GMO Technology Diffusion and Sustainable Agriculture in Developing Countries: The Case Study of RR Soybean in Argentina

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Abstract

This paper presents an empirical analysis of the impact of the diffusion of genetically modified Soybean (Roundup Ready variety) on the level of inter-crop diversity in Argentina, the country with the biggest transgenic Soybean area worldwide.
Farmers are progressively and quickly substituting local landraces with the transgenic Soybean owing to the best guarantee of profitability, that it represents in the short term.
The wide adoption of this genetically modified crop risks of reducing the level of inter-crop diversity and of promoting monoculture in large scale, with a potential effects of loss of resilience at the level of the agro-ecological system as a whole, that could affect its stability and cause a loss in the farmers' expected welfare.
These hypotheses are tested using a two stage estimation approach with a time series data analysis. Findings suggest that the rate of diffusion of the Roundup Ready Soybean is associated with a decrease in the level of inter-crop diversity, and that inter-crop diversity is positively correlated with an increase in the variance in soybeans' yield, with possible negative outcomes for the sustainability of the agriculture, for the food safety system and for the economic stability of the market oriented agriculture of the country, more and more focused on the production and the exportation of soybean.

Key words
Transgenic crops, RR Soybean, biodiversity, agro-ecosystems, sustainable agriculture

1. INTRODUCTION

Inter-crop diversity refers to the diversity among domesticated plants, including crop plants. It is a component of agro-biodiversity, a broad term that comprises all components of biological diversity in agroecosystems that are necessary to sustain its key functions, structures and processes, including crops, livestock, wild relatives and all interacting species of pollinators, symbionts, pests, parasites, predators and competitors (Qualset et al. 1995, Wood and Lenne, 1999).

The importance of inter-crop diversity is widely recognized in both the agricultural and agro-ecological literatures. Recent ecological experiments have shown that greater plant diversity allows access to a greater proportion of available resources, leading to increased total resource uptake by plants, lower nutrient losses from the ecosystems, increased net primary productivity and temporal stability (Rao, 1986, Hooper and al. 1997, Tilman et al. 1997, Hector et al. 1999**,** Reich et al. 2001).

An array of options increases the goodness of fit between species traits and environmental conditions (Tilman et al. 2004). Since the performance of different species varies with biotic and abiotic events, greater species diversity enables the system to maintain productivity over a wider range of conditions, reducing the variance of outcomes and thus providing insurance against losses (Naeem et al., 1994, Chapin et al., 1997).

One element in the insurance value of species diversity consists in the capacity of the agro-ecosystem to regulate insect pest and pathogen populations (Byerlee, 1996, Wood and Lenne 1999). A central result from epidemiology is that both the number of diseases and the incidence of disease increase in proportion to host abundance. The distribution of pathogens by type is not exogenously given but is influenced by the distribution of host types (Tilman et al, 2002). It follows that if an area is characterized by a high level of inter-crop diversity, the susceptible pool for any pathogen and hence the probability of an outbreak will be lower than if intercrop diversity is low. In this sense, intercrop diversity contributes to both the resilience and sustainability of agroecosystems (Giller et al. 1997, Heal et al. 2002).

Agroecosystems are, by definition, strongly influenced by humans. The level of inter-crop diversity is determined less by environmental conditions than by farmers' decisions about variety choice, seed selection and crop management. These decisions reflect the opportunity costs of alternative crop mixes, and depend on experience, tradition, economic circumstances, social and cultural constraints as well as the information available to farmers (Smale, 2005).

This paper considers the opportunity cost of the widespread and rapid diffusion in Argentina of genetically modified Soybean, one of the most promising and innovative technologies in agricultural systems, and the contemporaneous abandonment of traditional varieties and landraces in favour of the new transgenic variety. It distinguishes between the private and social cost of farmers' choices, drawing attention to the external costs of decisions that increase the homogeneity of the agricultural landscape, or that reduce inter-crop diversity. It is the fact that transgenic crops offer private advantages over non transgenic crops that makes them attractive to farmers, and lies behind the abandonment of traditional landraces and non-genetically modified commercial crops (Witcombe, 1999).

The social costs of farmers' decisions relates to the fact that the spread of this transgenic crop with most resistant genotype to herbicides promotes monocultures on a large scale (Garcia et al. 2005, Altieri, 2005), that in turn may lead to a potential loss of resilience at the level of the system as a whole. This is due to both environmental simplification and genetic uniformity. These potentially increase the risks of crop failure as a result of biotic and abiotic stress factors, and reduce the ability of agroecosystems to provide other ecosystem services, causing a loss of social welfare. The social effects of GMO adoption on inter-crop diversity may be worse in developing countries, where farmers depend more on the diversity of their crops to cope with risks than in developed countries, and where the alternatives to agriculture are limited.

The empirical objectives of the paper are as follows:

1. To analyze data at the country level on the rate of diffusion of Roundup Ready Soybean in Argentina. It has been chosen the Argentine case study both for the impressive rate of adoption of the RR Soybean variety (Roundup Ready soybeans comprise 99% of Argentine soybean hectarage) and for the relevance that the Soybean's cultivation plays for the country, being currently the most important crop for the country
2. To test the relationship between Roundup Ready Soybean diffusion and inter-crop diversity
3. To test the relationship between inter-crop diversity and the stability of Soybean's yield after the adoption of the transgenic variety, as a proxy for agroecosystem resilience.

The structure of the paper is the following. The next section describes the path of adoption of Roundup Ready (RR) Soybean in Argentina. Section 3 presents the conceptual framework behind the hypotheses to be tested in the study, explaining farmers' decisions on crop allocation, and the possible consequences of the wide adoption of transgenic soybean.

In the fourth section we present the methodology of the empirical approach used to investigate the relationship between herbicide tolerant soybean diffusion and inter-crop diversity, and between inter-crop diversity and Soybean yield stability. Findings are then discussed and the final section offers some conclusions.

2. ROUND UP READY SOYBEAN'S ADOPTION AND DIFFUSION IN ARGENTINA

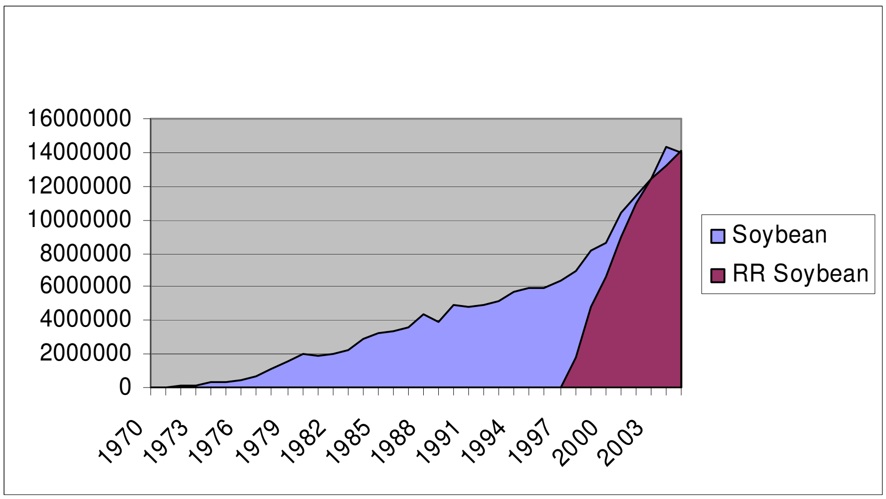
Since the 1960s, it began a process of agriculturization[1] in the Argentine Pampa[2], that in the following decades it extended also towards zones of the extra Pampean regions, such as the Northeast (NEA) and Northwest (NOA). The introduction of high yielding varieties and accompanying technological changes generally known as the "green revolution." were the main features characterizing this new era (Sábato, 1983). These new varieties required adequate soil moisture, protection against weeds, and protection against pests and that were provided through the use of chemical fertilizers, irrigation where necessary, and the application of herbicides and pesticides. In order to reduce labour costs and increase efficiency, farm operations were mechanized as much as possible. The processes mentioned led to rapid changes in different management areas including the classical Pampean rotation of wheat and alfalfa, and the substitution of maize by systems based on soybeans and the double cropping of wheat and soybeans. This was made possible by the introduction of earlier maturing wheat varieties based on Mexican dwarf wheat, that allowed for the first ever double-cropping in the northern area of Buenos Aires province (Solbrig and Vera, 2000). As a result of this process, it verified an enormous change in the types of crops planted with increases in yield and productivity and the expansion of the cultivation of soybean, in large measure at the expense of maize. Agricultural activity and in particular way grain and oil crops production increased at a very high rate; between 1970 and 2006 the agricultural surface grew at an annual average rate of 2%; in the campaign 2005/2006 the harvested area reached 28,4 million of hectares (FAOSTAT database).

[1] "Agriculturization" can be defined as the permanent substitution of agriculture for the crop-livestock rotation, which was the dominant farming system used in Argentina until the mid-1970s.
[2] The Pampa plain occupies most of the Province of Buenos Aires, the centre and the south of the Province of Santa Fe, most of the Province of Cordoba, the centre and south of San Luis Province and part of La Pampa.

In the last decade this growth has presented a very peculiar feature; it has been produced almost exclusively by the protagonism reached by the soybean, variety that at the present is the country's main crop, representing the 50% of the total crop surface (SAGPYA data, 2006).

Even thought the increase of soybean has been permanent since its introduction in the country in the seventies, the appearance of the transgenic variety – during the campaign 1996/1997, represent a point of inflection, since then this oleaginous begun rapidly to spread all over the country (Della Valle and Begenesic, 2002).

Table 3.1.: Evolution of the Soybeans area (hectares)



Data from FAO Statistic Division 2006 and Asociation Semilleros Argentinos (ASA)

Genetically modified organisms fall into a second set of innovations, in this case of biotechnological nature, developed abroad and adapted by the Argentine agricultural sector (Trigo et al, 2002). Argentina can be considered a pioneer in the introduction of GM crops both in Latin America and in the rest of the world; the country is second only to the United States in terms of the area planted with transgenic crops.

The first transgenic crop commercially released into the country was the herbicide resistant soybean. Later, transgenic varieties of corn and cotton tolerant to herbicides and resistant to insects have been approved.

The transgenic soybean variety introduced has been the Roundup Ready soybean (RR). RR technology features a gene from the soil bacterium *Agrobacterium tumefaciens,* which makes the recipient plant tolerant to a broad spectrum herbicide glyphosate. It was developed for various crop species by Monsanto[3], the private company that also provide glyphosate under the brand name Roundup.

There is quantitative evidence that the technological change is in great measure responsible for the increase in the area of Soybean cultivation. The comparison of the rate of growth of Soybean area harvested between the period 1988/1989-1995/1996, characterized by the use of traditional seed and the period 1996/97-2004/2005, in which the seed resistant to the glyphosate has been commercialized, shows how the soybean surface after the introduction of RR variety increased with a rate, clearly bigger than the preceding period.

Soybean: Average rate of growth

PERIOD	TOTAL SOYBEAN AREA HARVESTED
1988/1990-2004/2005	7.40%
1988/1989-1995/1996	3.27%
1996/1997-2004/2005	9.00%

Source: FAO Statistic Division 2006

The introduction of GM soy in the country was accomplished very quickly, from less than 1% of the total area planted with soybean, in the 1996/1997 season, to more than 98% in the 2004/2005 season. This represents the most comprehensive adoption of GM soy in the world, with almost the total of national soy production based on a genetically modified variety. This rate of adoption is even higher than that in the United States, which was the first country to introduce this technology. Midwestern US states took about 15 years to exceed 90% adoption, whereas in the Argentinean growing region that level was reached in seven seasons. Adoption curves are also steeper than those of other well-known and popular technologies, such as corn hybrids (Trigo and Cap 2003). At the present the Republic of Argentina is the third world producer of soybean and the first world exporter of soybean oil.

The consequent transformation of the rural sector and of the landscape has been notable.
The following graph and table summarize the trend of the main Argentinean cultivations and their relative rate of growth.

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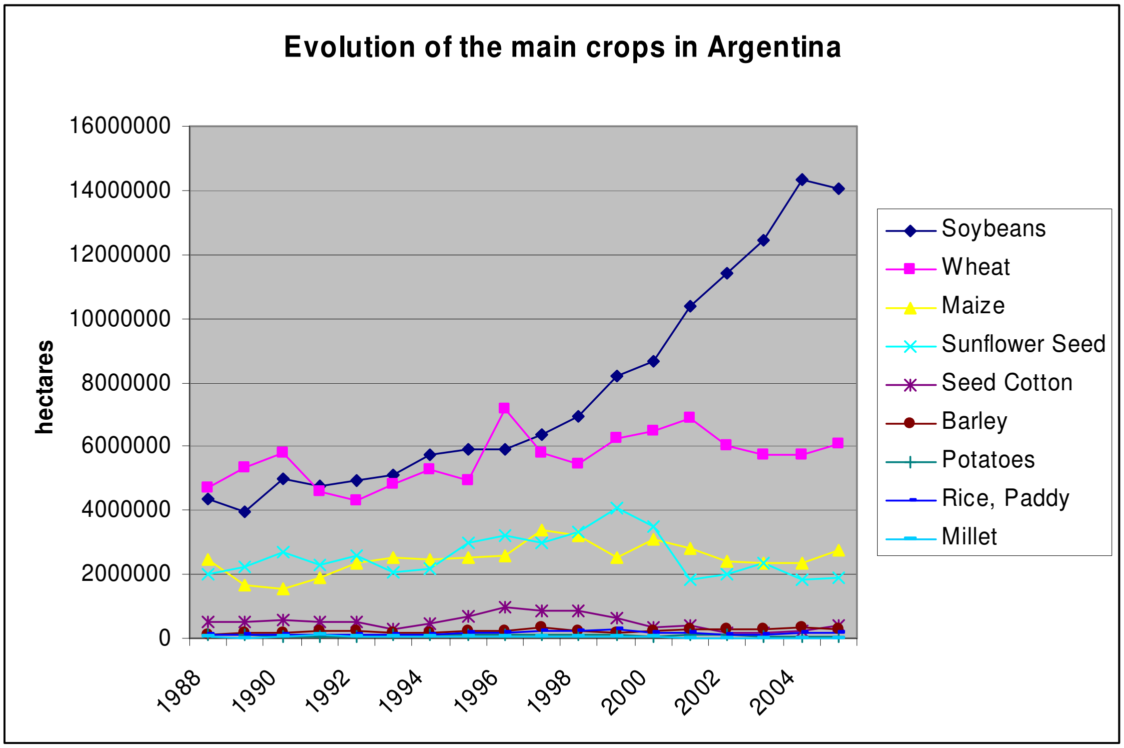
[3] However the first company to commercially release RR soybean varieties in Argentina was Nidera, a multinational agribusiness company with a big seed enterprise in Argentina that received royalty-free access to Monsanto's RR technology in the late 1980s.



Source: FAO Statistic Division 2006

Rate of growth of the main Argentinean crops

	CROP	1988/89- 1995/1996	1996/97-2003/2004
AVERAGE RATE OF GROWTH	Soybeans	4.3%	↑ 11.8%
	Wheat	7.0%	↓ - 2.3%
	Maize	2.2%	↓ - 0.1%
	Sunflower	7.4%	↓ - 4.0%
	Seed Cotton	13.5%	↓ - 7.9%
	Barley	10.7%	6.0%
	Potatoes	- 0.4%	↓ - 3.3%
	Rice, Paddy	12.3%	1.1%
	Millet	9.4%	↓ -19.1%

Source: FAO Statistic Division 2006

From the analysis of data, it stands out that soybean area has increased to the detriment of other cultivations such as wheat, sunflower seeds, cotton, millet, with significant consequences for the country's food sovereignty and agro-biodiversity. In the Pampean region, for example, 4.6 million hectares of land previously dedicated to dairy, fruit trees, horticulture, cattle and grain has been displaced by soybean production since 2004. Areas planted with sunflowers have been reduced by 9.6%, and areas cultivated with maize by 5.6% (Pengue, 2004). The transgenic soybean has favoured the extension of the agricultural frontier towards more marginal areas, previously devoted to forest or dairy production (Della Valle, Begenesic, 2002). In very few years, thousands of hectares of virgin lands have been transformed. Between 1998 and 2002, deforestation in *Chaco State* affected 117.974 ha (Montenegro et al.).

3. CAUSES AND CONSEGUENCES OF THE REMARKABLE ADOPTION OF RR SOYBEAN IN ARGENTINA

To understand the remarkable adoption and diffusion path of RR Soybean since 1996, the year of the first commercialization in Argentina, we need to start from farmers' behaviour. In the short run, the decision on how allocate crops between the available land is driven by issues of costs and returns, and efficiency in terms of labour, energy and use of external inputs (Griliches, 1957).

A farmer, who has previously cultivated local landraces, may decide to grow genetically modified crops for the first time if the new variety offers higher returns than the traditional varieties (Morris and Heisey 1998), taking all privately relevant factors into account. These include the constraints imposed on growers of transgenic crops by the seed companies. GM seeds are in fact generally sold and grown exclusively under contract, their costs are in general higher than for non-GM crops, and include both payment of the so called "technological fee"[4], and an agreement not to save seeds.

The following section analyses the main drivers of the adoption of RR soybean in Argentina.

One of the determining factor of the rapid and widespread adoption of the RR soybean is the complementary synergy resulting from the interaction between GM soybean and no-till practices. With this system, seed is sown directly on the land without ploughing or any other

[4] It results from the private origin of the technology as payment for the patenting rights. Generally it is first paid by seed firms and is later transferred on farmers

form of cultivation; it provides the opportunity to move up the planting date earlier and speeds up the pace of production (Popp et al., 2003), allowing a "virtual"[5] expansion of the agricultural frontier, by means of expanding the area suitable for double cropping, in which soybeans follows wheat in the same season.

The technique keeps the soil covered with dead vegetation, which after decomposition serves as a natural fertilizers and protects the soil from erosion and from extreme temperature shifts. Owing to the serious problem of soil erosion in the Pampa, Argentinean farmers began to raise in 1990s soybean, using the direct planting, which progressively replaced the more aggressive conventional tillage systems. (Senigagliesi and others, 1993, Taboada 1998).

The coupling of no-till planting with herbicide tolerant soybean has combined two technological concepts: on the one hand, a new mechanical technologies which modify the crop's interaction with the soil; on the other hand, the utilization of general use, full range herbicides (with glyphosate in first place) which are environmentally neutral, due to their high effectiveness in controlling any kind of weeds, and their lack of a residual effect (Trigo et al., 2002). Introduced to a plant, Roundup-ready technology has facilitated weed management in farmers' fields substantially, killing the weeds that grow alongside the soy plant and allowing producers to use one herbicide without causing crop damage.

The adoption of glyphosate tolerant soybean has so reduce production costs, both because glyphosate is a substituted for an array of more expensive herbicides and because when the adoption process of RR soybean started, the patent for Roundup (Monsanto's commercial brand of glyphosate) had expired several years earlier. In 2001, the price of glyphosate was less than 30% of its 1993/94 level. From a price of $ 28/litre it goes down now to $ 3/litre. The reduction in the glyphosate price has been so significant to compensate the more intense use of glyphosate, that less than 1,000,000 liters at the beginning of the 90´s, have passed in 2003/2004 to 150,000,000 liters (Trigo et al., 2002).

Time needed for harvesting and machinery and labour costs are so decreased (Qaim and Traxler, 2005), allowing farmers to have more time in off-farm activities (Fernandez Cornejo, 2005).

The other determining cause of the wide adoption of transgenic soybean concerns the peculiar situation of the Intellectual Property Rights (IPR) system. In Argentina, farmers do not pay

[5] The expansion of soybean cultivation has not been only virtual, through doubling cropping, but also occurred also in new areas with high biodiversity, opening a new agricultural borders in important ecosystems like Yungas, Great Chaco and the Mesopotamian Forest (Pengue, 2004)

technology fees for herbicide tolerant seeds as a consequence of a series of circumstances that made the technology non-patentable at the time when the formal application was submitted[6]. Because of the lack of the enforcement of the IPRs for RR soybean, farmers can buy the seeds paying a small premium of less than 3 $ per hectare. (Pengue 2004). The weakness in the patent system has consequently determined a competitive market for RR soybean seeds with several companies providing different RR varieties and can be considered a as a facilitating mechanism for its rapid adoption, thanks to the cheap market price (Qaim & Traxler, 2005).

In this context characterized by a deficiency in the protection mechanisms of market of herbicide tolerant soybean seeds, farmers have begun to reproduce the new transgenic seeds in theirs fields, generating a sizeable and growing informal market, which has further reduced the prices of soybean seeds, forcing the legal sellers to adjust their prices to the black market prices. In 1997, when Roundup Ready was introduced, the price of a 50lb bag of transgenic seed was $25, while the price on the black market was $15. By 1999, the legal price had dropped to $9, very close to the price of the black market, which was slightly lower. An estimated 25 to 50 percent of the soybean seeds grown are sold in Argentina. (US General Accounting Office, 2000).

Since this practice is against the economic aims of the companies, the lack of patent protection has been the source of much tension between the Argentinean government and foreign companies until to reach the breaking point was in 2004, when Monsanto announced the withdrawal from the Argentinean self-pollinated soybean seeds market (Burke, 2004).

In the agricultural world trade context, the low price for RR soybean, approaching the black-market one, has so constituted a competitive advantage for Argentina on the other soybean producers, in particular on United States[7], where soybean prices are far above the argentine prices. This advantage has been further supported by the growing demand for soybean due to the global increase in meat consumption, much of which is produced with soybean meal. Besides the low water content, high nutritive value and its capacity to yield a variety of

[6] Asgrow International, which at that time was owned bu Upjohn, had an agreement with Monsanto to introduce RR technology into their soybean breeding lines. Shortly after this, Upjohn decide to sell or close its subsidiaries in the southern hemisphere. Nidera bought Asgrow Argentina, and with this purchase, acquired the right to use all Asgrow International germplasm. In the mid-1990s Monsanto bought the grain and oilseed business of Asgrow International and terminated the free access agreement with Nidera for newly developed breeding lines. He already existing material, however, remained unaffected, including soybean lines that contained the RR gene. Nidera channelled the technology throught the Argentine biosafety process and received commercial approval for several soybean varieties in 1996. Monsanto itself and other companies only fellowed in subsequent years

[7] In USA the sale and use of RR technology is protected through patents and sales contracts with farmers.

products (human food, animal food, oil, and industrial derivates) of soybean have reduced its vulnerability to market fluctuations and storage and transportation costs (Grau et al, 2005).

The low mark-up paid by farmers for herbicide resistant soybean has represented an incentive for the adoption of the technology, that in a short period of time has become one of the most success stories of technological adoption of the last decade, with consequent advantage in minimizing production costs due to its interaction with other technologies (no tillage practice) but also due to its global macroeconomic effect through their impact on the country's agricultural soybean exports.

The export of products made from soybean accounted for one-fourth of Argentina's export earnings in 2003, and soybean exports have increased by 125% since 1997. Soybean exports are an important source of government tax receipts that contributes to the funding of social projects for the mitigation of the consequences of the socio-economic crisis that the country is going through. (Della Valle, Begenesic, 2002).

However, the expansion of soy in Argentina represents an example of the potential conflict between economic priorities and social-environmental ones. It is clear that short-term economic objectives are taking precedence over medium and long-term environmental and social-economic concerns and that this positive trend is not balanced with an equivalent preoccupation for the conservation of natural resources and the sustainability of agro-ecosystems.

Since large numbers of farmers possess similar resource endowments, knowledge, and technical skills, the profitability of RR soybean for farmers in Argentina derived from the simplification and flexibility of agricultural work, the virtuous interaction with other technologies (no tillage practice) and the low mark-up paid because of to the lack of enforcement of IP rights of RR, have encouraged and will generally encourage many farmers to select genetically modified soybean and to abandon local landraces.

The potential social costs of adoption are harder to see. The spread of herbicide tolerant soybean risks to promote the cultivation of soybean in a large scale, that would affect the commercial position of Argentina in the meantime.

If RR soybean adoption and diffusion results in a decrease in inter- crop diversity, it could lead to a potential loss of resilience at the level of the system as a whole, due to environmental simplification and genetic uniformity, through for example the emersion of new diseases and tolerant weeds in response to the establishment of GM Soybean monocultures. If pest and diseases outbreaks occur, from their which Soybeans have not been designed, it could verify sizable and negative consequences on yields and farmers' income, particularly amongst low-income farmers. Conserving and using numerous species is of value because each species generates the greatest value for a small range of environmental conditions. For short-lived organisms, such as annual crops receiving inputs of water, fertilizers, pesticides, etc., the greatest value in a given year might be generated by a single variety of a single species, but different species and/or crop varieties would perform better in different years depending on conditions. In either case, losing species will mean that lower value is produced for some environmental conditions/years.

In a context characterized by a wide adoption of GM varieties and by no alternative methods of insuring against crop failure, if pest and disease outbreaks occur (in plants that are not protected), they could have a sizable and negative impact on farmers'incomes and aggregate yields. This creates a form of social trap, a situation where farmers in the attempt of maximising profit according to their own interests and without the knowledge of other farmers' actions in mind, produce a result that is socially undesiderable.

The individual farmer does not consider the general implications of heir choices for the overall pattern of diversity, and the implications that this has for the risks that society as a whole faces. Nor does she assess accurately the risks that she personally will face as a result of her choices (Heal et al. 2002). The presence of external effects between farmers implies that the overall allocations of risks in society and indeed the overall allocation of resources will be inefficient.

To the extent that transgenic crops may threat the diversity and increase the vulnerability of agro ecosystem, they furthermore may impede farmers from using a plethora of alternative methods of struggle the uncertainty, increasing their exposure to risk (Altieri, 1996).

4. EMPIRICAL APPROACH

To analyse the relation between RR soybean' diffusion and the level of inter-crop diversity and then, between inter-crop diversity and soybeans' yield variance, we focus on the area comprehensive all crop surface of Argentina.

Estimation was conducted in two stages. To assess the effect of the GM Soybean's diffusion on inter-crop diversity, an inter-crop diversity index was regressed against the rate of development in percentage of the total GM area on the total crop land area of Argentina. In the second stage, to test the effect of diversity on the stability of the agroecosystem, the variance of Soybeans' yield, calculated on a three year moving trend, was regressed against the diversity index. The next subsection describes the data sources, followed by the econometric specifications corresponding to each stage of analysis.

Data

Analysis is based on national time series of Argentina, that include years from 1997 to 2005, and estimated with OLS.

Data on the evolution of the RR Soybean adoption, were obtained from the Asociación Semilleros Argentinos (ASA).

Table 4.1: Evolution of the surface cultivated with RR Soybean in Argentina (in thousand of hectares)

	1997/1998	1998	1999	2000	2001	2002	2003	2004	2005
Hectares	37	1756	4800	6640	9000	10925	12446	13230	14058

Source: ASA, Asociación Semilleros Argentinos 2006

Data on national crop area for each commercial variety come from the FAOSTAT database.

The same data on the area committed to each crop in each country were used to calculate a Simpson's index of inter-crop biodiversity, the metric developed by the ecological literature that we have chosen as a measure of the diversity of crops in this area

$$S = \Sigma\, pi^2$$

where p_i is the population share of the *i*th species in a reference region. Since the Simpson' index is expressed as the sum of squared shares of the area planted to each crop, area shares are assumed to represent population shares. Here, p_i is the crop area planted to the *i*th crop in Argentina.

The index is both a measure of proportional abundance and richness, but is heavily weighted toward the most abundant species in the sample while being less sensitive to species richness (Magurran, 1988: p. 40).

An index value close to one, indicates that almost all of the crop area is allocated to one single crop. An index close to zero indicates a large number of crops planted on a very small area. The measure of inter-crop diversity in this paper is limited to diversity among domesticated plants, and in particular to the commercialized varieties for which data on the area harvested are available on the FAOSTAT database. The following table summarises the results for the calculation of the Simpson index for every year from 1997 to 2005 ($S_t = \Sigma p_t i^2$).

Table 4.2: Simpson's index in Argentina

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Index	0.179	0.181	0.200	0.212	0.252	0.276	0.293	0.324	0.305

Source: Author's calculations based on FAOSTAT database 2006

Soybean's yield data come from the SAGPYA database.

Table 4.3: Soybeans' yield in Argentina (Kg for hectare)

	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05
Yield	26937	24450	23386	25829	26441	28017	21997	27285

Source: SAGPYA 2006

The variance of the Soybeans' yield on a moving three years period, after the adoption of the herbicide-tolerant variety, has been used as a proxy of the agro ecosystem's resilience

Stage 1: Crop biodiversity and GMOs' adoption

To select an appropriate specification for the inter-crop diversity and the RR Soybean' adoption a linear model was estimated and tested. Letting D_t the level of inter-crop diversity and T the hectares of RR Soybean area, the estimated model was:

$$D_t = B_1 + B_2 T_t + \mu, \qquad t = 1,2, \ldots, n.$$

Stage 2: Crop biodiversity and Soybeans' yield variance

A linear model was also chosen to describe the relationship between crop biodiversity and the variance of soybeans's yield variance. The dependent variable I, is the variance of the soybeans' yield, taken over a moving three year interval. S_t, is our index of inter-crop diversity, calculated as the as the average Simpson's index over the same period as the dependent variable. The estimated model is:

$$I_t = B_1 + B_2 S_t + \mu \qquad t = 1,2, \ldots, n$$

5. RESULTS

Table 5.1 reports the effects of RR Soybean on inter-crop diversity measured for Argentina. The overall fit and significance of the model is good. It shows that the rate of adoption of RR Soybean, in terms of hectares of land planted in GM soybean, is positively correlated with a loss in inter-crop diversity. If the value of the Simpson's index increases, the level of inter-crop diversity decreases.

Table 5.1: The effect of RR Soybean's diffusion on inter-crop diversity

Variables	Coefficient	Std. Error	t-statistics	p-value
Costant	0,161343*	0,00933877	17,2767	<0,00001
GMOs rate of diffusion	1,05719e-08*	9,91684e-010	10,6606	0,00001

R^2:0,94198 R^2 CORRECTED: 0,933691
Durbin-Watson Statistics: 1,46038
Significance: * = 1%

Table 5.2 reports the estimated model in the second stage.

Table 5.2: The effect of inter-crop diversity on the variance of Soybeans' yield

Variables	Coefficient	Std. Error	t-statistics	p-value
Costant	-1,73199E+07**	5,97289E+06	-2,900	0,03380
Inter-crop diversity index	9,49903E+07**	2,37727E+07	3,996	0,01037

R^2: 0,761521 R^2CORRECTED: 0,713825
Durbin-Watson Statistics: 1,68846
Significance: **= 5%

The econometric analysis shows that a decrease in the level of inter-crop diversity, corresponding to an increase in the index's value, is positively related to an increase in the variance of Soybean's yield over the period from 1997 to 2005, and that this is significant at the 5% level.

6. CONCLUSION

This study contributes to the ongoing debate on the benefits and costs of GMOs' diffusion in Argentina by analyzing the relationship between RR Soybean adoption and changes in the variance of Soybean's yield. It tests the hypothesis that actions which reduce levels of inter-crop diversity, even though they may reduce risks in the production of soybean, will increase the variance in soybean's yield.

The study proceeds in two stages. First, we consider the impact of RR Soybean's adoption on inter-crop diversity. In this respect it is shown that adoption of RR Soybean in Argentina clearly reduced the overall genetic diversity of crops as measured by a Simpson's index of inter-crop diversity. This finding likely reflects how the adoption of such variety does not reduce necessarily crop diversity, but it's depends on their rate of diffusion and moreover on the relative importance of the area sown with transgenic crops on the total national crop area. On his turn, it depends on the expected profitability about transgenic varieties.

In their decisions about the allocation of land between different crops, farmers are driven primarily by the private net benefits of the alternatives, in our case RR Soybean, which yielded substantial competitive advantages in comparison to local landraces.

Roundup Ready soy facilitates weed control, particularly when associated with a no-till planting system and the technological package offered with GM seeds, accompanied by reduced prices for herbicides and the low mark up paid for RR soybean seeds, is thus very attractive for Argentinean farmers.

This has led to a reduction in the number of varieties grown and to specialization of Argentina in soybean cultivation. The social costs of this trend – not taken into account by individual farmers – is that the resulting monoculture itself involves risks.

The risk of loss of biodiversity seems thus to be larger, in countries where the GMOs' characteristics make them more profitable and easier their cultivation than other varieties' cultivation. Furthermore, the attempt of stabilize crops' yield and revenue, through the elimination of risk derived to biotic and abiotic stress, alters farmers' risk aversion, a driving force for crop biodiversity conservation.

Put another way, although the adoption of RR soybean offered farmers an advantage, at least in the short term, it also generated negative externalities in the form of a loss of resilience at the level of the agroecological system as a whole, and this has been reflected in an increase in the variance soybean 's yield and a consequential reduction in expected farmer welfare.

The second stage of the analysis shows that the decrease in the inter-crop diversity has positively affected instability of the agro ecosystem of the whole area analyzed, increasing the variance of the Soybean's yield.

To conclude, the public good externalities of individual variety choice due to the widespread adoption of RR Soybean can lead to a lower level of inter-crop diversity than is desirable from a social perspective, and consequently to a level of risk that farmers would not themselves choose. Besides the overwhelming dependence on transgenic soybeans would make Argentine farmers and the country especially vulnerable to any changes in the national and global soybean markets.

This has obvious policy implications. Since the social cost of the adoptions of GM technologies is higher than the private cost, and since it increases as the area under GM crops increases, there should be a 'density-dependent' tax on adoptions. Even though the process of GMO diffusion is recent, the widespread adoption of transgenic Soybean in Argentina suggests the need for mechanisms to ensure that the diffusion of GM crops proceeds at the socially optimal rate. This requires a change in the incentives to farmers wherever a reduction in crop-diversity increases the risks born by society.

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