Ten Years of Genetically Modified Crops in Argentine Agriculture

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About ArgenBio:

ArgenBio (Argentine Council for Information and Development of Biotechnology) is a non-profit organization whose mission is to make available information on biotechnology, contributing to its understanding through education and promoting its development.

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EXECUTIVE SUMMARY

The first genetically modified (GM) crop incorporated into Argentina's agriculture was herbicide-tolerant soybeans. From that date on, almost 900 field tests have been conducted on different crops and traits and nine additional events have been released commercially both for maize and cotton (herbicide tolerance and insect resistance). A rapid diffusion process of these technologies followed. In the last growing season, GM varieties represented over 90% of planted area with soybeans, 70% in the case of maize and 60% for cotton. Along this process, Argentina has become the second largest producer of GM crops, after the United States, with over 17 million hectares planted.

The magnitude of the area with GM Technologies constitutes an important fact by itself, but the speed at which the adoption process evolved is even more significant. In Argentina, these new technologies were made available to farmers at the same time as in the countries of origin and their adoption occurred at surprisingly high rates, exceeding the ones recorded for other successful technologies that preceded them, such as hybrid maize and wheat varieties with Mexican germplasm. In the case of soybeans, it took only seven years for the GM varieties to occupy virtually all the area planted with the crop. This outcome was the result of a number of determinants that converged to make it possible. Among them, it is worth mentioning a number of policy changes that improved the dynamics of the growth process in the agricultural sector but, most of all, the fact that by the time when these technologies were made available, Argentina had already in place a set of institutions, such as standards for risk and biosafety analysis. On the other hand, the special synergy resulting from the interaction between no-till practices and GM soybeans has been another determining factor of its rapid adoption, since it allowed a "virtual" expansion of the agricultural frontier, by means of expanding the area suitable for double cropping, in which soybeans follows wheat in the same season.

This process of incorporation of new technologies has had a deep transforming impact, not limited to Argentina's agricultural sector, but including the economy as a whole. Benefits generated by all three GM crops were estimated, based on results from a mathematical simulation model, SIGMA, developed by INTA, on excess of 20 billion US dollars. In the case of herbicide-tolerant soybeans, total accumulated benefits for the 1996-2005 period, net of substitution for other activities (sunflower, cotton, pastures) were estimated at 19.7 billion US dollars, distributed as follows: 77.45% to the farmers, 3.90% to seed suppliers, 5.25% to herbicide suppliers and 13.39% to the National Government (revenues collected through an export tax, imposed in 2002). In the case of maize with insect resistance, total accumulated benefits for the 1998-2005 period were estimated at 481.7 million US dollars, distributed among farmers (43.19%), seed suppliers (41.14%) and the National Government (15.67%). Finally, for insect-resistant cotton, total accumulated benefits for the 1998-2005, were estimated at 20.8 million US dollars, with the following distribution: 86.19% to farmers, 8.94% to seed suppliers and 4.87% to the National Government.

Based on data collected for the 2002 National Agricultural Census, it was calculated that 49,064 farms, (less than 15% of the total, some 333 thousand) had planted soybeans in the previous growing season. Out of that number, more than 90% were located in the Pampean Region, suggesting that the far-reaching farming systems' transformation process that was triggered by the release of herbicide-tolerant soybeans has in fact been mostly a "pampean" story. Small farms, less than 100 hectares in size, devoted 70% of available land to plant soybeans. On the other end of the spectrum, farms with 1,000 hectares or more devoted just 27% of available land to soybeans. The implications of these results are far-reaching: they make clear that small farmers chose, as part of a profit-maximization strategy, to rely heavily on this crop, in order to contribute to the (short-term) economic viability of their farms, strategy that is, naturally, inconsistent with the inter-generational (long-term) environmental sustainability of these farming systems (given that they are, for all practical purposes, monocultures). This inconsistency arises as a pressing issue that should be addressed from the public policy side to strike a balance between the private socio-economic and the social environmental sustainability dimensions. The above described strategy, selected by small farmers, does not appear to be causally linked with the commercial availability of herbicide-tolerant soybean varieties, in 1996: replicating the analysis presented in this section, but with data from the 1988 Agricultural Census, it can be shown that, by the 1987/1988 growing season, almost a decade before the introduction of the new technology, farms with less than 100 hectares, were already planting soybeans in 65% of the available land.

A process of this nature and magnitude is not, of course, free both of costs, particularly related to both the quality and the productivity of the natural resources involved and of indirect effects on the rest of the economy. With respect to the magnitude of the area planted with soybeans and its negative implications on the fertility of soils, the cost of “restocking” the soils with the phosphorus exported with the beans over the 10-year period, was estimated at 2.3 billion US dollars (11.6% of total benefits). This means that, even if corrective measures to compensate for the loss of fertility were to be taken, net benefits would still exceed 17 billion US dollars.

As to the indirect impacts, the document discusses the mechanisms by which the expansion of the soybean crop, attributable to the release of materials with tolerance to herbicides, induced positive effects on the productivity of livestock production systems, both, beef and dairy. In this regard, it was estimated that, during the period 1996-2005, the area with pastures has suffered a reduction of more that 5 million hectares, without a decrease in output of beef and a strong recovery in the production of milk (in both cases, there is a net positive balance for those 10 years). These increases in productivity have not been recorded by the statistics, due to the fact that the yield indicators commonly used, that is, extraction rate (slaughtered heads per year / stock), in the case of beef and volume of milk for dairy, are computed without reference to the area on which that output is produced.

From a more general perspective, the impacts of the above described process on the gross domestic product (GDP) and other economic variables, such as job creation, were analyzed. It was concluded that the release of herbicide-tolerant soybeans may have contributed to the creation of almost 1 million jobs (whole economy-wide), representing a 36% of the total increase in employment over the period under study. Following the same line of thought, it was estimated that the total benefits of this technology would have been enough to finance the construction of 28 million square meters, almost a 22% of the total area for which permits were issued.

Finally, an analysis was made of the impact on consumer, at the world level, of the increase of production of soybeans in Argentina attributable to the release of herbicide-tolerant varieties, through the drop in the price that the commodity would have reached in absence of that additional output. This accumulated savings in consumer spending was estimated at almost 26 billion US dollars.

All of these aspects, when taken together, highlight the fact that the first decade of GM crops in argentine agriculture has been a period of large benefits, not only for the agricultural sector, but for the economy as a whole. By now it has become clear that this process has not been one free of both costs and uncertainties, issues that remain open and should be addressed and widely debated from now on. On the other hand, it would have been surprising if a transformation process of the magnitude of the one above described did not have consequences of this nature. The tremendous expansion of the soybean crop has lead to a strong repositioning of agriculture within both the economy and the foreign trade of the country, which has raised concerns about the possible negative impacts of the “soyafication” process, on the one hand, due to the excessive dependence of exports on one single commodity and, on the other, due to its implications associated with the future fertility of the country’s soils and the potential detrimental effects of the crop expansion on fragile ecosystems. These concerns, as well as others that have not been addressed in the document, like, for instance, the future evolution of the international context for this type of technologies, are totally legitimate, but they should not be considered as a demerit of the clearly positive balance of the first decade of GM crops in Argentina. Nevertheless, they do emphasize the need for a debate that should take place, on ways to, both, optimize the potential of new innovations in this field, which seems to be growing on a daily basis, and limit the potential negative effects that they might cause. It is worth noting that a realistic look at the new technologies that might be forthcoming, leads to the conclusion that it is very unlikely that one like the case of herbicide-tolerant soybeans will be available in the near future.

CHAPTER 1
INTRODUCTION

Technological change is one of the key elements for the agricultural development and the improvement of farmers´ income. The dependency of the agricultural production on a fixed factor, land, and the nature of the agricultural products markets are at the source of its relevance. At the farmer's level, income is dependent directly on the productivity of available resources, given the fact that, for each individual farmer, price is an exogenous variable of his economic equation, non-modifiable from his perspective. This lack of flexibility is an incentive for the constant incorporation of technology as the only means to achieve a sustained income increase. This behavior also reflects in the sector aggregates and becomes an important determinant of its evolution and participation in the economy.

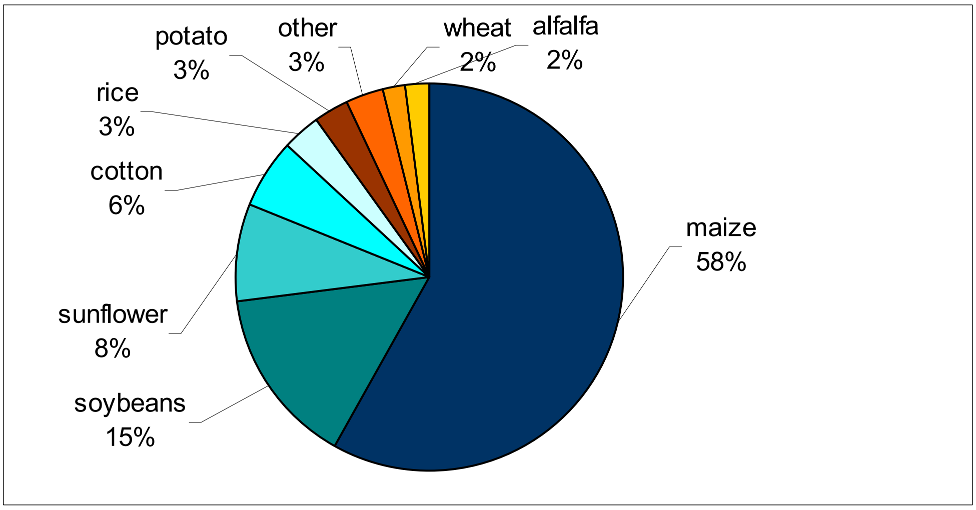
The decreasing participation of Argentina in the agricultural markets, during most of the past century, was the reflection of the agricultural sector's inability to adopt new technologies and the stagnation of its productivity (Obschatko. 1988, Barsky (ed.), 1991 and Barsky and Pucciarelli, 1997, among others). The changes over the last two decades show the reversion of this trend and the onset of a new cycle in which output grows rapidly to top 80 million tons of cereals and oilseeds. This growth has reflected both in a strong surge in exports –that reclaim part of the ground lost in the last decades– and in an increase of the sector's share in the GDP as well as its contribution to employment: in 2003, the number of jobs, adding the farm sector and the agroindustrial complex–, was one million higher than in 1997 levels (Llach, 2004).

Among the set of factors that determined these transformations, it is worth mentioning some of the structural reforms (such as privatizations of certain areas of infrastructure) and the economic policies implemented at the beginning of the 90´s (elimination of tax exports, reduction of import tariffs on capital goods and the opening of the economy), as well as the irruption, in the national production scenario, of a set of technological innovations, like genetically modified (GM) crops and no-till practices. These two technologies reinforced each other's potential, setting the stage for a new cycle of sector behavior. This document summarizes the key issues of this process and follows up with the evaluation of the economic benefits accrued from it as well a its distribution among the agents that play a part in the process of diffusion of these technologies. Including this introduction, the present study consists of four chapters. The second one briefly summarizes the most relevant issues dealing with the rate of adoption of these technologies by farmers, as well as some of the main hypothesis dealing with the determinants of the observed innovation dynamics. The third chapter focuses, mainly, on the sector-wide effects resulting from the innovation process, while the final chapter focuses on the analysis of the most relevant economic benefits resulting from it. This document concludes with some considerations on the nature of the process itself and touches on issues that have not been addressed but will need attention in a near future.

CHAPTER 2
GM CROPS IN ARGENTINE AGRICULTURE

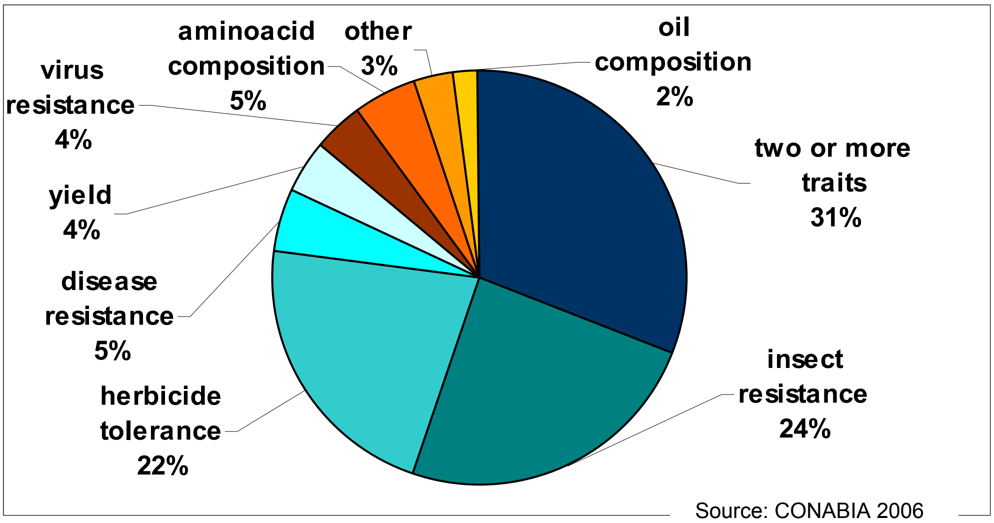
The first GM crop introduced in Argentina's agriculture was glyphosate-tolerant soybeans, released in 1996. Since then, field tests have been authorized for 883 events (Figure 2.1), being maize, soybean, sunflower and cotton, the crops with the largest share, although similar technologies are being field-tested in other important crops, such as wheat, rice and potato, as well as in forage crops (alfalfa). The most important events within that period are: herbicide tolerance, insect resistance and stacked ones (those that combine both traits), although, over the last years, other events, related to quality and abiotic stress tolerance, have also been tested (Figure 2.2).

Figure 2.1: Field tests by crop (1991-2005)



Source: CONABIA 2006

Figure 2.2: Field tests by trait (1991-2005)



In commercial terms, however, the number of innovations that have reached the market is notoriously lower and, after the release of herbicide-tolerant soybeans, only nine other events have been approved for commercial use: three herbicide-tolerant maize hybrids, three Lepidoptera-resistant maize hybrids (Bt), one herbicide-tolerant cotton variety, one Lepidoptera-resistant cotton variety, and one Lepidoptera-resistant and ammonium gluphosinate-tolerant maize hybrid (Table 2.1).

Table 2.1: Events released for commercialization in the Argentine market

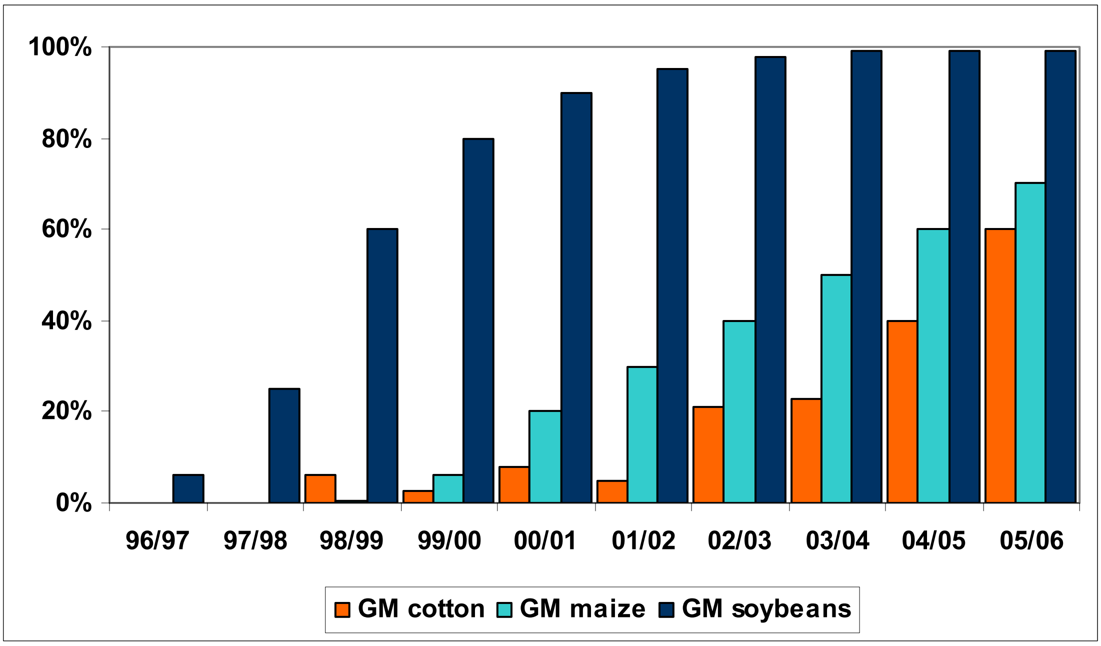
Species	Introduced feature	Applicant	Year of release
Soybeans	Glyphosate tolerance (40-3-2)	Nidera S. A.	1996
Maize	Lepidoptera resistance (176)	Ciba-Geigy	1998
Maize	Ammonium gluphosinate tolerance (T25)	AgrEvo S. A.	1998
Cotton	Lepidoptera resistance (Mon 531)	Monsanto Argentina S.A.I.C.	1998
Maize	Lepidoptera resistance (Mon 810)	Monsanto Argentina S.A.I.C.	1988
Cotton	Glyphosate tolerance (Mon 1445)	Monsanto Argentina S.A.I.C.	2001
Maize	Lepidoptera resistance (Bt 11)	Novartis Agrosem S.A.	2001
Maize	Glyphosate tolerance (NK 603)	Monsanto Argentina S.A.I.C.	2004
Maize	Lepidoptera resistance and Ammonium gluphosinate tolerance (TC 1507)	Dow AgroSciences S.A. y Pioneer Argentina S.A	2005
Maize	Glyphosate tolerance (GA 21)	Syngenta Seeds S.A.	2005

Source: CONABIA 2006

At the field level, for the 2004/05 season, out of approximately 16.5 million hectares planted with GM crops in Argentina, about 14 million hectares (nearly 86% of the total) were planted with herbicide-tolerant soybeans, about 2 million hectares with planted with maize (mostly Bt, since herbicide-tolerant maize has reached the market only very recently) that represents 13% of the total area and, finally, the remaining 1% (about 160 thousand hectares) were planted with cotton (105 thousand hectares with herbicide-tolerant, and 55 thousand with Bt). At the world level, these numbers position Argentina, in total planted area with GM crops, in second place, behind the United States, followed by Brazil and Canada with 9.4 and 5.8 million hectares, respectively (James 2005).

However, the most relevant aspect of the release of GM crops in Argentina's agriculture is not related only to the magnitude of its share –which is undoubtedly important– but to the fact that its release happened at the same time those technologies were made available abroad and also to its subsequent adoption path. At the farm level (Figure 2.3), towards the end of the first decade since the introduction of these technologies, virtually 100% of the area planted with soybeans was GM (herbicide-tolerant, HT), and nearly 70% of the area planted with maize was GM (Bt and HT), which describes an adoption process that proceeded at an unprecedented rate, only comparable to the case of hybrid maize in the state of Iowa (USA), during the 1930s, though much higher than both, the adoption rate of that same technology in the other states of the American "corn belt" and, later, what happened in other regions of the world with the so-called "green revolution" technologies. In Argentina, this adoption process compares favorably even with other agricultural innovations, such as hybrid maize and wheat with Mexican germplasm. It took 18 years for hybrid maize to reach 70% of the currently adoption level of GM maize, and Mexican wheat reached the current adoption level of soybeans (more than 90% of the market) after 16 years (López 2006). Several factors can be argued to explain this behavior.

Figure 2.3: TEvolution of the share of GM crops of the total planted area, by species



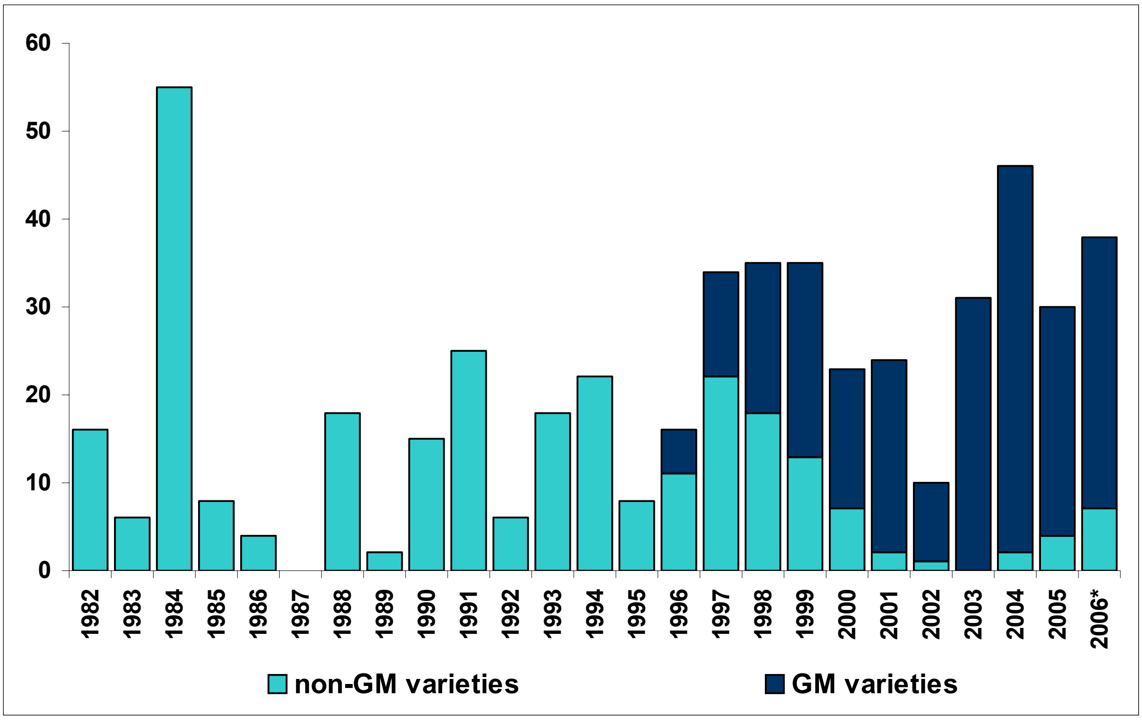
Source: ArgenBio 2006.

The nature of these technologies and the remarkable similarities between the agroecological conditions of the regions for which they were originally developed and those of the Pampean Region are, undoubtedly, important factors that explain why they were commercially available for that growing region in such a short period of time. These conditions not only facilitate the technology transfer –since it requires relatively little adaptation– but also constitute a powerful incentive to promote such transfer: the 26 million hectares of the argentine humid Pampas are almost the natural environment for the expansion of the technologies outside its "niche" or market of origin, for which they were developed.

A second relevant aspect is the fact that Argentina already had a consolidated technological service infrastructure that worked as a platform for the incorporation of new technological concepts. It is widely accepted that the commercial success of GM varieties requires both, the incorporation of the new genes to a genetic base that is well adapted agronomically to the local conditions and the existence of a seed industry able to deliver quickly and effectively the new varieties to the farmers. In the case of Argentina, both conditions were met.

By the time the first transgenic event (herbicide-tolerant soybeans) came along, there was a significant amount of ongoing plant breeding activity in Argentina, both in the public and private sectors, with a total of 147 registered soybean varieties, 15% originated in the public sector (mainly INTA) and the remainder in the private sector, which allowed the new genes to be rapidly incorporated to the productive cycle. From 1997 onwards, there is a quantitative leap forward in the number of registered varieties (Figure 2.4), most of them being GM varieties. According to Giancola (2002), by 1999-2000 season, 64% of the registered varieties were genetically modified, all of them developed by private firms (Nidera, Novartis, Pioneer, Monsanto and Don Mario), a share that kept increasing until it reached, at present, levels in excess of 85%.

Figure 2.4: Evolution of GM and non-GM soybean varieties registered in Argentina in the National Registry of Cultivars



* January - October 2006
Source: INASE, 2006

A third relevant aspect that explains the rate of incorporation of the new technologies is the fact that, by the time they came along, Argentina had already made progress in the development of the institutional framework required for the appropriate management of these technologies. On the one hand, since the 1970s, Argentina had in place the institutional framework for the protection of intellectual property and breeders' rights of plant varieties (Seed and Phytogenetic Creations Law, # 20247). On the other, in 1991, it was established, within the Secretariat of Agriculture, Livestock, Fisheries and Food (SAGPyA in Spanish), the National Advisory Committee for Agricultural Biosafety (CONABIA in Spanish), which is in charge of evaluating the risk of the new biotechnological events. This last feature was one of singular relevance, even though, at the time, the international debate on transgenics was not as heated and conflictive as it would become later on. The sheer existence of CONABIA, an institution highly regarded, not only for its scientific and technical merits but also for the transparency of its procedures, gave assurances to the public opinion as to the "safe use" of the new technologies and, at the same time, made it possible to avoid conflicts in the international trade arena, since it placed the soybeans produced in Argentina in the same standing as both, that of its competitors and of the export markets (The European Union, mainly) where the new events had also been released for commercial use, conditional upon the observance of the relevant biosafety requirements. [1]

Finally, the high dynamics of the adoption process also reflects the synergy between herbicide-tolerant soybeans and no-till farming (NTF) and, further along the cycle, the significant drop in the price of glyphosate, which was the result of the expiration of the patent on it and the multiplication of the supply sources of that product. [2]

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[1] For a more in-depth analysis of these issues, see Trigo, et. al. (2002)

[2] No-till consists basically on the placement of the seed in the soil at the required depth with a minimum disturbance of the soil structure. This is achieved through the use of machinery specially designed to that effect that eliminates the need for plowing and other tillage practices that were required to implant the crop.

No-till farming started to gain relevance in argentine agriculture by the end of the 1980s, due to the fact that, in many of the most important zones of the Pampean Region, the cumulative effects of soil erosion (resulting from "agriculturalization" based on traditional farming practices) already began to manifest itself as a drop in yields and, thus in the profitability of the farms[3]. This effect on the yields and, consequently, on the economic viability of agriculture, along with the fact that not only did the availability of adequate agricultural machinery improved (as a result of the opening of the economy) but also that the direct costs were reduced due to the elimination of tillage practices, were the optimum platform for the diffusion of no-till farming and to gain back at least some of the lost productivity. Its synergy with herbicide-tolerant soybeans items from the fact that no-till practices, by shortening the time span between wheat harvest and soybeans planting, enables the use of short-cycle soybeans as a double crop to take advantage of that window of opportunity and thus, makes a wheat-soybeans double cropping system a feasible option for areas in which that option was not available before.

This effect has been, no doubt, one of the main economic determinants of the changes in farmers' behavior, which was reinforced, towards the end of the 1990s and the beginning of the 2000s, by the accelerated drop in the price of glyphosate (it went from 10 US D/litre, by the end of the 90s, to less than 3 US Dollars/litre in 2000).

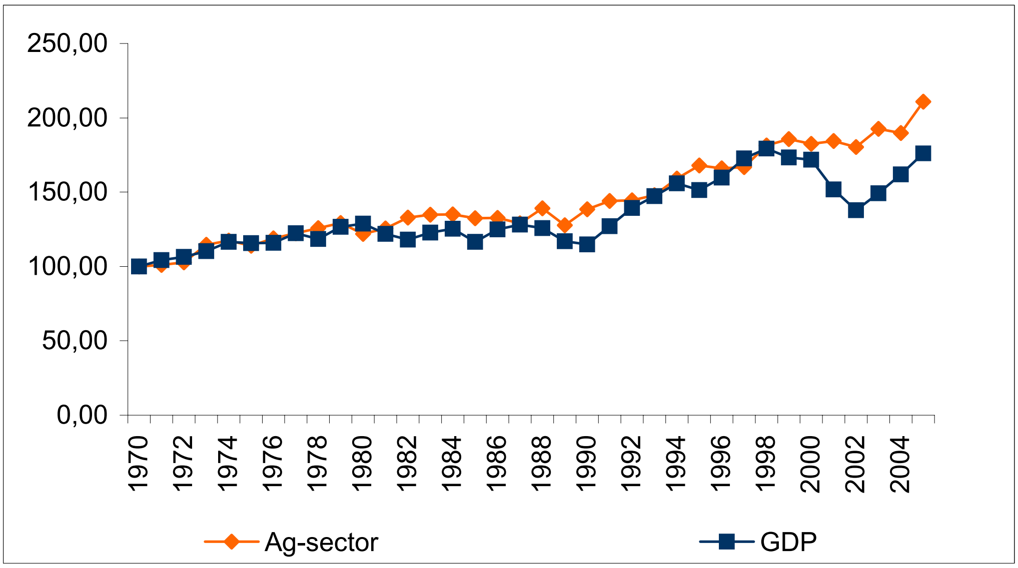
[3] "Agriculturalization" implies the substitution of the crop-pastures rotation systems, which were the prevailing productive strategy until the mid 70´s.

CHAPTER 3

THE PERFORMANCE OF THE AGRICULTURAL SECTOR DURING THE PERIOD 1996-2006

The agroindustrial complex accounts for over 30% of the goods component of the GDP and it shows itself as one of the most dynamic sectors of the economy. Moreover, it has steadily sustained positive growth even during the so called “Tequila Crisis” in 1995, as well as during the collapse of the convertibility system (in which the value of the US dollar was fixed by law at one peso), when the economy suffered a dramatic contraction, from which it is still recovering (Figure 3.1).

Figure 3.1: Evolution of the Argentine GDP and the Value Added contributed by the Agricultural Sector (1970-2006) - (Index of Physical Volume Base 1970=100)



Source: the authors, based on data by the National Ministry of Economy, Works and Public Utilities.

This evolution of the sector is based on the stunning growth of primary production –which rose from 38 million tons of grains and oilseeds, in 1990/91, to more than 80 million, in 2004/05– (Figure 3.2) that has translated into both, a significant increase in grains and oils exports (Figure 3.3) and an accelerated transformation and repositioning process of the agrifood sector.

This process includes significant investments downstream from the primary production –namely storage infrastructure, processing, ports- and a significant inflow of international capital to finance its activities, as well as mergers and acquisitions. [4] [5] [6]

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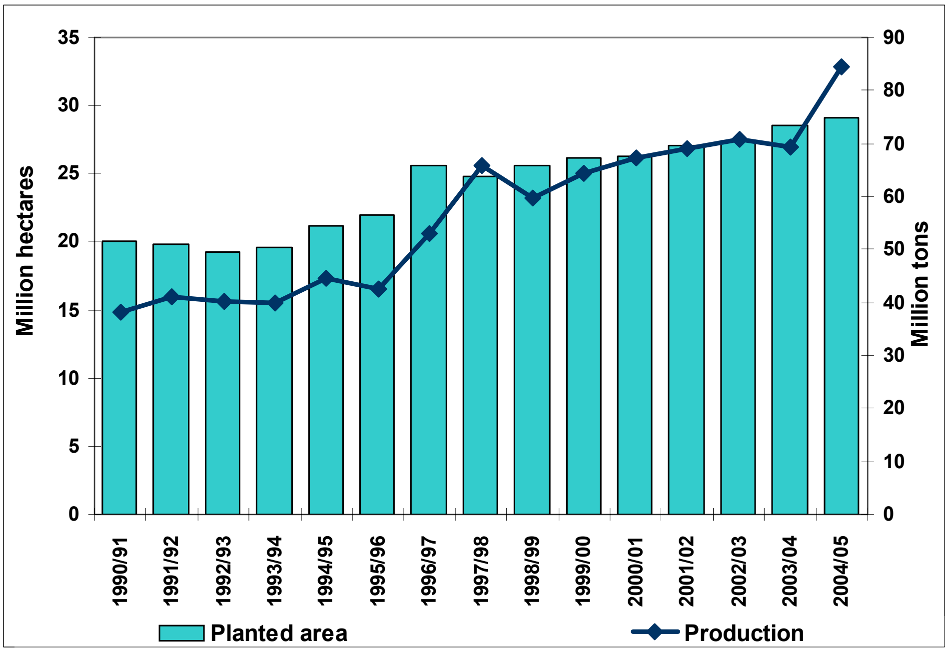
[4] The installed capacity for crushing of soybeans, sunflower and combined ones, went from 15 million tons/year in the mid 90´s to 45 million at the present time (www.ciaracec.com.ar). In parallel with this growth, a large foreign capital inflow took place, reflected by the fact that 60% of installed capacity is currently in the hands of multinational corporations (López, 2006).

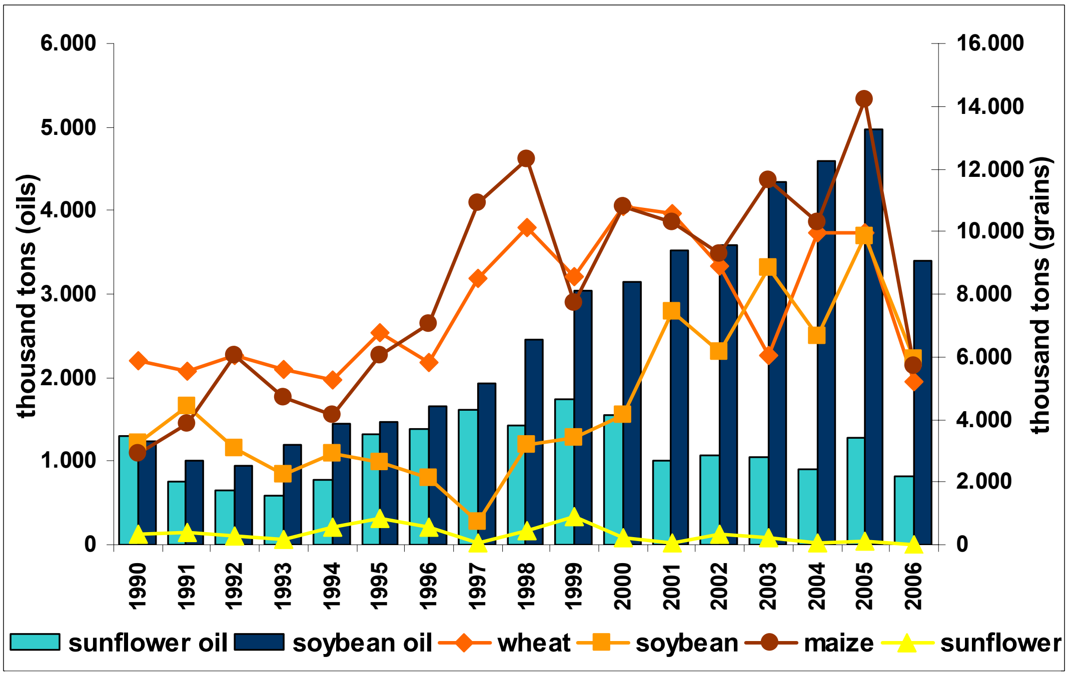
[5] The flow of foreign capital into the primary sector has also been important, but, in this case, the most relevant feature is the strong growth of variations of the so-called “sowing pools” and fiduciary funds, as tools for financing farm activities, through which land ownership becomes detached from farm management, that is transferred to companies that outsource the remaining production factors. Although no reliable data is available neither on the extension of this practice nor on the size of the funds that are channeled through them, some sources have estimated that they might represent close to 50% of total production of grains and oilseeds (Álvarez, 2003).

Figure 3.2: Argentina: Evolution of Planted Area and Agricultural Production



Source: SAGPyA

Figure 3.3: Argentina: Evolution of grains, oilseeds and oil exports



Source: SAGPyA

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[6] IICA. "Informe de Coyuntura. Sector Agroalimentario Argentino" (Status Report. Argentine Agrifood Sector). Instituto Interamericano de Cooperación para la Agricultura (Inter American Cooperation Institute for Agricultura). Several Issues; 2000-2005.

This transformation, whose onset coincided with the change, in the 1990´s, in the orientation of the macroeconomic policies, involves almost every commodity, although grains and oilseeds (maize, wheat, soybeans and sunflower) and the Pampean region, have been, without a doubt, its flagship sectors. [7] This evolution is attributable to the combination of two clearly differentiated factors, linked to economic variables (relative prices of commodities) and technological variables that include a significant expansion of the planted area and the increase of productivity of land (yield), that resulted from a remarkable adoption process of the new technologies. In the Pampean Region, the increase in the planted area was done at the expense of pastures, and by the growth of double cropped soybeans, mainly, following wheat –in what may be considered a "virtual" expansion of the agricultural frontier-. Something similar occurred in the Northwestern and Northeastern region where, between the 1988 and 2002 agricultural census, the planted area rose from 2.5 to 4.3 million hectares. A significant part of this area came from pastures as well as land that originally was covered by native forests that had undergone a degradation process.

As to the technological change process, it is worth mentioning that it includes not only the intensification in the way of an increased use of fertilizers, agrochemicals (herbicides and insecticides) and farm machinery, but also a substantial change in terms of genetic inputs: the introduction of GM crops or transgenics in Argentina's agriculture (as it has already been discussed in the previous chapter). [8]

To summarize, the changes in productive trends described above seem to suggest that the reorientation of the macroeconomic policies that had been in place until 1990, were a point of inflexion in the productive behavior of the farm sector (especially in the case of cereals and oilseeds) and the choice of a new strategy, significantly more intensive in the use of technological inputs. The mobilizing agent of the process has been a deep change in the expectations of the economic agents (both within and outside of the farm sector) in the sense that, on the one hand, farm sector and its associated value chains would no longer be discriminated against in favor of other sectors of the economy and, on the other, that the rent seeking opportunities created by the economic policies that were in place until then (multiple exchange rates, for instance), and by inflation, were a thing of the past. It is worth noting that the elimination of the export tax, by itself, would have hardly been able to catalyze a process of the magnitude of the one unleashed: its effect would have been comparable to an equivalent increase in world prices, which is something that has happened numerous times along the history of the farm sector, with little structural consequences. This perception has been extensively confirmed when one looks at what has happened during the period of time that followed the economic crisis that led to the collapse of the convertibility system in 2002: the trends that were prevalent in the period of time preceding this event, far from reverting themselves, tended to get stronger and the relative importance of the farm sector within the national economy increased significantly.

This assertion can be discussed and analyzed from several perspectives, but that task is beyond the scope of this document. Having said that and with the aim of moving forward in the discussion of possible futures, as well as set the right fundamentals for the evaluation of the effects of the above described transformations, it is worth addressing, on the one hand, some questions dealing with environmental issues and, on the other, the evolution of the social indicators linked to agricultural production.

With regard to environmental issues, the key question to be asked is whether, as a consequence of the "intensification" of Argentina's agriculture, it has lost its label as an

[7] Rice, cotton, other cereals, and regional products, such as wine and citrus fruits, have also shown a significant production and productivity growth, but not of a magnitude comparable to the one recorded for cereals and oilseeds.

[8] A good indicator of this evolution is what happens with the use of fertilizers, which goes from 1.2 million tons in 1995 to more than 2.5 million tons in 2005. For a more detailed analysis on the subject of trends and impacts of technological change, see Manciana *et.al.* (2006).

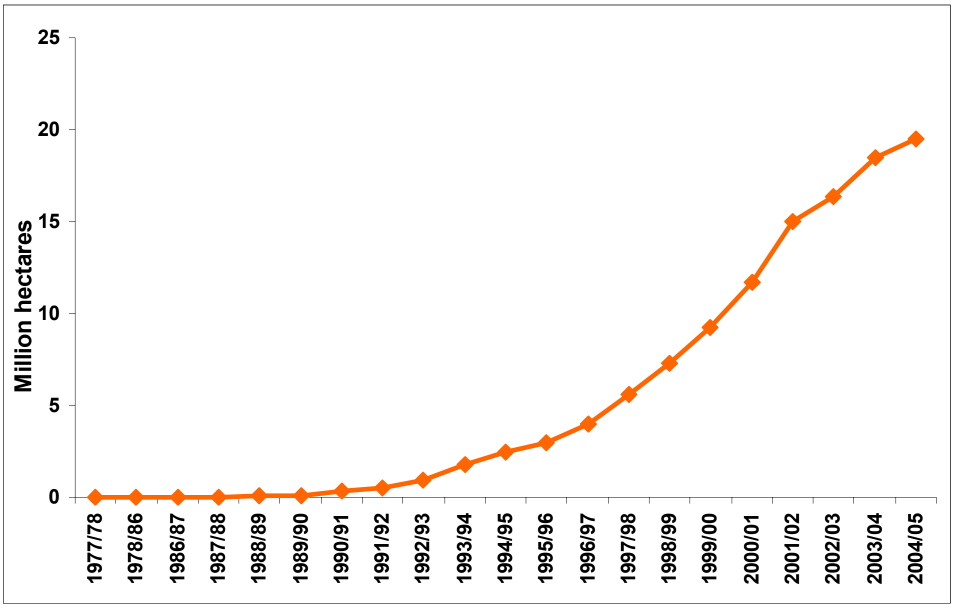
"environment friendly" producer it used to hold while its farming strategies were based on extensive production systems. As to the social dimension, the discussion centers around the evolution of the farming sector structure and the contributions that it has made to alleviate the negative effects of the crisis that started with the fall of convertibility, in 2002.

3.1 Environmental impacts of agricultural intensification

From the standpoint of the environmental impact of the enormous increase in Argentina's agricultural production during the past decade, the main issue at stake is the fact, already referred to in a previous section of this document, that this growth has taken place, *pari pasu,* with a phenomenal expansion of no-till farming practices that became the main crop management strategy in the pampean region.

As it is shown in figure 3.4, that charts the evolution of total planted area under no-till, the use of this practice has gone from 300 thousand hectares in 1990/91, to over 19 million hectares in the 2004/05 growing season. This increase had its source in a number of determinants, mentioned in a previous section, that converged to induce a behavioral change but, from the perspective that is of interest to us, the most important feature is the nature of the interaction between GM soybeans and no-till farming.

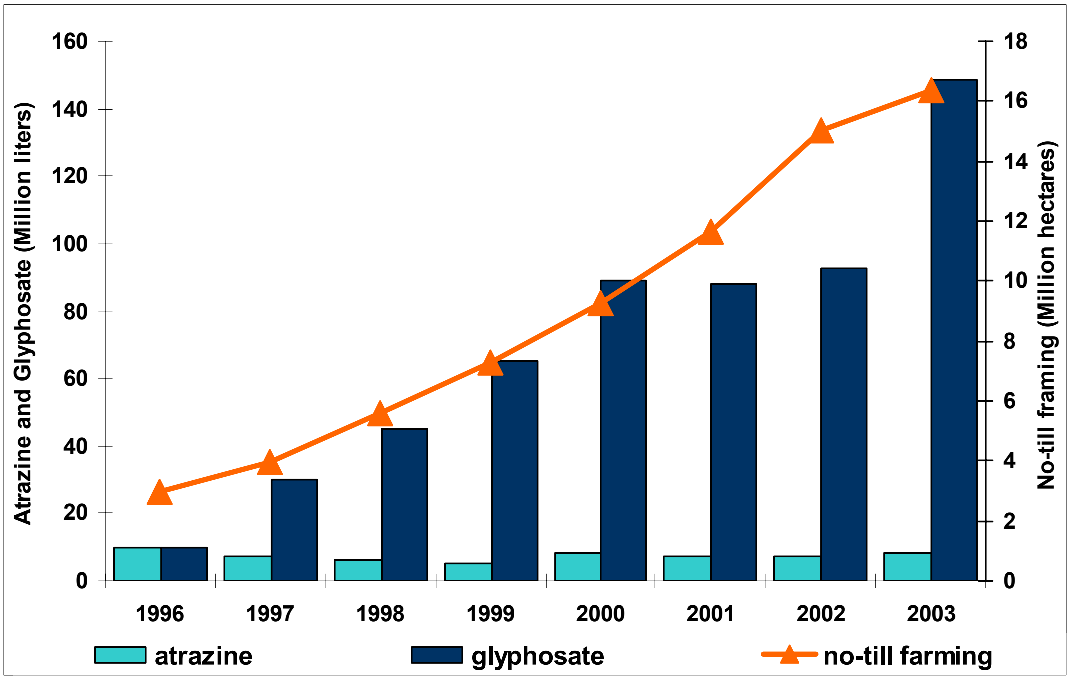
Figure 3.4: Evolution of total area planted with no-till farming



Source: AAPRESID, 2006

The combination NTF + herbicide-tolerant soybeans integrates two technological concepts, one of them consists on new mechanical technologies that modify the soil-crop interaction; the other one is based in the use of a total herbicide (glyphosate) that is environmentally neutral, due to its high effectiveness to control all kind of weeds and its lack of residual effects. Both these concepts imply a higher intensity of input use, which is generally described as "hard" intensification. However, as can be seen in figure 3.5, this "hard" intensification is, at the same time, an environmentally friendly one, since it has induced a parallel reduction in the use of atrazine, which is a herbicide that has high residual effects and, as such, is environmentally negative. It is hard to quantify the benefits of this synergy between herbicide-tolerant soybeans and no-till farming, but one cannot ignore the potential positive effects on soil fertility and thus, on present and future land productivity. The same holds for other positive externalities, such as its contribution to the mitigation of the "greenhouse effect".[9] [10]

Figure 3.5: Evolution of the area planted with no-till farming and type of herbicide used



Sources: AAPRESID and CASAFE

Table 3.1 reinforces the arguments made above, but from the standpoint of the public health risks due to intoxication by herbicides. In this regard, according to the classification of the World Health Organization (1998), glyphosate is included in the group of herbicides of toxicity Class IV, "virtually non-toxic" and, according to 2001 data, the release of herbicide-tolerant soybeans triggered a substantial increase in the use of glyphosate, both in total volume and in the number of applications, but it also induced an 83% drop in the use of herbicides Class II and the total phasing out of the ones classified as Class III, both of them more dangerous to human health.[11]

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[9] From the standpoint of the recovery of the soil organic matter content, Casas (2005), indicates that in no-till farming systems with crop rotations that include wheat, maize or sorghum, the annual soil losses are lower than 2t/ha, way under the tolerable maximum (10t/ha). However, in a good portion of the planted area, much of this potential benefits would be lost as a result of the monoculture of soybeans.

[10] Some experimental data (To the Rescue of the Environment, La Nación Campo, October 24, 1998), suggest that NTF, substituting for conventional tillage practices, could sequester up to 17 million metric tons of carbon (MMTC) for each million hectares. Extrapolating these numbers to Argentina, the 16 million hectares farmed under no-till in 2004/2005, would be able to sequester up to 272 MMTC. This subject could be eventually turned into an asset for the argentine negotiating position in the framework of the Kyoto Protocol, which includes the formalization of an international clearing market for carbon emissions (it is worth mentioning, though, that this market of sinks and emissions has been thought of for countries included in Annex I, to which Argentina does not belong). A study by the School of Agriculture of the University of Buenos Aires (FAUBA) and the National Institute for Agricultural Technology (INTA) quoted by López (2006), points in the same direction, since it reports that, based on the monitoring of 3.3 million hectares over a period of 9 years, the increase in organic matter content, in soils farmed under no-till, is equivalent to the sequester some 40t/ha of atmospheric carbon dioxide.

[11] Although this study dates back to 2001, there are no relevant reasons to argue that this relationship has changed significantly with the increase on the use of GM varieties that followed.

Table 3.1: Class and utilization of herbicides on conventional and glyphosate-tolerant soybean

	Conventional Soybeans	Glyphosate-tolerant soybeans	Percentage change
# of applications of herbicides	1,97	2,30	+16,8
Total herbicide used (l/ha)	2,68	5,57	+107,8
Class II toxicity herbicides (l/ha)	0,42	0,07	-83,3
Class III toxicity herbicides (l/ha)	0,68	0,00	-100,0
Class IV toxicity herbicides (l/ha)	1,58	5,50	+248,1

Source: Qaim and Traxler (2002) quoted on Trigo *et al*. (2002)

The fact that the above mentioned synergy has been highlighted does not imply that the implicit risks of the relative low levels of fertilization recorded for Argentina, in terms of loss of nutrients, are being ignored. The same applies to the deterioration of the fragile ecosystems in the northwestern and northeastern regions (NOA and NEA, their Spanish acronyms), that have been just recently added to the areas planted with soybeans[12]. Regarding this last case, the fact is that there is little objective information to assess the impacts of this process. However, it is worth mentioning that, although soybeans have been the main component of "agriculturalization", this process started quite some time before its irruption in Argentina's agricultural scenario and a good portion of the area currently planted with soybeans was already under cultivation. One frequently mentioned concern, that is, the threat to the biodiversity and the environmental services provided by some of the ecosystems of those regions, such as the so called "Yungas", appears to have been somewhat exaggerated, since the changes in farming systems are restricted to the foothills plains, while the sloped foothills and hills, where most of the several hundred of thousand hectares of Yungas' biodiversity and its sources of environmental services are located, are not threatened by the expansion of soybeans (see Grau, Gasparri y Aide, 2005). In other "new" soybeans growing areas, such as North of Córdoba, North of Santa Fe and Chaco, the changes in soil use seem to be in response to other determinants and, moreover, they can be traced back to before soybeans appeared on the picture (Zak and Cabido, 2005; Paruelo and Oesterheld, 2004). Among the most significant ones, changes in rainfall patterns, that made it possible to farm land that could not be farmed before.

In summary, from the environment standpoint, the process that has spanned two decades shows has positive elements as well as uncertainties. This should not be surprising, since, in general terms, agriculture becomes less sustainable as it is makes a more intensive use of factors and inputs and this is a cycle that has been taking place since ancient times, although it should keep constituting a source of concern and at the same time, induce a constant search for alternatives in the way of both technologies and farm policies. One conclusion that stands out from this analysis is that the NTF + herbicide-tolerant soybeans package improves on the preexisting farming systems, but it is also clear that, by itself, it does not solve all the sustainability issues linked with agricultural intensification. The evolution of this ongoing process should be monitored, so as to anticipate problems that might arise from it, even more so when new agroecological

[12] Casas (2006) states that *"if one considers, as an example, the annual consumption of nutrients by crops, it is observed that it reaches 4 million tons, while its replenishment is slightly higher than 1 million tons of nutrients per year (equivalent to 2.5 million tons of fertilizers). This simple equation indicates a 25 to 30 percent replenishment level, with a negative balance that will most certainly condition the goals in productivity at a national level*". Following the same line of thought, Fontanetto (2004), quoted on SAGPyA's website (http://www.sagpya.mecon.gov.ar/new/0-0 /agricultura/otros/granos/fertilizantes.php), arrived to similar conclusions, by estimating that net exports of soils, in 2004, could be set at a figure between 5.5 to 7.0 million tons.

zones are being incorporated to soybeans production. Attention should be granted not only to soil fertility issues, but also to those dealing with disease and pest control.

3.2 Some indicators of the social impact of farming system changes

As to the social dimension of the above described process, the large diversity of situations involved and, in many cases, the lack of reliable information makes it hard to make a clear assessment of its potential implications. Nevertheless, the analysis of available data provides enough information to challenge some of the widely quoted consequences of this process, like the alleged increase in the rate of rural-urban migration, as well as the role of the farm sector in the socio-economic dimension, that seems to have a much more strategic role than when looked at solely from its strictly economic contribution, like, for instance, its share on total exports.

Looking at the farm consolidation process, according to data from the 1988 and 2002 Agricultural Census, total number of commercial farms dropped by 20.9% (from 421 to 333 thousand, respectively). It should be noted, however, that this does not constitute a break in the pre-existing decades long trend, since the annualized rate of the differences between the last two census (around 1.8%) remains within the range observed since the late 1960´s. This same trend has been recorded for other important agricultural producers, such as Canada, Australia and the United States, all of them sharing with Argentina a common technological development path, that is, a preeminence of labor-saving technologies that, naturally, induce consolidation of farms, so as to take advantage of economies of scale, made possible by the introduction of ever bigger and more powerful farm equipment. [13]

As to the subject of social impacts stemming from the significant changes in farming systems in the "new" soybeans areas, that is, NEA and NOA, a recent study by the School of Agriculture of the University of Buenos Aires (Paruelo and Oesterheld, 2004), based on data from the 1988 and 2004 Agricultural Census and covering 96 counties in the provinces of Formosa, Chaco, Santiago del Estero, Salta, Santa Fe and Corrientes, finds a significant increase in the population of those counties, as well as a reduction in the share of households with "unsatisfied basic needs" (NBI, for its acronym in Spanish), which is a proxy for poverty, of 3.6% (average for the region), 7,5% for Chaco, 8% for the Salta counties included in the study and 1.1% for Santiago del Estero. It is worth mentioning that no correlation was found, for those counties where agriculture grew most, between this process and the above mentioned reduction in NBI[14].

Looking at the status of farm employment, according to data from the Directorate of National Accounts, for the period 1993-2005, total number of jobs in the farm sector has remained stable, at a level that oscillates between 1.2 and 1.3 million. However, the methodology used by the National Institute of Statistics and Census (INDEC, for its Spanish acronym) to classified this data, might be underestimating the labor market share of the farm sector, since it does not include, in the category of farm sector jobs, certain activities directly related with it, such as those involved in animal health services. These figures are, nevertheless, a solid piece of evidence of the contribution of the sector, even more so if one takes into consideration the fact that the labor market status, for that same period, worsened to the point where the unemployment rate hit one of the

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[13] This is a process that took place (and still does) in most countries with exporting farm sectors. In the United States, for instance, the average farm size tripled between 1934 and 1994, reaching 448 acres, some 168 hectares (Economic Research Service. *Structural and Financial Characteristics of U.S. Farms*, 1994: 19th Annual Farm Report to Congress. AIB-735. August 1997). If not for the federal crop programs´ umbrella (set-asides, deficiency payments, etc), this process would have most likely intensified. That same study by the Economic Research Service (USDA) (*Op. Cit.*), states that 66% of all commercial farms in the United States get subsidies.

[14] This result could be attributed to the fact that this correlation, should it exist, would be found at the local level (town), but this cannot be confirmed empirically, since data on NBI is only available at county level (Martín Osterheld, 2006, personal communication).

highest levels in history, which makes the stability observed in the number of jobs of farm sector even more significant.

One final issue worth rising in connection to the changes in farming systems brought about by the release of herbicide-tolerant soybeans, has to do with its contribution to the tax revenues collected by the National Government. To the preexisting tax burden on the farm sector and following the fall of the convertibility monetary system in 2002, an additional tax, this time an *ad-valorem* one on agricultural exports, was imposed. According to recent estimates (López, 2006), the soybeans complex's total accumulated tax bill since then, amounts to 6.1 billion dollars, 3.5 billion of which can be attributed to the increase in production linked to the release of herbicide-tolerant varieties. The following chapter will include a more in-depth analysis of the subject.

CHAPTER 4

ECONOMIC IMPACTS OF THE GM CROPS RELEASE IN ARGENTINE AGRICULTURE

4.1 Introduction and methodological approach

The analytical tool used to estimate the economic impacts of GM events availability in Argentina's agricultural sector is a dynamic simulation model (SIGMA), developed by INTA (National Institute of Agricultural Technology). The model replicates, through simulations, the situations that occur in the field in countries like Argentina, that show a great diversity of technological and productive realities, that cannot be attributed to agroecological differences but to socio-economic factors (both at the micro and macro levels).

The key component of the model is the replication of the farmer's adoption process of technological innovations that introduce changes in the production function, inducing a more efficient use of resources, which in turn leads to a reduction in unit costs and/or to an improvement in the quality of the product (expressed as an increase in price) and/or to an expansion of the area potentially suitable for its commercial production.

The model can be used for both, *ex-ante* and *ex-post* analysis and the final result is an estimation of the effects on aggregate output (regional or national) of alternative scenarios for R&D and adoption of technology. That is, SIGMA calculates the additional output that could be produced (both in volume and in value), with reference to a given baseline, by the adoption (along paths that differ according to the farmer's profile), of technologies already available commercially or still in the R&D process (for further details, see Annex I).

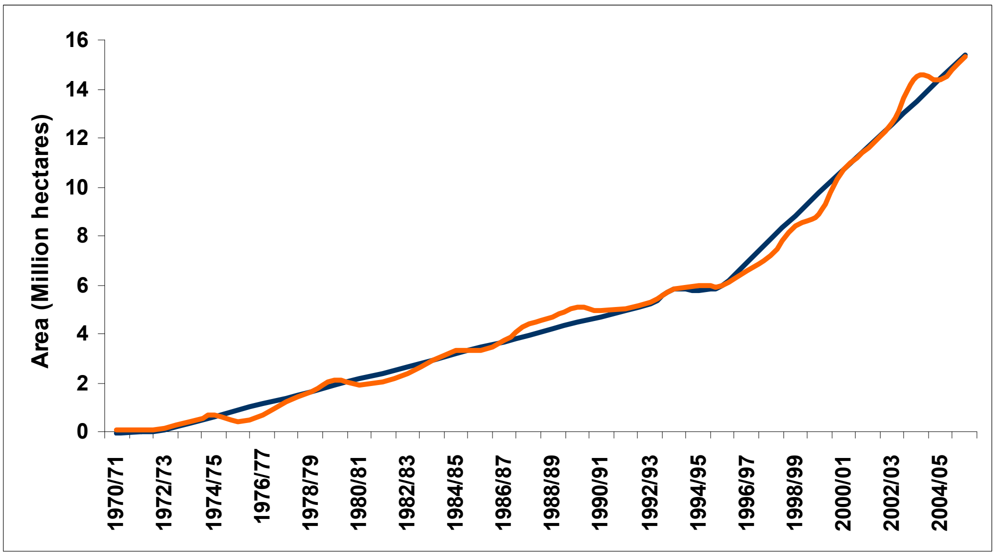
Most of the data used in the simulation runs described in this chapter (broken down at the homogeneous agroecological zone level), were taken from the *Technological Profile of Argentina's Agricultural Sector* (INTA, 2002), ArgenBio, INDEC and FAO.

4.2 The case of herbicide-tolerant soybeans

The introduction of glyphosate tolerant GM soybeans in the argentine market, in 1996, marked the beginning of a process whose effects and implications have not, after ten years, been fully analyzed and evaluated.

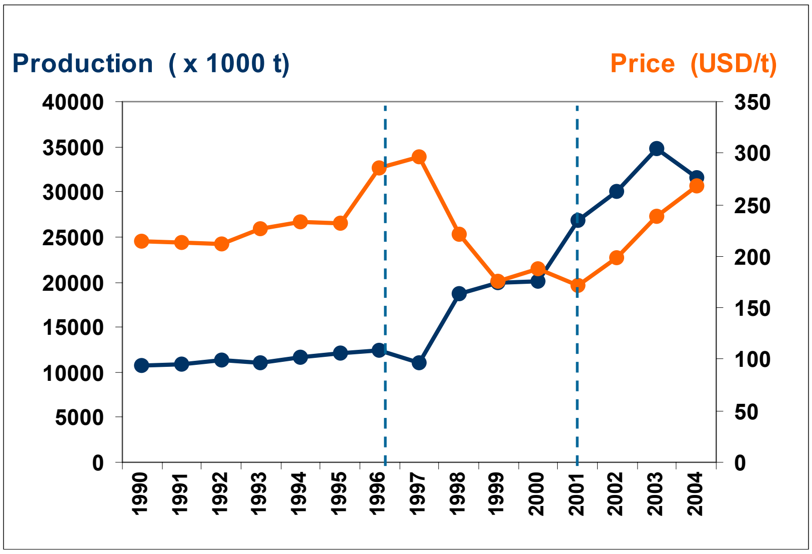
The magnitude of this change can be fully appreciated if one looks at the evolution of the area planted with soybeans in Argentina, which underwent a dramatic upward change in trend in 1996-97, when the annual rate of increase in planted area tripled (from 3.3 to 10%/year) to remain at that level to this date (see Figure 4.1).This process was not driven by the traditional market forces, according to which, the allocation of land to different productive activities is the outcome of changes in relative prices of the products that compete for available land. Generally, the response of the farmers (measured by the final land allocation among commodities) is a function of the product supply price-elasticities, both own and cross. Let us take a closer look at the case of soybeans. Figure 4.2 shows the evolution of both production in Argentina and of FOB prices.

Figure 4.1: Argentina: Evolution of the area planted with soybeans (1970/71 - 2005/06)



Source: Brescia, V. (2006), based on data from SAGPyA

Figure 4.2: Argentina: Evolution of soybean production and prices (FOB-Buenos Aires)



Source: SAGPyA (2006)

Between 1996 and 2001, the supply of soybeans in Argentina (that is, the visible manifestation of the optimizing decisions made by thousands of individual farmers), behaved as if the price-elasticity of that particular commodity simply had the wrong sign (the prices dropped and the supply increased). The truth of the matter is that the supply response was not to an increase in product price but to the introduction of a new technology that lowered the production costs but, additionally, reduced the inelasticity of supply of land suitable for its cultivation. This means that the farmers´ optimization equation included for the first time an increase in the stock of potentially available land (at the tune of millions of hectares). Another section of this document will look at this subject and will address its technological and economic implications.

4.2.1 The direct economic impacts

Within this context, the estimation of the economic impacts of the introduction of the new technology (GM soybeans) was done assuming the existence of two main sources of benefits. The first one is an average cost reduction of 20 US dollars/ha[15], as a result of the adoption of the new technology. This benefit applies to, both, soybeans as a first crop as well as to those that are part of a double-cropping scheme (after wheat) and it is caused by the elimination of inputs and practices associated with the use of selective pre and post-emergent selective herbicides, required in the case of conventional varieties. Thus, this particular benefit accrues each year to the entire planted area, adjusted by the accumulated adoption rate estimated for that year. Figure 4.1 shows a summary of the values calculated, consolidated at the national level.

Table 4.1: Evolution of gross benefits of the introduction of GM soybeans-Costs reduction.

SEASON	AREA WITH GM SOYBEANS (ha)	GROSS BENEFITS (M USD)
1996/97	370,000	7.40
1997/98	1,800,000	36.00
1998/99	4,875,396	97.51
1999/00	6,870,511	137.41
2000/01	8,783,542	175.67
2001/02	10,381,943	207.64
2002/03	11,756,084	235.12
2003/04	13,057,989	261.16
2004/05	14,407,585	288.15
2005/06	15,859,058	317.18
		1,763.24

Source: the authors, based on data from ArgenBio and the results of SIGMA simulation runs.

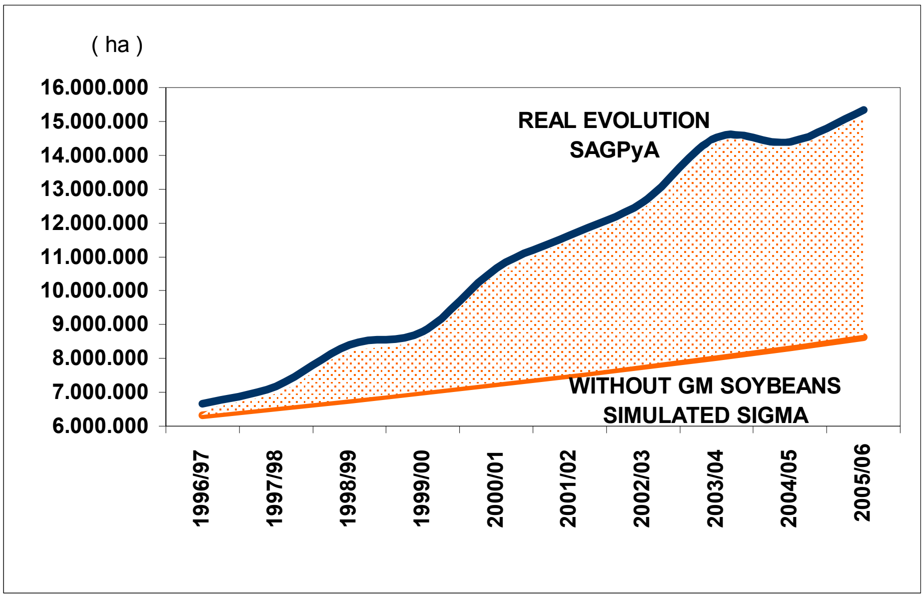
The second source of benefits has its source in the expansion of the area planted with soybeans, above the trend pre-existing before 1996. This occurred through two mechanisms: the first one was the increase in double-cropping, especially through the combination no-till farming–GM soybeans. This implies that this segment of the area expansion took place without substitution for other crops. The second one is the widening of the "agricultural frontier" of soybeans towards non-Pampean regions where it substituted for other crops, especially cotton and also ventured into areas considered, until then, "marginal" for agriculture, where it substituted for livestock production, resulting in an increase in the stock of arable land, induced by a technological innovation.

In order to calculate this component of the benefits, a comparison was made between the observed evolution of the planted area (based on statistical data from SAGPyA) and the simulation (applying the SIGMA model) of "a past that did not happen", that is, the one would have described the evolution of the soybean growing area in Argentina, should the new technology had not been available. To that effect, a baseline was built for the 1996-2006 period, projecting the pre-1996 trend that is, assuming GM soybeans were made not available when they were and the resulting values were compared with the past that did happen. Figure 4.3 shows the graphical representation

[15] See Penna, J. and Lema, D. (2003). "Adoption of Herbicide Tolerant Soybeans in Argentina: An Economic Analysis" in *The Economic and Environmental Impacts of Agbiotech. A Global Perspective.* Nicholas Kalaitzandonakes (ed.). 2003. Kluwer Academic/Plenum Publishers, New York.

of both pasts. The quantitative differences between the observed and the simulated evolution have been summarized in Table 4.2. On the other hand, Table 4.3 summarizes the gross benefits that have accrued from the expansion of the area planted with soybeans, while Table 4.4 presents the combined benefits of both effects.

Figure 4.3: Evolution of the actual planted area (SAGPyA) vs. Planted area without the release of GM soybeans (simulated)



Source: the authors, based on SAGPyA data and SIGMA runs.

Table 4.2. Actual area planted with soybeans since the introduction of GM varieties (SAGPyA data) and simulated planted area without GM soybeans (SIGMA)

SEASON	PLANTED AREA (ha)		
	SAGPyA	SIMULATED WITHOUT GM SOYBEANS	GM DIFFERENCE
1996/97	6,669,500	6,291,689	**377,811**
1997/98	7,176,250	6,369,623	**806,627**
1998/99	8,400,000	7,107,989	**1,292,011**
1999/00	8,790,500	6,950,402	**1,840,098**
2000/01	10,664,330	8,206,674	**2,457,656**
2001/02	11,639,240	8,487,098	**3,152,142**
2002/03	12,606,845	8,675,062	**3,931,783**
2003/04	14,526,606	9,720,962	**4,805,644**
2004/05	14,399,998	8,616,285	**5,783,713**
2005/06	15,329,000	8,451,997	**6,877,003**

Source: the authors, based on SAGPyA data and SIGMA runs.

Table 4.3: Evolution of gross benefits of the introduction of GM soybeans due to the expansion of the area suitable for agriculture.

SEASON	PLANTED AREA GM DIFFERENCE (ha)	YIELD SAGPyA (t/ha)	FOB PRICE (USD/t)	GROSS BENEFITS (M USD)
1996/97	377,811	1.7212	296.50	**192.81**
1997/98	806,627	2.6937	221.83	**482.00**
1998/99	1,292,011	2.4450	175.33	**553.87**
1999/00	1,840,098	2.3312	187.42	**803.95**
2000/01	2,457,656	2.5846	171.50	**1,089.40**
2001/02	3,152,142	2.6304	198.00	**1,641.68**
2002/03	3,931,783	2.8034	238.42	**2,627.94**
2003/04	4,805,644	2.2075	268.08	**2,843.90**
2004/05	5,783,713	2.7285	230.67	**3,640.06**
2005/06	6,877,003	2.6421	225.56	**4,098.21**
				17,973.81

Source: the authors, based on data from SAGPyA and results from SIGMA simulation runs.

Table 4.4: Evolution of the total gross benefit of the introduction of GM soybeans

SEASON	GROSS BENEFITS ACCRUED BY COSTS REDUCTION (M USD)	GROSS BENEFIT ACCRUED BY AREA EXPANSION (M USD)	TOTAL GROSS BENEFITS OF GM SOYBEANS (M USD)
1996/97	7.40	192.81	**200.21**
1997/98	36.00	482.00	**518.00**
1998/99	97.51	553.87	**651.38**
1999/00	137.41	803.95	**941.36**
2000/01	175.67	1,089.40	**1,265.07**
2001/02	207.64	1,641.68	**1,849.32**
2002/03	235.12	2,627.94	**2,863.06**
2003/04	261.16	2,843.90	**3,105.06**
2004/05	288.15	3,640.06	**3,928.21**
2005/06	317.18	4,098.21	**4,415.39**
	1,763.24	**17,973.81**	**19,737.06**

Source: the authors, based on results from SIGMA simulation runs.

4.2.2 Benefits adjusted by the substitution effects between products and distribution among actors of the sector

The benefits estimated in the previous section need to be adjusted by the impact that the expansion of GM soybeans had on the areas allocated to other crops and/or activities, such as livestock production. The figure assigned to the change in area allocated for livestock (beef and dairy) was calculated through a process of elimination, assigning to that subsector the loss in hectares still unexplained once the reductions on the area planted with cotton and sunflower were accounted for (the changes for sorghum have been minor, with a net reduction of about 90 thousand hectares). Therefore, it has been estimated that, between 1996 and 2006, the area with pastures dropped by more than 5 million hectares. In all likelihood, a significant fraction of it is represented by the area actually planted with forage crops (especially in the case of dairy, but also applicable to beef in some regions). Table 4.5 summarizes the changes in area allocated to each activity throughout the last decade and Tables 4.6 to 4.8 show a summary on the procedure used to calculate the benefits of the introduction of the glyphosate-tolerant soybeans varieties, net of the substitution effects for other productive activities. Finally, Table 4.9 shows the evolution of the benefits of the introduction of GM soybeans, net of those substitution effects, as well as the accumulated value for the period under analysis that was of 19.82 billion US dollars.

Table 4.5: Changes in the area allocated for first crop-soybeans, double cropping soybeans, cotton, sunflower and pastures

SEASON	Δ ha	Δ ha	Δ ha	Δ ha	Δ ha
	SOYBEANS	DOUBLE CROPPING SOYBEANS	COTTON	SUNFLOWER	PASTURES
1996/97	667,345	838,800	-54,240	-290,850	516,545
1997/98	506,750	-575,900	177,590	391,650	-1,651,890
1998/99	1,223,750	-74,160	-382,220	732,400	-1,648,090
1999/00	390,500	442,010	-404,980	-656,800	1,113,290
2000/01	1,873,830	326,900	64,955	-1,610,880	-1,005
2001/02	974,910	232,510	-236,862	74,245	-579,783
2002/03	967,605	-431,581	-15,834	327,635	-1,710,987
2003/04	1,919,761	219,108	108,178	-530,037	-1,278,794
2004/05	-126,608	1,168,122	140,034	118,636	1,036,060
2005/06	929,002	141,917	-97,421	293,401	-983,065
95/96 - 05/06	**9,326,845**	**2,287,726**	**-700,800**	**-1,150,600**	**-5,187,719**

Source: the authors, based on data from SAGPyA.

Table 4.6: Changes on the planted area and production of cotton and its valuation

SEASON	Δ ha	Δ Q	COTTON		VALUE
	COTTON	COTTON	Price(USD/t)	Yield (t/ha)	Δ COTTON (M USD)
1996/97	-54,240	-62,966	400.00	1.1609	-25.19
1997/98	177,590	199,588	400.00	1.1239	79.84
1998/99	-382,220	-368,986	400.00	0.9654	-147.59
1999/00	-404,980	-509,356	400.00	1.2577	-203.74
2000/01	64,955	85,246	400.00	1.3124	34.10
2001/02	-236,862	-313,685	400.00	1.3243	-125.47
2002/03	-15,834	-21,895	400.00	1.3828	-8.76
2003/04	108,178	150,142	400.00	1.3879	60.06
2004/05	140,034	167,546	400.00	1.1965	67.02
2005/06	-97,421	-131,786	400.00	1.3528	-52.71
1995/96 - 2005/06	**-700,800**	**-806,153**			**-322.46**

Source: the authors, based on data from SAGPyA.

Table 4.7: Changes in planted area and production of sunflower and its value

SEASON	Δ ha	Δ Q	SUNFLOWER		VALUE
	SUNFLOWER	SUNFLOWER	Price (USD/t)	Yield (t/ha)	Δ SUNFLOWER (M USD)
1996/97	-290,850	-527,065	249.08	1.8122	-131.28
1997/98	391,650	658,340	280.58	1.6809	184.72
1998/99	732,400	1,282,846	196.67	1.7516	252.29
1999/00	-656,800	-1,146,509	160.58	1.7456	-184.11
2000/01	-1,610,880	-2,689,737	188.67	1.6697	-507.46
2001/02	74,245	141,627	233.29	1.9076	33.04
2002/03	327,635	523,481	246.75	1.5978	129.17
2003/04	-530,037	-912,837	251.75	1.7222	-229.81
2004/05	118,636	225,938	260.09	1.9045	58.76
2005/06	293,401	493,329	226.27	1.6814	111.63
1995/96 - 2005/06	**-1,150,600**	**-1,950,587**			**-283.05**

Source: the authors, based on data from SAGPyA.

Table 4.8: Changes in volume of beef and dairy production and its value

YEAR	Δ BOVINE MEAT (x1000 t) (cwe)	VALUE Δ BOVINE MEAT (M USD)	Δ FLUID MILK (M litres)	VALUE Δ FUILD MILK (M USD)
1996	26	31.20	-0.18	-0.03
1997	18	21.60	231.97	34.80
1998	-243	-291.60	470.14	70.52
1999	250	300.00	807.27	121.09
2000	0	0.00	-527.87	-79.18
2001	-251	-301.20	-646.33	-96.95
2002	58	69.60	-946.00	-141.90
2003	138	165.60	-578.00	-86.70
2004	468	561.60	1,355.00	203.25
2005	0	0.00	698.00	104.70
1996 - 2005	**464**	**556.80**	**864.00**	**129.60**

Sources: the authors, based on data from FAO and SAGPyA.
NOTE: Prices used: beef: 1200 USD/t cwe. Fluid milk: 0.15 USD/litre.

Table 4.9: Evolution of net benefits of the introduction of GM soybeans

SEASON	GROSS BENEFITS GM	VALUE Δ SUNFLOWER	VALUE Δ COTTON	VALUE Δ BEEF	VALUE Δ FLUID MILK	NET BENEFITS GM
	(M USD)	(M USD)	(M USD)	(M USD)	(M USD)	(M USD)
1996/97	200.21	-131.28	-25.19	31.20	-0.03	**74.91**
1997/98	518.00	184.72	79.84	21.60	34.80	**838.95**
1998/99	651.38	252.29	-147.59	-291.60	70.52	**535.00**
1999/00	941.36	-184.11	-203.74	300.00	121.09	**974.60**
2000/01	1,265.07	-507.46	34.10	0.00	-79.18	**712.52**
2001/02	1,849.32	33.04	-125.47	-301.20	-96.95	**1,358.73**
2002/03	2,863.06	129.17	-8.76	69.60	-141.90	**2,911.17**
2003/04	3,105.06	-229.81	60.06	165.60	-86.70	**3,014.21**
2004/05	3,928.21	58.76	67.02	561.60	203.25	**4,818.84**
2005/06	4,415.39	111.63	-52.71	0.00	104.70	**4,579.00**
95/96-05/06	**19,737.06**	**-283.05**	**-322.46**	**556.80**	**129.60**	**19,817.94**

Source: the authors, based on data from SIGMA runs and SAGPyA.

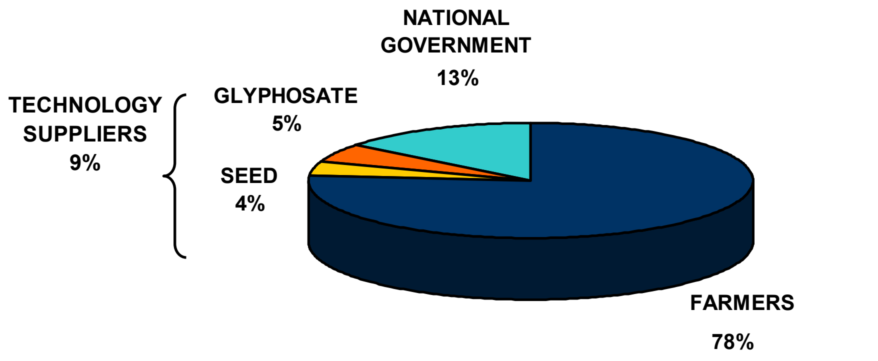
Finally, based on the simulation runs used to generate the results presented above, the distribution of the net benefits among the main actors involved, that is, farmers, seed suppliers and the National Government (based on revenues from the export tax in force since the 2002/03 season), was estimated. Table 4.10 and Figure 4.4 present these results.

Table 4.10: Distribution of the benefits of GM soybeans

SEASON	GROSS BENEFITS GM	AREA PLANTED WITH GM	FARMERS (M USD)	TECHNOLOGY SUPPLIERS (M USD)		NATIONAL GOVERNMENT (M USD)
	(M USD)	(ha)		SEEDS (*)	GLYPHOSATE	
1996/97	200.21	370,000	189.41	5.62	5.18	0.00
1997/98	518.00	1,800,000	467.24	27.36	23.40	0.00
1998/99	651.38	4,875,396	526.08	74.11	51.19	0.00
1999/00	941.36	6,870,511	722.33	109.93	109.10	0.00
2000/01	1,265.07	8,783,542	1,062.35	71.67	131.05	0.00
2001/02	1,849.32	10,381,943	1,640.85	83.06	125.41	0.00
2002/03	2,863.06	11,756,084	2,132.45	82.76	122.26	525.59
2003/04	3,105.06	13,057,989	2,322.13	94.02	120.13	568.78
2004/05	3,928.21	14,407,585	2,928.18	87.60	184.42	728.01
2005/06	4,415.39	15,859,058	3,296.33	134.48	164.93	819.64
TOTAL	**19,737.06**		**15,287.34**	**770.61**	**1,037.09**	**2,642.02**
				1,807.70		
PERCENTAGE	**100.00**		**77.45**	**3.90**	**5.25**	**13.39**

(*) To calculate this number it was assumed that, throughout the period under study, 20% of the area was planted with certified seed (the remaining 80% was assumed to be split two ways as follows: own use; 32% and illegal seed ("white bag"); 48%). Source: the authors, based on data from SIGMA runs, Márgenes Agropecuarios, and Costamagna, O. (2004).

Figure 4.4: Distribution of the accumulated benefits generated by GM soybeans during the 1996-2005 period.



Source: Table 4.10

4.2.3 A look at the soybean farmer by number, size and geographical location. Implications for social and environmental sustainability

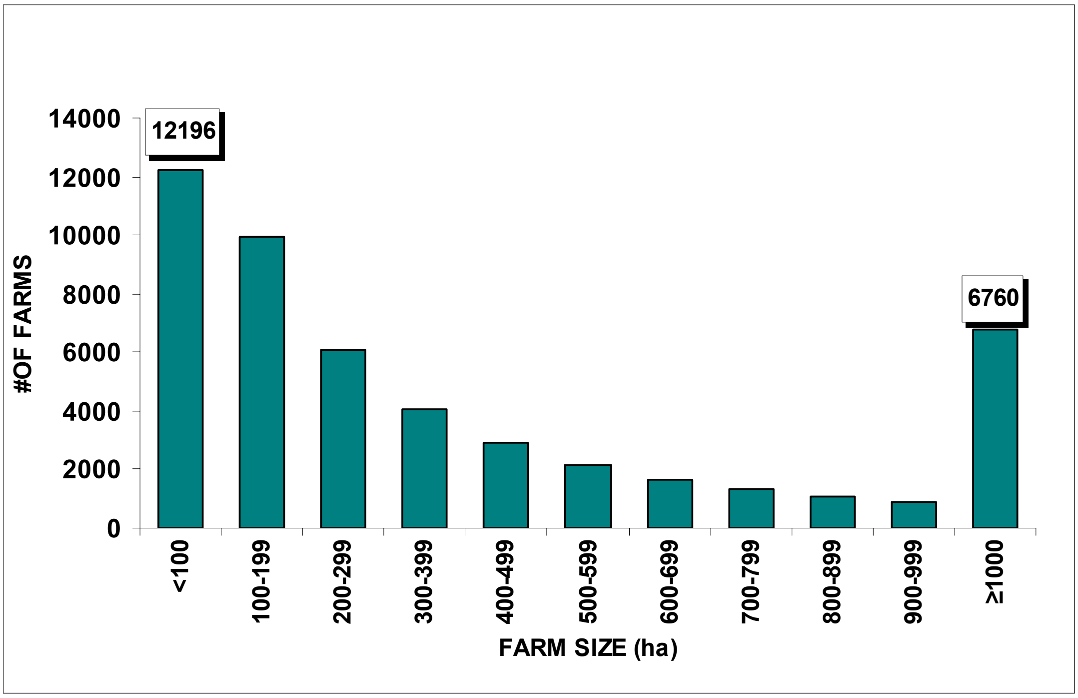
A detailed review of data collected for the 2002 National Agricultural Census (CNA for its Spanish acronym), sheds some light on issues that have been intensively debated over the last few years, particularly with regard to the biases, within the farming sector, associated with the process of “soyafication” and which groups of farmers benefited from have benefited the most from it. To begin with, out of 333,533 commercial farms (EAPs for its Spanish acronym), only 49,064 (14.71%) planted that year at least 10 hectares of soybeans[16], which means that 85.29% of all farms did not plant soybeans during the 2001/2002 growing season. Total planted area with soybeans was, for that growing season, of10.8 million hectares. Figure 4.5 shows the distribution, by size, of the EAPs that did plant soybeans, presented in ascending order, from left to right, increasing in intervals of 100 hectares. The first column from the left corresponds to farms that have less than 100 hectares of available land (12,196, or 24.85%) and the last column to the right shows the number of EAPs that are at least of 1,000 hectares in size (6,760, or 13,78%).

Out of the 49,064 farms that planted soybeans in 2001/2002, 45,169, that is, 92%, are located in the Pampean Region[17] (see Figure 4.6). Planted area with soybeans for this region, was, for that growing season, of 9.45 million hectares, which represents 87.41% of the 10.81 million hectares planted country-wide (a result that is consistent with the proportion that is calculated when the number of farms is used). These figures indicate that the far-reaching farming systems’ transformation process that was triggered by the release of herbicide-tolerant soybeans has in fact been mostly a “pampean” story. Even though in percentage terms the evolution of the area with soybeans has been important within the non-pampean provinces, the fact of the matter is that its share in the national totals is small and, except for Salta and, to a lesser extent, Formosa, the size of the planted area appears to have stabilized since 2001/02 (see Figure 4.7).

[16] Source: the authors, based on data from the 2002 CNA (INDEC).

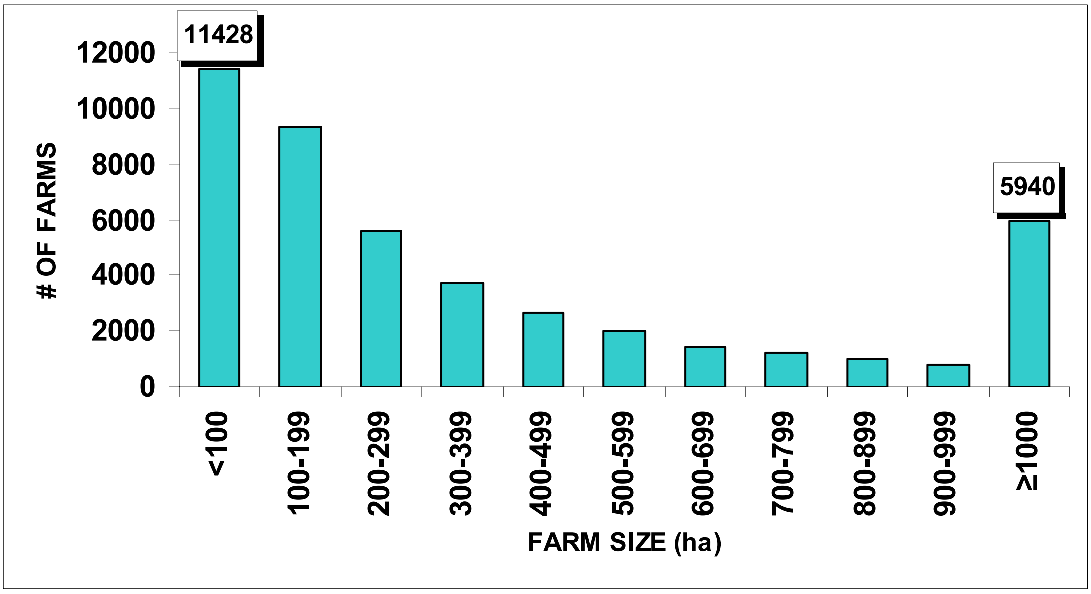
[17] The 2002 CNA defines the Pampean Region as the consolidated areas of the following provinces: Buenos Aires, Córdoba, Santa Fe, Entre Ríos, La Pampa and San Luis.

Figure 4.5: Distribution, by size, of the 49,064 soybeans growing EAPs. Total for the country.



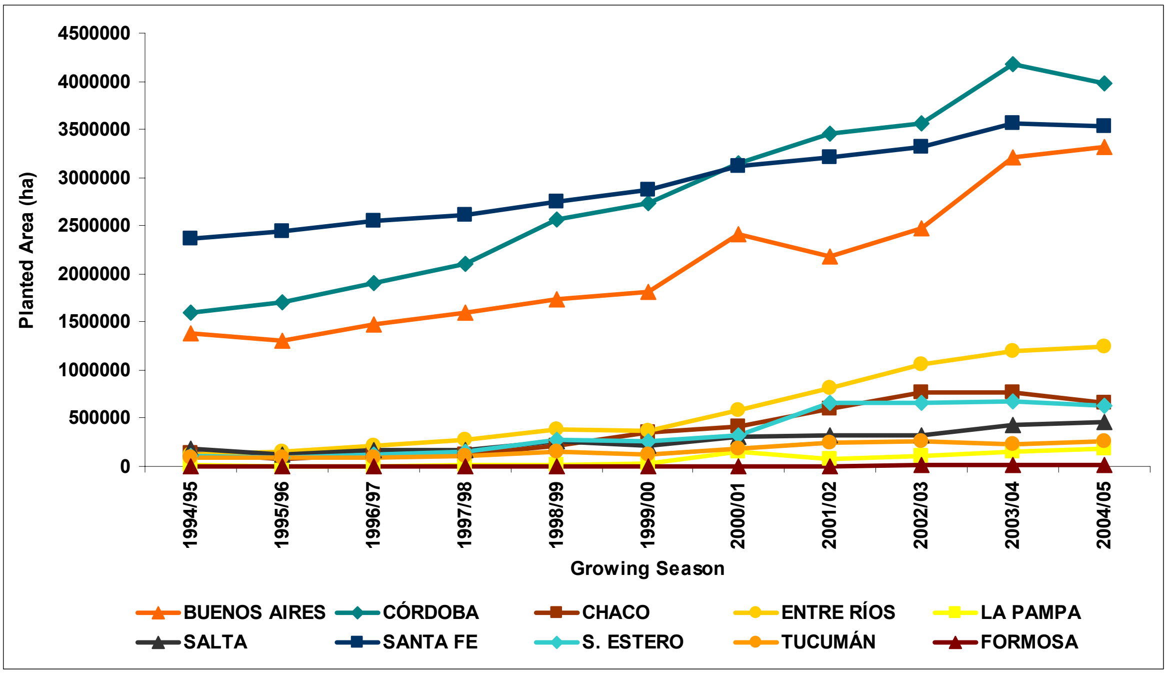
Source: the authors, based on data from the 2002 CNA (INDEC).

Figure 4.6: Distribution by size, of the 45,169 farms that include soybeans in their rotations. Pampean Region.



Source: the authors, based on data from the 2002 CNA (INDEC).

Figure 4.7: Evolution of area planted with soybeans, by province (1994/95-2004/05).

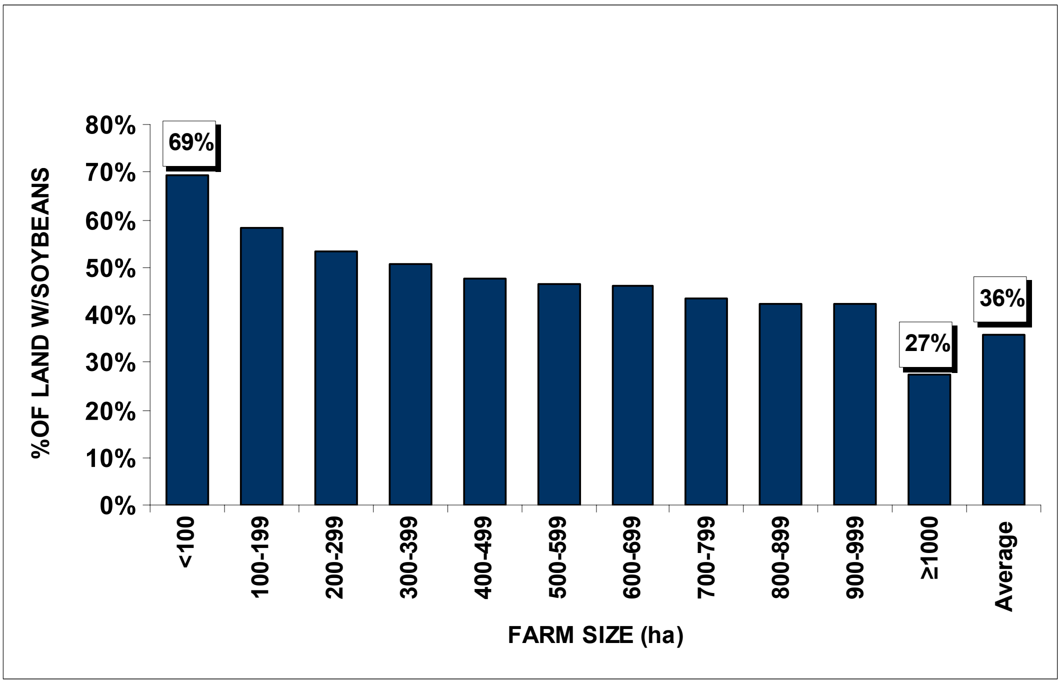


Source: the authors, based on data from SAGPyA, Coordination of Delegations Directorate.

The relative importance of soybeans in the universe of existing farming systems grows dramatically as farms get smaller. Figure 4.8 shows a summary of this correlation. In 2002, farms that are smaller than 100 hectares, planted 69% of available land with soybeans (both, as a first crop and as part of a double-cropping scheme, following wheat). On the other end of the spectrum, farms with 1,000 hectares or more devoted just 27% of available land to soybeans. The average for all EAPs was 36%. If we look at the situation in the Pampean Region, it can be seen that the fraction allocated to soybeans in farms of less than 100 hectares in size, was 70% of total available land (see Figure 4.9), that is, virtually the same proportion found at the national level.

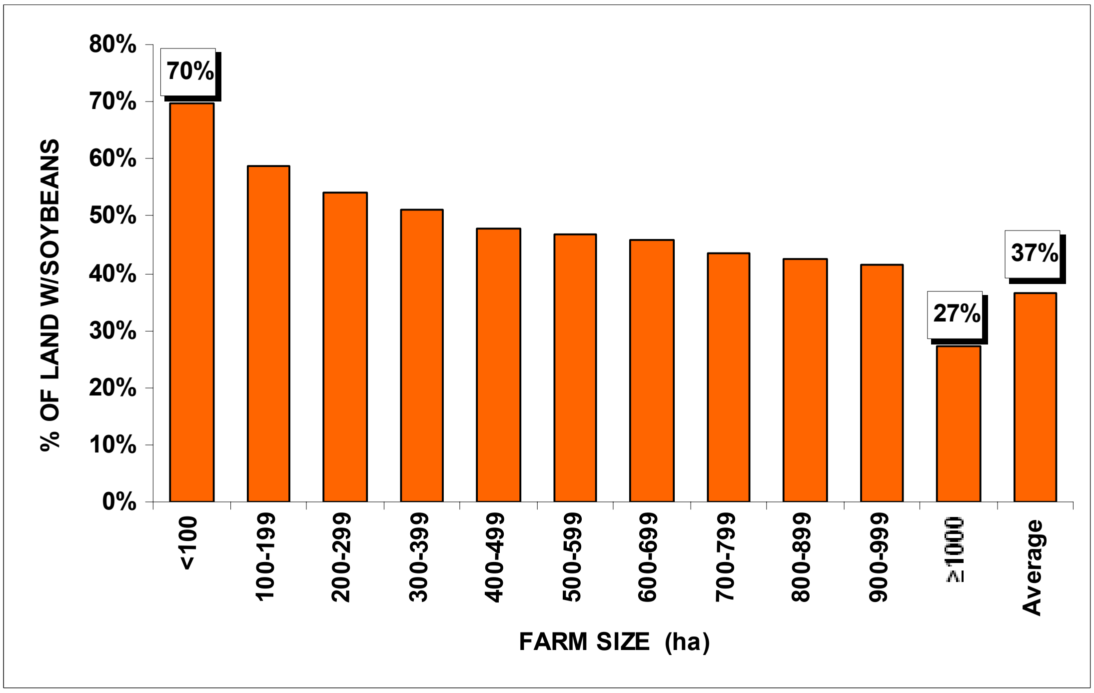
The implications of these results are far-reaching: they tell us that small farmers made a choice, as part of a profit-maximization strategy, to rely heavily on this crop, in order to enhance the (short-term) economic viability of their farms, strategy that is, naturally, inconsistent with the inter-generational (long-term) environmental sustainability of these farming systems (given that they are, for all practical purposes, monocultures) and the high recorded figures are, no doubt, an indication of the absence in those farming systems ,of the minimum required rotations in order to maintain soil fertility in the medium and long term. A good portion of this behavior is explained by the relative profitability of the crops involved, where the advantage is clearly on the side of soybeans, *vis a vis* maize and wheat. During the 1994/95-2004/05 period, the net margins of soybeans were lower to those of maize in only two seasons (1995/96 and 1998/99) and they were significantly more favorable in the rest, even reaching ratios of 3 to 1 in certain cases (2001/02 and 2003/04). These results were even more favorable to soybeans when compared with wheat (see López, 2006).

Figure 4.8: Correlation between farm size and percentage of land planted with soybeans, country totals.



Source: the authors, based on data from the 2002 CNA (INDEC).

Figure 4.9: Correlation between farm size and percentage of available land cropped with soybeans. Pampean Region.



Source: the authors, based on data from the 2002 CNA (INDEC).

The above described behavior by small farmers does not appear to be causally linked with the commercial availability of herbicide-tolerant soybean varieties, in 1996: replicating the analysis presented in this section, but with data from the 1988 Agricultural Census, it can be shown that, by the 1987/1988 growing season, almost a decade before the introduction of the new technology, farms with less than 100 hectares, were already planting soybeans in 62.54% of the available land[18].

4.2.4 The costs incurred in terms of the nutrient balance of the soil

It has been frequently said that the expansion of the area planted with soybeans, driven by the introduction of GM varieties is not sustainable in the long run, because of its negative incidence in the nutrient balance of the soil, particularly in terms of the availability of phosphorus, given the amount of fertilizer used (insufficient to replace the loss). In view of the importance of this discussion and based on the nutrient extraction indexes calculated by Cruzate and Casas[19], the total volume of nutrients "exported" as soybeans was estimated, expressed as tons of Triple Superphosphate (TSP) and, stemming from this, the costs of its replacement through fertilization. Table 4.11 shows the results of this exercise for the 1995-2005 decade.

Table 4.11: Net exports of phosphorus as soybeans grain (super phosphate equivalent) by and replacement cost

SEASON	SOYBEAN HA	EXPORTED TONS OF TSP	TSP PRICE (USD/T)	REPLACEMENT COST (M USD)
1996/97	6,669,500	458,861	270	**123.89**
1997/98	7,176,250	493,726	290	**143.18**
1998/99	8,400,000	577,920	290	**167.60**
1999/00	8,790,500	604,786	310	**187.48**
2000/01	10,664,330	733,706	300	**220.11**
2001/02	11,639,240	800,780	300	**240.23**
2002/03	12,606,845	867,351	295	**255.87**
2003/04	14,526,606	999,430	290	**289.83**
2004/05	14,399,998	990,720	340	**336.84**
2005/06	15,329,000	1,054,635	320	**337.48**
		7,581,916	**TOTAL**	**2,302.53**

Source: the authors, based on a net extraction rate (exports as grain) of 68.8 kg/ha of triple superphosphate, estimated by Cruzate y Casas (2003), SAGPyA for planted area, and Márgenes Agropecuarios magazine for prices of TSP.

According to the results of this exercise, total exports as soybean grains amount to 7.6 million tons of phosphorus, in terms of triple superphosphate, while its total replacement cost is 2.3 billion US dollars.

Given the magnitude of the process and its evolution throughout the period 1996-2005, summarized in Table 4.11, it is clear that, rather sooner that later, it will reflect, negatively, on the productivity of the area currently planted with soybeans, even though that drop might be masked, at least for a while, by the results of the plant breeding activities both, in the public as well as in the private sectors. The dynamics of the soils is, necessarily, complex and heterogeneous, making it difficult to set a time horizon to the expression, as a loss of profitability, of this constant loss of chemical fertility, but specialists agree that the sustainability of the current situation has entered a risk zone. However, analyzing this issue from a cost-benefit perspective, the conclusion differs significantly from the pessimist point of view, since the benefits generated by the

[18] Source: INTA-INDEC-Fundación ArgenINTA, based on data from the 1988 and 2002 CNA.
[19] Cruzate G. and Casas R. (2003): *Balance of Nutrients (Balance de Nutrientes)*. Revista Fertilizar INTA, Año 8, Número Especial "Sostenibilidad", ISSN 1666.8812, pp 7-13, December.

adoption of the new technologies are more than enough to replace, with fertilization, the nutrients “exported” as grain. As it can be seen comparing the numbers shown in Tables 4.9 and 4.11, the estimated replacement cost of the phosphorus exported throughout the period under study represents less than 12% of the total net benefits that accrue to society from the new technology. It is important to point out that, although this is an strictly economic feasibility approach, it has been put forward in a framework defined by the existence of a negative externality associated with a productive system, that is, we are faced with a social cost, represented by the fertility loss of the soils, social because it is widely acknowledged that the fertility of the soils is a good that belongs to the society at large, not just the owners of the land, that is also endowed with an inter-generational nature, because its negative effects appear before their expression as private costs, in the way of yield losses. One of the defining features of a negative externality (a “market failure” in the economics literature) is the lack of price signals that could induce the economic agents, through market mechanisms, to introduce adjustments in the production functions, so as to “internalize” this externality (in this particular case, by applying enough fertilizer to compensate for the nutrient extraction). Therefore, the design and implementation of targeted policies will be required, in order to generate incentives for these actors (land owners and tenants), to start accounting for the social costs incurred, incorporating them to into their private costs structures, which, in turn, will improve the environmental sustainability of farming systems that include soybeans.

In the same line of thought, we should probably include the negative externality associated with the reduction of organic matter content in soils subjected to a soybeans monoculture system (that is, with no rotation with maize, for instance), that shares with the previous one its long-term unsustainability. This one, though, is a lot harder to quantify (to begin with, there exists no substitute for organic matter in the inputs market, as it is the case with fertilizers) and besides that, its discussion greatly exceeds the scope of this study. Nevertheless, given the sheer magnitude of the negative implications for the future of our agriculture, both market failures should be the subject of comprehensive research studies (involving the technological, sociological, legal and regulatory dimensions of them), working in a multi-disciplinary environment[20], so as to come up with proposed solutions that would require, for its effective implementation, a previously achieved wide and enlightened consensus within the society as a whole

4.3 The case of GM maize

4.3.1 Lepidoptera-resistant (Bt) maize

The benefit of the adoption of the Bt technology consists in the prevention of yield losses caused by the attack of an insect plague, *Diatraea saccharalis* (Sugarcane Borer), in its larval stage. In fact, the final net result of the crop-plague-Bt germplasm is actually a stochastic variable and, therefore, the modelization of its impact is quite more complex than in a deterministic case, like the improvement on productivity indicators, like, for instance, a cost reduction or a yield increase, where the stochastic component is associated almost exclusively to the climate risk, that is, temperatures, on the one hand and rainfall, on the other.

Ianonne (2002) [21], estimated that, for the most important maize-growing region, the damage level varies between 10 to 50%, depending on the severity of the attack and on the planting date (the later the planting, the bigger the damage, reaching a maximum level in double-cropping farming systems). In this study, the author estimated that the annual losses in the Pampean region reach 170 million US dollars.

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[20] The research done by the Producir Conservando Foundation, AAPRESID and INTA projects on valuation of the environmental services of production systems, among others, are important contributions in that sense.

[21] Iannone, N., 2002. Servicio técnico *Diatraea* en maíz. INTA Pergamino. www.elsitioagricola.com / plagas /intapergamino / diatraea20020502.asp

To estimate the benefits of this technology using the SIGMA model, a conservative assumption was formulated: in average, throughout the period under analysis (1998-2005), the adoption of Bt hybrids increased by 10% maize crop yields (which is the same as stating that it has prevented losses of the same magnitude).

The benefits to technology suppliers was calculated based on the difference between the price of Bt hybrid seed and that of a conventional hybrid, that is, the direct additional cost per hectare associated with the adoption of the technology introduced commercially into the market in 1998.

Table 4.12 shows the simulated evolution of the area planted with Bt maize, as well as the benefits accrued and its distribution among farmers, technology suppliers and the National Government (Figure 4.10).

Using as a benchmark the figure estimated by Ianonne (2002)[22], that is, 170 million US dollars of losses in the Pampean region, the 2004-2005 average of the gross benefits of the adoption by farmers of Bt technology represents about 105 million US dollars, that is to say that it prevented 60% of the expected losses without the use of agrochemicals. These results are also in line with the adoption level reported by ArgenBio for the 2005/06 season (65%).

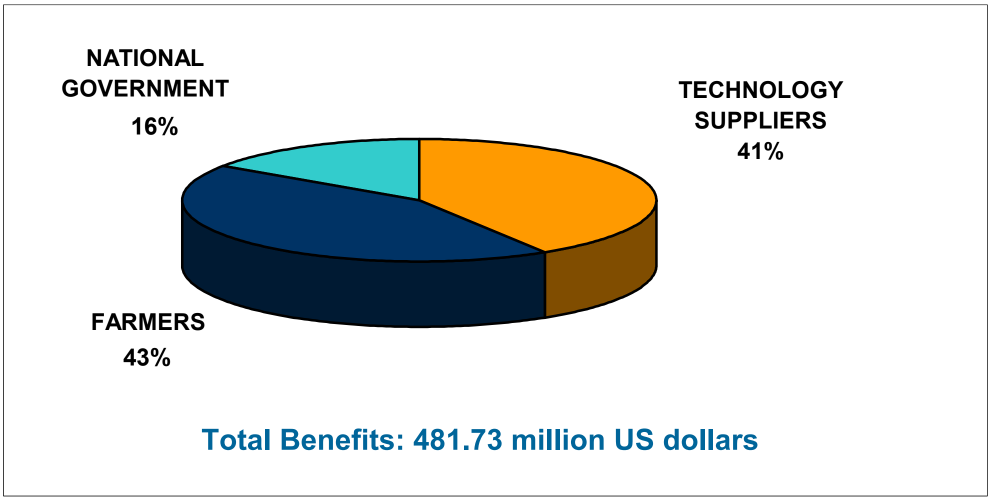
Table 4.12: Evolution and distribution of the benefits of Bt maize

YEAR	AREA WITH Bt AREA (ha)	GROSS BENEFITS (M USD)	ADDITIONAL COST Bt (USD/ha)	NET BENEFITS (USD)		
				SUPPLIERS (M USD)	FARMERS (M USD)	NATIONAL GOVERNMENT (M USD)
1998	113,738	7.58	20.00	2.27	3.79	0
1999	270,884	16.63	20.00	5.42	7.89	0
2000	557,665	31.72	20.00	11.15	14.22	0
2001	944,280	48.41	5.00	4.72	34.01	0
2002	1,315,787	71.91	18.00	23.68	33.84	14.38
2003	1,574,408	94.60	25.00	39.36	36.32	18.92
2004	1,713,267	118.76	34.00	58.25	36.76	23.75
2005	1,777,478	92.14	30.00	53.32	20.38	18.43
TOTAL		**481.73**		**198.19**	**208.06**	**75.48**
Percentage				**41.14**	**43.19**	**15.67**

Source: the authors, based on SIGMA model runs and prices from Márgenes Agropecuarios magazine.

[22] Iannone, N. (2002), *Op. Cit.*

Figure 4.10: Distribution of consolidated benefits resulting from the adoption of Bt maize



Source: the authors, based on data from Table 4.12

4.3.2 Glyphosate tolerant maize

Released for its commercialization in 2004, the hybrids of genetically modified herbicide-tolerant maize covered, in the last season (2005/06), 70 thousand hectares (according to estimations by ArgenBio), that is, approximately 2% of the total area planted with that crop in that season (3.4 million hectares). The barely two years since this material have been available make an *ex-post* estimation of the adoption of this technology not recommendable. The insufficiency of the available information on the agricultural performance of the herbicide-tolerant maize, *vis a vis* unmodified similar materials, constitutes an additional argument in that regard.

Some general considerations on the future perspectives of this technology are in order, especially when analyzing the changes that have taken place in the marketplace these past few months: the remarkable increase on the price of maize seems to be strongly correlated to upward trend in the price of oil. The idea that these two commodities were substitutes was, until a relatively short time ago, a subject of academic speculation associated to the probability that developed countries would induce, through either legislation or regulatory mechanisms, an even larger substitution of fossil fuels by biofuels, as a response to the increasingly politically correct social demand, for the reduction of net emissions of greenhouse effect gasses (manifested in the partially failed Kyoto Protocol). Lately, this situation seems to have transcended this restricted context and began have an effect on the markets.

After a prolonged period of time in which the price of oil has remained above the of 50 US Dollars per barrel threshold, it seems that a perception has manage to settle among economic agents, in the sense that what has happened (due in no minor part to China's and India's demand), constitutes a "structural" change in relative prices of energy, large enough to generate expectations in the sense that, in the end, it will be the markets and not the governments, that will induce such substitution. The enormous planned investments in industrial plants to produce ethanol from maize in the next 15 years (80 billion US dollars)[23] are one of the most visible manifestations of this perception.

If the "perfect substitutes" nature of maize and oilseeds on the one hand and of oil on the other, becomes consolidated, market signal reaching farmers will represent the combined effects of the respective supply and demand schedules of both sectors (agriculture and energy) that, until now, participated in different segments of the market

[23] http://www.engineerlive.com/european-process-engineer/16346/and3680-billion-investment-in-ethanol-plants.thtml

(oil and its subproducts as inputs for the production of agricultural commodities, for instance). It looks like it is a whole new ball game. Maybe the economists should start working on new cross elasticities (both, supply and demand), such as maize-oil and soybeans-oil.

It is like a new match had begun. Even the economists should start working on the estimation of new price-elasticities, like maize-oil and soybean-oil, own and cross (for supply as well as demand).

With the price of maize at 120 US dollars per ton, it is reasonable to think of the expansion of this crop beyond the Pampean Region, where it would compete for land with soybeans. The possibility of maize substituting for soybeans in double-cropping schemes (following wheat) within the Pampean Region cannot be dismissed either. Previous studies have evaluated this alternative in a quantitative fashion and the results (in a scenario of a simulated top price of 100 US dollars per ton) appear to be encouraging, at the micro as well as the macro level, but they ought to be considered also from the perspective of sector-specific policies, since it would be a feasible tool for "leveling the playing field", now strongly biased in favor of soybeans, which, in turn, would generate alternatives that would be both economically and environmentally sustainable, besides reducing the current vulnerability of the farming system, without the need of costly inter-sector transfers (such as fiscal incentives, like tax exemptions).

4.4 The case of GM cotton

4.4.1 Lepidoptera-resistant (Bt) cotton

The estimation of benefits to accruing to farmers and input suppliers was made using the simulation model SIGMA V. 2.0, for the NEA and NOA regions and the Province of Santa Fe.

Based on results from a previous study by Elena[24], the impact of the adoption of Bt cotton was assessed as the equivalent of a 30% increase in net yield per hectare, with maximum adoption ceilings increasing as the technological level (TL) of adopting farmers moves upwards: 40% for LTL (low tech level), 50% for MTL (medium tech level) and 70% HTL (high tech level), reflecting the restrictions to sources of operating capital needed to afford the cost of the transgenic seed.

The large fluctuations in the area planted area with cotton in the period under analysis, due both to market signals (low prices, substitution for GM soybeans) and to climatic events (floods), cannot be simulated SIGMA. Therefore, it was assumed that the total area allocated for this crop remained at 400,000 hectares throughout the period.

The increase in yield as a consequence of the adoption of the Bt variety is, as in the case of Bt maize, due to the reduction in the losses caused by lepidoptera attacks, that is, there is no actual increase on the yield per hectare of cotton, compared to the average levels recorded when there are no lepidoptera attacks.

Table 4.13 summarizes the evolution of the area planted with Bt, as well as the benefit accrued and its distribution among farmers, technology suppliers (estimated at 54 US dollars/ha, which is the price differential between the conventional seed -16 US dollars/ha and Bt -70 US dollars/ha) and the National Government (a 5% *ad-valorem* tax levied on exports was applied, starting in 2002/2003). Figure 4.11 is a graphical representation of the results.

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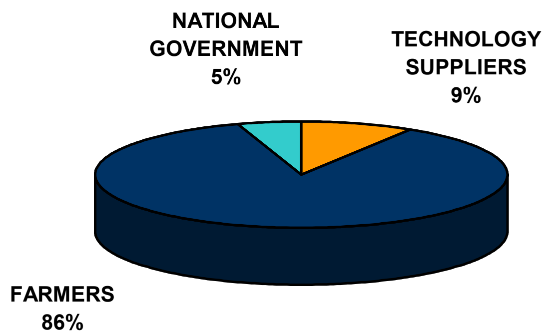
[24] Elena, M.G. *Economic advantages of transgenic cotton in Argentina (Ventajas Económicas del Algodón Transgénico en Argentina)*. INTA. Estación Experimental Sáenz Peña. Chaco. Documento de trabajo. 2001.

Table 4.13. Evolution of benefits of Bt cotton and its distribution

YEAR	AREA WITH Bt (ha)	GROSS BENEFIT (M USD)	NET BENEFIT (USD)		
			SUPPLIERS (M USD)	FARMERS (M USD)	GOVERNMENT (M USD)
1998	82	0,00	0,00	0,00	0,00
1999	226	0,05	0,00	0,05	0,00
2000	620	0,14	0,01	0,12	0,00
2001	1.688	0,37	0,03	0,34	0,00
2002	4.521	0,98	0,08	0,85	0,05
2003	11.675	2,46	0,21	2,13	0,12
2004	27.856	5,63	0,50	4,86	0,28
2005	57.720	11,18	1,03	9,59	0,56
TOTAL		**20,81**	**1,86**	**17,93**	**1,01**
Percentage			**8,94**	**86,19**	**4,87**

Sources: the authors, based on results from SIGMA runs, data from the Márgenes Agropecuarios magazine and Cueto Rúa, P. (2006), personal communication. Benefits to suppliers were assumed to be equivalent to the 33% of the price of certified seed (70 US dollars/ha), so as to capture the effect of the "white bag" (not certified) seed (estimated at 66% of total area planted with Bt)

Figure 4.11: Distribution of accumulated benefits accrued by the adoption of Bt cotton (1998-2005).



Source: Table 4.13

4.4.2 Glyphosate-tolerant cotton

The Guasuncho 2000 cotton cultivar was commercially available in 2002. According to ArgenBio estimates, in 2005, the total area planted with this material was of about 165 thousand hectares, approximately 40% of total area with cotton. However, the estimation of the benefits of the adoption of this technology is particularly difficult, given that:

1. The costs of weed control are higher with Guasuncho 2000 than with the conventional varieties (non-GM).
2. There are no recorded improvements in yield and/or quality, attributable to the expression of the introduced gen.

3. Sales of certified GM seed are enough to plant 20% of the total area with that cultivar (P. Cueto Rúa, personal communication, 2006). That is, the other 80% is marketed under the "white bag" (non-certified) system.
4. Farmers that purchase certified seed (at a cost of 52 US dollars per hectare), do so for the positive features of its non-GM genetic base (Guasuncho 2000) and not, necessarily, for the potential benefits of the introduced gen. This reasoning can be applied, therefore, to the rest of the area planted with the GM cultivar.

Taking into consideration the arguments made in the previous paragraph, it was concluded that to make an estimation of a benefits flow associated to the introduction of this particular GM cultivar was not methodologically feasible, especially given that the source of those benefits is still is in a stage of evaluation and, thus, it is almost impossible to separate out, the differential impact of traditional plant breeding from the expression of the gene introduced in the transformed material.

4.5 Indirect impacts of GM crops

In addition to the impacts addressed in the previous section, the introduction of GM crops generated a set of other effects, both in the farming sector itself as well as in an economy-wide scale. The relevance of the country in the global oilseed production makes the transformations that took place in Argentina, reflect on the economics of this crop at a global level and, through this, impacts on the welfare of consumers in other countries. The estimations of these impacts are presented in the following sections; however, these only consider those related to GM soybeans since, given the asymmetries in magnitudes involved, the effects of the other cases get diluted and, taking into consideration the methodological complexity that it would imply, their analysis was deemed not justified.

4.5.1 The increase of productivity in the beef sector

The adoption of glyphosate-tolerant GM soybeans unleashed far-reaching changes in the structure of Argentina's farming sector, with ripple effects that even transcend it. But still within the sector, one of the first things that comes to our attention is the significant improvement in the productivity indicators of the subsector that was most affected by the land allocation process associated with the substitution with soybeans: livestock (beef and dairy). The fact is that, despite the reduction of more than 5 million hectares allocated for the activity, it has not lead to a drop in output but, to the contrary, there ha been an increase in the supply of both, beef and milk, comparing the numbers back to back (1996 and 2006).

This situation has gone virtually unnoticed, due to the fact that the indicators of both subsectors (beef and dairy) are computed as to flows; for beef it is the extraction rate = heads slaughtered per year/ stock of heads and in the case of dairy, volumes of fluid milk per year (millions of liters). Except for studies that describe specific production systems (usually, narrowly bounded and, thus, hard to extrapolate), the consolidated production data does not refer to the area where the livestock systems operate, especially when dealing when cow-calf activities are included. Even the used the extraction rate, widely used, has been criticized as a not very dependable indicator of productivity, due to doubts concerning the accuracy of the statistical data for both slaughter and stock[25].

Given the lack of statistical data, it is reasonable to assume that a fraction of hectares that are no longer allocated to livestock production comes from the area that had been planted with pastures. By comparing data from the 1988 National Agricultural

[25] Rearte, D. (2003). *El Futuro de la Ganadería Argentina (The Future of Argentina´s Livestock Sector)*. Publication for the Course: "Producción Bovina de Carne" (Beef Production). Facultad de Agronomía y Veterinaria, Universidad Nacional de Río Cuarto, Córdoba, Argentina.

Census with those of 2002[26], it can be seen that the total area allocated to pastures dropped, in that period, from 14.9 to 11.9 million hectares, that is, a reduction of 3 million. On the other hand, data for the NOA and NEA region shows an increase in the area implanted with pastures, from 829 to 904 thousand hectares. However, in those two regions, the natural pastures decreased by almost 2 million hectares (in the Province of Buenos Aires, on the other hand, the reduction was of only about 455 thousand hectares, over a total of 10.8 million). From all this data it can be concluded that, in the 1996-2005 period, in the Pampean region, the livestock area that was taken over by soybeans was made up mainly by annual and perennial pastures and, in the NOA and NEA regions, by natural pastures and forests.

How could this "invisible" increase in livestock productivity be explained by using economic theory analytical tools? Unlike the case of GM soybeans' adoption process, which was induced by determinants not linked to either factor or product prices, but to an expansion of the production possibilities frontier, as a result of the availability a new technological alternative, changes in productivity of Argentina's livestock sector, may very well constitute a microeconomic theory textbook case.

Figure 4.12 represents the evolution of the price of land in cow-calf scheme areas. Figure 4.13 represents an attempt to graphically explain the above mentioned increase in productivity. Let us assume that the isoquant curve (iso=equal, quant=quantity) that is located farthest from the origin of both axes represents all of the land-input combinations that produce an X quantity of calf meat (liveweight) per hectare and per year. Let us suppose that, for the 1996 price level of land in cow-calf areas (312 US dollars/hectare), the optimum land-inputs combination is at the point where the line that represents the relative price vector between land and inputs is tangent to the isoquant at point **A.** Assigning a value of 6% to the rate of return to land (in line with historic records), the cost to rent it would be of 20 US dollars/ha/year. Therefore, the production of calves that resulted from the land-input combinations represented by that isoquant should be enough to cover the costs of renting the land as well all the other direct, indirect and structural costs. According to data from the Study of the Technological Profile of Argentina's Agricultural Sector[27], the producers of the Salado River Basin (traditional cow-calf region) that operate at the low tech level, had a yield, in 2001, of 88 kg/ha/year (level that, probably, was enough to pay for all those costs and still make a profit). Now, in 2006, the price of that same land jumped to 1100 US dollars/ha. According to Márgenes Agropecuarios magazine[28] the cost of renting a hectare of land reached, in October 2006, 70 kg/calf/year (about 58 US dollars, assuming a price of 0.83 US dollars per kilogram (liveweight) of calf that comes to 5.2 % of the price of a hectare of land). It is obvious that, should the firm continue to operate on the original isoquant (that can be thought of as a production function), the scheme would generate an income level that would be enough to pay for land rental and a few other costs hardly, but nothing else. Thus, the farmer is faced to two options: either change its production scheme (for instance, planting soybeans) or improve the productivity of the current one to, at least, a level such that income is enough to pay all factors at their opportunity cost. Should he choose the second option, this decision could be graphically depicted as a migration of the production function to a different isoquant, closer to the origin of coordinates (that is, more efficient), which implies lower intensity in the use of land (5.2 million less hectares, on aggregate) and a higher intensity in the use of inputs (fertilizers, feed supplements, etc). Graphically, the new optimizing combination of factors is represented by point **B**. This explains why total production has not decreased

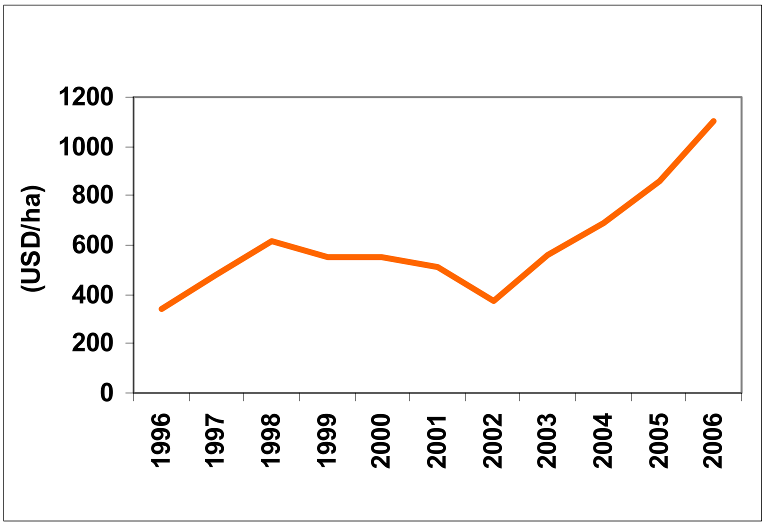
[26] Dowbley, V. (2006). Personal communication, based on data from INDEC (from available analysis, in the case of the 1988 CNA and from microdata in the case of the 2002 CNA). Unidad Conjunta INTA-INDEC-FUNDACIÓN. Buenos Aires, Argentina.

[27] www1.inta.gov.ar/ies/perfil tecnológico

[28] # 256 - October 2006.

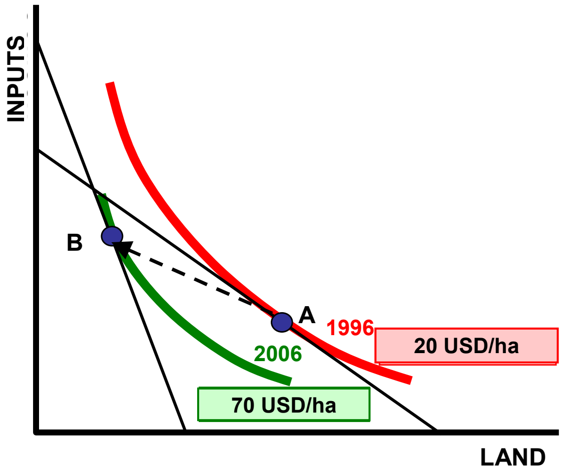
(in fact , over the last two years, it actually increased but the discussion of the causality of this event is beyond the scope of this study).

Figure 4.12: Land values in the Pampean Region – Cow-calf areas (USD/t).



Source: Márgenes Agropecuarios magazine (# 256 - October 2006).

Figure 4.13: Livestock: Technology adoption induced by a change in relative prices



Sources: the authors, based on data from the Study of the Technological Profile of Argentina's Agricultural Sector and from Márgenes Agropecuarios magazine (October 1996-October 2006).

4.5.2 Some thoughts on the impact on GDP growth and on job creation

The methodology currently used to calculate the Agricultural Gross Product (AGP) probably underestimates the impacts of the sector on the rest of the economy[29]. The AGP is calculated multiplying volumes of all types of agricultural output by their respective prices, plus services provided to the sector to produce that output (but not all of them, for instance, the ones linked to the immunization of herds are computed in a different section of the National Accounts –Health-). Even more significant, though, is the fact that the effects of changes in total agricultural supply are computed with a restrictive

[29] Llach, J. J., Harriague, M. M. and O'Connor, E., 2004. *La generación de empleo en las cadenas agroindustriales.* Fundación Producir Conservando. (The generation of employment in the agroindustrial chains. Foundation Producing while Conserving). Buenos Aires, Argentina.

criterion, recording those changes as well as the additional services required to produce the additional quantities, but decoupling them from the effects on the rest of the economy. When these changes are not incremental in nature, as it has been the case with soybeans production, that almost quadrupled over the 1996-2005 period, this restrictive criterion did not identify the agricultural sector as the primary source of the growth in such economic activities like, for instance, investments in storage capacity and transport of agricultural commodities.

The existence of a correlation does not necessarily constitute, *per se*, evidence of causality. With this *caveat* in mind, we believe it is of interest to do a numerical exercise, correlating the contribution to the Gross Domestic Product (GDP) of the release of GM herbicide-tolerant soybeans, with employment growth over the decade under study. The ration between goods and services in the 2005 GDP (source: INDEC), is 1.22, that is, for each current peso recorded in the goods chapter, 1.22 pesos are recorded in the services chapter. To carry out the exercise mentioned above, we will assume that this ratio holds for GM soybeans too, but it will be set at a lower level (1.0), so as to minimize the likelihood of an overestimation of the "multiplying effect" of this particular activity, which is, thus, assumed to be equal to 2.0, that is, the benefits accrued from the adoption of GM soybeans, as estimated in a previous section, times 2, represent its contribution to GDP growth (∆ GDP, from this point onwards). As it can be seen in Table 4.14 the accumulated "∆ GM soybeans-GDP" for the period 1996-2005, would be then be equivalent to 39.47 billion US dollars. Given the methodological difficulties to interpret that figure, due to the collapse of the convertibility monetary system in 2002, we have decided to compute, instead, the sum of the annual values expressed in current pesos. The final figure computed this way comes to a total of 93.86 billion US dollars.

Table 4.14. Correlation between of GDP growth, benefits from GM soybeans and job creation.

YEAR	GDP CURRENT PESOS	CHANGE W/RESPECT TO PREVIOUS YEAR	INDEX 1996=100	∆ GM GDP (M USD)	∆ GDP GM (M CURRENT $ PESOS-)
1996	272,149,757,811		100	400.42	400.42
1997	292,858,877,330	7.60%	107.6	1,036.00	1,036.00
1998	298,948,358,554	2.10%	109.8	1,302.75	1,302.75
1999	283,523,023,981	-5.20%	104.2	1,882.72	1,882.72
2000	284,203,739,315	0.20%	104.4	2,530.14	2,530.14
2001	268,696,708,834	-5.50%	98.7	3,698.63	3,698.63
2002	312,580,143,860	16.30%	114.9	5,726.12	14,315.31
2003	375,909,361,397	20.30%	138.1	6,210.13	18,630.38
2004	447,643,425,642	19.10%	164.5	7,856.42	23,569.26
2005	531,938,722,296	18.80%	195.5	8,830.78	26,492.33
∆ PBI	**259,788,964,485**			**39,474.11**	**93,857.95**
$ current/job	**94,024.24**			**GM Jobs**	**998,231**
				% total	**36.13%**

Source: the authors, based on data from INDEC and results of SIGMA runs.

The National Accounts Directorate, based on data from household surveys, estimates that, between 1996 and 2005, 2.76 million jobs were created, which means that the GDP growth/jobs ratio was, for that decade, of about 94 thousand current pesos/job (that is, each job "costs" 94 thousand pesos in terms of GDP). Following in this line of thought and taking into consideration (if the above mentioned assumption holds) that the accumulated contribution to GDP, generated by the adoption of GM soybeans was of almost 260 billion pesos. If this figure is divided by the 94,000 pesos Δ GDP/job ratio, the result would be almost one million jobs, created, as an indirect effect of the GM technology, during the decade, economy-wide (not restricted to the farm sector), which, in turn, represents 36% of the total.

The consistency of the results shown above can be checked against another indicator of the economic activity, strongly correlated with job creation, due to the labor-intensive nature of the activity: construction. The building permits for the 1996-2005 period, totaled 129 million square meters[30] (for 2005, given the fact that the data point was not yet available, the figure for 2004 was used). Taking into consideration the average annual construction costs per square meter, expressed in current US dollars, estimated from data by INDEC[31] (highest: 1129 US dollars in 1996; lowest: 526 US dollars in 2003), the estimated gross accumulated benefit, attributable to the release of GM soybeans (19.74 billion US dollars, see Table 4.11) would have been enough to finance the construction of 28 million square meters, that is, 21.73% of the total authorized area for that period.

Acknowledging that the previous paragraphs are mostly speculations based on bold assumptions, we nevertheless believe that the numbers involved are of such a magnitude that they suggest the need for an in-depth review of the methodology currently in use to estimate GDP (particularly in connection to the definition and characterization of the sectors that make up the economy of Argentina) given that, in its present configuration, it might have induced, in the past, errors in macreconomic, trade and/or sector specific policies.

4.5.3 Impact on world consumers

The world production of soybeans in 1996 was of 130.21 million tons. The annual accumulated increase, above that number, for the period 1996-2005, was 422.9 million tons. Considering that the accumulated increase of soybeans production in Argentina, attributable to the availability of the GM technology was estimated at 93.7 million tons (see Table 4.15), the adoption of that technology in this country would explain 22.15% of the total global growth. What was the impact of that additional supply of soybeans on international prices? A brief summary of the procedure used for its estimation is presented next.

As it was mentioned in the previous section, supply price-elasticity is a parameter that quantifies the $\Delta Q/\Delta p$ relationship, formula that, put in words, is the expected change in the volume supplied by farmers as a fraction of a change in the price of the commodity, known to farmers before the time at which the decision to plant is made. For example, a supply price-elasticity of 0.7 means that, for each 1% change in the price, supply will respond with a change of 0.7%, in the same direction (it goes up if the price is higher, and goes down if the price drops).

The inverse of the elasticity, that is, $\Delta p/\Delta Q$, is called flexibility, and it measures the response of the price to changes in the volume supplied. Econometricians warn, however, about the error of taking the estimated value of elasticity, reverse it it and work with the resulting number as if it were an accurate estimation of the flexibility[32]. With this

[30] Source: INDEC

[31] Dowbley, V. (2006). Personal communication. Unidad Conjunta INTA-INDEC-FUNDACIÓN. Buenos Aires, Argentina.

[32] Huang, K. (2006). *A Look at Food Price Elasticities and Flexibilitie*s. Poster Paper. 26th Conference of the International Association of Agricultural Economists. 12-18 de agosto de 2006. Gold Coast, Queensland, Australia. The problem is that the sum of residuals is minimized along the quantity axis in the estimation of an ordinary demand system, whereas it is minimized along the price axis in the estimation of an inverse demand system. These two parameters (elasticity and flexibility) are reciprocal to each other in the economic sense, but not in the statistical one.

caveat, we decided to use the inverse of an estimation of the supply price-elasticity of soybeans for the United States, the world's biggest producer, of 0.80 (other estimates were cited for this parameter, in the range of 0.22 to 0.92)[33], assuming it was the real value of the parameter, instead of an estimation. This way, its inverse (1.25) could be considered as the real price-flexibility. If our assumption holds, we can estimate the effect that the additional supply originated in Argentina, attributable to the release of GM varieties, had on the world price of soybeans, in the decade under analysis.

Table 4.15 shows a summary of the results. It is particularly interesting to look at the estimated impact (in terms of the increase that did NOT occurred), on the world price of soybeans, of 10.53 and 11.39% for the years 2004 and 2005, respectively. In terms of savings to consumers, as a reduction in food expenditures (savings from which the argentine consumers were almost excluded due to the low domestic consumption levels), the total figure, accumulated for the 1996-2005 period, was estimated at 25.96 billion US dollars. Remains to be seen whether these savings were effectively passed on to consumers by the other actors in the value chains in which this commodity participates as an input or, if, to the contrary, it was captured as rent by them. In any event, that figure should be added to the net benefits on the supply side (19.8 billion US dollars) estimated in a previous section, to reach a total accumulated global impact of the release of GM soybeans technology in Argentina, of 46.76 billion US dollars.

Table 4.15. Soybeans: Evolution of world production, Argentina's additional supply attributable to GM soybeans, impact on world price and reduction in food expenditures of consumers worldwide.

SEASON	SOYBEANS WORLD TOTAL PRODUCTION (t)	ADDITIONAL SUPPLY GM SOYBEANS ARGENTINA (t)	WORLD PRICE (USD/t)	IMPACT ON WORLD PRICE (%)	Δ CONSUMER EXPENDITURES (M USD)
1996/97	130,209,870	774,870	296.50	-0.74	-280.24
1997/98	144,412,830	2,512,725	221.83	-2.17	-970.54
1998/99	160,098,390	3,842,527	175.33	-3.00	-1.088.72
1999/00	157,800,470	4,935,955	187.42	-3.91	-1,028.32
2000/01	161,405,690	7,897,136	171.50	-6.12	-1,895.31
2001/02	177,935,970	10,157,698	198.00	-7.14	-2,014.61
2002/03	181,735,440	13,230,491	238.42	-9.10	-2,927.25
2003/04	190,595,630	13,209,410	268.08	-8.66	-3,649.10
2004/05	206,461,490	17,385,401	230.67	-10.53	-6,454.33
2005/06	214,347,289	19,725,414	225.56	-11.39	-5,656.36
TOTAL	**1,725,003,069**	**93,671,627**			**-25,964.78**

Source: the authors, based on data from FAO, SAGPyA and results from SIGMA runs.

[33]Prize, G. *et al* (2003). *Size and Distribution of Market Benefits from Adopting Biotech Crops*. United States Department of Agriculture. Electronic Report from the Economic Research Service. Technical Bulletin Number 1906. November.

CHAPTER 5

SOME COMMENTS AND FINAL CONSIDERATIONS

The analyses of the preceding chapters lend credibility to a widely shared "perception", that is, that the introduction of GM crops in Argentina's agriculture represented a turning point for the farm sector and, given its relevance in the economy, for the development path of the country as a whole. The magnitudes involved leave no room for doubt with regard to this statement and highlight the importance of both the public policies and the decisions made by farmers that made this outcome possible. The balance of this decade has been highly positive, not only for farmers, but also for society as a whole and the impacts on GDP growth and employment, as well as on fiscal revenues and through these on the rate of recovery from the crisis of 2001/2002, strongly support this conclusion.

Having said that, this process has not been one without costs as well as uncertainties that are still out there and need to be addressed in a near future. It would have been surprising if that have not been the case, given the magnitude of the transformation process that has been described. The tremendous expansion of soybeans has resulted, as we have seen, in a strong repositioning of the farm sector within the national economy as well as in the international trade, generating a set of concerns about the possible negative impacts of "soyafication", not only for the excessive dependency of foreign trade on just one commodity, but also for the sustainability of the entire process, given its detrimental effects on soil fertility and the potential negative impacts of the expansion of the crop to more fragile ecosystems. These concerns, together with other ones that have not been discussed in this document like, for instance, the ones dealing with the future evolution of the international context with regard to this type of technologies, are absolutely legitimate but, nevertheless, they do not demerit the clearly positive balance of the first decade with GM crops in Argentina. However, they do highlight the need for a debate on how to optimize the management of the upcoming new innovations in this field that seems to be growing in number on a daily basis, so as to have enough time to take action in order to reduce their possible negative impacts. It should be pointed out that a realistic look at what lays ahead, leads us to believe that the occurrence of another case similar to the herbicide-tolerant soybeans one is highly unlikely.

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ANNEX I

SIGMA V 2.2: A SIMULATION MODEL TO ESTIMATE THE IMPACT OF R&D AND DIFFUSION OF AGRICULTURAL TECHNOLOGY

1. Introduction and general description

The analytical tool used is a dynamic mathematical model (SIGMA), developed by INTA to simulate in a simultaneous fashion the multiple paths by which farmers adopt technology and to estimate the economic impact of it. It can be used either for *ex-ante* and *ex-post* simulations to estimate the effects over production, of the realization of alternative scenarios of R&D and technology transfer, that is, SIGMA calculates the increase in output, with reference to a baseline, attributable to the adoption, at farm level, of technologies either commercially or still in the R&D stage.

The data sets for the runs used in this document were taken from the Technological Profile Study of the Argentine Agricultural Sector (Estudio del Perfil Tecnológico del Sector Agropecuario Argentino) (INTA, 2002), which were collected at the level of homogeneous agroecological zone (HAZ).

The explicit assumptions of the model are the following:

- For each HAZ, farms operate under one of three technological levels (TL): low (LTL), medium (MTL) and high (HTL), each one of them associated respectively with differential practices, inputs and productivity (measured as yields) (see Fig. 1).
- The adoption path of technology by farmers follows a non-linear function (sigmoid), whose parameters are dependent both upon the nature of the innovation and to the socio-economic profile of the target farm population.

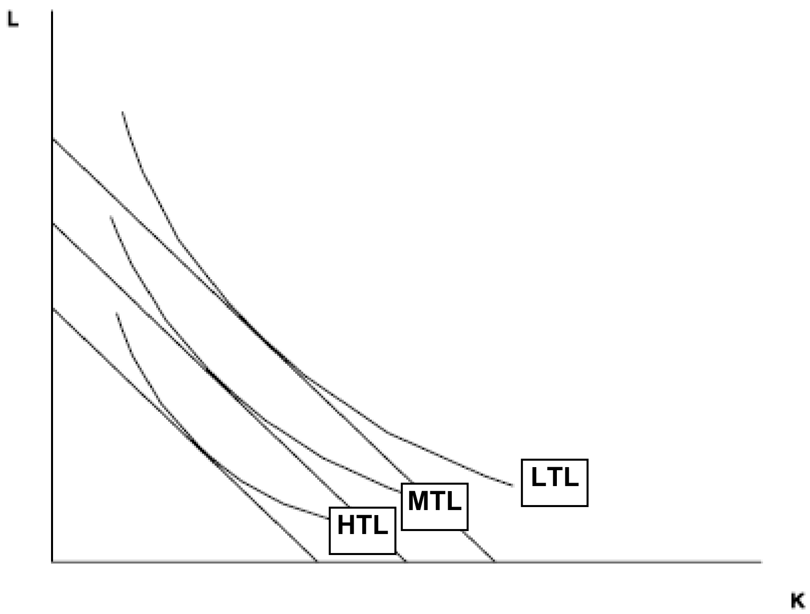

Figure 1: Schematic representation of three technological levels, as coexisting production functions that generate the same output with three different combinations of inputs, assuming farmers choose the profit-maximizing combination of L and K.

The model's key component is the reconstruction of the process of adoption, by farmers, of technological innovations that shift the isoquant that represents their production functions (as a combination of inputs and factors), achieving a more efficient use of resources, which, in turn, implies a reduction in unit costs and/or an increase in product quality (leading to higher output prices). The most significant implicit assumption that SIGMA makes is that the coexistence both in time and space of the three technological levels (TLs) cannot be satisfactorily explained resorting to the simple (non-restricted) profit maximization model provided by neoclassical economic theory, since according to it, farmers should maximize profit and thus, migrate to the production function represented by the "available" isoquant nearest to the origin (HTL in Fig 1), *i.e.*, they all would adopt the profit-maximizing technology. This does not imply that the rationality of farmers is being questioned. Instead, it recognizes the existence of multiple constraints faced by farmers (hard to capture using econometric techniques without detailed and accurate information at farm level), associated with incomplete and/or non-existent markets, as well as of restrictions to the adoption of available technology and its optimum utilization, caused by the undersupply of strictly public goods (such as infrastructure- public underinvestments-), strictly private ones (like refrigeration or storage capacity- private underinvestments-) or combined ones, such as farm management skills. [34].

2. <u>Data required to run the model (by homogeneous agroecological zone)</u>

2.1 Ex-ante version (used for soybeans in this document)

- Area under production and yield, per technological level, at time t=0 (present time).
- Increase in productivity, reduction in costs or improvement in quality (reflected as a change in output price) resulting from the adoption of technology.
- Adoption ceiling per technological level (maximum percentage or area, per technological level, that could adopt the new technology). It is a function of the restrictions faced by farmers to adopt the technology (*i.e.* diseconomies of scale).
- Size of the area (as a fraction of total area) affected by the problem to be solved by the new technology (or that is to benefit from its adoption).
- Year of availability of the technology.
- Time horizon of the simulation.

[34] Some of the constraints identified in a previous study are the following: (1) inadequate profitability of the implementation of the new technology; (2) problems with inputs supply; (3) difficulties in obtaining the required labor —in terms of quantity and/or qualification— to implement the new technology; (4) Lack of bank loans at rates consistent with the rates of return from models with the new technology; (5) lack of articulation with agro-industry in order to adjust production to the requirements of the demand (6) lack of knowledge on the part of farmers about the existence and/or implementation of technological alternatives; (7) lack of entrepreneurial attitude (willingness to take risks, implementation of corporate planning practices as well as management and control systems, etc.); (8) lack of professional extension services (public or private); (9) difficulties in marketing higher production volumes (lack of local markets, poor coordination with marketing agents in wholesale markets, transport constraints); (10) Incomplete information on marketing of commodities with no established channels (i.e., new fruits and vegetables, special products responding to specific demands from importing countries, etc.); (11) restrictions derived from farm scale limitations; (12) restrictions resulting from the social organization of production (leasing, sharecropping, hiring, etc.); (13) poor conservation legislation. Cap, E. *et al* (1993). *Perfil Tecnológico de la Producción Agropecuaria Argentina* (Technological Profile of the Argentine Agricultural Production). 2 vol. INTA, Directorate of Strategic Planning. Buenos Aires, Argentina.

2.2 Ex-post version (used for maize and cotton in this document)

- Area under production and yield, per technological level, at time t0-x (t0 being present time and x the year of availability of the technology).
- Increase in productivity, reduction in costs or improvement in quality (reflected as a change in output price) and/or expansion of the area potentially suitable for the production of the commodity resulting from the adoption of technology.
- Adoption ceiling per technological level (maximum percentage or area, per technological level, that could adopt the new technology). It is a function of the restrictions faced by farmers to adopt the technology (*i.e.* diseconomies of scale).
- Size of the area (as a fraction of total area) affected by the problem to be solved by the new technology (or that is to benefit from its adoption).
- Observed adoption rate (as a percentage of total growing area) at t0 (end of simulation)

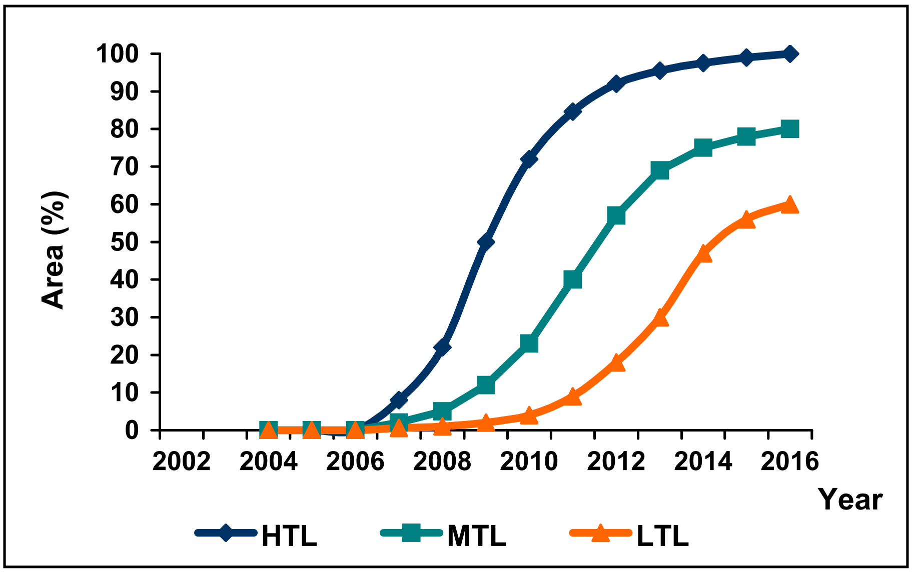

Figure 2: An example of SIGMA-simulated adoption paths, measured as % of area under cultivation, of a technology available in 2006, by farmers that operate in three technological levels: low, medium and high, with (respectively) increasing adoption rates and diminishing constraints to adoption.

2. Mathematical appendix

To simulate the dynamics of the technology adoption paths, a combination of two functional forms was used; the logistic and the sigmoid functions (the latter as a special case of the former).

The logistic function has the following mathematical expression:

$$\mathbf{P\ (t) = K\ \{1 + me^{-(t-\varnothing)} / 1 + ne^{-(t-\varnothing)}\}} \quad (1)$$

$$\lim_{t \to \infty} P\ (t) = K$$

The sigmoid function is a variant of (1), by setting **K=1**, **m=0**, **∅=0** and **n=1**, so that:

$$P(t) = (1 / 1 + e\text{-}t) \quad (2)$$

$$\lim_{t \to \infty} P(t) = 1$$

The functional form used in the SIGMA simulation model was obtained by setting **m=0** and **n=1** in (1), which implies an expansion of the sigmoid function (allowing for the limit P (t), t → ∞ ≤ 1). This variant also allows fort ∅ to take on values ≥ 0, making it possible to select a point along the **t** axis, at which P(t)´´ changes sign, from + to -. This way, we can choose and modify the adoption half-time, that is, the number of years that elapse until 50% of the area with the commodity adopts the new technology. The final mathematical expression is the following:

$$P(t) = K\{1 / 1 + e\text{-}(t\text{-}\varnothing)\} \quad (3)$$

The model uses (3) to simulate the dynamics of the technology adoption paths, included in the following empirical formulation:

$$P(t) = \sum_{t=0}^{T} \sum_{i=1}^{3} [\beta i * \{(Ki /(1 + e^{-(t-\varnothing i))} * Ait \}]$$

where:

P: additional output.

t: time (year)

i: technological level, i ε [1,2,3], where: 1=Low, 2=Medium, 3=High.

β *i*: productivity gap, per technological level, between current and potential values.

Ki: technology potential adoption ceiling ε [0,1].

e: base of natural logs.

∅i: adoption half-time (# of years that elapse before the time at which 50% of the area with TL i adopts the technology under analysis).

Ait: area (in ha) of TLi, at time t (A*it* = f (*Ait-1*, mobility rate[35] ε [0, 1], area expansion rate ε [0, ∞]).

[35] Defined as the percentage of area of TL i (i=1,2) that "promotes" yearly to the next TL (as the result of a combination of determinants, such as the improvement in farm management skills (frequently observed when the farm changes ownership) that leads to higher productivity unrelated to the technology under study. The model sets this rate at 1%/year and it has been included to control for an empirically observed "technical upward mobility" process that could lead to an overestimation of the effects of the adoption of new technologies.