be limited, however, by the current seed distribution system, which is based upon a farm type-specific pattern of variety use. Many small and medium-scale farmers—especially those cultivating in higher altitudes—often use local red colored varieties, which are less susceptible to potato late blight than imported cultivars. But wealthier large-scale farmers, the primary market for certified seeds, never use these red varieties. Private seed producers, therefore, have no incentive to sell them. In fact, Mexico has no formal seed market for colored potato varieties. Establishing a seed distribution system for these potato varieties is essential to making the benefits of biotechnology available to all of Mexico's potato farmers. While CINVESTAV works to transform the most important red variety—Rosita—for virus resistance, and while transgenic breeder material will be available at the R&D level, the institutional bottleneck in the current seed distribution system will hamper efforts to multiply and disseminate it. Without particular programs developed to address these constraints, the adoption of biotechnology by resource-poor farmers would be unsatisfactory, and this would create greater income disparities between large and small-scale farmers.

In order to increase the participation of small and medium-scale farmers in the new technology, a subsidized seed distribution mechanism for the transgenic Rosita variety is proposed. Its implementation could be based on an already existing instrument for the country's maize and bean sectors under the national program *Alianza para el Campo.* To speed up the adoption of improved varieties by smaller farmers, government organizations buy certified seeds of maize and beans at commercial prices and sell them to resource-poor farmers at subsidized rates. Extending this program to include potatoes would help to equalize the benefits of the recombinant technology. The guaranteed demand for transgenic Rositas by the state would automatically create enough incentive for private seed producers to start handling this variety. Moreover, these subsidies would exclusively address those most in need, since wealthier large-scale farmers do not use the red variety Rosita. Scenario calculations demonstrate that the proposed distribution mechanism would have positive implications in terms of equity and would enhance overall efficiency at the same time: the IRR would rise from 50 to 59 percent. These results clearly show that a new technology's general agronomic suitability for a certain environment is only one element that influences its actual effects. The institutional factors and support systems that make possible the technology's diffusion and application are also crucial aspects that determine its social and economic impacts.

Apart from the immediate advantages to Mexico's potato sector, the biotechnology transfer project will have positive repercussions of a much broader scope. The transgenic potatoes are the first recombinant technology to be released by national organizations in Mexico. To this point, institutional constraints in the NARS and a lack of effective cooperation between institutes have prevented biotechnology from reaching farmers' fields. Under the project, new inter-organizational connections have been established between CINVESTAV, a leader in molecular research, and INIFAP, with its experience in potato breeding. The transfer also significantly contributed to human-capacity building, increased self-confidence and directed R&D to well-defined goals. Moreover, it enhanced international relations between involved researchers and stake-holders. The experience the NARS gained through the transfer project can already be seen, for instance, in the 50 percent reduction in time needed to develop PLRV resistance in comparison to the first PVX-PVY technology. This positive institutional evolution will facilitate Mexico's own biotechnology generation, as well as the acquisition and adaptation of foreign technologies in the future. In addition, the project established and consolidated biotechnology regulatory mechanisms in Mexico, a *sine qua non* for any country wishing to take part in the biotechnology revolution. All these developments might produce positive technology spillovers for other developing countries too.

If appropriate social support mechanisms can be implemented, the project could successfully demonstrate that modern proprietary agricultural biotechnology applications can help low- and middle-income countries meet their urgent development objectives. Donor organizations should recognize that such transfer programs are great opportunities to promote an equitable international biotechnology evolution that will open up new vistas of technological and institutional innovation.

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List of Abbreviations and Acronyms

ABC	Agricultural Biosafety Committee
APHIS	Animal and Plant Health Inspection Service of the USDA
c.i.f.	Cost Insurance Freight
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo (International Maize and Wheat Improvement Center)
CINVESTAV	Centro de Investigación y de Estudios Avanzados (Center for Research and Advanced Studies)
CIP	Centro Internacional de la Papa (International Potato Center)
CONPAPA	Confederación Nacional de Productores de Papa (National Potato Confederation)
f.o.b.	Free on Board
FAO	Food and Agriculture Organization of the United Nations
GM	Gross Margin
INEGI	Instituto Nacional de Estadística, Geografía e Informática (Mexican Statistical Institute)
INIFAP	Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (National Institute for Agricultural Research)
IPRs	Intellectual Property Rights
IRR	Internal Rate of Return
ISAAA	International Service for the Acquisition of Agri-biotech Applications
M$	Mexican Peso
NAFTA	North American Free Trade Agreement
NARS	National Agricultural Research System
NGO	Non Governmental Organization
NPV	Net Present Value
NYG	Net Yield Gain
PLRV	Potato Leafroll Virus
PVX	Potato Virus X
PVY	Potato Virus Y
R&D	Research and Development
SAGAR	Secretaría de Agricultura, Ganadería y Desarrollo Rural (Ministry of Agriculture)
SECOFI	Secretaría de Comercio y Fomento Industrial (Ministry of Foreign Trade)
SNICS	Servicio Nacional de Inspección y Certificación de Semillas (National Service for Seed Inspection and Certification)
SNIM	Servicio Nacional de Información de Mercados
Std. Dev.	Standard Deviation
UNAM	Universidad Nacional Autónoma de México (National Autonomous University)
UPOV	Union pour la Protection des Obtentions Végétales (Union for the Protection of New Varieties of Plants)
US$	United States Dollar
USDA	United States Department of Agriculture
ZEF	Zentrum für Entwicklungsforschung (Center for Development Research)

1. Introduction

Although modern biotechnology holds great promise for developing countries, the application of biotechnology in these countries is more a matter of heated debate than reality. Meanwhile, the technology evolution in the industrialized world continues to rapidly progress (James, 1997). Developing countries and development organizations are eager to identify strategies that will ensure that the new technology does not bypass them—especially the small-scale farmers who stand to benefit most. They seek to harness its potential in order to meet stated development objectives, which involves not only defining their R&D priorities but also developing policies to adequately shape their institutional frameworks. Because genetic engineering differs from other technologies in many respects, policies derived from previous technology experience might be inappropriate (Cohen, 1994). More specific information, therefore, is needed to guide the decision-making process. This study attempts to provide such information through an *ex ante* analysis of the socioeconomic implications of new transgenic potato technology in Mexico.

In 1991, a North-South biotechnology transfer between the private life-sciences company Monsanto (USA) and the Center for Research and Advanced Studies (CINVESTAV), a public Mexican organization, was initiated. The project was brokered by the International Service for the Acquisition of Agri-biotech Applications (ISAAA), which also provides institutional support throughout the implementation phase. Funding for the transfer project was provided by the Rockefeller Foundation. The transfer agreement includes Monsanto's donation of genes and know-how to CINVESTAV for the development of local varieties of virus-resistant, transgenic potatoes. In the following years, related research was conducted both at Monsanto and CINVESTAV. Transgenic potatoes were field tested in Mexico for the first time in 1993, and multi-location field trials have been taking place since 1997 in cooperation with the National Institute for Agricultural Research (INIFAP). The commercial release of the first mature technology is expected in 1999. This will be one of the first approved transgenic crop varieties that local scientists in a developing country have produced through gene transfer and product development. The project is also of particular interest because of its explicit private-public interaction. The dominance in industrial countries of private sector biotechnology research requires the international community to identify and develop new and innovative models of technology transfer for the benefit of developing countries. An analysis of the Monsanto-Mexico project—one of the first of its kind worldwide—can provide some initial insights into this challenge.

The transfer project's main beneficiaries will be the producers and consumers of Mexico's potato sector, which will be directly impacted by the use of transgenic potatoes. This study evaluates and quantifies the benefit potentials produced by technology improvements through a market equilibrium displacement model; in a further step these benefits are contrasted to the corresponding costs of research and extension. Moreover, the equity implications of the technology are explicitly analyzed. Poverty in Mexican agriculture is a widespread phenomenon and small-scale farmers are particularly affected (McKinley and Alarcón, 1995). The project regards resource-poor small-scale farmers as the main target group. Therefore, distribution effects are scrutinized in terms of farm sizes. Strategies to disseminate the technology and place it in the hands of small-scale farmers have not yet been identified. It is hoped that the study can provide some impetus in this respect, too. To gain a better understanding of the importance of developing such strategies, the impacts of different policy alternatives on efficiency and equity are juxtaposed within scenario considerations. In addition to the direct benefit potentials of the technology in the Mexican potato sector, the transfer project also produces more indirect institutional benefits in the national agricultural research system (NARS). Because these indirect benefits are difficult to be quantified, they are qualitatively discussed.

Chapter 2 briefly presents the conceptual framework of the pre-release technology study and of the data collection procedures. Chapter 3 offers an overview of the Mexican potato sector, discussing the general aspects of its role in Mexican agriculture and describing the different potato farming systems. Details of the North-South biotechnology transfer and characteristics of the recombinant potato technology are discussed in chapter 4, and its economic evaluation in terms of benefits and costs for different defined scenarios is carried out in chapter 5. The last chapter draws conclusions and discusses the policy implications of the results of the study, one of the first quantitative in depth analyses of the socioeconomic implications of modern biotechnologies in a developing country.

2. Conceptual Framework

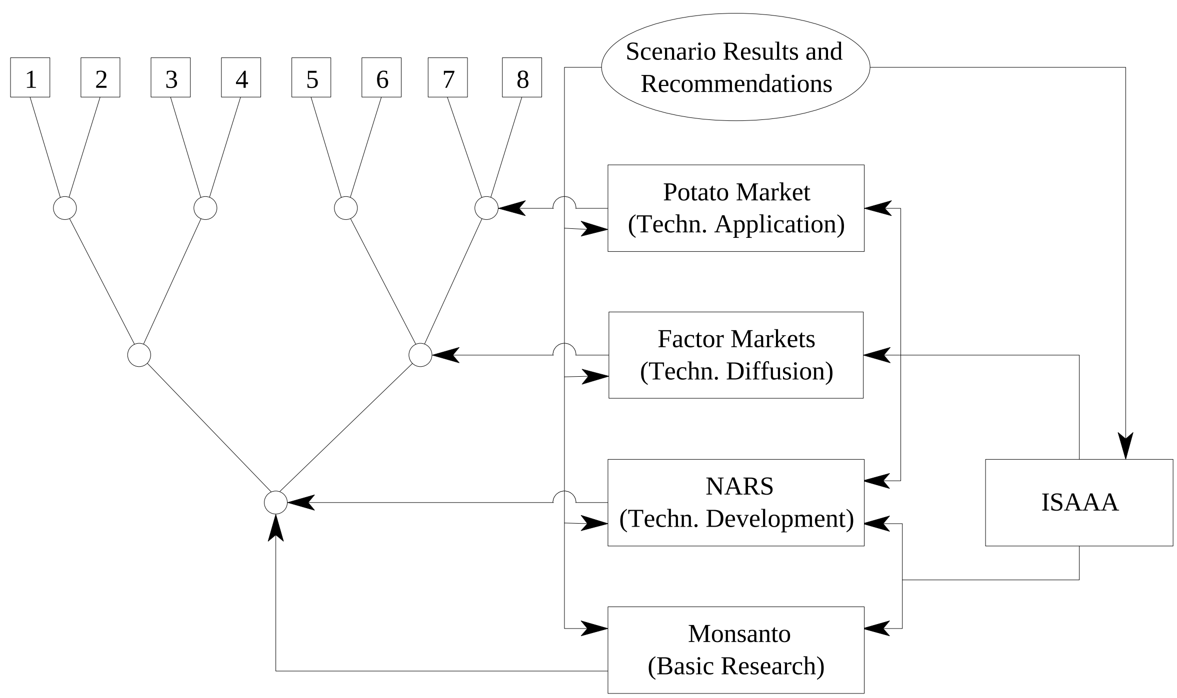
Recombinant potato technology in Mexico has not yet been commercially released—it has not yet been planted in farmers' fields. It could be argued that it is too early for a quantitative evaluation because nothing is actually observable. However, evaluating technology only after *ex post* data is available suffers from the disadvantage of producing results that cannot serve as policy guidelines for optimizing the technology's socioeconomic effects. An *ex ante* framework, therefore, has been developed to deliver quantitative and timely information on the potential implications of the introduction of biotechnology. For a more detailed discussion of the conceptual issues regarding *ex ante* biotechnology evaluations, see Qaim and von Braun (1998).

2. 1 Scenario Approach

Ex ante analyses of technology are associated with uncertainty. Many future events are unknown and must be anticipated. The basic research for the project analyzed here has already been carried out by Monsanto, and the project itself is in the final stages of technology development. Much is already known, therefore, about the technology itself. Still, we lack facts about the future diffusion and application of the technology. Appropriate assumptions for these stages are necessary to arrive at realistic conclusions. The structure of these assumptions can be visualized by a branched tree as shown in Figure 1. Events—and thus assumptions (shown as little circles) —are not mere chance parameters but depend on policy decisions at different levels. The degree and speed of technology adoption by farmers, for example, depends on institutional mechanisms at the level of factor and input markets (e.g., seed prices, extension efforts, access to rural credit, etc.). Similarly, the technology's influence on producer prices depends on the national potato market price and trade policies, among others. The assumption patterns lead to different scenarios, which are numbered from 1 to 8 in Figure 1.

Carrying out benefit-cost calculations for these scenarios will reveal the economic effects of policy alternatives yet to be determined. Thus, constraints in the institutional arrangements can be identified and adjustment decisions made accordingly. Although the technology has almost left the development stage, testing different assumptions within R&D is still worthwhile because the contractual arrangements between Monsanto and CINVESTAV are flexible. Inquiring about the effects of transforming different potato varieties, for example, may suggest policy and

Figure 1: Conceptual framework for *ex ante* technology analysis



strategy changes. The evolution of technology is not a unidirectional process, but consists of linkages and feed backs between different stages of its development. The framework depicted in Figure 1 represents these dynamics, and its use will help shape optimal technology support mechanisms.

2.2 Methodology

Time is an important factor when evaluating the economic impacts of technology. The benefits of research usually lag significantly behind the research investments themselves, and neglecting this fact leads to overestimating net benefits. In our case, the consideration period will start in 1991 (year 0), the beginning of the technology transfer project. This means that the cost of the basic research for the technology is not considered. Since we merely analyze the technology transfer project to Mexico, this is correct because the basic research itself carried out by Monsanto will have impacts in other countries, too. The analysis captures a period of time up until the year 2015 (year 24), during which benefits and costs will be juxtaposed on an annual basis. After that time frame, the technology may become obsolete or be substituted by other innovations. Moreover, costs or benefits accruing after that period will not considerably change the results because of the discounting procedure. We calculate the Net Present Value (NPV) and the Internal Rate of Return (IRR) as economic summary indicators of the technology. Equations (1) and (2) show the underlying formulas:

$$NPV = \sum_{t=0}^{24} \frac{B_t - C_t}{(1+r)^t} \qquad (1)$$

$$0 = \sum_{t=0}^{24} \frac{B_t - C_t}{(1+IRR)^t} \qquad (2)$$

where r is the discount rate, and B_t and C_t is the stream of benefits and costs in year t, respectively.

<u>How to Measure Technological Benefits</u>

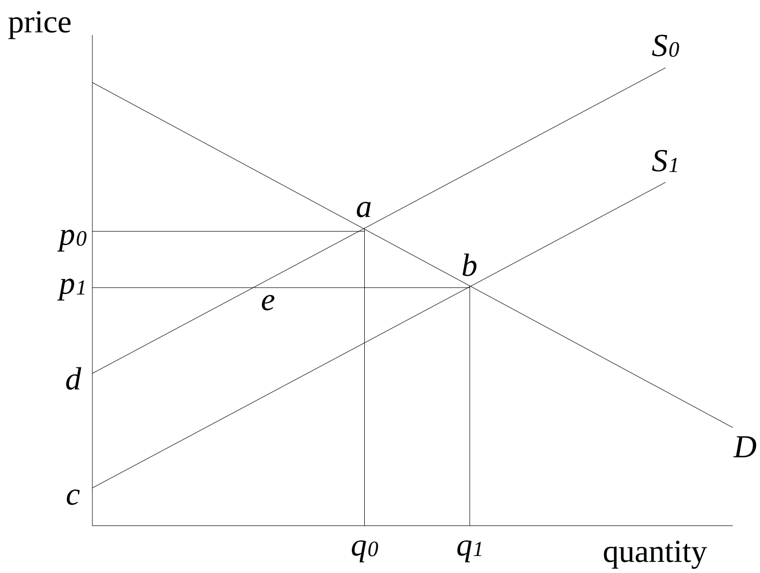
When dealing with the quantification of technological benefits, the question of adequate welfare measures arises. The use of welfare measures in benefit-cost analyses has been extensively discussed in the economic literature. Like most of the other empirical studies, we use economic surplus criteria. Although from a theoretical point of view this procedure does not correctly treat the income effect of price changes, this problem is qualified by other sources of inaccuracy in technology evaluations, such as estimating technology-induced productivity change (cf. Alston et al., 1995). Different authors have shown that agricultural technologies related to one market may also have positive repercussions on other markets even beyond the farm sector (e.g., Hazell and Ramasamy, 1991). For the purpose of the quantitative model, however, we focus only on the potato market. This appears justified because potato production employs only a very small fraction of all the factors involved in Mexican agriculture, and so no significant spillover into other markets should be expected. The possibility of technological innovation creating broader institutional innovation, which could further facilitate biotechnology dissemination in Mexico, is disregarded in the model. These possible benefits receive separate attention in a qualitative discussion.

Starting from an initial price and quantity equilibrium in the Mexican potato market, the new transgenic virus resistant varieties will increase the productivity of potato production and will therefore cause the potato supply curve to shift downwards. This is conceptually shown in Figure 2, where S_0 is the supply curve without, and S_1 is the supply curve with the introduction of the transgenic varieties. The shift of the supply curve (equilibrium displacement) changes the welfare of potato producers and consumers. The change in producer surplus is equal to area *ebcd* minus area p_0aep_1. Whether this is a net gain or a loss for producers depends on the price elasticities of supply and demand.[1] Consumers realize a benefit through the lower prices they have to pay for a unit of potatoes. The gain in consumer surplus is represented by area p_0abp_1. As chapter 3 demonstrates, this conclusion holds for a closed potato economy such as Mexico's. Imports of fresh potatoes from the USA and Canada, however, could increase in the future due to the NAFTA. Taking into account potato production volumes in the NAFTA member countries, Mexico would then be a small potato importing country in the terminology of trade. Potato producers would then face a totally elastic demand curve so that the technology would not entail a change of the potato market price. All of the change in economic surplus would accrue to potato producers. Since it is not clear exactly how trade flows will develop over time, the open economy alternative will be accounted for in the scenario calculations.

There has been a controversial debate in the literature about the nature of the supply curve shift (cf. Norton and Davis, 1981). Whether the shift is parallel, implying the same absolute shift for high and low cost producers, or pivotal, indicating a lower absolute shift for low cost producers, has not been determined on theoretical grounds. The issue remains an empirical

[1] For non-economists it might be surprising that producers could suffer a welfare loss through new agricultural technologies under certain market constellations. This is so because the productivity gain will induce increases of the produced quantities, which in turn decreases the equilibrium price. If the percentage price loss is greater than the production increase, the farmer has lower revenues than in the initial situation without the technology. Price decreases are particularly relevant if price responsiveness of consumers is low for the commodity of interest.

Figure 2: Technical change on the Mexican potato market



question. In subsequent chapters this study argues that a parallel shift is the more likely alternative for Mexico's potato technology. To formulate supply and demand functions, we assume linear curves to make handling them algebraically easier. Although little is known about the true shape of the curves, different authors have shown that errors of functional mis-specification in many cases are small, particularly when the research induced supply shift is parallel (e.g., Voon and Edwards, 1991; Zhao et al., 1997).

Distribution Aspects

New agricultural technologies have often been criticized for reinforcing inequality among producers and fostering income concentration (e.g., Griffen, 1974). Resource-poor, small-scale farmers are the primary target group of this technology project, so a special focus on this group of farmers is appropriate when analyzing its technological implications. This requires, however, some modifications to the basic market model outlined above. Binswanger (1980) and Hayami and Herdt (1977) were the first to include aspects of producer income distribution into the equilibrium displacement framework. The approach anticipates a disaggregation of the total industry supply curve into the partial supply curves of defined producer groups. We consider producer groups of different farm sizes, all facing the same aggregate demand curve. This allows for divergent rates of technical change attained by individual farm groups, which is important because the technology's adoption rates and potential to increase productivity may vary among different farming systems. The following model assumes market clearing at a single price—potatoes are assumed to be an homogeneous product, regardless of who produces them or where they are produced:

Supply:

$$q_{s,i} = q_{s,i}\left(p, tc_i\right) \quad (3)$$

Demand:

$$q_d = q_d\left(p\right) \quad (4)$$

Market clearing:

$$\sum_{i=1}^{n} q_{s,i} = q_d \quad (5)$$

where $q_{s,i}$ is the potato quantity supplied and tc_i is the technical change realized by producer group *i*. q_d is the total quantity demanded while *p* is the price being the same for consumers and all *n* producer groups. Differentiating equations (3) to (5) leads to the following system:

Supply:

$$\frac{dq_{s,i}}{q_{s,i}} = e_{s,i}\left(\frac{dp}{p} + K_i\right) \quad (6)$$

Demand:

$$\frac{dq_d}{q_d} = e_d \cdot \frac{dp}{p} \tag{7}$$

Market change:

$$\sum_{i=1}^{n} ss_i \cdot \frac{dq_{s,i}}{q_{s,i}} = \frac{dq_d}{q_d} \tag{8}$$

where $e_{s,i}$ is the price elasticity of supply and ss_i is the supply share of producer group *i*. e_d is the price elasticity of demand. K_i is the proportionate vertical shift down in the *i*th supply curve due to a cost reduction. Equation (8) can be solved for the relative change of the equilibrium price:

$$\sum_{i=1}^{n}\left[ss_i \cdot e_{s,i}\left(\frac{dp}{p} + K_i\right)\right] = e_d \cdot \frac{dp}{p} \tag{9}$$

$$\Leftrightarrow \quad \frac{dp}{p} = \frac{\sum_{i=1}^{n}\left(ss_i \cdot e_{s,i} \cdot K_i\right)}{e_d - \sum_{i=1}^{n}\left(ss_i \cdot e_{s,i}\right)} \tag{10}$$

The change in the equilibrium price and the changes in the quantities produced and consumed are sufficient for calculating the implications of the economic surplus. Annual change in producer surplus (*PS*) for the individual producer groups, annual change in consumer surplus (*CS*) and the change in total economic surplus (*TS*) due to technical progress are defined as follows (cf. Alston et al., 1995):

Change in *PS*:

$$\Delta PS_i = p \cdot q_{s,i}\left(\frac{dp}{p} + K_i\right)\cdot\left(1 + 0.5 \cdot \frac{dq_{s,i}}{q_{s,i}}\right) \tag{11}$$

Change in *CS*:

$$\Delta CS = -p \cdot q_d \cdot \frac{dp}{p}\left(1 + 0.5 \cdot \frac{dq_d}{q_d}\right) \tag{12}$$

Change in *TS*:

$$\Delta TS = \sum_{i=1}^{n} \Delta PS_i + \Delta CS \tag{13}$$

In the open economy alternative, there is no change in consumer surplus. The change in producer surplus for the individual groups is:

Change in *PS*:

$$\Delta PS_i = p \cdot q_{s,i} \cdot K_i\left(1 + 0.5 \cdot K_i \cdot e_{s,i}\right) \tag{14}$$

This model is appropriate for analyzing the distributional consequences of the new transgenic potato varieties among different farm sizes. It will be the basis for the aggregate benefit calculations in chapter 5. The calculations have to be carried out for all the years of the consideration period in which shifts of the supply curve are caused by the technology. For the summary measures of economic effects, the change in *TS* can then be inserted in equations (1) and (2) to represent the gross annual benefit (*B*) in a given year *t*.

2.3 Data for Analysis

Data requirements for the study can be subdivided into two broad categories. First, potato market data is needed. As the algebraic formulations indicate, this involves produced and consumed quantities, prices and price elasticities associated with supply and demand. On the producer side, the data must be disaggregated in accordance with the different farm groups. This market related data was taken from the available literature and from Mexican agricultural statistics. Special considerations must also be made about the evolution of the figures over time. Details on that as well as the individual published sources are given throughout the text when the data are presented. Second, information on the technology itself and its implications for agricultural practice are needed. The downward shift factor of the supply curve is summarized in the model formulation as *K*, which contains the different parts of information that are not observable yet. $K_{i,t}$, (i.e., the shift factor for the individual producer group *i* in a given year *t*), is defined as:

$$K_{i,t} = C_{i,pot} \cdot A_{i,t} \tag{15}$$

where $C_{i,pot}$ is the potential per unit cost reduction of group *i* attributable to the transgenic technology, and $A_{i,t}$ is the group and time-specific technology adoption rate. In the case of neutral technical change, $C_{i,pot}$ can be calculated as the technology-induced potential net yield gain (*NYG*) divided by the price elasticity of supply. But the transgenic potato varieties tend to save land, so we compare enterprise budgets for the individual groups both with and without the anticipated technology in order to derive realistic estimates of the per unit cost reduction.

As indicated in section 2.1, the different parameters needed for the analysis are not just unknown future facts but depend a great deal on decisions made at the different stages of the technology evolution (see Figure 1). In order to get a better understanding of this framework, two interview surveys were carried out, one in the Mexican NARS, and the other one in the potato farmers' surroundings. These surveys also helped to supplement market-related data that were not available in secondary sources.

NARS Survey

Compiling information at the stage of the NARS predominantly aimed to learn more about the recombinant virus resistance technology. This involved data on R&D costs, a time pattern of the technology evolution, and information to derive the aforementioned potential net yield gain (*NYG*). Semi-structured interviews with eight researchers directly associated with the technology project—four from CINVESTAV and four from INIFAP—were conducted for this purpose. In addition, one potato seed producer that had already multiplied transgenic potatoes for field trial purposes was surveyed. To gain an insight into the contractual arrangements of the North-South technology transfer, one representative each from Monsanto and ISAAA was contacted. Taking into account the statements of people directly associated with the research project raises the problem of biased information due to vested interests or subjective viewpoints (cf. Mills and Karanja, 1997). So we included in the survey a number of interviews with independent researchers and experts of the potato sector to get a more objective picture. This was particularly important because published data on current yield losses caused by viruses—a crucial determinant to derive the *NYG*—are hardly available in Mexico or elsewhere. Furthermore, different scientists from the International Potato Center (CIP) in Peru were interviewed to obtain external viewpoints about potatoes and their problems. A complete list of the contacted experts is given in Appendix B.

Farmers Survey

The survey in the farmers' surroundings focused on gathering insights into potato farming systems. The semi-structured interviews concentrated on farmers' access to markets, sources of tuber seeds, experiences with other technologies, the input-output relations of potato production, and other specific problems associated with growing potatoes. These data made it possible to realistically anticipate how the technology could change current production patterns and per unit cost figures. Another crucial variable obtained from this information is the technology adoption rate (*A*). For the analysis of the distributional consequences of the new potato varieties, potato farmers were subdivided into three groups according to farm size (small-scale, medium-scale, and large-scale). 12 interviews with each group—36 interviews in all—were carried out in six of the most important potato producing states of Mexico. The surveyed states are Sinaloa, Coahuila, and Nuevo Leon in the northern part of the country and Michoacan, Mexico-State, and Puebla in the central and southern regions. In all of these states, the survey of the farmers was supplemented with field experience and by two interviews with agricultural engineers (12 in total) of different provincial rural organizations.

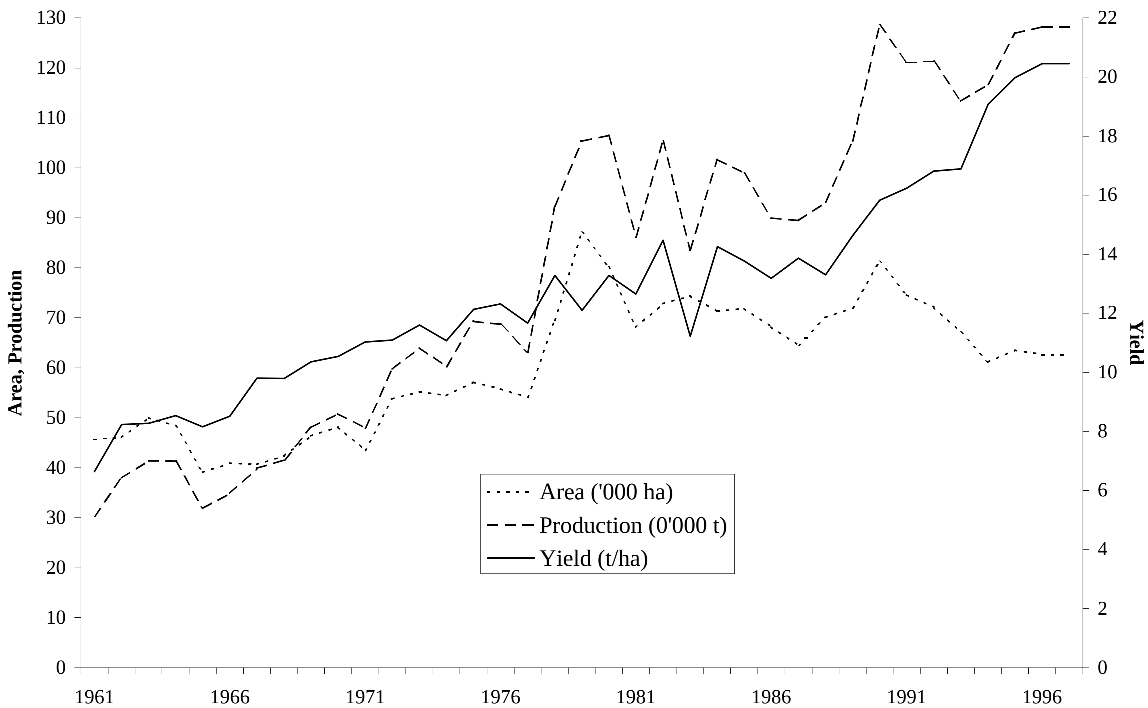
3. The Mexican Potato Sector

Although potato production in industrialized countries has declined during the last 30 years, this trend was more than offset by production increases in developing countries, which actually caused worldwide production to rise (FAO/CIP, 1995). In the early 1960s, developing countries accounted for approximately 11 percent of worldwide potato production. In the early 1990s they accounted for 31 percent. Significantly, the area cultivated with potatoes in this group of countries has grown faster than that of any other major food crop over the past 30 years. Scott (1996) mentions different reasons for the greater interest of developing countries in potatoes. On the production side, the increased use of high yielding rice and wheat varieties with shorter duration have enabled farmers to grow an additional crop on the same fields, and potatoes fit very well into these rotation patterns. On the consumption side, the growing incomes of food consumers have diversified poor people's cereal-based diets, increasing demand for potatoes. Thus, potatoes become an increasingly important source of food, rural employment, and income in developing countries. These global trends will likely continue into the future. From a global viewpoint, Mexico is not a very large producer of potatoes, but among the Latin American countries it ranks fifth after Colombia, Brazil, Argentina and Peru.

3.1 National Potato Production

Figure 3 shows the development in Mexico of the potato area, production, and average yields from

Figure 3: Development of potato production in Mexico (1961-1997)



Source: Based on data from FAO (1998).

1961 to 1997. The area cultivated with potatoes grew significantly up until the late 1970s. Over the last twenty years there has been a slight decreasing trend. In 1996, about 63,000 hectares of potatoes were harvested, accounting for 0.4 percent of the country's total land under annual crops. In Mexico, however, potato is viewed as a horticultural crop, and among the annual horticultures it ranks second after tomato in terms of area. In 1996, potatoes made up 2.6 percent of the national plant production sector's value (INEGI, 1997a), a significant rise given the previous figure of only 1 percent in 1985 (Bonilla et al. 1992). Potato yields and overall potato production increased considerably. Yields per hectare tripled from 1961 to 1997, and national production even quadrupled. Due to intensified production and technical progress in the potato sector, the close convergence of area and production in the 1960s and 1970s has since loosened somewhat. Current average yields in Mexico of 20.5 tons per hectare are lower than those of the United States or Western Europe (33 t), but they are among the highest in Latin America. While the importance of potato production for processing purposes has also increased during the last ten years and will continue to do so, the lion's share of total production in Mexico is for the fresh market. It is estimated that 70 percent of the production volumes are sold as fresh potatoes, 15 percent are used as tuber seeds, and the remaining 15 percent are sold to the food processing industry (SAGAR/INIFAP, 1997).[2]

3.1.1 Potato Varieties

The most important potato variety in Mexico is Alpha, accounting for 60 percent of the total production volume. Alpha is an old, white-colored Dutch variety that was introduced to the Mexican market over 50 years ago. It can be marketed as fresh potato or for industry use. While Alpha was formerly important in the United States, it has since almost completely disappeared due to the availability of superior varieties with higher yields and better quality for processing purposes. The same holds true for other potato producing regions in the world. In Mexico, however, Alpha is still the dominant variety because of its positive post-harvest performance. Mexico is one of the few countries where potatoes are washed before arriving at retail outlets. Moreover, in the Mexican marketing chain, potatoes are often exposed to sunlight. Alpha can stand these conditions better than other varieties, leading to lower post-harvest losses and better consumer acceptance. But when industry demand for

[2] For comparison: In the USA, 60 percent of potato production is for processing purposes (FAO/CIP, 1995).

processing potatoes rose during the past ten years, new white varieties entered the Mexican market, slightly reducing Alpha's importance. Varieties with better processing characteristics, such as Atlantic, Gigant, Herta and others, are gaining ground in Mexico. The basic germplasm for these varieties is predominantly imported from Canada, the United States, or The Netherlands. All white varieties together account for 85 percent of Mexico's national potato production.

The remaining 15 percent are local red-colored varieties, Rosita being the most important. The national potato-breeding program of INIFAP breeds the local varieties.[3] Many of these varieties are highly resistant to late blight (*Phytophtora infestans*) (cf. Flores and Cadena, 1996; Parga and Flores, 1995). Because the Central Plateau of Mexico is the geographic origin of *Phytophtora infestans*, a great number of wild potato species possess resistance to this fungus pathogen (Niederhauser, 1989). This makes Mexico a favorable breeding location for late blight resistance. Varieties bred by INIFAP are even used in parts of Asia and Africa. In Mexico, however, larger farmers never use the colored, local varieties. Notwithstanding the much higher susceptibility of Alpha, Atlantic, and other imported varieties to late blight, resource-rich farmers prefer them because they are better accepted by consumers and industry. Resource-poor farmers, in turn, often cannot afford the necessary heavy fungicide applications. And so those cultivating potatoes under the highland conditions of Central Mexico frequently use red local potato varieties.

3.1.2 Phytosanitary Aspects

Economically, the most important potato disease in Mexico is late blight, caused by the fungus *Phytophtora infestans*. Although local varieties with a high degree of resistance to late blight have been released by INIFAP, many of them were not widely adopted. Especially among larger farmers, the disease is controlled by the extensive use of fungicides; in some cases up to 30 fungicide applications per crop cycle have been reported (Parga and Flores, 1995). According to the interviewed experts, the second most important potato disease in Mexico is purple top wilt.[4] This is caused by mycoplasma pathogens transmitted either through the tuber seed or by leafhoppers as vectors. Viruses follow next in economic importance. Among the viruses, the potato leafroll virus (PLRV) causes the most severe yield losses, followed by potato virus Y (PVY), and potato virus X (PVX) (Salazar, 1997). Apart from virus transmission through infected seed material (secondary infection), PLRV and PVY are spread by aphids (primary infection). Primary infection of PVX is through direct physical contact. In general, secondary infections cause greater yield losses than primary infections alone because the virus invades the growing plant systematically (Hill, 1990). There are no chemical means to directly combat viruses or mycoplasmas. Prophylactic measures include using certified pathogen-free seeds and controlling insect-vectors with insecticides. Other potato diseases with economic importance in Mexico are blackleg, caused by bacteria, nematodes, and other fungal diseases (*Fusarium* and *Verticillium*). Because of the great susceptibility of potatoes to different diseases—aggravated by favorable climatic conditions for pests in Mexico—the crop receives some of the highest amounts of pesticides in the country.

3.1.3 Potato Producing Regions

24 of the 32 Mexican states produce potatoes. The geographic location of some of the major producing states is shown in the map in Figure 4. Only five of these states (Sinaloa, Nuevo Leon, Mexico-State, Guanajuato, and Puebla) make up 54 percent of the national production. Individual production shares of the main potato producing states are shown in Figure A1 in Appendix A. Due to the diverse agroclimatic conditions in its different regions, Mexico is one of the few countries worldwide where potato production takes place year round and fresh potatoes enter the market every month. National production peaks in late summer and fall, the harvesting time of the spring-summer cropping season. Still, around 40 percent of all potatoes are produced in the fall-winter season (SAGAR, 1996). In some regions (e.g., Sinaloa on the Pacific Coast) it is too hot to produce potatoes during the summer months. In other regions, however, a considerable proportion of farmers—especially those with access to irrigation—cultivates potatoes in two cycles per year.

Production conditions in the North vary significantly from those in central and southern Mexico. Potato production in the North is predominantly an activity of large-scale farmers cultivating white varieties using advanced production technologies. In the central and southern regions, by contrast, there are also many small-scale farmers engaged in potato production, particularly in the states of Puebla, Tlaxcala, Veracruz, and Mexico-State, where potatoes are sometimes grown more than 3000 m above sea level. As Table 1 indicates, almost all of the production in the North takes place under irrigated conditions, while less than half of the production in the South is irrigated. Analogously, average yields are significantly higher in the North. Highest yields are obtained in the region of Coahuila and Nuevo Leon, with an average of some 35 tons per hectare. In Puebla and Veracruz, on the other hand, average yields only reach around

[3] INIFAP also bred white local varieties like Ireri, Michoacan, Norteña and others, some of which are also suitable for processing. Yet, these varieties did not yet find large-scale applications.

[4] The local Spanish name of the disease is *punta morada*.

Figure 4: Map of the main potato producing states of Mexico

Table 1: Regional differences in Mexican potato production

	Share of Irrigated Prod.	Prod. Share of Farm Types: Small (< 5ha)	Medium (5-20 ha)	Large (> 20 ha)	Share of White Varieties	Aver. Yield (t/ha) [a]
North	0.96	0.01	0.19	0.80	1.00	23.5
Central and South	0.46	0.23	0.28	0.48	0.70	17.0
Total Mexico	0.72	0.12	0.24	0.64	0.85	19.8

[a] This is a 1994-1996 average.

Sources: See Table A1 in Appendix A.

11 tons. Given these facts, it is not surprising that the northern states account for some 52 percent of total production, while they make up only 44 percent of the national potato area. A more complete description of the individual states' indicators can be found in Table A 1 in Appendix A.

3.1.4 Potato Farming Systems

Before the 1992 land reform, 42 percent of the total agricultural land in Mexico was common ejido land (Randall, 1996). The ejidatarios (ejido members) had user rights but were not allowed to rent or sell the land. Although some forms of common production existed, most of the potato enterprises operated on an individual basis. The 1992 agrarian reform gave formal land titles to the ejidatarios. Today, potato production is almost exclusively a private and individual activity, and so no differentiation will be made between ejido and non-ejido farming systems.

In many Latin American countries, potato cultivation takes place predominantly in small production units—often less than one hectare—with much of the produce kept for household consumption (cf. Scott, 1985; Zeballos, 1997). This is different in Mexico. Although no reliable statistical data on farm sizes in the Mexican potato sector exist, it is evident that potato producers are larger on average than producers of basic food crops.[5] Potato farms of less than one hectare are rare, and production is first and foremost for commercial purposes. Even on the smaller farms the share of potatoes kept for household consumption is below 10 percent. Because potato is a much more input intensive crop than are basic cereals grown in Mexico, cash income is needed to produce it, which is why it is primarily a commercial crop. The production cost per hectare of potatoes under small-holder conditions is usually two to three times higher than that of maize (Biarnès, 1995). The substantial cash outlay for agricultural inputs along with high interannual price and yield fluctuations make potato production a comparatively risky business, particularly in rain-fed areas. In unfavorable years resource-poor potato farmers must abandon their production. Still, the average expected income from potato cultivation is higher than that of other crops, which makes it attractive. Colin (1995) found that scarce financial resources are the main constraint to expanding potato production for small-scale farmers in Mexico. For the purpose of this study, we subdivide all Mexican potato producers into three groups according to the area cropped with potatoes. The parameter area has a close correlation with other variables, such as overall household income, technology level, and potato yields, which makes it a good indicator of living standards for potato producing farm households (cf. Santiago and Ruvalcaba, 1995).

- The first group consists of small-scale farmers with less than 5 hectares of potatoes. Almost non-existent in the northern potato regions, this group makes up the majority of all potato farmers in many central and southern states—an estimated 70 percent in Puebla and Veracruz, for instance. In highland areas, small-scale farming systems are the only form of agricultural use. Most of the small potato producers cultivate potatoes for commercialization, in addition to maize and beans partly for home consumption. In altitudes over 3000 m, where potatoes can still be grown, farmers practice a cropping rotation with feeding oats. Here, the cultivation of red potato varieties predominates. Small-scale farmers generally do not have access to irrigation. Due to low average yields on comparatively small holdings, the production share of this group is much smaller than the number of production units might suggest. As Table 1 shows, the small-scale farmers make up about 12 percent of the total national production.
- The second group consists of medium-scale farmers with potato growing areas between 5 and 20 hectares. While in the northern states such farms would be considered small, in many central and southern states farmers with 20 hectares are among the largest producers of the region. Medium-scale potato farmers grow mostly basic food crops in addition to potatoes. Depending on the region, some of them also engage in the production of other horticultural crops. It is estimated that about half of the medium-scale farmers have access to irrigation facilities. Medium-scale farmers cultivate white potato varieties as well as local red ones. The contribution of this group to national potato production is 24 percent.
- The third group consists of large-scale farmers with potato growing areas of more than 20 hectares. This is the dominant potato farm type in northern Mexico, where many producers have holdings of more than 100 hectares. Apart from basic food production, cropping patterns often include vegetables and other horticultural crops for national and international markets. Almost 100 percent of the large-scale farmers produce potatoes under irrigated conditions. They use only white potato varieties. Large-scale farmers account for 64 percent of the national potato production.

3.1.5 Potato Seed Industry

According to Pray and Ramaswami (1991), the seed industry is considered to consist of all enterprises that produce or distribute seeds.[6] Thus, the seed industry comprises the levels of plant breeding research, seed production, and seed distribution.

Potato Breeding

As stated earlier, INIFAP, partly in cooperation with university research potato breeding, conducts Mexico's national potato program. INIFAP's main location for its potato program is near the city of Toluca. In addition, new potato lines are developed and evaluated at other INIFAP sites in Mexico to test their regional suitability. The responsible authority for the approval of variety release and registration is the National Service for Seed Inspection and Certification (SNICS). Apart from INIFAP, there are also foreign sources of potato germplasm. While Alpha material

[5] The latest Mexican Agricultural Census of 1991 gives average hectare amounts per potato producing unit by state. However, this refers to the official situation before the 1992 land reform. These figures do crucially underestimate the size of today's production units because since 1992, many ejido farmers rented or sold their land to larger producers, which was officially prohibited before the reform.

[6] When talking of potato seeds, potato tuber seed is meant here. The use of true potato seed in Mexican agriculture is negligible.

has already been in use in Mexico for a long time, in recent years the use of other externally bred varieties (Atlantic, Gigant, Herta, etc.) gained importance in the country's potato sector. Much of the basic breeder material for these varieties is imported from Canada. Other countries exporting potato germplasm to Mexico are the United States and The Netherlands.

Seed Production

Although seed production for basic crop species was traditionally the task of the National Seed Production Company (PRONASE), private enterprises, in fact, have carried out potato seed production. Until the late 1980s, however, the major share of certified potato seeds (some 75 percent) was imported primarily from Canada. Superior technology and more favorable climatic conditions gave Canadian seed producers a cost advantage in spite of the high transportation cost. This situation changed somewhat in 1988, when the use of tissue culture techniques was introduced into the Mexican seed industry (Fernández, 1989). Furthermore, an import ban on potato seeds from 1992 to 1995 helped to develop a more competitive national seed production sector.[7]

Today, there are 17 private producers of certified potato seeds in 7 different states of Mexico (Mexico-State, Chihuahua, Guanajuato, Baja-California, Coahuila, Nuevo Leon, and Sinaloa). The seed producers obtain the basic germplasm for the varieties in the form of seedlings or minitubers from INIFAP or from foreign suppliers. 10 of the 17 enterprises have their own laboratory equipment, which allows them to use high temperature treatment and micropropagation techniques in order to obtain pathogen-free seedlings. These seedlings are planted for one cycle in green houses before several cycles of field cultivation follow for seed multiplication. Table 2 shows the different cycles as well as the corresponding seed categories of the national certification system. Prices per unit of seeds decrease in each cycle, and commercial sales to potato farmers seldom take place before the level of registered I seeds.

Seed Distribution

No special seed distribution system exists in Mexico. Those farmers that use certified or registered seeds buy the material directly from the seed producing enterprises without intermediaries. Often, potato farmers producing in one region personally travel to other regions in order to choose their planting material for the next season. The farmer covers the cost of seed transportation. Because of interregional trade and the comparatively high number of seed suppliers in different regions, the potato seed market in Mexico can be regarded as quite competitive. Only some 23 percent of the area devoted to potato production, however, is cultivated with registered or certified seed material (i.e., 77 percent is planted with seeds from informal sources (CONPAPA, 1996)).

Large-scale farmers buy potato seeds in regular intervals and often recycle them for two to three production cycles. Although many of them acquire certified seeds annually, they usually buy fresh material only for part of their total potato area. Some of the large-scale farmers have green house equipment so that they can produce their own high quality potato seeds—often with foreign germplasm. Medium-scale farmers rarely use certified seeds. The majority of them acquire seeds from informal markets (i.e., they buy potatoes destined for the fresh market from larger farmers and use them as seed material.) The purchased potatoes are usually recycled for a couple of years. Small-scale farmers never buy potato seeds on formal seed markets. For the most part they recycle their own seeds from the previous harvest. Small amounts of potatoes for sowing are sometimes bought from neighbors or farmers of the same region, so there is little renovation of seed material.

There are several factors that limit a more widespread use of certified potato seeds, especially among smaller farmers. Lack of information about the advantages of using high quality seeds is surely one of them. One should keep in mind, however, that seeds account for a large share of the total cost of potato production (see section 3.1.7). Using certified seeds at a significantly higher cost increases risk and presupposes timely liquidity. Another constraint for small-scale farmers is that they have limited access to formal seed markets. As mentioned above, there are no traders to mediate between seed producers and consumers. While it makes sense for large-scale farmers to travel to distant regions to buy seeds, this is grossly inefficient for the small amounts small-scale farmers need.

The described patterns of seed sources for the individual farm groups have different implications for different potato varieties. As described in section 3.1.4, large-scale farmers—the primary consumers of the formal seed market—exclusively cultivate white varieties. Local red varieties are only grown by small-scale and to some extent by medium-scale farmers in higher altitudes. These farmers do not buy certified seeds, so there is no effective demand for formal seed markets to sell red varieties. Consequently, there is no incentive for potato seed producers to handle them. In fact, no enterprise produces certified seeds for red varieties. Figure 5 represents the potato seed industry. As the figure indicates, medium and small-scale farmers producing red varieties are completely disconnected from the formal system.

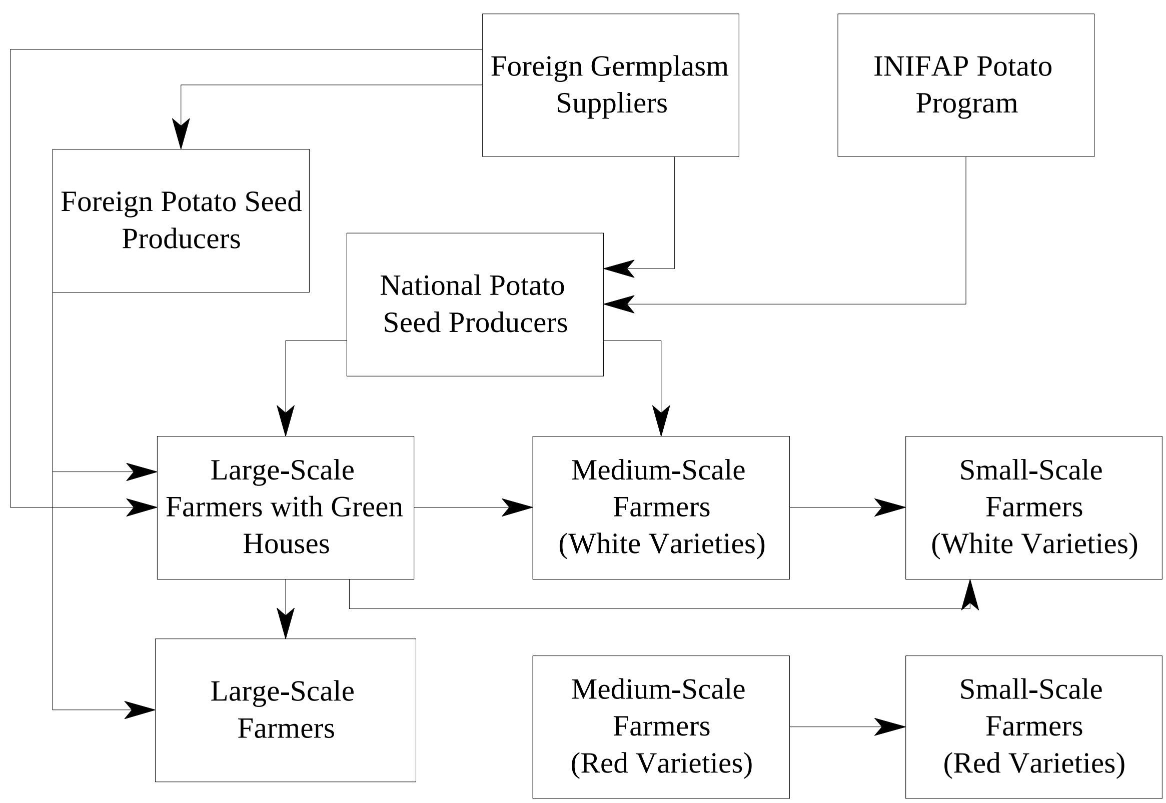
[7] For 1996 and 1997 it is estimated that around 20 percent of the certified potato seeds used in Mexico were imported (CONPAPA, 1997a). Moreover, basic germplasm is imported for seed production within the country.

Table 2: Cycles in certified potato seed production

Cycle	0	1	2	3	4	5	6	7
Location	Laboratory	Green House	Field	Field	Field	Field	Field	Field
Result	Tissue Cultured Seedlings	Minitubers	Pre-Basic Seeds	Basic Seeds	Registered I Seeds	Registered II Seeds	Registered III Seeds	Certified Seeds

Source: Gálvez (1997).

Figure 5: The potato seed distribution system in Mexico



3.1.6 Other Factor Markets and Rural Institutions

Credit

Public development banks have traditionally provided the main share of agricultural credit in Mexico. Low repayment rates, subsidized interest rates—partly negative in real terms—and the difficulty of mobilizing rural savings led to inefficiencies and constantly shrinking amounts of loan disbursements (Arroyo and León, 1996). Because of the higher relative transaction cost when dealing with small amounts of credit, small-scale farmers were particularly affected by these developments. The financial system was restructured in 1988, and private banks gained in importance. Farmers' access to credit remained limited, however, due to the lack of collateral within the ejido sector and the inflationary problems associated with high and volatile nominal interest rates. Even with the introduction of formal land titles for ejido land in 1992, the situation did not improve because of deeper structural impediments in the rural economy, which were exacerbated by tightened monetary policies during the 1994/95 financial crisis. As stated earlier, potato production is a much riskier business than the cultivation of other crops. As a result, credit for potato growing is almost unavailable. Again, smaller farmers—producing potatoes under rain-fed conditions—are the most affected. Only two of the interviewed small and medium-scale potato farmers reported that they had some experience with formal agricultural credit at all, and this was under the subsidized interest rate circumstances of the 1980s. Informal credits based on family kinship or friendship generally involve smaller amounts of money for consumptive purposes, and they are mostly only on a short-term basis (Colin, 1995). It was argued in section 3.1.5 that the lack of timely financial resource availability is one reason for the scant use of certified, clean potato seeds among smaller farmers. Myhre (1996) even includes limited access to credit as one of the main constraints for rural modernization in Mexico.

Extension and Technical Assistance

Traditionally, different public institutions implemented agricultural extension in Mexico.[8] Partly, this service was combined with credit provision. The main emphasis of the government-implemented advisory services has always been on staple food production, mostly maize, beans, and to a lesser extent other basic grains. But within the overall structural adjustment efforts, the Mexican agricultural extension service was thoroughly reformed and government expenditures were sharply reduced (OECD, 1997). Currently, occasional training for suppliers of private services and temporary cost-sharing programs for farmers that contract private specialists are supporting the privatization of technical assistance. In the 1995-2000 National Development Plan the program *Alianza para el Campo* was launched. *Alianza para el Campo* seeks to stimulate technological developments in the Mexican agricultural sector (cf. SAGAR, 1997). The program fosters the decentralization of decision-making in agricultural policies, and its individual components are tailored to the specific needs of different producer groups. Experts stated that they believed *Alianza para el Campo* might be an effective instrument to modernize the agricultural sector, provided that the program continues over time. The program's components, however, once again predominantly focus on basic grains—potato production is not included. And so, while the larger potato producers of northern Mexico hire their own full-time agricultural engineers, small-holder potato growers have no access to technical assistance. This hampers the dissemination of innovations in the potato sector among small-scale farmers. An indication of this gap between applied research and agricultural production is that several local, well-adapted new potato varieties that have been bred and released by the INIFAP potato program have so far not been widely adopted by Mexican farmers.

Producer Organizations

In 1988, the National Potato Confederation (CONPAPA) was established to integrate different local and regional producer associations, some of which existed previous to that date. CONPAPA represents potato producers vis à vis state and federal governments and vis à vis upstream and downstream potato market enterprises (CONPAPA, 1997b). A major activity of CONPAPA in the early 1990s was the successful protection of potato producers' interests in the NAFTA negotiations with the United States and Canada. Since then, the organization has sought to improve potato production and marketing by providing information through seminars, documentation services, and other activities. Membership in CONPAPA presupposes the existence of a local producer organization. Although today there are 29 affiliated local associations, CONPAPA mostly represents larger potato producers. None of the interviewed small-scale producers reported membership in a potato growers' association. It is evident that a better organization among smaller farmers could be beneficial for many reasons, the most important of which being a more efficient commercialization of their potato crops and better access to financial and technical services.

3.1.7 Cost of Potato Production

Table 3 shows the average variable cost of potato production differentiated by farm type. The underlying sample consists of 36 farmers, 12 for each of the three groups. Corresponding to the less intensive cropping patterns of small potato growers, their cost of production per hectare is much lower than it is for the larger farmers. Nevertheless, even for small-scale farmers the cost of production in absolute terms is substantial. Small-holders also use considerable proportions of purchased inputs, which underscores the crop's status as predominantly commercial for all farm types in Mexico. The different figures of the farm types' enterprise budgets are derived as arithmetic means of the individual farmers' statements in the survey. In some cases, the variation of statements is high (see Table 4 for standard deviations of important variables). This is particularly so between individual states, with a notable North-South gradient. Large-scale farmers in Coahuila and Nuevo Leon, for example, have average variable costs of almost 50,000 M$ per hectare, whereas the same category of farmers in Puebla only invests about half of this amount. The main differences are due to agro-chemical use, with the highest intensities in the northern and northeastern potato regions of Mexico.

[8] Often, the establishment of new governments in six-year cycles was associated with the creation of additional organizations in the rural economy. Over time this led to an exaggerated number of organizations entailing inefficiencies due to a wide spreading of available resources, lack of continuity of individual programs and uncertainties in implementing because of partly overlapping mandates.

Table 3: Average potato enterprise budgets per ha by farm type (in 1998 M$)

	Small-Scale	Medium-Scale	Large-Scale
Amount of Seed Potatoes (t/ha)	3.00	3.13	3.72
Cost per t of Seed Potatoes [a]	1880.13	2385.58	3047.07
		Gross Margin Calculation	
Rent for Area	166.67	587.50	831.67
Cost for Seed Potatoes	5640.40	7466.88	11335.08
Chemical Seed Treatment [b]	350.00	350.0	730.00
Irrigation (Operation Cost)	0.00	420.00	1216.67
Fertilizers	2144.44	4076.25	6059.67
Pesticides	2100.00	4743.75	9897.17
Hired Labor	1358.33	3606.25	4577.92
Total Variable Cost	**11759.84**	**21250.63**	**34648.17**
Yield (t/ha)	11.10	20.86	31.75
Farm-Gate price per t	1568.33	1963.75	1947.83
Gross Revenue	17408.50	40963.83	61843.71
Gross Margin	**5648.66**	**19713.20**	**27195.54**

Notes: 1 US$ = 8.30 M$ according to the average official exchange rate in early 1998. Minor deviations from the expected sums and products in the enterprise budgets are due to rounding errors.

[a] The cost per t of seed potatoes is not an observable market price. For the derivation of the figures, the frequency of seed purchases among farm types and the individual seed sources were accounted for. Farm-saved seeds were valued at 20 percent above the farm-gate price of fresh potatoes to adjust for the cost of storing the tubers, including storage losses.

[b] Often, the seeds are treated with fungicides and nematicides before sowing.

Source: Author's interview survey (1998).

Per hectare cost differences, however, do not give information about the competitiveness of farmers in different regions because the obtained yield levels are also significantly different (see below for competitiveness considerations).

Cost Structure

In all cases, seed potatoes account for the largest proportion of the total cost of production. While seeds make up around one third of the variable cost for medium and large-scale farmers, they represent almost half of the cost for small-holders. But it should be noted that because they usually use farm-saved seeds this cost is not associated with an equal monetary outlay for small farmers. This is also why the cost per unit of seed potatoes is higher for medium and large-scale producers who purchase seed material more often. For purchased seeds, the cost per unit includes the cost of transportation from the seed supplier to the potato farm. The given figures also take into account the fact that medium and large-scale farmers occasionally reproduce their own seed material (cf. section 3.1.5).

Pesticides also make up a considerable share of the production cost for all three farm types. For small-scale farmers, pesticides rank third after seeds and fertilizers, but for the other two farm types they rank second in the overall cost structure. On average, fungicides account for half of the total pesticide cost. The share can even be higher, particularly for farmers growing varieties with a great susceptibility to late blight. Insecticides make up the rest of the pesticide budget.[9] They are primarily used to control virus and mycoplasma vectors, and to a much lower extent to avoid direct insect damages. In general, pesticide applications on potatoes are very high in comparison to other field crops grown in Mexico. Especially in the large-scale farming systems of the North, where the lack of financial resources is not a serious constraint, pesticide deployment is often overdone. Although many large farmers have hired private agricultural engineers for technical assistance, knowledge of efficient, environmentally sound pest management is rather low. Against the background of trade liberali-

[9] Weed hoeing is usually done manually so that herbicides are used only seldom. Although nematicides are used sometimes, too, the cost is negligible on average.

zation and increasing competition with foreign potato producers, introducing integrated pest management strategies could be important for improving productivity, especially in the large farm sector.

Although fertilizer budgets between farm types vary considerably in absolute terms, the importance of fertilizers in relative terms is more or less the same for all three groups: it accounts for 18 percent of the total variable cost of production. As regards hired labor, even small-scale farmers employ seasonal workers. Potato is a labor-intensive crop, and labor requirements exceed the on-hand labor capacity of the farm family, especially during the peak sowing and harvesting season. To a great extent, both sowing and harvesting procedures are carried out manually. This is also true for many of the large farms, which are usually highly mechanized otherwise, because of the comparatively low cost of unskilled labor in Mexico. Since harvesting activities claim by far the highest amount of total labor, overall labor requirements per unit area may vary significantly according to obtained yields. The statements of surveyed farmers on total labor employed in the potato crop varied between 45 and 120 man-days per hectare and production cycle. A similar range is reported by Santiago and Ruvalcaba (1995), with a national average of 90 man-days.

Productivities

As could be expected from the production intensities, average potato yields increase with the farm size and so do gross revenues per hectare. Farm-gate prices received by small-scale farmers are lower than they are for the other groups. This divergence can mainly be attributed to three factors:

- Small-scale farmers have limited price information and comparatively low amounts of potatoes to sell, so they have little power to negotiate prices.
- Small-scale farmers often live in more remote areas, which makes the cost of marketing the produce higher and results in lower farm-gate prices.
- The quality of potatoes produced by smallholders is often below that of larger farmers in terms of form, size, and physical defects of tubers. Moreover, small farmers often produce red potato varieties, which command lower prices than white varieties.

The lower yields and lower prices received by small-scale farmers entail significantly lower revenues and gross margins in comparison to the other groups. The small-scale farmers' average gross margin per hectare is only 29 percent, and 21 percent of that for the medium and large-scale farmers, respectively. From a market efficiency point of view, however, it is more appropriate to consider the cost of production per unit of produce instead of the gross margin. The unit cost of potato production for the different farm types is shown in Table 4.

It is somewhat surprising that—despite significantly distinct production conditions and intensities—the costs of production per unit of output are similar for the three farm types. The same holds true for the total unit cost, including the fixed cost. Direct data on fixed costs were not collected within the interview survey. Valdivia (1995), however, could show that the average per hectare cost for machinery in Michoacan—expressed as a percentage value of the variable cost—is almost identical between the different potato farming systems (approximately 8 percent). We make the same assumption for other fixed cost items, which is realistic because substantial economy-of-scale-effects do not occur. Large-scale farmers usually have sophisticated building facilities and they often employ several permanent workers and employees (including engineers, secretaries, etc.). Smaller producers do not face such overhead cost items. Given these considerations, fixed costs as about 10 percent of the variable costs appear to be a good approximation.

Table 4 also shows the standard deviations of the individual cost figures in the sample. As was mentioned above, the range of the individual farmers' per hectare values is quite high. But it is interesting that standard deviations of per unit costs within the groups are much lower. This strengthens the claim that the considerably different production patterns in Mexico do not have severe implications on capital productivity. As regards farm types, there are no significant efficiency differences between small and large potato producers, a finding consistent with Biarnès et al. (1995).[10]

3.2 Potato Marketing and Trade Channels

3.2.1 Potato Commercialization

The major wholesale markets for fresh potatoes in Mexico are Mexico-City, Guadalajara, and Monterrey, with smaller wholesale outlets in a few other cities. These wholesale markets may be supplied through different channels. Many farmers sell their potatoes directly to the wholesalers. Larger farmers have their own means of transportation; smaller farmers pay volume fees for hired trucks. Apart from this direct marketing channel, there are different local and regional agents acting as intermediaries between primary producers and wholesalers, especially for smaller farmers with limited amounts of potatoes. The form of payment that farmers receive from wholesalers or intermediary traders may vary within one year. During times of scarce supply, cash is paid when the produce is handed over. Often during times of mar-

[10] This statement assumes a homogeneous product produced by all farm types, i.e. it is abstracted from quality aspects.

Table 4: Average per unit cost of potato production by farm type (in 1998 M$)

	Small-Scale		Medium-Scale		Large-Scale	
	M$	**Std. Dev.**	**M$**	**Std. Dev.**	**M$**	**Std. Dev.**
Variable Cost per ha	11759.84	3162.73	21250.63	4398.41	34648.17	8975.20
Total Cost per ha	12935.83	3479.01	23375.69	4838.25	38112.98	9872.73
Var. Cost per t of Production	1059.45	30.81	1018.60	66.90	1091.28	102.59
Total Cost per t of Production	1165.39	33.89	1120.46	73.59	1200.41	112.85

Note: 1 US$ = 8.30 M$ according to the average official exchange rate in early 1998.

Source: Author's interview survey (1998).

ket saturation, however, producers sell their potatoes at uncertain prices on a commission type basis and receive their money after one or two weeks. One reason for the delayed payment is that the traders wash the potatoes, which often reveals problems of inferior quality (cf. Elizondo, 1989).

The wholesale markets are the main centers for the distribution of potatoes to the different retail outlets of the country. For the formation of prices according to supply and demand, the wholesale market of Mexico-City plays the pivotal role because of its national dominance in terms of traded potato volumes. Unlike other wholesale markets, Mexico-City receives potatoes from all parts of the country, and it is the only place that handles large amounts of red potatoes. Although physical distances can be substantial, there is a close price transmission between the different wholesale markets. As mentioned earlier, the supply of fresh potatoes takes place uninterruptedly during the whole year, but there are significant seasonal and interannual supply differences that make potato prices variable. Price variation was ranked as the potato crop's number one problem by the majority of interviewed farmers in the survey. While interannual price fluctuations are hard to predict, price developments within one year show a fairly regular pattern. The seasonal price fluctuation for Alpha and for red colored varieties is exemplary shown for 1996 in Figure 6.

Although prices for red varieties are always below that of Alpha potatoes, it can be seen that there is a close linkage between both price developments. The typical feature of the annual potato price evolution is that prices start rising in February until they reach a peak lasting from April to June, after which a constant decrease occurs during the second half of the year. The figure also provides the main harvesting seasons of Mexico's different potato producing regions. The principal beneficiaries of the price peak are the potato growers of Sinaloa, Sonora, and to some extent those of Guanajuato. The main potato harvest in most of the central and southern states—especially those with a high prevalence of small-scale farmers cultivating under rainfed conditions—is between July and December, when producers face much lower prices. This is also the reason for the more pronounced price decrease of red colored potatoes in comparison to the white ones. While Alpha is produced throughout the country, red potatoes are grown exclusively by small- and medium-scale farmers in the central and southern states (cf. Table 1 above). Larger producers of white varieties in these regions often have their own cooled storing facilities, which allows them to delay their sales and circumvent low prices without significant storage losses.

The commercialization channel of potatoes for industry use is different from that of fresh potatoes. Besides a couple of smaller firms, there are two main enterprises (Sabritas and Barcel) with different plants in Mexico that buy potatoes directly from farmers without intermediaries.[11] Large-scale farmers in the north are the dominant suppliers. These farmers often have contractual agreements with the industry that determine varietal selection, quality standards, and prices in advance. Farmers usually receive prices from the processing enterprises that are less than the average prices for fresh market potatoes, but the agreements are attractive because there is less uncertainty associated with industry sales.

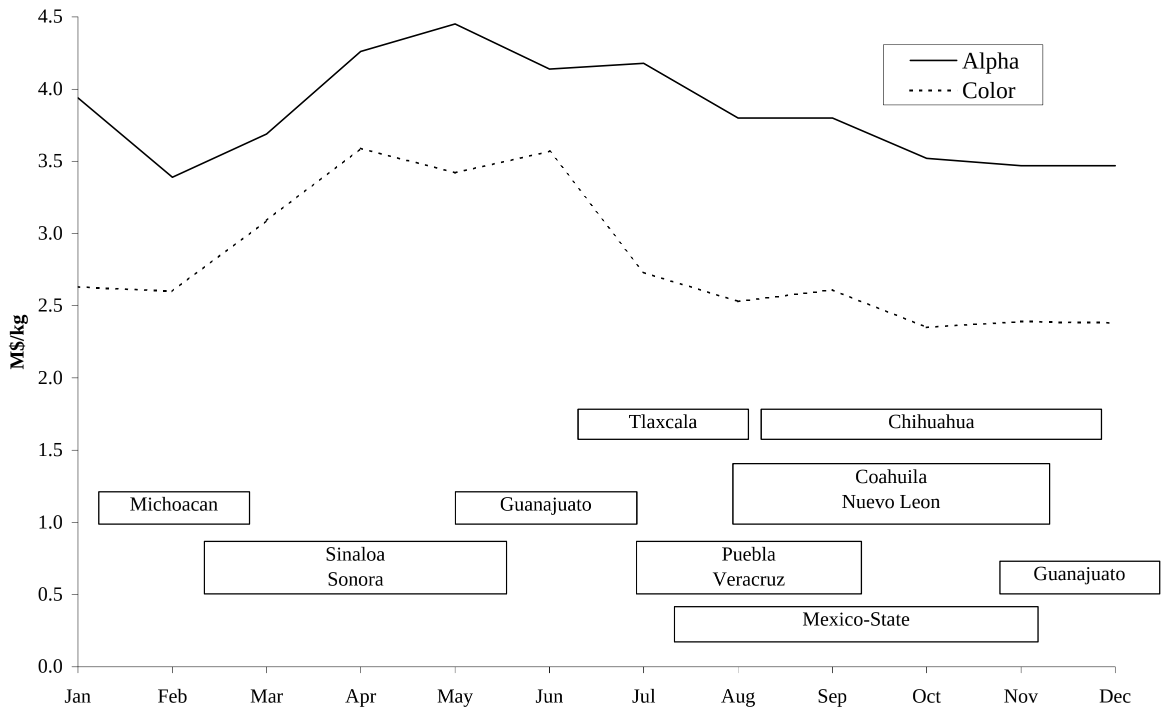
3.2.2 International Potato Trade

<u>Fresh Potatoes</u>

Mexico can be regarded as a closed economy in terms of its fresh potato market. Potato exports are almost zero, while the importation of fresh potatoes

[11] The processing industry in Mexico predominantly produces potato crisps and to a lesser extent dehydrated potatoes (cf. Gómez, 1995).

Figure 6: Wholesale potato price development in Mexico-City during 1996 and main harvesting seasons of important potato producing states



Notes: The average 1996 exchange rate of the Mexican peso with respect to the US dollar was: 1 US$ = 7.60 M$ (INEGI, 1997b). Besides the indicated main harvesting season, there is a smaller second season in several states.

Source: Author's presentation based on data provided by CONPAPA and SNIM.

(including seed potatoes) accounted for only 3 percent of the national production in 1996, an amount which is more or less representative for preceding years (CONPAPA, 1997a). Consumer preferences for locally used varieties as well as tariff and non-tariff barriers have traditionally been the impediments to the integration of Mexico into the international potato markets. Furthermore, due to the successful representation of potato farmers' interests in the NAFTA negotiations through the National Potato Confederation (CONPAPA, see section 3.1.6), the potato sector received special attention. Notwithstanding the comparatively low importance of potatoes in the overall Mexican economy, the crop received in the NAFTA regulations the highest degree of protection among all agricultural products (CONPAPA, 1996).

With the beginning of the NAFTA in 1994, fresh potatoes started with an import tariff of 272 percent.[12]

[12] In contrast to fresh potatoes for consumption, seed potatoes in Mexico can be imported tariff-free from NAFTA member countries.

This tariff must be reduced to zero within a time period of 10 years. And there are also certain quotas for fresh potatoes that can be imported tariff-free from the United States and Canada. These quotas increase annually by 3 percent until complete trade liberalization is achieved in 2004. The developments of import tariffs and quotas for fresh potatoes are shown in Table 5.

Because of the reduced barriers to potato trade in the NAFTA, international potato flows will likely increase significantly from 2004 onwards. Transportation costs should not represent a serious constraint because even today potatoes are moved over long distances within Mexico or within the United States—crossing the border will not make a big difference. Furthermore, in other parts of the world transportation costs have not prevented a considerable expansion of the international potato trade in the last few decades (FAO/CIP, 1995). Given the higher production costs in Mexico as compared to the United States and Canada, liberalized trade will probably lead to rising potato imports into the country.

Table 5: Development of Mexico's import tariffs and quotas for fresh potatoes within the NAFTA (1994-2004)

Year	Import Tariff (Percent)	Import Quota (t)	
		USA	Canada
1994	272	15,000	4,000
1995	261	15,450	4,120
1996	250	15,914	4,244
1997	239	16,391	4,371
1998	228	16,883	4,502
1999	217	17,389	4,637
2000	206	17,910	4,776
2001	155	18,448	4,919
2002	104	19,001	5,067
2003	52	19,572	5,219
2004	0	Free	Free

Source: SECOFI (1994).

Table 6: Cost of potato production in Mexico and in the USA (in 1998 M$)

	Mexico			USA	
	Small-Scale	Medium-Scale	Large-Scale	Idaho	North Dakota
Total Cost of Production (M$/ha)	12935.83	23375.69	38112.98	33576.37	23141.04
Average Yield (t/ha)	11.10	20.86	31.75	38.90	27.60
Cost per t of Production (M$/t)	1165.39	1120.46	1200.41	863.15	838.44

Note: 1 US$ = 8.30 M$ according to the average official exchange rate in early 1998.

Sources: Author's interview survey (1998) for data on Mexico. Patterson et al. (1993), Preston (1996) and USDA (1997) for data on the USA.

The low average competitiveness of the national potato sector is illustrated in Table 6 above which juxtaposes the unit cost of production in Mexico with the corresponding figure for Idaho and North Dakota, two of the major potato producing states in the USA. The increase of imports at lower prices would imply a decrease in Mexican potato production. Non-competitive national producers would have to exit from the potato sector. It is generally held that mostly small-scale producers would abandon their production. This might be the case because of their slightly lower quality standards. In terms of production costs, however, Table 6 again stresses that small-scale farmers are as competitive as large-scale producers.

On the other hand, there are arguments against an extended trade flow of fresh potatoes from North to South (cf. Gómez, 1995). Mexican potato consumers prefer the Alpha variety, but the dominant variety in the United States is Russet Burbank. Moreover, there are certain consumer groups in Mexico that prefer red potatoes, which are not produced in the other NAFTA countries. Such preferences can be expected to gradually change with increased international market integration, but adjustment processes take time. Furthermore, seasonal aspects of potato production might play a role. In the United States and Canada, the potato harvest is in the fall, but in Mexico fresh potatoes are available all year around, which makes seasonal exports from Mexico conceivable if certain quality standards can be met. Such South-North seasonal trade flows of potatoes are important, for example, from the Mediterranean countries of North Africa to the European Union during the winter months. How potato trade flows within the NAFTA region will develop in the future cannot be anticipated with absolute certainty in the *ex ante* framework. Of course, international potato trade will have an impact on the change in economic surplus within the quantitative model. We will deal with it by analyzing the two extremes: a closed economy and an open economy alternative.

Processed Potatoes

International trade in processed potatoes—particularly imports—significantly increased in Latin America during the 1990s (Scott et al., 1997). Therefore, referring only to the flow of fresh potatoes might be misleading when the implications of trade for national producers are analyzed. In volume terms, processed potatoes—converted to fresh tuber equivalents—accounted for half of Mexico's total potato imports in 1996. In terms of value they even accounted for two thirds. Most of these processed potato imports are in the form of frozen French Fries coming from the United States. Although there are several industry plants producing potato crisps in Mexico, there is almost no capacity to produce frozen French Fries. Within the NAFTA regulations, trade protection for processed potato products is much lower than that given to fresh tubers. Import tariffs in 1994 started between 15 and 20 percent (according to the individual processed products) with a reduction to zero by 2004 (cf. Gómez, 1995). The future development of processed potato trade flows will depend more on the evolution of national consumer preferences and the ability of the Mexican food industry to react efficiently to changing national demand patterns rather than on tariff trade-barriers.

3.2.3 Potato Consumption

Mexican consumers view potato not as a staple food but more as a vegetable. With an average annual demand of 12.3 kg per capita in the early 1990s, potato consumption is much lower than in those regions of the world where the crop represents a primary source of food energy (FAO/CIP, 1995).

Table 7 shows the potato budget shares for households according to the 1993 household income and expenditure survey. The average food expenditure relative to total household expenditure in Mexico is 33 percent.

As might be expected for a vegetable-type food, the weight of potatoes in total household expenditure is in general rather small. It is, however, much larger for the poorer segments of the population than it is for the better off. Although distributional implications of the transgenic potatoes on the consumer side are not explicitly considered in the market model, this expenditure pattern reveals that potato price reductions created by the technology would have a greater impact on poorer people's real incomes and improve income distribution.

Looking back to historic potato consumption figures, the per capita intake of potatoes in Mexico has increased remarkably. During the early 1960s, for instance, per capita consumption was only 7.5 kg per year. The income elasticity of potatoes is 0.82 (Ibarra, 1986), which appears quite high in comparison to the elasticity estimates for countries where potato is a staple food (see e.g. Horton, 1987). In many industrial countries, the potato income elasticity is even negative (i.e., potato consumption declines with increasing incomes). By contrast, rising living standards in Mexico would diversify the population's diet, which is based on maize and beans, towards potatoes. Today, 70 percent of all potatoes are consumed as fresh tubers in Mexico. It is likely, however, that potato consumption will shift more and more towards processed potatoes in the future. The demand for French Fries will especially increase since fast-food is gaining popularity. A change in Mexican food habits is fostered by the liberalized trade conditions with the United States and Canada.

Aggregate consumption projections for the future must take into account the expected growth rates of the population and of per capita income. The population increased at an annual rate of 1.9 percent in the 1990-95 period (World Bank, 1997), a figure that we extrapolate into the future for the time horizon of the analysis. Following Norton et al. (1987), we impose a corresponding exogenous rightward shift on the national potato demand curve in the quantitative market model. Per capita income growth, in turn, is neglected. The average annual growth rate of the per capita Gross National Product was only 0.1 percent during the last decade, and its future development is uncertain.

Price elasticities of potato demand are important for the quantitative analysis of technology implications,

Table 7: Potato expenditure shares of Mexican households (percent)

Exp. Share of Potatoes in	Total	Expenditure Deciles [a] I	II	IX	X
Total Monetary Household Expenditure	0.42	0.86	0.70	0.33	0.19
Monetary Household Food Expenditure	1.28	1.53	1.30	1.00	0.84

[a] The total population is subdivided into 10 different strata according to their overall household expenditure, with decile I representing the relatively poorest and decile X the richest households.

Source: INEGI (1993).

but reliable estimates for Mexico could not be found in the literature. Still, by using consumer theory and imposing the restriction of pointwise separability, the own price elasticity of demand (e_d) can be calculated with a method developed by Frisch (1959):

$$e_d = \frac{1}{w} \cdot h\left(1 - b \cdot h\right) - b \cdot h \qquad (16)$$

where h is the income elasticity of potato demand, b is the potato budget share and w is the flexibility of money, an elasticity coefficient describing how the marginal utility of income changes with changing incomes. The absolute value of w usually increases with lower levels of income and estimates range from –3 for different low income countries and –1 for the United States (cf. Sadoulet and de Janvry, 1995). For Mexico we assume a flexibility of money of –2. Thus, we obtain a coefficient of –0.41 for the price elasticity of potato demand.

4. The Recombinant Potato Technology

In this chapter, the technology transfer project between Monsanto and CINVESTAV, the technology development within Mexico, and the agronomic potentials and risks of the recombinant technology will be discussed. First, a brief overview of the relevant aspects of the Mexican agricultural biotechnology situation is provided.

4.1 Background of Agricultural Biotechnology in Mexico

Mexico is one of the more advanced countries in regards to agricultural biotechnology in Latin America.[13] Research in this area began in the 1970s with the establishment of a couple of tissue culture laboratories by different public organizations. That development continued during the 1980s, and today there are several biotechnology institutes in Mexico with considerable experience and high reputations both nationally and internationally (Pedraza et al., 1998). The Center for Research and Advanced Studies (CINVESTAV) in Irapuato, which belongs to the National Polytechnic Institute, is one of these outstanding organizations. It possesses a team of 71 researchers exclusively dedicated to basic and applied research in agricultural biotechnology. Many of the researchers received education and training in the United States or Europe. In the second half of the 1980s, CINVESTAV-Irapuato was also one of the first organizations in Latin America to begin research on plant genetic engineering.

Today, there are three institutes with experience in genetic engineering in Mexico, CINVESTAV-Irapuato, the Institute for Biotechnology of the National Autonomous University (UNAM), and the International Maize and Wheat Improvement Center (CIMMYT), which is one of the centers of the Consultative Group on International Agricultural Research (CGIAR). Yet until now no transgenic crop variety has been developed into a commercial application in Mexico.[14] The task of academic organizations—assigned by the government technology policy—is to focus on excellent research for evaluation by publication records in renowned scientific journals. For researchers in academic institutes there is little incentive to develop technology products up to the level of final release (cf. Solleiro et al., 1996). This latter task belongs to the private sector or—in the case of agriculture—to the National Institute for Agricultural Research (INIFAP), an administrative entity of the Mexican Ministry of Agriculture (SAGAR). Effective linkages between molecular research and agronomic product development have so far been missing.

INIFAP is now involved in the technology transfer project, too. Although INIFAP's engagement in biotechnology is still in its infancy because the institute embarked upon this area of research only in 1992,[15] it has excellent expertise in potato breeding and in more practical aspects of the Mexican agricultural sector. The virus resistant potatoes developed by CINVESTAV in collaboration with INIFAP will be the first transgenic varieties released by national institutions in Mexico or—excepting China—in any other developing country. These innovative institutional linkages and the capacity-building in the NARS initiated by the North-South technology transfer should also be seen as project benefits. They could open up channels for future biotechnology development and distribution in Mexico far beyond the potato technology itself.

4.2 The Biotechnology Transfer Project

The biotechnology transfer project between Monsanto and CINVESTAV was initiated in 1991. It involves the donation of coat protein genes—patented

[13] The most advanced countries in the region with respect to biotechnology are Argentina, Brazil, Cuba, and Mexico.

[14] Although already several thousands of hectares are grown with transgenic cotton and tomatoes in Mexico, these are products of the United States biotechnology industry (Monsanto and Calgene) (cf. James, 1997).

[15] INIFAP is planning to increase its biotechnology capacity substantially in the future.

by Monsanto—for resistance to Potato Virus X (PVX) and Potato Virus Y (PVY) and also the transfer of know-how for the corresponding genetic transformation process in potatoes. The project is facilitated and institutionally supported by ISAAA and is financially sponsored by the Rockefeller Foundation. The time frame of the technology transfer project is shown in Figure 7, and it is explained in the text below.

Resistance to PVX and PVY

During the first year of the project (1991), scientists from CINVESTAV were trained in Monsanto laboratories in the protocol for the transformation and regeneration of the Russet Burbank potato. The transfer of the genes is accomplished by the use of the Ti plasmid of *Agrobacterium tumefaciens*, which contains two coat proteins so that resistance to PVX and PVY can be conferred in a single transformation process.[16] The Russet Burbank protocols were subsequently adapted to the Alpha variety. After the establishment of the facilities at the CINVESTAV laboratories in Irapuato, the transformation of Alpha began in 1992. The first small field trial with transgenic Alphas was carried out in 1993 in Irapuato. Apart from Alpha, the contractual arrangements with Monsanto also allow CINVESTAV to transform other varieties for resistance to PVX and PVY. Imported varieties suitable for processing, however, are excluded from the agreement. In 1994, CINVESTAV transformed two more varieties, the red variety Rosita and the locally bred white variety Norteña (see section 3.1.1). In total, 189 breeding lines of the three varieties were transformed for resistance testing. In 1995, the first field trial outside CINVESTAV facilities with the objective to test for agronomic traits was carried out on 40 breeding lines in collaboration with INIFAP. The best performing lines out of each variety were then selected, and in 1997 multi-location field trials were conducted with 5 lines of Rosita and 10 lines of Alpha and Norteña, respectively. These multi-location trials took place at the agricultural stations of INIFAP in the states of Guanajuato, Mexico-State, Sonora, and Coahuila. Multi-location field tests are continuing in 1998. CINVESTAV and INIFAP are expected to release the first transgenic potatoes with resistance to PVX and PVY for commercial use in 1999. The transgenic breeder material will be transferred to the potato seed producers free of charge.

Resistance to PLRV

A new project phase began in 1997, when ISAAA brokered a further royalty-free licensing agreement with Monsanto to additionally donate a replicase gene to CINVESTAV that encodes for resistance to Potato Leafroll Virus (PLRV). The Rockefeller Foundation is also financially supporting this transfer. The replicase gene was identified and isolated more recently than the coat proteins for PVX and PVY, and so the PLRV technology was not available in 1991 when the original project begun.[17] CINVESTAV is allowed to use the PLRV resistance mechanism in Rosita, Norteña, and a dozen other varieties, but its use in Alpha is prohibited at this stage of the technology transfer agreement. The introduction of the replicase gene into PVX and PVY resistant Rosita and Norteña started in 1997. Large-scale field trials in cooperation with INIFAP are expected in 1999 and 2000. The first commercial release of the two transgenic varieties with combined resistance to the three virus types could occur as early as the year 2001.

Technology Transfer Arrangements

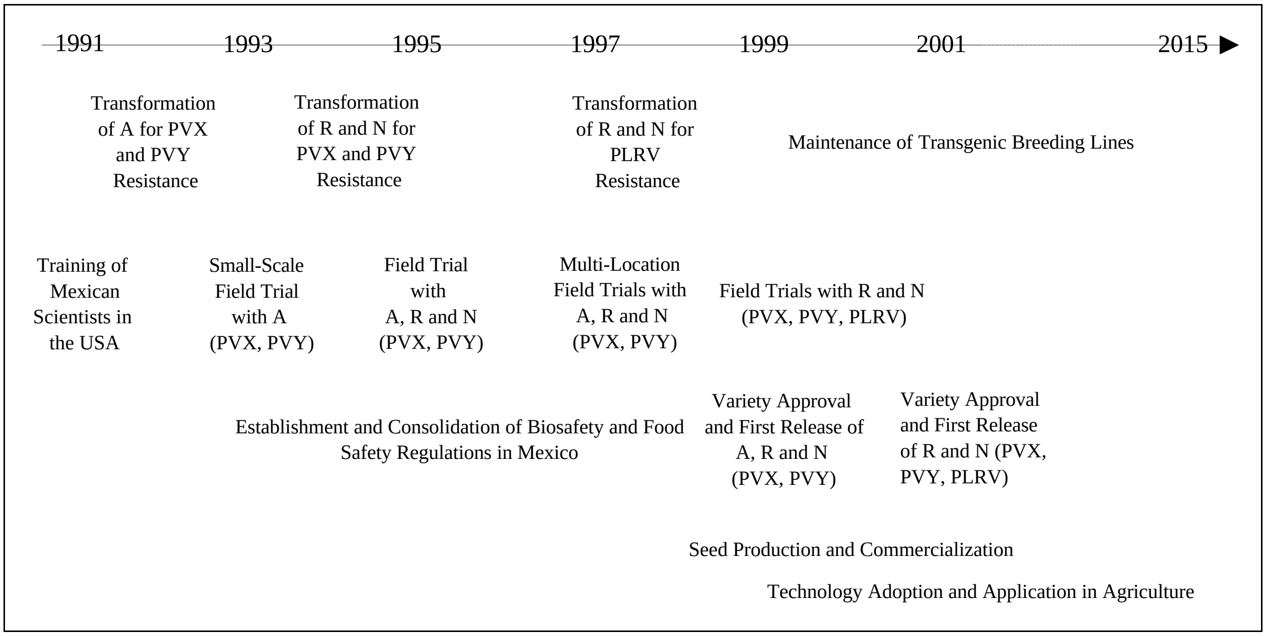
CINVESTAV received the genes and the transformation know-how from Monsanto free of charge. The PVX and PVY technology may be used for Alpha and other specified Mexican varieties. The contract, however, explicitly excludes the transformation of internationally used processing varieties, like Atlantic, Russet Burbank, etc. The use of the PLRV technology is exclusively confined to local varieties—Alpha is excluded in addition to the processing varieties. PLRV is economically much more important than PVX and PVY, and Alpha is the most important variety in Mexico among large-scale farmers who regularly buy certified seeds. Monsanto could have, therefore, a commercial interest in transforming and releasing the variety in the future. On the other hand, Alpha is not widely grown in countries other than Mexico, and CINVESTAV/INIFAP already have experience in transformation and product development with this variety. It is conceivable, therefore, that Monsanto will finally give its permission to CINVESTAV to use PLRV resistance technology in the Alpha variety.

CINVESTAV and INIFAP are allowed to protect the transformed varieties under the national Intellectual Property Rights (IPRs) regulations. Since 1994, plant varieties in Mexico can be protected by the legislation of Plant Breeders' Rights under the UPOV act of 1991. The varieties will eventually be protected for defensive reasons, but not for commercial purposes. Mexico is allowed to share the technology and the transgenic products with all the countries of Latin America and Africa. The export of any of the transformed material to the USA or to other countries where Monsanto patented its technology is explicitly excluded in the contract. New negotiations will be required if Mexican potato exports become relevant in the future.

[16] For more technical details see Rivera-Bustamante (1995) and Kaniewski et al. (1990).

[17] Monsanto released PLRV resistant Russet Burbank potatoes in the USA in 1996. PVX and PVY resistance is also a mature technology there, but these two viruses are of minor importance in the potato producing regions of the USA. There is no commercial application of this technology in that country.

Figure 7: Time frame of the biotechnology transfer project



Note: A means Alpha, R is Rosita and N is Norteña.

Monsanto's Interest in the Project

Since Monsanto *donated* the virus resistance technology to Mexico, the underlying incentives for the company to participate in the North-South transfer project are not initially obvious. Private enterprises have to maximize their profits, so we don't expect idealistic behavior from them. We can find the forces behind such behavior, however, by adopting a long-term strategic perspective:

- There are still public concerns about biotechnology and genetic engineering in general—and against the "Global Players" in particular. To demonstrate that farmers in developing countries can also benefit from proprietary transgenic technologies improves the status of biotechnology and of private industry.
- Through the technology donation, Monsanto improves its own image as a "responsible global citizen" against the backdrop of North-South inequalities and food insecurity in the Third World. The cost of this public relations effect is relatively low because—due to the specific contractual agreements—Monsanto does not forego current short-term commercial potentials (cf. Commandeur, 1996).
- While quantitative seed demand in most industrialized countries is stagnating, the seed markets of developing countries are growing and will continue to grow in the future. There are long-term market potentials for the private seed industry of the North if they expand their focus to include the needs of developing countries. The transfer project allows Monsanto to test its recombinant technology under unique climatic and socioeconomic conditions (cf. Massieu, 1998).
- So far, private enterprises from industrialized countries have been active only to a limited extent in developing country seed markets, particularly with respect to biotechnology. The project gives Monsanto the opportunity to gain new experiences and to build up an institutional network. This involves not only direct cooperation with local partner organizations but also the establishment of mechanisms to facilitate future commercial technology projects (e.g. biosafety issues and biotechnology distribution channels).

4.3 Agronomic Technology Potentials

Potential Effects on Potato Yields

Section 3.1.2 observed that PVX, PVY, and PLRV are the economically most important potato viruses in Mexico. They cause losses in terms of yield quantity and quality. Virus-induced quality reduction also often leads to non-marketable output, so quality losses can be translated into commercial yield losses as well. This is accounted for in the subsequent considerations.

There is very little published information available about average potato yield losses caused by viruses in Mexico. To make up for this lack, a review of the available national and international literature (SAGAR/INIFAP, 1997; Rivera-Bustamante, 1997; Salazar, 1997; Marks et al., 1992; CIP, 1990; Hill, 1990; Piña, 1984; Debrot, 1975) was supplemented by interviews with Mexican potato experts (see section 2.3). They were asked to give estimates on average yield losses induced by the three virus types, both when there is infection by only one virus and when the infection is multi-viral. The range of answers was rather narrow. An arithmetic mean was calculated from the individual statements, which was then cross-checked with potato researchers from the International Potato Center (CIP) in Peru and with Monsanto's experience in transgenic Russet Burbanks in the United States. This procedure resulted in the following estimates: Average yield reduction in Mexico due to PVX is 5 percent, with little variation across the country. Due to climatic factors, greater regional differences in the severity of infections can be observed for PVY and PLRV. While PVY is more widespread in the North and North-West of Mexico, PLRV causes greater problems in the temperate zones of the Central Plateau. Nonetheless, both virus types can be found throughout all regions. Countrywide average estimates for yield reductions are 10 percent for PVY and 17 percent for PLRV. When different viruses infect potatoes at the same time, the combined effects often are far more severe than those of either infection alone, although individual yield losses do not simply sum up. The average yield reduction of PVX and PVY together is estimated at 12 percent. When all three viruses are prevalent, which is typical in Mexico, the average loss is 25 percent. Differences in losses between potato varieties can occur, but they are negligible.

Using the transgenic technology will avoid yield losses. A translation into potential net yield gains (*NYG*) can be derived by taking the actual obtained yield—with virus infections—as the reference basis.[18] Keep in mind that resistance genes do not confer absolute immunity (Ascencio, 1998). A certain degree of infection cannot be avoided despite resistance. Although the resistance mechanism itself is not lost through vegetative propagation, the remaining infection might increase when farmers repeatedly reproduce the transgenic tuber. Little is yet known about the performance of the resistance-degree over time. Given the assumption that transgenic seeds are renewed every five to seven years by potato producers, experts estimate a resistance-degree of 85 percent (i.e., the technology could reduce the current yield losses by this percentage).

Because distributional implications of the technology have yet to be assessed, it is important to note that significant variations in virus-induced yield losses exist between farming systems. Large-scale farmers regularly renew their seeds with certified material, so that they have better control over secondary virus infections than smaller farmers, who often recycle their own tubers or purchase seeds in informal markets. Moreover, larger farmers use higher amounts of insecticides, which reduces the number of primary PVY and PLRV infections transmitted through aphids. The potential, therefore, of the transgenic virus resistance to reduce yield losses is greater in the case of small-scale farmers. Yield losses and corresponding potential technology net yield gains are shown in Table 8 for the individual farm types. Regional differences have been accounted for by referring to the major locations of farm types in the country (i.e., larger farmers are dominant in the North whereas smaller farmers predominate in the Central and South).

Potential Effects on Pest Management Strategies

It might be argued that, particularly in the case of large-scale farmers, the technology could lower the cost of pest management in addition to having direct effects on commercial yields. But this is not very likely because there are no specific management strategies exclusively directed at virus problems. The technology will probably not influence the intervals of purchasing certified seeds for larger farmers since other pathogens (mycoplasmas, fungi, and bacteria) are also spread through the tuber. The application of insecticides should also not be expected to decrease considerably because in most instances the chemicals employed are not specific. The same insecticides that control the leafhoppers that transmit mycoplasmas usually control the aphids that transmit PVY and PLRV. Aphids and leafhoppers often have different times of activity in spreading pathogens to potatoes, and so timely chemical applications—targeted to either of the insects—could considerably reduce insecticide amounts. But this requires increased knowledge of efficient pest management among farmers—not virus resistant potato varieties.

Advantage of Transgenic Potatoes Over Conventional Technology

There are essentially two ways to keep economic losses caused by secondary virus infections in pota-

[18] Although PVX and PVY resistant potatoes have already been field-tested, the trial procedure did not allow statements on technology-induced yield effects. Therefore, potential net yield gains of the technology are based on an appropriate translation of estimated data on current virus losses. Percentage yield loss statements do not refer to actual yields, but to hypothetical yield levels without virus problems.

Table 8: Current average virus-induced potato yield losses and potential net yield gains through transgenic resistance by farm type (percent)

	Small-Scale	Medium-Scale	Large-Scale
		Current Yield Losses [a]	
PVX and PVY	15	12	7
PLRV	25	17	10
PVX, PVY and PLRV	35	25	15
		Technology Net Yield Gains [b]	
Resistance to PVX and PVY	9	7	4
Resistance to PLRV	21	13	7
Resistance to PVX, PVY and PLRV	46	28	15

[a] These values are percentages from the hypothetically obtainable yield without virus problems.

[b] These values are percentages from the current actual yield. It is assumed that all three viruses are prevalent and that the resistance-degree is 85 percent.

Sources: Author's calculations based on the interview survey (1998) and different available literature sources indicated in the text.

toes low.[19] The first alternative is to develop aconventional seed production program, which through the use of virus detection, eradication, and tissue culture techniques delivers pathogen-tested certified planting material to potato farmers. In most developed countries, seed production programs are efficient and farmers regularly buy certified potato tuber seeds. These countries have only minor virus-induced yield and quality losses (CIP, 1990). In many developing countries, however, farmers often reproduce their own potato seeds, which creates a constant virus buildup in the stock. Institutional requirements to establish a well-functioning seed program, where all types of farmers regularly purchase clean seeds, are substantial. In Mexico, commercial seed producers already propagate virus-free seed material, but its use is rather limited, especially among small and medium-scale farmers (cf. section 3.1.5).

The second alternative is the development of genetic resistance, transmitted through vegetative propagation, which makes its practical implementation much easier in developing countries. Resistance can generally be achieved by either traditional breeding or by genetic transformation. Because potato is tetraploid, its improvement by breeding and selection is very difficult. CIP scientists have identified genes in the potato germplasm that confer extreme resistance to PVX and PVY, and through marker-assisted breeding it is tried to develop resistant varieties. Good sources of PLRV resistance, however, could not yet be found inside the potato germplasm (Ghislain et al., 1997). Direct gene transfer—in which other organisms can also be the source of resistance—offers the advantage of bringing forth technologies that would not otherwise be available at this stage. The genetic transformation of potatoes in comparison to other crops is comparatively easy and inexpensive, which makes it an appropriate technology for developing countries. It remains to be seen how effectively the transgenic virus resistant potatoes can be reproduced by farmers themselves.

There is another major advantage of gene technology-mediated resistance over conventional resistance breeding in potatoes. In countries with a mature potato industry, varietal replacement is usually much slower in potato than for other arable crops (Walker, 1994). Established market qualities and known yield performances of certain varieties lead to a low acceptance among farmers of new varieties. In Mexico, this is reflected by the long durability of the Alpha variety. Conventional crossbreeding produces new varieties with yield and quality characteristics that are often distinct from the varieties used before. With transgenic resistance technology only one desired gene is added to the genome of a well established variety, and so farmers' acceptance and adoption of the technology will be much higher.

4.4 Technology Adoption

4.4.1 Adoption by Producers

As discussed in chapter 2, the potential technology adoption rate of potato producers is a crucial variable for assessing the economic impact of the new varie-

[19] A third alternative is the introduction of botanical potato seeds (true potato seeds). Viruses are usually not transmitted through the sexual seed of the potato. CIP has some positive experience with true potato seed programs, but so far their worldwide use is still very limited.

ties. Adoption is defined here as the proportion of total potato production under the new transgenic technology. Important factors that influence technology adoption are the expected profitability of the innovation from the farmers' point of view, the complexity of understanding and handling it, and its divisibility. Of course, adoption may vary over farm types according to the peculiarities of the technology. Biotechnologies integrated into seeds are expected to be rather scale-neutral in this respect (Qaim and von Braun, 1998).

The adoption of new crop varieties is usually associated with a certain degree of risk for the farmer, since the exact yield, quality performance, and necessary adjustments to the traditional cropping intensities are unknown. This is one reason why the adoption of new varieties over time has often been modeled as an S-shaped logistic function (see e.g. CIMMYT, 1993). The previous section argued that this uncertainty aspect is somewhat different in the case of transgenic potatoes, for in this instance only one new resistance mechanism has been introduced into varieties that are already well established. Rather than being a function of the subjective risk perception, the attractiveness of using the technology is primarily a question of the transgenic seed price, which farmers will weigh against the expected net yield gain. CINVESTAV and INIFAP plan for all seed producers to receive the technology incorporated into the breeder material free of charge. This will make the operation of producing certified seeds—and thus the cost—equivalent for transgenic and non-transgenic potatoes. Given the competitive structure of Mexican potato seed markets, seed prices are primarily determined by the cost of seed production. Except for possible production bottlenecks in the first year after technology release, seed prices of transgenic and non-transgenic potatoes are expected to be the same. It is therefore presumed that the adoption of the transgenic technology by Mexican potato producers is a linear function determined by the given pattern of variety use and farmers' behavior in respect to renewing their seed material. The function is kinked at the upper bound of technology adoption, which is equal to the current production share of the three varieties Alpha, Rosita, and Norteña. These shares are shown in Table 9.

We let the share of Rosita be represented by the share of all red-colored varieties. As Rosita is the most important of the red varieties, this might be simplified but it is not an unrealistic approximation. Although the use of varieties is subject to change over time, Walker (1994) showed in a cross-country study that this is usually a rather slow process. It is assumed that the slightly declining trend observed in recent years in the use of Alpha will be halted due to the advantages of the new technology, and that variety use over the consideration period will stay more or less constant.

Technology adoption needs to be considered separately for the PVX-PVY resistance in Alpha, and for PVX-PVY-PLRV resistance in Rosita and Norteña from 2001 onwards. Although 1999 marks the first release of PVX and PVY resistant varieties, significant adoption will not start before 2000 because it will take a year to multiply sufficient amounts of seeds. Likewise, noticeable adoption of PVX-PVY-PLRV resistant varieties will not occur before 2002.

Adoption Based on the Current Seed Distribution System

On the basis of the seed market observations described in section 3.1.5, seed purchase and technology adoption behavior is defined as follows: large-scale farmers buy certified seeds every year for 33 percent of their total potato area, which means that there will be complete seed renovation with transgenic material after three years for the respective varieties. Medium and small-scale farmers annually buy seeds for only 20 percent and 15 percent of their potato area, respectively. Although medium and small-scale farmers usually purchase seeds from informal markets, in the

Table 9: Production shares of different potato varieties by farm type

Variety	Small-Scale	Medium-Scale	Large-Scale	Total
Alpha	0.29	0.50	0.69	0.60
Norteña	0.01	0.01	0.02	0.02
Red-Colored Varieties	0.69	0.27	0.00	0.15
Other Varieties	0.01	0.22	0.29	0.23
Total	**1.00**	**1.00**	**1.00**	**1.00**

Sources: SAGAR/INIFAP (1997) supplemented by the interview survey (1998).

case of white varieties transgenic potatoes will also penetrate these markets after about two years.[20] For red varieties, however, this is different. Seed exchange of red varieties takes place only in informal markets. The existence of a formal seed market for a certain variety is the precondition for the introduction of the technology into this variety. Under the current seed distribution system, therefore, transgenic virus resistance will not be disseminated in red varieties. This leaves small and medium-scale farmers out of the loop.[21] Even though transgenic Rositas are available from a technical point of view, there is no commercial incentive for private seed producers to multiply them. Alpha with resistance to PVX and PVY and Norteña with resistance to PVX, PVY, and PLRV will be in fact the only transgenic varieties reaching farmers' fields. Table A 2 in Appendix A shows the technology adoption profile of the individual farm types against the background of these assumptions.

<u>Establishment of a Special Seed Distribution Mechanism</u>

Establishing a special seed distribution mechanism would be one way to make transgenic Rositas available to small and medium-scale farms. Because of market failures (high transaction costs on factor and input markets) targeted government intervention is required. There are two major alternatives. The first is to sell transgenic Rositas at commercial prices. It would then be necessary to establish a subsidized extension service for the potato crop that would persuade farmers of the profitability of entering formal seed markets to access the technology. The emergence of these markets for red varieties would need to be promoted by the state. Since smaller farmers are not used to buying certified seeds, this could be a prolonged process and would require a more profound restructuring of factor market institutions (e.g., access to credit, see 3.1.6). The second alternative is to sell transgenic potato seeds at subsidized prices. One advantage for farmers of transgenic potatoes is that they do not need to buy the technology every year they use it. Once they have acquired the material they can reproduce their own seeds for a certain length of time. We argue, therefore, that the subsidized seed alternative appears to be the more efficient one. A mechanism to distribute improved seeds of maize and beans to small-scale farmers has recently been established in Mexico under the program *Alianza para el Campo* (cf. section 3.1.6). The component is called *Kilo por Kilo* and offers small farmers with less than five hectares an exchange of one kilogram of harvested grain (or its monetary equivalent) for one kilogram of improved certified seeds (SAGAR, 1997). The cost of improved seeds for farmers remains exactly the same as if they used farm-saved material. The implementation of *Kilo por Kilo* is based mainly on a decision at the level of the individual state, which underlines the government's objective of decentralizing decision-making in agricultural policies. Those interviewed stated that extending this initiative to the red potato sub-sector was imaginable, and that the upper bound of transgenic Rosita adoption could then be reached within two years. The adoption profile shown in Table A 3 in Appendix A is based on the assumption that all small and medium-scale red potato growers will benefit from *Kilo por Kilo* or a similar mechanism implemented in the years 2002 and 2003. In order to maintain the resistance-degree in Rosita, it might be necessary to repeat the two-year-lasting distribution program after a couple of years. For illustrative purposes, we assume that *Kilo por Kilo* is initiated on a country-wide basis. The actual implementation, however, could begin with pilot projects in individual states or communities. Administratively, state institutions would buy certified seeds from commercial seed producers in order to sell them to identified red potato producers at lower prices. Identifying eligible smaller producers would not be a problem because large-scale farmers do not use red varieties anyway. The guaranteed demand for transgenic Rositas at commercial prices by the state would automatically create enough incentive for private seed producers to start handling this variety—the additional promotion of formal seed markets for red varieties would not be required.

4.4.2 Acceptance by Consumers

In many industrial countries—especially in Europe—food consumers are skeptical about purchasing genetically engineered products. Consumers do not consider transgenic and non-transgenic food items as the same, even if they are in scientific terms. Of course, such caveats matter for *ex ante* economic analyses, since they crucially impact on the marketing potentials of biotechnology-derived food products. In developing countries, there is little experience with consumers' acceptance of gene technology applied in agriculture. It is hypothesized, however, that an extreme reservation against transgenic food is a phenomenon pertinent only to the richer countries, where the availability of food in quantitative terms is not a serious constraint.[22] In Mexico, public awareness of and knowledge about biotechnology is rather

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[20] It needs to be stressed again that the development of the resistance-degree is uncertain when the tubers are repeatedly reproduced. Here it is assumed that informal markets receive enough fresh material so that the net yield gain of the technology can be kept stable over time.

[21] The involved organizations are planning the development of a specific dissemination program to reach small-scale farmers in cooperation with local NGOs, but a clear strategy has not yet been identified.

[22] This statement should not be misinterpreted to suggest that food safety is not an important issue in countries with scarce food supplies. But the task of food-safety regulations is the control of potential harmful effects on human health, as opposed to moral and ethical reservations against gene technology.

low (cf. Chauvet and Massieu, 1996), and so consumers are not expected to reject the transgenic potatoes. For the purpose of modeling the potato market, we consider transgenic and conventional potatoes as an homogenous good.

4.5 Technology-Inherent Risks

In the debate about genetic engineering, the risks of the technology often rise to the fore. Critiques insist that the direct manipulation of the genetic make-up of organisms will create new and unpredictable risk dimensions for the environment and for human health. Although scientific knowledge in this area is still limited, thorough and extended risk studies have been conducted in the recent past. These have concluded that there are no risk elements associated with transgenic plants that are specific to gene technology. Certain risks do exist, but the same phenomena could occur in conventionally bred plants as well. There are no new risk dimensions associated with gene technology as a whole, and risk assessments should be carried out for individual technologies on a case-by-case basis. Virus resistant transgenic potatoes in Mexico present four different categories of risks:

- First, there is the risk of a vertical gene transfer into the environment. Relatives of domesticated potato varieties grow wild in Mexico, which makes gene exchange possible (Hannemann, 1994). Because of clonal propagation techniques, however, male fertility of domesticated potato varieties is generally low. Moreover, outcrossing is very unlikely to occur between transgenic and wild species beyond physical distances of 20 m (McPartlan and Dale, 1994). Still, an undesired gene flow could theoretically take place, and so attributes of weediness need to be considered. Although the introduction of virus resistance possesses a certain fitness advantage for natural relatives, this advantage is not likely to be very dominant. Viruses are not the first limiting factor for wild potato species in their biotopes, and virus pressure at one location may vary substantially from year to year.
- Second, new and more aggressive virus types could emerge through a transgenic recombination between viral genomes or a heteroencapsidation phenomenon (Tepfer, 1993). There is particular concern about this when using transgenes derived from viruses (both coat protein and replicase are viral genes). The probability of a transgenic recombination event, however, is much lower than that of a natural recombination between viruses infecting the same plant (Ghislain and Golmirzaie, 1998). This risk in regards to transgenic technology is therefore below the naturally occurring risk.
- Third, there is the risk of resistance-breaking through a selection of resistant virus strains. Little is known about the probability of this, but so far there is no evidence that it will happen with great speed. From this point of view it is advantageous that the transgenes do not confer absolute immunity, which would increase the selection pressure for viruses. In general, resistance-breaking is more likely to occur in the PVY technology, because this virus type has a high genetic variation, thus increasing the probability of existing resistant strains. The genetic variation is lower for PVX and lowest for PLRV. Overall, in comparison to pathogen-derived genes that are used for the considered transgenic potatoes, the risk of resistance-breaking is lower when plant-derived transgenes are used (Ghislain et al., 1997). It should be mentioned, however, that the risk of breaking down does not constitute a risk for human health or the environment. It is an economic risk that would render the technology useless.
- Fourth, food safety issues should always be considered for all transgenics destined for human consumption. In the case of coat protein and replicase-mediated virus resistance in potatoes, no special risk for human health has been identified. The transgenes are isolated from viruses that always infect potatoes to some extent. Therefore, human digestion is confronted with these viral genes whenever any potatoes are consumed. The Food and Drug Administration, which is responsible for food-safety regulations in the United States, has deregulated the release of the used gene constructs.

The very low probability of events and the limited knowledge about the possible costs of such events prevent us from including risk aspects into the quantitative analysis. Summarizing the different aspects in qualitative terms, the inherent risks of the virus resistance technology are low and therefore acceptable from a social point of view. But biosafety issues in relation to the technology should receive further attention—now and after they are commercially released. In particular, the risk of a potential gene flow into the center of genetic diversity must be carefully monitored.

4.6 Biosafety Developments

In 1988, the Campbell company wanted to conduct the first field trials of transgenic crops in Mexico dealing with *Bacillus thuringiensis* (*Bt*) tomatoes. The Mexican authorities gave permission for these trials without further investigation, and they were conducted in 1988/89.

The need for biosafety regulatory mechanisms was realized at that moment, and so SAGAR established a biosafety working group in 1988, which was institutionalized as the Mexican Agricultural Biosaftey Committee (ABC) a year later (Carreón, 1994). The Committee consists of representatives from government organizations and of members of leading national biotechnology research institutes. It closely follows the USDA/APHIS guidelines.

With CINVESTAV's application for the first field testing of transgenic Alphas in 1993, new regulatory issues arose for the ABC. This was the first field test with genetically modified organisms carried out by a national organization, and it also involved a transgenic variety that had not been tested elsewhere in the world. In 1992, ISAAA organized a regional biosafety workshop in Costa Rica to provide information about the experience of several developed countries in capacity building (see Krattiger and Rosemarin, 1994). Institutional promotion through the exchange of consultants and advice is ongoing between Mexican organizations, Monsanto, and ISAAA. The ABC is a flexible institution and meetings are held according to the number of received applications, on average twice a year. Before approval is given for the commercial release of a new transgenic variety, three full cycles of field tests are required. The Committee is now also responsible for handling food-safety issues. Variety registration by SNICS presupposes the approval of the ABC when recombinant technology is involved.

5. Counting Potential Technology Benefits and Costs

In this chapter, the measurable quantitative effects of the recombinant potato technology are assessed. First, in section 5.1, the potential impacts on potato enterprise budgets will be discussed at the level of the individual farm. The different scenarios to be analyzed on an aggregate level are presented in section 5.2, and the rest of the chapter is dedicated to the calculation of benefits and costs of the technology project based on the individual scenario assumptions.

5.1 Benefits at the Individual Farm Level

This section juxtaposes potato enterprise budgets currently observed in the Mexican potato sector (see section 3.1.7) with hypothetical budgets where the transgenic virus resistance technology has been introduced. These with-technology budgets take into account the technological features and potentials discussed in section 4.3.1. Table 10 shows the comparison for the PVX-PVY technology.

The technology has the greatest potential to increase household income from potato production for small-scale farmers, followed by medium-scale farmers, and with the lowest potential increase for large-scale farmers. This pattern is not surprising given the current virus-induced yield losses for the individual farm types. That the percentage increases of the gross margins are much higher than the aforementioned net yield gains of the technology is due to the cost of production being held constant. This is realistic under the assumption that small and medium-scale producers do not change their seed purchase behavior and can acquire transgenic potatoes on informal seed markets. If, however, all farmers bought certified transgenic seeds on formal seed markets (at a realistic price of 3500 M$ per t), the increases of the gross margin would be negative for the small and medium-scale farmers, at least in the first year of acquiring the technology.[23] For large-scale farmers, the increase of the gross margin would then be around 2.5 percent. These figures underline that PVX and PVY are not the most pressing problems in Mexican potato production. Resistance to these two viruses alone is beneficial for farmers only if it is not associated with an extra cost. The indicated per unit cost reduction only refers to the variable cost. The technology is not expected to affect the fixed cost of potato production.

Table 11 shows the same comparison of enterprise budgets for the combined resistance to PVX, PVY, and PLRV. Under the assumption of constant costs of production, the technology-induced percentage increase of the gross margin is substantial, with highest potentials again for the smaller farmers. Even if farmers bought transgenic seeds at formal market prices, the gain would be 56 percent, 40 percent, and 28 percent for the small, medium, and large-scale farmers, respectively. This shows that the combined technology with resistance to all three viruses also has large commercial capabilities. Moreover, it clearly demonstrates that the benefits of gene technology must not be confined to larger producers. On the contrary, the advantages of the transgenic potato technology could be much greater for small-scale farmers.

To prevent misinterpretations of the potential benefits on the individual farm level, two aspects should be mentioned:

- The with-technology enterprise budgets shown in this section assume per se that farmers are using the transgenic potatoes. It is abstracted from

[23] A neglected aspect here is that when buying fresh, certified seeds, yields would further be increased, because the infection with mycoplasmas and other tuber-spread pathogens would also be lower. This, however, cannot be considered a net yield gain of the virus resistance technology.

Table 10: Potato enterprise budgets per hectare without technology and with PVX-PVY resistance technology by farm type (in 1998 M$)

	Small-Scale		Medium-Scale		Large-Scale	
	Without Technol.	With Technol.	Without Technol.	With Technol.	Without Technol.	With Technol.
Variable Cost of Production	11759.84	11759.84	21250.63	21250.63	34648.17	34648.17
Yield (t)	11.10	12.01	20.86	22.32	31.75	33.02
Var. Cost per t of Production	1059.45	979.17	1018.60	952.09	1091.28	1049.31
Farm-Gate Price per t	1568.33	1568.33	1963.75	1963.75	1947.83	1947.83
Gross Revenue	17408.50	18835.64	40963.83	43830.90	61843.71	64317.35
Gross Margin (GM)	5648.66	7075.80	19713.20	22580.27	27195.54	29669.18
GM Increase (Percent)	**-**	**25.27**	**-**	**14.54**	**-**	**9.10**
Unit Cost Reduction (Percent)	**-**	**7.58**	**-**	**6.53**	**-**	**3.85**

Note: 1 US$ = 8.30 M$ according to the average official exchange rate in early 1998.

Source: Author's calculations.

Table 11: Potato enterprise budgets per hectare without technology and with PVX-PVY-PLRV resistance technology by farm type (in 1998 M$)

	Small-Scale		Medium-Scale		Large-Scale	
	Without Technol.	With Technol.	Without Technol.	With Technol.	Without Technol.	With Technol.
Variable Cost of Production	11759.84	11759.84	21250.63	21250.63	34648.17	34648.17
Yield (t)	11.10	16.21	20.86	26.70	31.75	36.51
Var. Cost per t of Production	1059.45	725.47	1018.60	795.90	1091.28	949.00
Farm-Gate Price per t	1568.33	1568.33	1963.75	1963.75	1947.83	1947.83
Gross Revenue	17408.50	25422.63	40963.83	52432.13	61843.71	71115.27
Gross Margin (GM)	5648.66	13662.79	19713.20	31181.50	27195.54	36467.10
GM Increase (Percent)	**-**	**141.88**	**-**	**58.18**	**-**	**34.09**
Unit Cost Reduction (Percent)	**-**	**31.52**	**-**	**21.86**	**-**	**13.04**

Note: 1 US$ = 8.30 M$ according to the average official exchange rate in early 1998.

Source: Author's calculations.

institutional bottlenecks that might restrict farmers' access to the technology. It has already been mentioned in preceding chapters that these institutional constraints are significant in the Mexican potato sector.

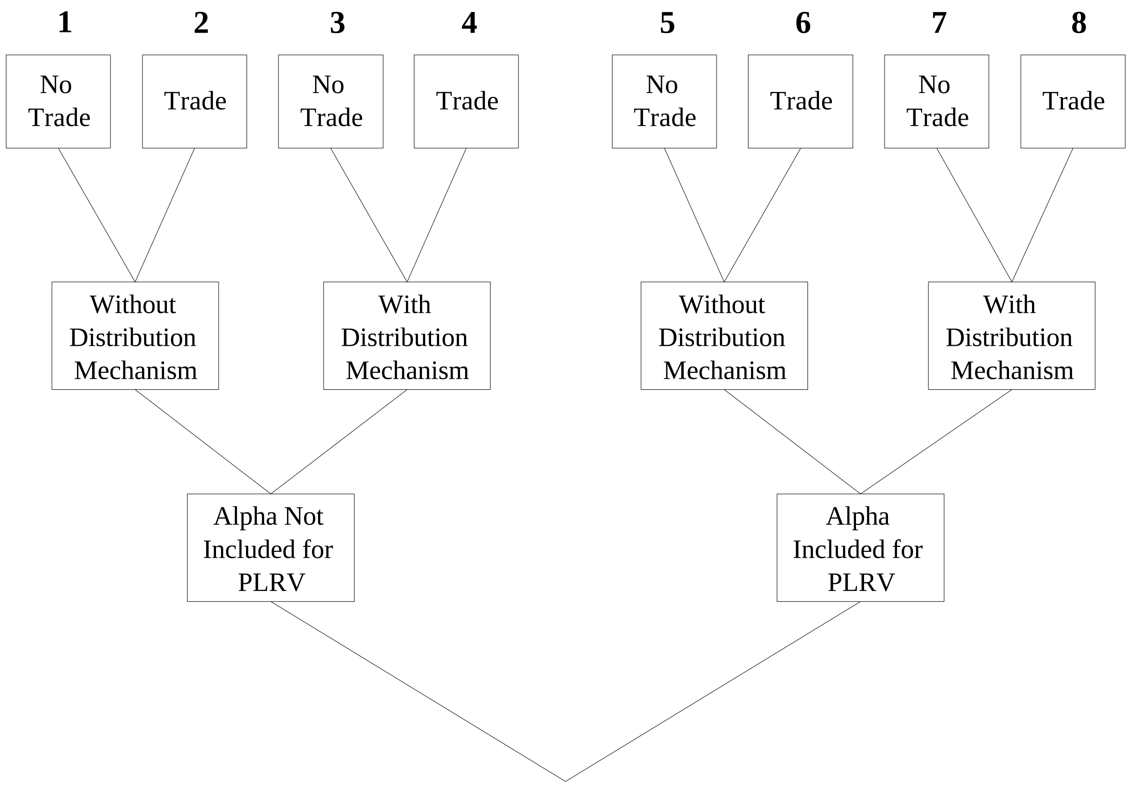
- The enterprise budgets build on the assumption that potato farm-gate prices will not change due to technology use. While this might be realistic for some early adopters, a more widespread technical change will lower potato prices, as producers face a downward sloping demand curve.

Both aspects are taken into account in the market equilibrium displacement model explained in chapter 2 and carried out in the subsequent sections.

5.2 Structure of Scenarios to be Analyzed

It was indicated earlier that the quantitative analysis would be carried out for different scenarios. Critical parameters that are subject either to project-endogenous policy decisions or to exogenous uncertainty factors have been stressed in previous chapters. Before benefits and costs are computed, this section is meant to shed light on the assumptions for the differ-

Figure 8: Structure of analyzed scenarios



ent scenarios to be analyzed. The structure of this is visualized in Figure 8. According to the descriptions in Section 2.1, assumptions have to be made at three different levels.

- **Level of R&D:** Current contractual arrangements between Monsanto and CINVESTAV prohibit the use of the PLRV resistance in the Alpha variety. It is conceivable, however, that ongoing negotiations will result in permission to also include Alpha. To show the implications of this potential new agreement, an 'Alpha Not Included' alternative, representing the current situation, and an 'Alpha Included' alternative is analyzed. The 'Alpha Included' alternative assumes that PVX-PVY-PLRV resistant Alpha could be released together with Rosita and Norteña in the year 2001, which would not be unrealistic given a quick consent by Monsanto.

- **Level of Factor Markets:** Given the current institutional arrangements in the seed distribution system, technology adoption by small and medium-scale farmers will be rather slow, and transgenic Rositas will not be distributed at all. In section 4.4.1, the possible establishment of a special mechanism to distribute transgenic Rositas at subsidized prices was discussed (the *Kilo por Kilo* mechanism). The analysis will include a 'Without Distribution Mechanism' alternative, which corresponds to the actual situation, and a 'With Distribution Mechanism' alternative.

- **Level of the Potato Market:** This analyzes the impact of increased international potato trade on the technology-induced change in economic surplus. Today, Mexico is essentially a closed potato economy. But, as mentioned in section 3.2.2, this could change within the NAFTA area after the year 2004. Therefore, a 'No Trade' and a 'Trade' case will be considered as the two extremes. In the 'No Trade' case, only the national demand curve is relevant, which is downward sloping and shifting rightwards over time due to population growth (cf. section 3.2.3). In the 'Trade' case, we assume—from 2004 onwards—a totally elastic demand curve at the average c.i.f. import price of fresh potatoes at the Mexican border observed in 1996. The horizontal demand curve is a good approximation because Mexico's share in total potato production within the NAFTA region was only 4.6 percent in 1996 (FAO, 1998).

The different alternatives on the first two levels hinge on decisions made within the framework of the technology project itself. The scenario results constitute, therefore, an appropriate base of information for decision-makers. Of course, the assumptions have to take into account both the benefits and the costs. The development of trade flows, on the other hand, is more or less exogenous to the technology project. Technical change in the Mexican potato sector will of course impact on the competitiveness of national production, but technical change should also to be expected in the USA and Canada. Therefore, the 'No Trade' and the 'Trade' alternatives account for uncertainty about exogenous future developments—not for particular policy decisions to be made within the project.

5.3 Aggregate Benefits and Distributional Effects

Before the technology-induced changes of economic surplus in the Mexican potato market are analyzed within the individual scenarios, there are some general issues and assumptions to be explained that apply to all of the different cases. First, the analysis is carried out at the farm level (i.e. market clearing is assumed at farm production quantities and farm-gate prices). For both figures, an arithmetic average for the 1994-1996 period is taken, and the mean 1996 level of the Mexican peso is the monetary reference (see Table A 1 in Appendix A). Second, the endogenous shift of the supply curve is modeled as a parallel one (cf. section 2.2). This is a reasonable assumption against the background of the empirical findings on cost patterns in Mexican potato production. Although the rate of technical change will differ among farm types because of divergent potential per unit cost reductions and anticipated adoption rates, no pronounced contrasts in the efficiency of production could be traced to farm types. Third, for the without-technology benchmark we assume a constant supply curve over time. Notwithstanding some technical change even without the considered project, this conventional progress would come in addition to the transgenic progress in the with project alternative. Therefore, the relative distance of the with and without supply curve is the same, regardless of whether there is an exogenous shift or not (cf. Qaim and von Braun, 1998). Fourth, price elasticities of potato production could not be found in the literature and are based on assumptions. Given the fact that price responsiveness of larger high input farmers is usually higher than that of small-holders, supply elasticities of 0.3, 0.4, and 0.5 for the small-, medium-, and large-scale farmers are assumed, respectively. These values are consistent with figures in other studies on the economic impacts of potato technologies in various developing countries (cf. Walker and Crissman, 1996).

The farm type specific patterns of the shift factor *K* are shown in Tables A 4 and A 5 in Appendix A for the different scenarios. The estimates for *K* are based on the farm type and technology specific unit cost reductions derived in section 5.1 multiplied by the anticipated rates of adoption (see section 4.4.1). The complete results of the calculations on the technology-induced surplus changes for Mexican potato producers and consumers are given in Tables A 6 and A 7. They are summarized in Table 12.

The overall technology-induced changes in the economic surplus measures are significantly positive for all scenarios. It should be stressed again that the calculations are built on the assumption that farmers will use the technology without paying a higher price for the potato seeds as compared to their traditional sources of seed material (i.e., farmers do not carry the cost of the technology). If seed prices increase, per unit cost reductions and technology adoption rates would decrease—particularly for small- and medium-scale farmers—with a concomitant fall in economic surplus measures.

<u>'No Trade' Scenarios</u>

In all four different scenarios, the technology has positive impacts on the different potato producer groups and on potato consumers. There are, however, significant differences in the absolute amounts of benefits that can be realized according to the different assumptions. The relatively lowest additional surplus is created under the current framework conditions (i.e., Alpha is excluded from transformation for PLRV resistance and there is no mechanism to distribute transgenic Rositas). Establishing a Rosita distribution mechanism would double the overall benefits, and including the Alpha variety for PLRV resistance would triple them. Together, the combined adjustments would more than quadruple the economic surplus. The distribution mechanism is also very desirable because of equity considerations. The share of the producer surplus attributable to small-scale farmers in the 'Without Distribution Mechanism' scenarios is significantly below their initial production share. So, while small-holders would not loose through the technology in absolute terms, they would in relative terms (i.e., there would be an increasing income concentration among Mexican potato producers). As Table 12 indicates, the proposed *Kilo por Kilo* seed diffusion program for Rosita would not only avoid increasing concentration but would also significantly improve income distribution in the potato sector. In both 'With Distribution Mechanism' scenarios, small-scale farmers capture the highest share of the total change in producer surplus. The proportion attributable to medium-scale farmers would also rise considerably. The surplus for large-scale farmers, on the

Table 12: Benefits and distributional effects of the technology for the different scenarios

	Producers				Producers			
	Small	Medium	Large	Consum.	Small	Medium	Large	Consum.
N o T r a d e								
	Alpha Not Incl. / Without Distr. Mechan.				**Alpha Incl. / Without Distr. Mechan.**			
Annuity [a]	1110	9045	28097	43874	420	22071	84522	127590
Share [b]	0.03	0.24	0.74	0.53	0.04	0.20	0.76	0.54
	Alpha Not Incl. / With Distr. Mechan.				**Alpha Incl. / With Distr. Mechan.**			
Annuity [a]	70521	38485	133	87656	74038	51738	56132	172076
Share [b]	0.65	0.35	0.00	0.45	0.41	0.28	0.31	0.49
T r a d e								
	Alpha Not Incl. / Without Distr. Mechan.				**Alpha Incl. / Without Distr. Mechan.**			
Annuity [a]	2662	9657	33106	9184	9251	26747	98806	15351
Share [b]	0.06	0.21	0.73	0.17	0.07	0.20	0.73	0.10
	Alpha Not Incl. / With Distr. Mechan.				**Alpha Incl. / With Distr. Mechan.**			
Annuity [a]	50475	34140	28864	15832	57498	51637	94522	22030
Share [b]	0.45	0.30	0.25	0.12	0.28	0.25	0.47	0.10

[a] The annuity is calculated over the 1999-2015 period for the annual changes of producer and consumer surplus, respectively. A discount rate of 10 percent is used. Figures are in thousand 1996 M$. The average 1996 exchange rate with respect to the US dollar was: 1 US$ = 7.60 M$ (INEGI, 1997b).

[b] For the producers, the share refers to the farm type's proportion in the change of total producer surplus. These values can be compared with the farm types' initial production shares (small: 0.12; medium: 0.24; large: 0.64) in order to test for distributional effects of the technology. For the consumers, the share refers to the part of the overall economic surplus change captured by potato consumers.

Source: Author's calculations.

other hand, would shrink to zero should Alpha remain excluded from PLRV transformation. These scenario results clearly demonstrate how important institutional framework conditions are for analyzing a technology's implications, and they emphasize the need for intelligent decisions in order to eliminate bottlenecks in the system. Furthermore, it is worth mentioning that consumers capture around half of the overall change in economic surplus in all scenarios, due to falling potato prices caused by increasing outputs. Confining the analysis to agricultural producers crucially underestimates the total benefit of a technology, particularly in the case of non-traded commodities. Falling potato prices in Mexico will entail positive distributional effects among consumers, because poorer people spend higher proportions of their income on potatoes (see section 3.2.3).

'Trade' Scenarios

For the 'Trade' scenarios a totally elastic demand curve is assumed from 2004 onwards, when import tariffs for fresh potatoes in Mexico are reduced to zero. The average c.i.f. import price for potatoes was used as the constant reference for the model computations. It was 2,146 M$ in 1996 (CONPAPA, 1997). When adjusted for the cost of transportation and handling, this figure is consistent with f.o.b. export prices of different US potato producing states provided by the USDA (1997). This price is 12 percent below the 1996 domestic price in Mexico, so that national production would fall accordingly. Although price responsiveness slightly differs across farm types, it is assumed that the farmer groups equally reduce their production in relative terms, so that production shares remain constant. This is realistic because high cost producers will have to leave the sector, and they can be found among the smaller as well as among the larger farmers. Because the technology does not lower producer prices, the technology-induced change in producer surplus is higher in the open economy in comparison to the 'No Trade' scenarios. The price decrease in 2004 is an effect of the trade liberalization and must not be attributed to the new transgenic varieties. Correspondingly, the change in consumer surplus is zero after 2004, so that the consumers' proportion in overall economic benefits is much lower than in a closed potato economy. Although producer surplus measures differ in their absolute magnitude when comparing the 'Trade' and the 'No Trade' scenarios, the results are similar in relative terms. Trade actually enhances the large producers' benefit share in the 'With Distribution Mechanism' scenarios, but still the small-scale farmers' proportion of technology gains is much higher than their initial production share. The two analyzed alternatives—no trade at all, and free trade—are the two extremes, and it can be expected that the future will lie somewhere in-between. It could be shown, however, that the international trade situation does not alter the validity of the above given statements concerning desired institutional adjustments to fully reap the technology potentials.

5.4 Costs of the Technology Project

As explained in section 4.2.1, there are different organizations involved in financing and implementing the technology project. The financial costs carried by these organizations are explained separately. An overview of the financial costs is given in Table A 8 in Appendix A.

Basic Cost

- **Rockefeller Foundation:** The Rockefeller Foundation sponsored the technology transfer from Monsanto to Mexico. The budget includes the salary for one researcher and technical staff at CINVESTAV, training of Mexican scientists at Monsanto, laboratory equipment, operation costs, costs for large-scale field trials carried out in cooperation with INIFAP, and administrative overheads.
- **CINVESTAV:** Notwithstanding the support by the Rockefeller Foundation, there are certain material contributions also made by CINVESTAV. These contributions consist of the salaries for additional involved national researchers, part of the laboratory and green house equipment and operation cost, and the cost for the first small-scale transgenic field trial in 1993. The salary and operation cost will continue until the release of the PVX-PVY-PLRV resistant varieties in 2001. From 2002 onwards, only a minor cost for the maintenance of the transgenic breeding lines is incurred.
- **Monsanto:** The cost for Monsanto consists of the opportunity cost for management personnel, lawyers for negotiating the transfer agreements, and other project-related expenses, such as travelling to Mexico. An opportunity cost of the technology itself is not considered.
- **ISAAA:** The cost incurred by ISAAA is predominantly due to its facilitating functions, technology assessment activities (e.g. biosafety), and administrative operations, such as initiating and maintaining relationships with the technology donor, the recipient, and the funding organization.

These basic costs are equal for all the different scenarios. Moreover, an institutional amount is added for the 1993-2002 period to cover the cost of inter-organizational contacts within Mexico and the consolidation and implementation of bio- and food safety regulatory mechanisms.

Additional Cost for Scenario Assumptions

In the 'Alpha Included for PLRV' scenarios, the extra cost that arises from transforming and developing an additional transgenic variety is accounted for. This extra cost is rather low because the know-how and the equipment are already available.

In the 'With Distribution Mechanism' scenarios, in which transgenic Rosita is diffused by a *Kilo por Kilo*-type program, the following calculation was conducted. Approximately 15,000 hectares are cultivated with red varieties in Mexico. The average sowing rate is 3 tons of seeds per hectare, so that 45,000 tons of transgenic Rosita tuber seeds are required to cover the total area. A common price for certified seeds is about 3,500 M$ per ton, which is on average 1,500 M$ above the cost of farm-saved seeds. This difference is the amount of the seed subsidy, so that the total subsidy is 67.5 million M$ for the entire area cropped with red potato varieties. An administrative cost of 12.5 million M$ for carrying out the diffusion program is added. The overall cost is spread over the two-year implementation phase (2002-2003). It is assumed that the program will be repeated in 2010-2011 in order to maintain the resistance-degree. This is a substantial cost because the whole country is included for illustrative purposes. Yet, as mentioned before, a seed distribution program could also first begin with a smaller pilot project level. Moreover, it might be possible to provide subsidized transgenic seeds to only a part of the red variety area, which would then diffuse into the remaining area via informal markets.

5.5 Summary Measures of Economic Effects

Benefits and costs of the biotechnology transfer project are confronted over the whole 1991-2015 period. The cost of basic research carried out by Monsanto is not considered because it will create much broader international benefits, and it would be misleading to include it into an analysis confined to Mexico. The results of the summary benefit-cost measures are given in Table 13 for the individual scenarios.

The Internal Rates of Return (IRRs) are in a reasonable dimension for long term technology projects (i.e., although the benefits only occur after a considerable

Table 13: Summary measures of economic effects for different scenarios

	Alpha Not Included Without Distr. Mech.	Alpha Not Included With Distr. Mech.	Alpha Included Without Distr. Mech.	Alpha Included With Distr. Mech.
		N o T r a d e		
NPV	330594	764100	974575	1410269
IRR	49.9	58.5	59.7	64.4
		T r a d e		
NPV	217328	485573	610492	882158
IRR	47.7	55.9	57.0	61.7

Notes: The Measures are calculated over the whole 1991-2015 period. IRRs are in percentage terms. For NPV computations, a discount rate of 10 percent is used. NPV figures are given in thousand 1996 M$. The average 1996 exchange rate with respect to the US dollar was: 1 US$ = 7.60 M$ (INEGI, 1997b).

Source: Author's calculations.

time lag behind the R&D investments, there is a sufficiently high return in the future to compensate for the opportunity cost of investments). This holds true for all assumptions, but there are significant differences between the individual scenarios. The economic measures are lowest under the current framework conditions ('Alpha Not Included for PLRV' and 'Without Distribution Mechanism for Rosita'). It was discussed in the previous section that establishing a subsidized seed distribution system for transgenic Rosita is very expensive. Nonetheless, the benefit-cost figures demonstrate that this investment is not only justified from an equity point of view but would also considerably enhance efficiency. The same efficiency statement also applies for the inclusion of the Alpha variety into the PLRV resistance transformation, the cost of which would be rather low. It should be stressed that the cost side embraces the total cost of the transfer (i.e., cost items associated with the project but carried by organizations outside of Mexico are also considered). If only the national cost was included, the benefit-cost relationship would be even higher.

5.6 Sensitivity of Results

In the analysis, there are a lot of parameters involved that are subject to uncertainty because of the unavailability of precise data or because they refer to future events. Therefore, the sensitivity of the results and statements shall be tested with respect to the key variables. First of all, although great effort was made to acquire realistic data, the exact potential net yield gain (*NYG*) and hence the per unit cost reduction (*C*) of the technology is not known. Of course, these are pivotal variables that influence the supply curve's shift factor (*K*). Still, even with a 90 percent reduction of *C* for the individual farm types, none of the IRR figures falls below the 10 percent cut-off point—representing the opportunity cost of money. The same robustness applies for variations of the adoption rate (*A*). Even when the adoption is delayed by 10 years, the project does not lose its profitability. These variations have no impacts on distributional effects when parameters are modified proportionally for all producer groups.

Furthermore, the sensitivity of the scenario results was tested with respect to the price responsiveness of consumers and producers. We varied the price elasticity of potato demand within a range of 0 and –2, and the elasticity of supply between 0 and 2. While the overall profitability as well as the total changes in economic surplus remain positive over these variations, the distributional effects change. The lower the value of the demand elasticity in absolute terms, the larger the benefit share that is captured by potato consumers and vice versa. Distribution among producer groups also differs, with a variation of the demand elasticity. Values between 0 and –0.25 entail negative changes in producer surplus for the small-scale farmers when no special distribution mechanism for red varieties is established. Likewise, rising supply responsiveness leads to distributional effects in favor of consumers and larger farmers, at the cost of small-scale producers when institutional framework conditions are not improved. Supply elasticity values above 0.8 lead to negative results for smallholders in the 'Without Distribution Mechanism' scenarios. Strikingly, however, with the establishment of a special distribution mechanism, the opposite is true—the small-holder share of the producer surplus is even larger with a high price responsiveness of supply in comparison to lower elasticity values. These findings stress the paramount importance of institutional adjustments to eliminate bottlenecks that prevent small-holder participation in technology benefits. In general, the sensitivity analysis reveals the robustness of the statements over a wide range of parameter variation.

6. Conclusions and Policy Implications

The recombinant PVX, PVY, and PLRV resistance technology has the potential to increase the productivity of Mexico's potato sector. The benefits will be realized predominantly by per unit cost reductions in potato production through higher obtained yields. A significant technology-induced change in cropping intensities and pest management strategies, such as the reduction of insecticide applications, cannot be expected. Three potato varieties (Alpha, Rosita, Norteña) have successfully been transformed with PVX and PVY resistance. Although PVX and PVY are economically important in Mexico, yield losses due to PLRV are much higher. Transformation for PLRV resistance has also been carried out by CINVESTAV in Rosita and Norteña, but Alpha—the most widely used variety in Mexico—is still excluded from PLRV resistance in the transfer agreements with Monsanto. The scenario results show that the overall technology benefits could be tripled if Monsanto would give permission to CINVESTAV to introduce the PLRV resistance-gene into Alpha. Due to the increasing experience of Mexican organizations, the cost of developing PLRV resistant Alphas would be rather low. Furthermore, because Alpha is not widely cultivated in other countries besides Mexico, Monsanto's own commercial interest in the variety is reduced, which makes a modification of the technology transfer agreements conceivable.

The analysis places particular emphasis on scrutinizing the distributional implications of the technology. If the current potato trade situation for Mexico—with only minor imports and exports—continues into the future, domestic potato consumers will benefit substantially from the technical progress through falling potato prices. The technology-induced change in the consumer surplus accounts for about half of the total economic benefit caused by the transgenic potato varieties. The advantages to consumers of agricultural technologies were often neglected in economic studies of the Green Revolution. Since poor consumers in Mexico spend larger proportions of their income on potatoes, the positive real income effects are higher for them than they are for richer households. An increased international trade with potatoes in the future would reduce the benefits accruing to food consumers.

Potato farming-systems in Mexico are very diverse. On the one hand, there are resource-poor farmers with only small potato holdings farming in high altitudes under rainfed conditions. On the other hand, potatoes are also grown by large-scale farmers under irrigated and input-intensive conditions. New agricultural technologies have often been criticized for being biased towards large-scale producers, thus reinforcing inequality and income concentration among farmers. But resistance technologies incorporated into seeds do not require additional complementary inputs, so they fit very well into small-holder farming systems. The transgenic resistance in potatoes has, furthermore, the advantage of building upon the genome of already established varieties. The risk of adopting the technology is minimized in comparison to conventional crossbreeding, where genome modification is more profound.

Regarding the distributional implications of transgenic virus resistant potatoes among producers, two different aspects must be considered. First, there are the agronomic technology potentials. These are highest for small-holders because small-scale farmers primarily use farm-saved seeds and apply less pesticides. Current yield losses due to primary and secondary virus infections are more substantial than for larger producers. Second, the access to the technology matters. Although the red variety Rosita, which is used mostly by smaller producers, has been transformed with resistance for PVX, PVY, and PLRV, it is unlikely that under the current seed and factor market situation transgenic Rositas will reach farmers' fields. Suppliers of certified seeds do not handle this variety because there is no demand for it by larger farmers, the primary customers of formal seed markets. Smaller farmers do not purchase certified seeds yet, so formal seed markets—a precondition for technology dissemination—are non-existent for red varieties. If bottlenecks in the multiplication and diffusion system of the technology cannot be eliminated through public action, then technology adoption by small farmers will be limited in spite of its great suitability. In order to prevent increased income concentration among potato producers, a state-implemented subsidized distribution mechanism for the transgenic Rosita variety is suggested. The Mexican program *Alianza para el Campo* models seed technology transfers to resource-poor farmers by a mechanism called *Kilo por Kilo* in the maize and bean sectors. If such a mechanism were extended to the red potato sub-sector, it would be a promising alternative for smaller farmers to access the recombinant technology. Identifying eligible farmers would be rather easy, because wealthy farmers do not use Rosita anyway (i.e., the variety has an incorporated self-selection characteristic). Although a high subsidy amount would be required to guarantee the speedy adoption of the technology by small-holders, scenario calculations demonstrate that the cost is justified on economic grounds. A subsidized seed distribution system would significantly improve the equity and efficiency implications of the technology at the same time.

Although the quantitative analysis is restricted to the potential benefits of the transgenic technology in the Mexican potato sector, it must be remembered that the biotechnology transfer project will have much wider positive repercussions in the national agricultural research system. Virus resistant potatoes will be the first transgenic product developed by Mexican research organizations, significantly increasing knowledge, self-confidence, and international relations between involved researchers and stake-holders. For product development, new linkages between CINVESTAV (experienced in molecular research) and INIFAP (with experience in potato breeding) have been established. This is of special importance because bringing biotechnology research results to farmers' fields is a serious constraint for the Mexican NARS. Moreover, the development of biosafety and food safety regulations was an essential part of this transfer project. Although the Agricultural Biosafety Committee responsible for these issues already existed, it was consolidated and guidelines were further developed within the project.

The experience gained by the NARS through the transfer project can already be seen, for instance, in the 50 percent reduction of the time needed to develop PLRV resistance in comparison to the first PVX-PVY technology. This positive institutional evolution will facilitate Mexico's own biotechnology generation, as well as the acquisition and adaptation of foreign technologies in the future. Moreover, these developments might produce positive technology spillovers for other developing countries. Kenya's interest in acquiring transgenic Rositas from Mexico is a case in point. South-South technology transfers between countries with similar agronomic requirements but divergent technological capabilities could be an important pathway for poor countries to gain better access to modern biotechnologies. These wider benefit potentials of the technology project are not easily quantified, but they are likely much greater than the direct productivity increases in the Mexican potato sector.

To highlight the main points of the use of modern biotechnologies in low and middle income countries and of biotechnology transfer programs:

- Agricultural biotechnologies hold great economic potentials for food producers and consumers in developing countries. The private biotechnology sector of industrial countries can play an important role in making certain basic technologies available.
- Transgenic resistance incorporated into seeds fits very well into small-scale and large-scale farming systems alike, making possible equitable technology participation. Benefit potentials might even be greater for small-scale producers.
- The actual impacts of a biotechnology innovation are not only a function of technological characteristics but also are very dependent on social and institutional support mechanisms. Technology policy in developing countries, therefore, should not be confined to R&D, but should also include technology diffusion and application. Timely socioeconomic information is sorely needed to identify and eliminate institutional bottlenecks.
- North-South technology transfers are an appropriate way to improve the biotechnology R&D and regulatory capacity of developing countries. But the institutional requirements of project implementation in recipient countries are substantial, requiring a certain minimum level of initial know-how and experience for a project's success. Capacity-formation associated with technology transfers will stimulate technology generation and application in a country and will also facilitate the assimilation of foreign technologies. The donation of proprietary technologies can pave the way for future commercial businesses of private enterprises.
- Target countries with a comparatively strong technological capability can later play important roles in delivering know-how and technology products to less developed countries within South-South biotechnology transfers.
- The international community in general and donor organizations in particular should more explicitly recognize the great opportunities of North-South and South-South biotechnology transfer programs that include partnerships with the private sector. The door is open to new technological and institutional innovations in developing countries that will promote an equitable international biotechnology evolution.

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Appendix A: Supplementary Tables and Figures

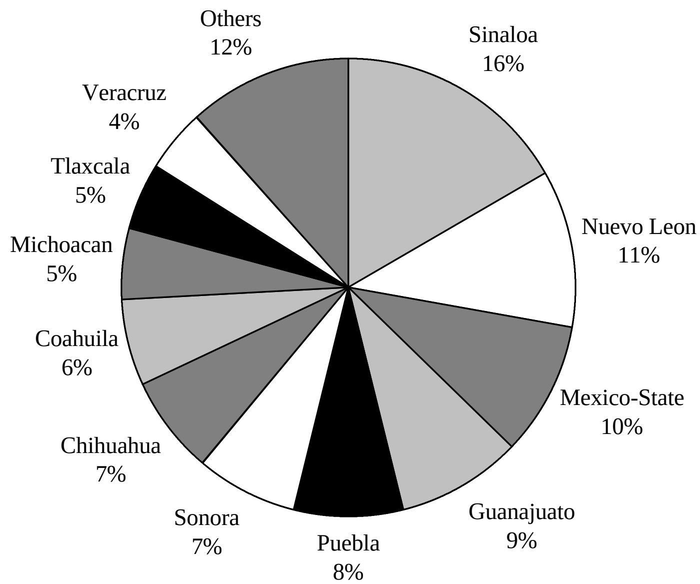
Table A 1: Regional indicators of potato production in Mexico

State	Production (t)	Area (ha)	Yield (t/ha)	Farm-Gate Price (M$/t)	Irrigated Prod.	Share of Red Varieties	Production Share of Farm Types Small	Medium	Large
Northern States									
Baja California	7589	289	26.6	2232.54	1.00	0.00	0.00	0.34	0.66
Baja California Sur	672	47	14.2	2238.85	1.00	0.00	0.00	0.00	1.00
Chihuahua	83590	6312	13.3	2278.95	0.76	0.00	0.00	0.37	0.64
Coahuila	76414	2084	36.6	3171.95	0.99	0.00	0.00	0.11	0.89
Durango	4362	622	7.0	3133.10	0.29	0.00	1.00	0.00	0.00
Nayarit	2432	141	16.3	1631.63	1.00	0.00	0.50	0.50	0.00
Nuevo Leon	138940	4217	32.9	3239.77	1.00	0.00	0.00	0.08	0.92
San Luis Potosi	814	48	11.1	4477.35	1.00	0.00	0.20	0.50	0.30
Sinaloa	205263	8992	22.8	2351.06	1.00	0.00	0.00	0.16	0.85
Sonora	90516	3536	25.6	2224.84	1.00	0.00	0.00	0.20	0.80
Zacatecas	27902	908	30.8	3059.48	1.00	0.00	0.06	0.64	0.30
Total North	**638495**	**27196**	**23.5**	**2650.1**	**0.96**	**0.00**	**0.01**	**0.19**	**0.80**
Central and Southern States									
Aguascalientes	15150	686	22.4	2798.67	1.00	0.00	0.00	0.50	0.50
Chiapas	11255	1240	9.1	2987.49	0.00	0.30	0.74	0.26	0.00
Distrito Federal	1892	132	14.2	2591.42	0.00	1.00	0.14	0.61	0.26
Guanajuato	109709	4119	26.6	2706.91	1.00	0.00	0.00	0.10	0.90
Guerrero	232	19	8.0	3928.88	0.00	0.00	1.00	0.00	0.00
Hidalgo	24770	1349	18.4	2041.29	0.33	0.70	0.20	0.33	0.48
Jalisco	46469	1233	37.8	1882.52	0.02	0.00	0.06	0.31	0.64
Mexico-State	118814	6370	18.5	2539.05	0.39	0.35	0.30	0.30	0.40
Michoacan	63114	3294	19.0	2003.58	0.76	0.00	0.17	0.38	0.45
Morelos	1557	108	14.7	2011.81	0.00	0.35	0.00	1.00	0.00
Puebla	95765	8643	11.1	2091.90	0.44	0.60	0.37	0.31	0.33
Tlaxcala	57675	3216	17.7	1603.69	0.15	0.75	0.38	0.37	0.26
Veracruz	54644	4849	11.3	1739.28	0.00	0.60	0.38	0.26	0.36
Total Central and S.	**601046**	**35257**	**17.0**	**2222.76**	**0.46**	**0.30**	**0.23**	**0.28**	**0.48**
Total Mexico	**1239540**	**62454**	**19.8**	**2442.89**	**0.72**	**0.15**	**0.12**	**0.24**	**0.64**

Notes: Data on production, area, yield and farm-gate prices are arithmetic averages from the 1994-1996 period. Farm-gate prices are inflated to 1996 Mexican pesos by agricultural price indices (INEGI, 1997b). Farm types are separated by hectares grown with potatoes: small-scale: <5ha, medium-scale: 5-20 ha, large-scale: >20 ha.

Sources: SAGAR (1994, 1995, 1996); For share of red varieties and production shares of farm types SAGAR/INIFAP (1997) supplemented by information from the author's interview survey (1998).

Figure A 1: Production shares of the main potato producing states of Mexico (1996)



Source: SAGAR (1996).

Table A 2: Cumulative technology adoption under the current seed distribution system
(without special distribution mechanism)

	Small-Scale		Medium-Scale		Large-Scale	
Year	**PVX-PVY**	**PVX-PVY-PLRV**	**PVX-PVY**	**PVX-PVY-PLRV**	**PVX-PVY**	**PVX-PVY-PLRV**
1999	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	0.000	0.000	0.234	0.000
2001	0.000	0.000	0.000	0.000	0.469	0.000
2002	0.044	0.000	0.100	0.000	0.690	0.007
2003	0.087	0.000	0.200	0.000	0.690	0.013
2004	0.131	0.002	0.300	0.002	0.690	0.020
2005	0.174	0.003	0.400	0.004	0.690	0.020
2006	0.218	0.005	0.500	0.006	0.690	0.020
2007	0.261	0.006	0.500	0.008	0.690	0.020
2008	0.290	0.008	0.500	0.010	0.690	0.020
2009	0.290	0.009	0.500	0.010	0.690	0.020
2010	0.290	0.010	0.500	0.010	0.690	0.020
2011	0.290	0.010	0.500	0.010	0.690	0.020
2012	0.290	0.010	0.500	0.010	0.690	0.020
2013	0.290	0.010	0.500	0.010	0.690	0.020
2014	0.290	0.010	0.500	0.010	0.690	0.020
2015	0.290	0.010	0.500	0.010	0.690	0.020

Note: In this Table, it is assumed that Alpha is not endowed with resistance to PLRV over the whole period. This assumption will be modified in other scenarios.

Source: Author's calculations based on assumptions explained in section 4.4.1.

Table A 3: Cumulative technology adoption under the assumption of a specially established seed distribution mechanism for transgenic Rositas

	Small-Scale		Medium-Scale		Large-Scale	
Year	**PVX-PVY**	**PVX-PVY-PLRV**	**PVX-PVY**	**PVX-PVY-PLRV**	**PVX-PVY**	**PVX-PVY-PLRV**
1999	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	0.000	0.000	0.234	0.000
2001	0.000	0.000	0.000	0.000	0.469	0.000
2002	0.044	0.345	0.100	0.135	0.690	0.007
2003	0.087	0.690	0.200	0.270	0.690	0.013
2004	0.131	0.692	0.300	0.272	0.690	0.020
2005	0.174	0.693	0.400	0.274	0.690	0.020
2006	0.218	0.695	0.500	0.276	0.690	0.020
2007	0.261	0.696	0.500	0.278	0.690	0.020
2008	0.290	0.698	0.500	0.280	0.690	0.020
2009	0.290	0.699	0.500	0.280	0.690	0.020
2010	0.290	0.700	0.500	0.280	0.690	0.020
2011	0.290	0.700	0.500	0.280	0.690	0.020
2012	0.290	0.700	0.500	0.280	0.690	0.020
2013	0.290	0.700	0.500	0.280	0.690	0.020
2014	0.290	0.700	0.500	0.280	0.690	0.020
2015	0.290	0.700	0.500	0.280	0.690	0.020

Note: In this Table, it is assumed that Alpha is not endowed with resistance to PLRV over the whole period. This assumption will be modified in other scenarios.

Source: Author's calculations based on assumptions explained in section 4.4.1.

Table A 4: Shift factor *K* without and with seed distribution mechanism for transgenic Rositas
(Alpha not included for PLRV)

	Small-Scale		Medium-Scale		Large-Scale	
Year	**Without Distribution Mechanism**	**With Distribution Mechanism**	**Without Distribution Mechanism**	**With Distribution Mechanism**	**Without Distribution Mechanism**	**With Distribution Mechanism**
1999	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	0.000	0.000	0.008	0.008
2001	0.000	0.000	0.000	0.000	0.017	0.017
2002	0.003	0.112	0.007	0.036	0.026	0.026
2003	0.007	0.224	0.013	0.072	0.027	0.027
2004	0.010	0.228	0.020	0.079	0.027	0.027
2005	0.014	0.232	0.027	0.086	0.027	0.027
2006	0.018	0.235	0.034	0.093	0.027	0.027
2007	0.022	0.239	0.034	0.093	0.027	0.027
2008	0.024	0.242	0.035	0.094	0.027	0.027
2009	0.025	0.242	0.035	0.094	0.027	0.027
2010	0.025	0.243	0.035	0.094	0.027	0.027
2011	0.025	0.243	0.035	0.094	0.027	0.027
2012	0.025	0.243	0.035	0.094	0.027	0.027
2013	0.025	0.243	0.035	0.094	0.027	0.027
2014	0.025	0.243	0.035	0.094	0.027	0.027
2015	0.025	0.243	0.035	0.094	0.027	0.027

Note: *K* is derived as the potential unit cost reduction multiplied by the technology adoption rate (cf. chapter 2).

Source: Author's calculations.

Table A 5: Shift factor *K* without and with seed distribution mechanism for transgenic Rositas
(Alpha included for PLRV)

Year	Small-Scale		Medium-Scale		Large-Scale	
	Without Distribution Mechanism	With Distribution Mechanism	Without Distribution Mechanism	With Distribution Mechanism	Without Distribution Mechanism	With Distribution Mechanism
1999	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	0.000	0.000	0.008	0.008
2001	0.000	0.000	0.000	0.000	0.017	0.017
2002	0.003	0.112	0.007	0.036	0.048	0.048
2003	0.007	0.224	0.013	0.072	0.063	0.063
2004	0.021	0.238	0.035	0.094	0.092	0.092
2005	0.028	0.246	0.045	0.104	0.092	0.092
2006	0.043	0.260	0.067	0.126	0.092	0.092
2007	0.058	0.274	0.089	0.148	0.092	0.092
2008	0.072	0.288	0.112	0.171	0.092	0.092
2009	0.085	0.302	0.112	0.171	0.092	0.092
2010	0.095	0.312	0.112	0.171	0.092	0.092
2011	0.095	0.312	0.112	0.171	0.092	0.092
2012	0.095	0.312	0.112	0.171	0.092	0.092
2013	0.095	0.312	0.112	0.171	0.092	0.092
2014	0.095	0.312	0.112	0.171	0.092	0.092
2015	0.095	0.312	0.112	0.171	0.092	0.092

Note: *K* is derived as the potential unit cost reduction multiplied by the technology adoption rate (cf. chapter 2).

Source: Author's calculations.

Table A 6: Annual technology-induced changes in economic surplus in the 'No Trade' scenarios
(in thousand 1996 M$)

	Alpha Not Included for PLRV							
	Without Distribution Mechanism				With Distribution Mechanism			
	Producers				Producers			
Year	Small	Medium	Large	Consum.	Small	Medium	Large	Consum.
1999	0	0	0	0	0	0	0	0
2000	-1184	-2368	10718	9881	-1184	-2368	10718	9881
2001	-2466	-4930	22355	20595	-2466	-4930	22355	20595
2002	-2909	-3201	33613	35656	39021	14691	16372	62600
2003	-2123	1212	34266	41358	86574	38720	-1570	97597
2004	-1091	6328	34791	47766	91352	45478	-2524	106367
2005	184	12184	33916	53361	96540	53054	-4928	114415
2006	1568	18529	32910	59340	102002	61194	-7526	122949
2007	3432	19531	33717	62671	108138	63970	-8391	128923
2008	4895	20634	34664	65974	114022	66920	-9187	134978
2009	5346	21468	36043	68800	119013	69673	-9625	140665
2010	5740	22343	37497	71715	124129	72546	-10064	146560
2011	5978	23269	39052	74689	129276	75554	-10481	152636
2012	6225	24234	40671	77785	134636	78686	-10916	158965
2013	6483	25239	42357	81010	140218	81949	-11369	165556
2014	6752	26285	44113	84369	146031	85346	-11840	172420
2015	7032	27375	45942	87867	152086	88885	-12331	179568

	Alpha Included for PLRV							
	Without Distribution Mechanism				With Distribution Mechanism			
	Producers				Producers			
Year	Small	Medium	Large	Consum.	Small	Medium	Large	Consum.
1999	0	0	0	0	0	0	0	0
2000	-1184	-2368	10718	9881	-1184	-2368	10718	9881
2001	-2466	-4930	22355	20595	-2466	-4930	22355	20595
2002	-6325	-10032	64914	64382	35502	7800	47552	91418
2003	-7828	-10214	86666	89427	80523	27094	50424	145973
2004	-8117	-3319	128077	146105	83900	35664	90043	205331
2005	-5588	3946	129946	157487	90417	44674	90362	219202
2006	-473	22812	127203	176623	99838	65552	86039	240976
2007	5095	43385	124021	197091	109902	88233	81216	264195
2008	11145	65780	120370	218970	120649	112839	75857	288943
2009	19079	67846	123602	230795	133571	116844	77257	303686
2010	25075	70199	127506	242270	144625	121221	79249	318196
2011	26114	73110	132792	252315	150621	126247	82535	331388
2012	27197	76141	138298	262776	156866	131481	85957	345128
2013	28325	79298	144032	273671	163370	136933	89520	359437
2014	29499	82585	150003	285018	170143	142610	93232	374340
2015	30722	86009	156223	296835	177197	148523	97097	389860

Source: Author's calculations.

Table A 7: Annual technology-induced changes in economic surplus in the 'Trade' scenarios
(in thousand 1996 M$)

	Alpha Not Included for PLRV							
	Without Distribution Mechanism				With Distribution Mechanism			
	Producers				Producers			
Year	Small	Medium	Large	Consum.	Small	Medium	Large	Consum.
1999	0	0	0	0	0	0	0	0
2000	-1184	-2368	10718	9881	-1184	-2368	10718	9881
2001	-2466	-4930	22355	20595	-2466	-4930	22355	20595
2002	-2909	-3201	33613	35656	39021	14691	16372	62600
2003	-2123	1212	34266	41358	86574	38720	-1570	97597
2004	3266	12566	46249	0	73923	50419	46249	0
2005	4457	16962	46249	0	75191	54918	46249	0
2006	5648	21370	46249	0	76460	59430	46249	0
2007	6841	21649	46249	0	77730	59715	46249	0
2008	7687	21928	46249	0	78631	60000	46249	0
2009	7837	21928	46249	0	78790	60000	46249	0
2010	7936	21928	46249	0	78896	60000	46249	0
2011	7936	21928	46249	0	78896	60000	46249	0
2012	7936	21928	46249	0	78896	60000	46249	0
2013	7936	21928	46249	0	78896	60000	46249	0
2014	7936	21928	46249	0	78896	60000	46249	0
2015	7936	21928	46249	0	78896	60000	46249	0

	Alpha Included for PLRV							
	Without Distribution Mechanism				With Distribution Mechanism			
	Producers				Producers			
Year	Small	Medium	Large	Consum.	Small	Medium	Large	Consum.
1999	0	0	0	0	0	0	0	0
2000	-1184	-2368	10718	9881	-1184	-2368	10718	9881
2001	-2466	-4930	22355	20595	-2466	-4930	22355	20595
2002	-6325	-10032	64914	64382	35502	7800	47552	91418
2003	-7828	-10214	86666	89427	80523	27094	50424	145973
2004	6545	22340	158074	0	77414	60422	158074	0
2005	8936	28296	158074	0	79961	66516	158074	0
2006	13433	42631	158074	0	84747	81184	158074	0
2007	17948	57093	158074	0	89553	95977	158074	0
2008	22482	71679	158074	0	94377	110895	158074	0
2009	27035	71679	158074	0	99220	110895	158074	0
2010	30081	71679	158074	0	102460	110895	158074	0
2011	30081	71679	158074	0	102460	110895	158074	0
2012	30081	71679	158074	0	102460	110895	158074	0
2013	30081	71679	158074	0	102460	110895	158074	0
2014	30081	71679	158074	0	102460	110895	158074	0
2015	30081	71679	158074	0	102460	110895	158074	0

Note: Free trade within the NAFTA region is assumed from 2004 onwards.

Source: Author's calculations.

Table A 8: Financial cost of the technology project
(in thousand 1996 M$)

Year	All Scenarios					Distribut. Mechanism	Alpha Incl. for PLRV
	Rockefeller Found.	CINVESTAV	Monsanto	ISAAA	Institutional Cost		
1991	666	144	760	152	0	0	0
1992	666	182	380	152	0	0	0
1993	666	160	190	152	50	0	0
1994	666	220	190	152	50	0	0
1995	666	144	152	152	50	0	0
1996	152	144	152	152	50	0	0
1997	405	144	152	76	50	0	0
1998	253	144	152	76	50	0	50
1999	253	144	152	76	50	0	100
2000	0	144	0	76	50	0	100
2001	0	72	0	0	50	0	50
2002	0	4	0	0	50	40000	0
2003	0	4	0	0	0	40000	0
2004	0	4	0	0	0	0	0
2005	0	4	0	0	0	0	0
2006	0	4	0	0	0	0	0
2007	0	4	0	0	0	0	0
2008	0	4	0	0	0	0	0
2009	0	4	0	0	0	0	0
2010	0	4	0	0	0	40000	0
2011	0	4	0	0	0	40000	0
2012	0	4	0	0	0	0	0
2013	0	4	0	0	0	0	0
2014	0	4	0	0	0	0	0
2015	0	4	0	0	0	0	0

Note: Values given in US dollars have been converted to Mexican pesos by the average 1996 exchange rate:
1 US$ = 7.60 M$ (INEGI, 1997b).

Source: Author's interview survey (1998).

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