Developing capabilities in the seed industry: which direction to follow?*

Anabel Marin**

Conicet/Cenit, Argentina

Lilia Stubrin

Cenit, Argentina

Patrick van Zwanenberg

Cenit, Argentina

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**Corresponding author: Conicet/Cenit Argentina. Address: Callao 353, 3er piso B - (CP 1022) Ciudad Autonóma de Buenos Aires – Argentina. Tel.: (5411) 4373-3714 | (5411) 5199-6393. Email: a.i.marin@fund-cenit.org.ar*

SUMMARY

Although modern plant biotechnology is not confined to the genetic engineering of plants, policy makers in a number of emerging economies often assume that genetic engineering represents the leading technological frontier in seed innovation, and that efforts to encourage domestic seed firms to 'catch up' with industry leaders need to focus on the development of capabilities in transgenic techniques. Such assumptions are reinforced by the claim that, where adopted, genetically engineered seed varieties have been responsible for significant improvements in seed and agricultural performance. In Argentina, for example, transgenic crops are widely assumed, by agricultural economists, the media, and government as largely or even entirely responsible for the spectacular growth in production, productivity, and internationally competitive performance of soy and maize in recent years.

In this paper we challenge all those assumptions and claims by exploring the role that transgenic technologies have played in explaining dynamism in the seed market, and wider agricultural economy, in Argentina, focusing on the case of soy. We make a distinction between three innovation approaches in the seed business (*genetic engineering*, *mutation* and *cross- breeding*) and then explore empirically the importance of each innovation approach for firms and markets in Argentina. We do so by estimating the relative contribution of each of the three approaches to the rate of innovation in the Argentinean soybean seed market; and the relative contribution of those different innovations to productivity gains in soybean production. We argue that transgenic technologies have accounted for only a small proportion of seed innovation in soy, and very little of the striking increase in productivity of the agricultural soy sector over the last 15 years. This stands in stark contrast to the portrayal of transgenic technologies as the main driver of the recent success of that sector. Firm case studies also illustrate the importance of non-transgenic technologies in explaining the striking dynamism of some domestic firms.

Our study has implications both for debates about the role of transgenic seed innovation in agricultural development, and for the 'catching up' literature. The latter typically assumes (often implicitly) that there is only one possible technology option within industries towards which technological capabilities should be accumulated; namely, the option adopted by industry leaders and favoured by institutions and markets in industrially advanced country contexts. Amongst other things, our study points to the importance of investigating other issues within the 'catching up' tradition, such as the nature of the different technology options that may be available within industries, whether some might be more or less useful than others for the development purposes of the country, and how particular options might be encouraged.

1. INTRODUCTION

Since the early 1990s, many governments in developing countries have viewed agricultural biotechnology and plant genetic engineering in particular as key to raising agricultural growth and productivity (Pray and Naseeem, 2007), mirroring similar sentiment in Europe and the USA (Commission of the European Communities, 2002; Smith, 2000).There have as a consequence been major government investments in the development of capabilities related to modern biotechnology, and plant genetic engineering specifically, in countries such as China, India, Brazil, Argentina, Egypt and South Africa, in an attempt to 'catch up' with what is seen as the leading technological frontier in seed innovation (Pray and Naseem, 2007; Uctu and Essop, 2013; Ministerio de Economía y Producción, Secretaria de Agricultura, Ganadería, Pesca y Alimentación de la Nación, Oficina de Biotecnología, 2004). Developing and emerging economies that have since encouraged the commercialisation of genetically engineered crops are often described by analysts as having enabled massive benefits to accrue to their agricultural sectors, with additional enormous promise for the future (Trigo, 2011; Trigo, Falck-Zepeda and Falconi, 2010; James, 2010; Brookes and Blume, 2012; Brookes and Barfoot, 2011; Pray, Huang, Hu and Rozelle 2002; Qaim M and Traxler G 2002); just so long as governments continue to invest in the scientific, regulatory and public relations support necessary to enable the further development of genetically engineered seeds (James, 2010; Qaim, 2009).

In this paper we wish to challenge some of the assumptions underlying these mainstream views on genetic engineering technologies and seed innovation. In particular the assumptions that genetic engineering, among other applications of molecular biology, represents the only leading frontier in seed innovation; that developing country governments should seek to 'catch up' in that area of biotechnology specifically; and that it has already been the leading technology for improving seeds and agricultural performance in those jurisdictions where it has been adopted. We do so by exploring (and reflecting on) the role that genetic engineering technologies have played in explaining dynamism in the seed market, and wider agricultural economy, in Argentina, focusing on the case of soy.

Argentina was one of the first developing countries to commercialise genetic engineered crops, introduced by multi-national firms, and is now the world's third largest producer of genetic engineered crops. It is a prominent commodity crop producer with a large and important seed market. The country is often showcased as a highly successful convert to the adoption of genetically engineered crops, soybean in particular, on the grounds that the technology has delivered considerable benefits to farmers, agricultural productivity, and overall agricultural production (Trigo, 2011; Ablin and Paz, 2002; Trigo and Cap, 2003; Penna and Lema, 2002).

In fact, genetic engineered crops are not only seen as having been highly beneficial to agriculture and agricultural production, but as largely or even entirely responsible for the revitalisation and internationally competitive performance of soy and maize production in Argentina in recent years. This is a widely shared view, articulated by agricultural economists,[1] the media,[2] and the Argentinean government. The following excerpt from the Government's 10 year (2005-2015) Strategic Plan for Agricultural Biotechnology published in 2005 is not untypical. It attributes recent agricultural gains entirely to genetic engineering innovations, and thus emphasises the importance of

[1]For example, in 2003 Trigo and Cap, two Argentinean economists specialising in the analysis of agricultural biotechnology argued that: "Since the early 1990s, Argentinean grain production underwent a dramatic increase in grains production (from 26 million tons in 1988/89 to over 75 million tons in 2002/2003). Several factors contributed to this "revolution," but probably one of the most important was the introduction of new genetic modification (GM) technologies, specifically herbicide-tolerant soybeans."

[2]See Renata Campos Motta (2013). The public debate about agrobiotechnology in Latin American countries: a comparative study of Argentina, Brazil and Mexico, ECLAC – Production Development Series No. 193.

ensuring that domestic capabilities are developed so as to ensure continued innovation in plant genetic engineering:

> "The rapid growth of grain production in the country, due to the introduction of biotech varieties of RR soybeans and Bt corn, has had an undeniable role in helping the country to mitigate the effects of economic crisis that occurred in late 2001 and early 2002. The tax on grain exports, in a context of high international prices, has allowed the national government to make available additional resources. In this way, the positive impact of biotechnology on society has been shown, albeit in a circumstantial manner, through its capacity for productive change in the generation of resources. But it is necessary to ensure the sustainability of productive growth by allocating resources to encourage innovation in new varieties."[3]

In order to analyse the role of genetic engineering technologies in explaining the dynamism of the Argentinean seed and soy markets we make a distinction between three technological options, or innovation approaches, in the seed business; namely, the *genetic engineering*[4] approach, the *mutation* approach and the *cross-breeding* approach. We argue that in principle all three can be highly knowledge intensive, drawing on knowledge on molecular biology. We then explore empirically the importance of each innovation approach for firms and markets in Argentina. First we estimate the relative contribution of each of the three approaches to the rate of innovation in the Argentinean soybean seed market; second, we estimate the relative contribution of those different innovations to productivity gains in soybean production; and third we analyse case histories of Argentinean seed firms active in the soybean market. These show how leading domestic firms are using and contributing to each technology approach.

We argue that genetic engineering technologies have accounted for only a small proportion of seed innovation in soy, and also very little of the striking increase in productivity of the agricultural soy sector over the last 15 years. Instead, the other approaches explain most of the dynamics. This stands in stark contrast to the portrayal of genetic engineering technologies as the main driver of the recent success of that sector. We also suggest that our case studies illustrate the diversity of seed innovation approaches available, and that within each approach domestic firms are achieving world leading capabilities. Thus far, however, the most successful of our case-study firms specialises in the cross-breeding approach

Our study makes an important contribution to the 'catching up' literature and to policy debates about the role of transgenic seed innovation in agricultural development. Catching up studies typically assume (often implicitly) that there is only one possible technology option within industries towards which technological capabilities should be accumulated; namely, the option adopted by industry leaders and favoured by institutions and markets in industrially advanced country contexts. Success in the process of catching up is therefore judged in terms of the levels of technological capability and

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[3]The Spanish text is as follows: "El vertiginoso crecimiento de la producción granaría del país, con motivo de la introducción de las variedades biotecnológicas de la soja RR y del maíz Bt, ha tenido un protagonismo indiscutible en ayudar al país a mitigar los efectos de la crisis economía ocurrida a fines del año 2001 y comienzos del 2002. Las Retenciones a las exportaciones de granos, en un contexto de elevados precios internacionales de estos, ha permitido al Gobierno nacional disponer de recursos adicionales para este fin. De esta forma se ha podido demostrar, si bien de manera coyuntural, el impacto positivo de la biotecnología en la sociedad mediante su capacidad de transformación productiva de generación de recursos. Pero es necesario garantizar la sostenibilidad del incremento productivo asignando recursos que fomenten la innovación en nuevas variedades." (Secretaría de Agricultura, Ganadería, Pesca y Alimentos 2004, Plan Estratégico 2005-2015 para el Desarrollo de la. Biotecnología Agropecuaria, p. 14)

4 Genetic engineering can involve, transgenesis, i.e. genetic manipulation using genes from different species, or can involve cisgenesis, i.e. genetic manipulation using genes from the same species. Since up to know only transgenic events have reached successfully the market and diffused, in these articles we use indistinctively genetic engineering or transgenesis.

the complexity of R&D and other innovative efforts performed by firms adopting this *single* option. By showing how there are competing options open for catching up in the seed industry, all of which can involve world class capabilities, but which have different implications for the host economy, our approach challenges this assumption. Our study points to the importance of investigating other issues within the ‘catching up’ tradition, such as the nature of the different technology options that may be available within industries, whether some might be more or less useful than others for the development purposes of the country, how such options emerge; and how they can be encouraged.

Policy debates about the role of transgenic seeds in agricultural development typically draw on analyses of the performance of the technology. Yet, such analyses are often confined to discussions of the benefits, risks, and costs of transgenic technologies in isolation; that is without comparing the technology with the performance of alternative techniques, especially where, as in this case, both transgenic and alternative technologies are used to create the same artefact. Neglecting to explore the performance of alternative techniques creates a misleading picture, which will be compounded if benefits from those alternatives are wrongly attributed to the transgenic component of seed innovation. This has material consequences where resources, public and private, are allocated on the basis of misleading analyses of performance, and may help shape non-optimal technological trajectories.

This paper is organised as follows. We first discuss the theoretical background of our research, highlighting the importance of within-industry options when thinking aboutpotential ‘catching up’ strategies. We then describe technology options in the seeds industry, and the capabilities required to perform those tan advanced level. Third, we analyse the evidence from the Argentinean case. This includes four subsections: a brief explanation of our empirical approach; background information about the seed market in Argentina; and an analysis of the importance of each technological option for the dynamism of the seed industry in Argentina, first from the point of view of markets first, and second from the point of view of firms. Finally, we reflect on the potential and challenges that each option raises as part of a ‘catching up’ strategy.

2. THEORETICAL BACKGROUND: FROM INDUSTRY CHOICES TO TECHNOLOGY CHOICES

The development literature has been concerned with technological alternatives or options for developing countries since the 1970’sand the Appropriate Technology movement. At that time, debates about technology options, following the neoclassical tradition, focused mostly on capital/labour ratios, and/or on issues related to the scale of production. Developing countries, which were assumed to be labour abundant, were advised to choose, among the infinite techniques that were supposed to be available, technologies – or factor proportions – which were intensive in labour, and that enabled small scale production. Such technologies were supposed to be more compatible with the reality of developing economies (Kaplinsky, 1990).[5] More recently, however, the development literature, particularly in Latin American countries, has abandoned ideas from the Appropriate Technology movement about different technological options and has started to focus almost exclusively on the question of industry options (ECLAC, 2007; ECLAC 2012). The discussion shifted from questions about which kinds of technologies to encourage, to questions about which kind of industries to encourage. The dominant idea was that developing countries should support and encourage dynamic industries, typically classified as high tech, because they have more potential for growth and therefore to contribute to development goals.

[5]The focus of this literature was certainly helpful in raising the question of alternative possibilities, and introducing some plurality into the discussion and analysis of technologies in emerging economies, although it said very little about how contexts might enable or constrain the ways in which choices between alternatives could be made.

These ideas closely matched understandings from the innovation literature which emphasised a correspondence, one to one, between industry and technology (Klevorick et al, 1995; Malerba, 2002). The literature on sectoral systems of innovation, in particular, argued that a dominant technological approach usually prevails within any industry – the best practice. It argued that during periods of change, several competing technologies may exist within an industry. Yet, eventually, one and only one technology emerges as dominant - the technology that most easily fits with existing market, institutional and political forces,[6] and that is most beneficial to existing businesses (Dosi, 1982; Perez, 2009, p.186). Industries, this literature argues, evolve by adopting this technology until it matures, and becomes unable to solve existing problems. Subsequently, a new set of technologies emerges and competition favours one or a few that again become dominant.[7] Incumbent industries play an important role in shaping this process.

The policy implications for developing countries that stem from this view are to select the most dynamic industries, and then to encourage the domestic development of advanced capabilities so that firms are able to master the dominant technologies within those industries, and thus become innovators themselves. Firms are expected to invest heavily in R&D, training and equipment to move up the ladder of capabilities. Capability development, however, is evaluated only in regard to one possible technology option; that which is dominant in the industry. As Bell (2009) notes, such capabilities are evaluated "along the technologies that had already been mapped out and elected by prior innovation in advanced economies".[8] We propose to enrich this view based on new insights from the innovation literature.

In particular, strands of the innovation literature on socio-technical transitions, suggests that alternative technological practices can and do co-exist with dominant technologies, and that assumptions about the inevitability of a singular direction of technical change are too rigid. That literature acknowledges that some technological solutions will be strongly favoured by existing market, institutional, political and social structures, but it also emphasizes the possibility, and desirability, of diversity, and the scope for human agency in shaping directions of change (Kemp et al, 1998; Smith et al, 2005). We build on this recognition of agency in socio-technological change to reframe the typical question in developing countries research on industrial development. Instead of asking 'Which industrial sectors to select, and how to encourage capabilities within these industries?' we ask 'How many technological options are available within an industry and which ones are more adequate than others for the development purposes of the country?

The seeds industry faces important unsettling forces which makes it an interesting case to study. It faces, amongst other things: (a) numerous scientific developments in the several knowledge based connected with seeds, such as genomics, which are opening up the potential for new directions of

[6]Selection is explained by issues such as: technological potential, relative costs, market acceptance, and functional coherence (Perez, 2009, p.186)6, pressures for change by (a) difficulties and unsolved technical and other problems, which put pressures on existing practices, thereby inducing change, (b) changes in consumers values, attitudes, behaviours, which influence the selection criteria on the basis of which technological trajectories are chosen and, (c) scientific developments, which open opportunities to solve problems in new ways, so challenging existing trajectories (Dosi, 1982).

[7]These changes in dominance are explained by three types of factors (a) difficulties and unsolved technical and other problems, which put pressures on existing practices, thereby inducing change, (b) changes in consumers values, attitudes, behaviours, which influence the selection criteria on the basis of which technological trajectories are chosen and, (c) scientific developments, which open opportunities to solve problems in new ways, so challenging existing trajectories (Dosi, 1982).

[8]These studies have emphasised the importance of incremental forms of innovation (as opposed to radical innovations) and organizational changes for emerging economies, the centrality of firms in the process of building and accumulating technological capabilities, the key role played by innovation capabilities as opposed to production or operational capabilities (the ones necessary to use existing capabilities), the importance of non R&D capabilities, such as design and engineering, entrepreneurial, marketing and project executing capabilities, learning activities within firms, increasing knowledge linkages between firms, and so on (Bell, 2009).

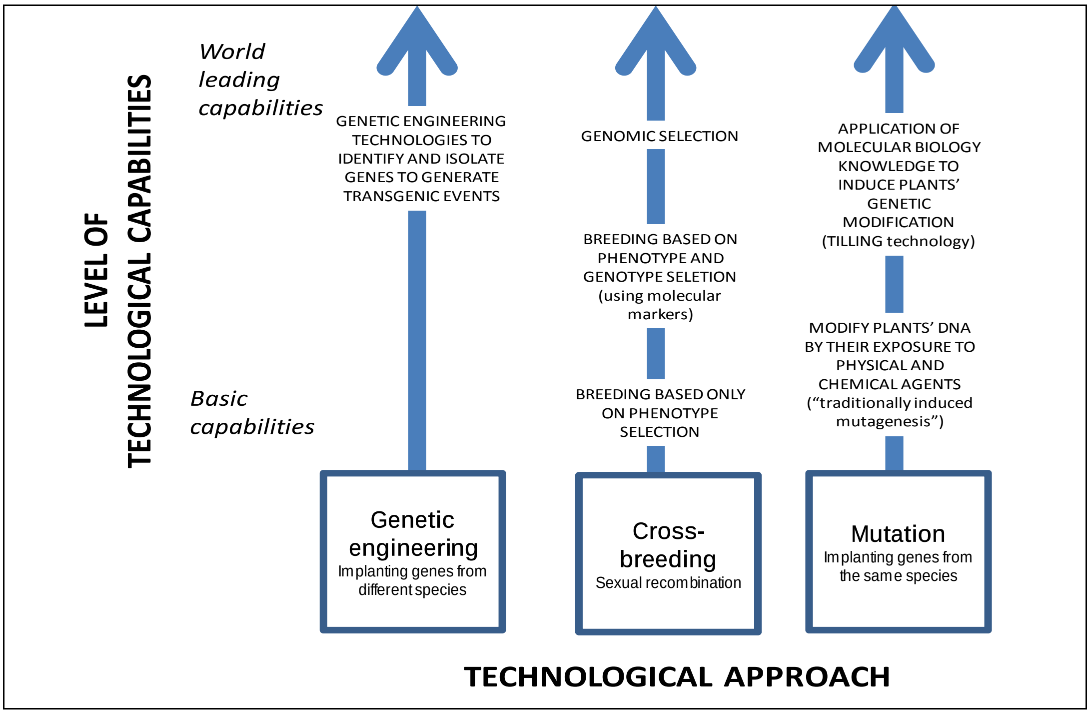
innovation and new ways of solving technical problems; (b) changing and diverse consumer attitudes towards genetic engineered crops; and (c) changing institutions and regulations (Dosi, 1982). This is an industry that is clearly in times of change, where a single best technological approach has not been selected, not even in advanced country contexts. It is therefore interesting to explore which direction of change, or technology trajectory might be more or less adequate in particular context and whether there is agency to select it and encourage it.

3. TECHNOLOGY OPTIONS IN THE SEED INDUSTRY

In this section we summarise the main characteristics of each of three approaches to seed innovation; namely cross-breeding, mutation and genetic engineering options. Essentially, cross-breeding involves organism-level changes achieved through normal mating processes, whilst both transgenic and mutation options involve changes at the genetic level (mutagenesis with genes from the same species and transgenesis using genes from different species). One of the main issues that we would like to illustrate here is that none of these approaches is superior to the others; they can be performed with different levels of innovative capability. We refer to these capabilities as ranging from “basic” to “world leading”, following the terminology used by other innovation researchers (See Figure 1) (see Katz, 1987; Lall, 1987; Hobday, 1995; Ariffin and Bell, 1999; Ariffin, 2000; Figueiredo, 2001, 2003; Ariffin and Figueiredo, 2004; Hobday et al., 2004).

Levels of technological capability are defined by the use and control of certain technologies and techniques, specific equipment and resources, and the capacity to obtain tangible outputs, such as patented genes, new seed varieties, or a new transgenic event (see Figure 1). For example, within the ¨cross breeding¨ approach, world leading capabilities involve the performance of plant breeding using knowledge about genomic selection and the equipment necessary to exploit that knowledge, whilst basic capabilities rely only on the observation of plants´ external characteristics. The latter is longer, more costly, and uncertain (and less science intensive). Similarly, mutation approaches can be performed with low levels of investments and capabilities or on the basis of world leading capabilities. The genetic engineering approach, on the other hand, can only be performed with an advanced level of scientific and technological capabilities, since as we will see it requires the use of advanced equipment and trained researchers. In what follows we explain in more detail how each one of these approaches work, and which kinds of capabilities are necessary to perform innovation at advanced levels.

Figure 1: Technological trajectories in the seed industry[9]



Source: Own elaboration.

The genetic engineering approach uses techniques[10] to identify, isolate and transfer gene sequences with the purpose of providing seed varieties with a code for characteristics that they did not originally have, such as resistance to a particular herbicide. Where genetic engineering involves the transfer of gene sequences from one species to another (e.g. using genes from bacteria to modify soy varieties), the plant varieties are known as transgenic plants.

World leading innovators within the genetic engineering approach are those that are able to identify genes (that code for certain desirable traits), isolate them and create new events by incorporating the isolated genes into plant varieties. R&D efforts at the frontier are based on knowledge of genetic engineering and molecular biology. The resulting innovation process leads to a GM event (such as the glyphosate-resistant soya) and the identification of traits that can be patented where IPR rules allow this (see Box 1). The genetic engineering approach has mainly been commercially successful in this 'world leading' way by a small number of multinational chemical and 'life-science' companies.

[9]For analytical reasons, we depict each technological approach in a separate fashion. However, as will be shown later, the technological approaches can be combined to develop a plant variety.

[10] Genetic engineering techniques, generally known as recombinant DNA techniques, use DNA molecules from different sources, which are combined into one molecule, to create a new set of genes. This new set of genes (or DNA) is then transferred into an organism, giving it modified or novel genes. The new organism is known as a genetically modified organism (GMO) or genetically engineered organism (GEO). One important characteristic of genetic engineering techniques is that, in principle at least, it preserves the integrity of the parental genotype, inserting only a small additional piece of information that controls a specific trait. There are two common ways to transfer an engineered gene sequence into a plant chromosome. A) Using a bacteria: Agrobacterium tumefaciens is a plant-pathogenic bacterium that has the ability to transfer a portion of its own genetic information into many plant species through a process called transformation, thereby causing the "crown gall" disease. B) Shooting gold particles: the engineered genes are shot into plant cells using tiny DNA-coated tungsten or gold particles as fine as dust. Although somewhat more expensive in terms of equipment requirements, the "gene gun" approach has the advantage of unlimited range of applicability.

A characteristic of the genetic engineering approach is that R&D and commercialisation costs are greater than for other approaches because they require very expensive equipment and in particular, for transgenic plants, because the costs of meeting regulatory hurdles are very large. Both the costs of patenting events, and of providing the testing required by regulatory rules, are too large for small and medium scale firms to afford. Thus, this approach is mostly adopted by large (multinational) firms or by small firms that are financially sponsored.

Box 1: Transgenic approach: outputs

The paradigmatic example of an innovation performed using transgenic is that of resistance to herbicides (Glyphosate), a transgenic event, which was originally introduced in the market by Monsanto in the USA in 1996 to be used with soya, but then diffused massively to other countries and other crops. In 1983, scientists at Monsanto and Washington University isolated the common soil bacteria, Agrobacterium tumefaciens strain CP4, which is highly tolerant to glyphosate because its EPSPS is less sensitive to inhibition by glyphosate than EPSPS found in plants (Watrud et al., 2004). By 1986, Monsanto had successfully inserted the cp4 epsps gene into the plant genome and obtained GR plants. Within 10 years, GR soybean was commercialized. The initial GR crops were one of the most quickly adopted technology in the history of agriculture (James, 2007). The rate of adoption continues at more than 10% per year in both developing and developed countries. In 2007, 12 million growers in 23 countries planted 114.3 million ha of biotech crops (James, 2007). By 2008, more than 79 million hectares worldwide were planted with herbicide resistant varieties of soybean, maize, canola, cotton, alfalfa, and sugar beets. By the same year, the glyphosate herbicide Roundup, a billion-dollar product that goes together with the new variety of seeds, generated about 40 percent of the company's annual revenue.

Mutation approaches are based on the modification of genes from the same species. Mutagenesis, as applied to seed innovation, dates from the 1920s. Intentional changes are generated in the plant by exposure to chemical or physical agents. The aim is to imitate and amplify the natural genetic variability of living entities. At a relatively basic level mutagenesis can be performed by exposing a plant to physical or chemical agents (such as radiation or nitrous acid) in order to produce a modification in the plants' DNA. Most seed companies have the knowledge and technological capabilities to pursue this technological approach at that basic level. However, substantial gains in productivity and precision can be gained by using the more sophisticated technique of sequence analyses. World leading capabilities involve the use of a molecular technology named TILLING (Targetting Induced Local Lesions in Genomes) which requires frontier genetic engineering knowledge and specialized equipment.

Box 2: The mutation approach: outputs

Since the discovery of X-rays induced mutations in the fruit fly Drosophila melanogaster (Muller, 1927) more than 2,252 mutant varieties have been officially released (Maluszynski et al., 2000). This technique has been successful in identifying traits that affect characters such as plant height, maturity, seed shattering, and disease resistance, all of which contribute to increased yield and quality of the plan. Some examples that have become famous because of impact they had are: the mutant variety Amaroo, released in 1987 in Australia. This has an improved average yield of 8.9 tons/ha and was used to cover 60-70% of total planted area in the country (Clampett et al., 2001 cited in Ahloowalia, Maluszynski and Nichterlein, 2004). In Pakistan, the release of cotton 'NIAB-78' in 1983, covering up to 70.8% of planted area in Punjab in 1988, is considered to have contributed significantly to the growth of the national textile industry, and was at the origin of the new mutant cultivar 'NIAB Karishma' (1996) that improved traits, such as heat tolerance and its potential yield (Ahloowalia, Maluszynski and Nichterlein, 2004). The Diamant variety of barley obtained with mutagenesis, which was 15 cm shorter than the parent cultivar 'Valticky,' had an increased grain yield of around 12%. In 1972, 43% of 600,000 ha of spring barley in Czechoslovakia was planted under either Diamant or mutant cultivars derived from Diamant. Roughly estimated, the total increase in grain yield was about 1,486,000 tons. During the same year, the spring barley cultivars that had mutated Diamant's denso gene in their pedigree were grown all over Europe on an area of 2.86 million ha (Bouma and Ohnoutka, 1991). The cultivars Golden Promise and Diamant have added billions of dollars to the value of the brewing and malting industry (Ahloowalia BS, et al 2004) .

In Argentina, INTA has recently developed the rice resistant to imidazolinone (an herbicide) developed using mutagenesis. The new rice variety has been successful in overcoming two important barriers for rice production: the low quality of the rice produced in Argentina and the spread of the weedy rice (weedy rice – or red rice- is a low yielding *rice that behaves like a weed in many rice-growing regions, reducing the area for rice production). The mutagen generated (that provides the desired trait) was patented, and is inserted in different rice varieties across the globe.*

Cross- breeding approaches are based on normal mating processes that are manipulated through human choice of the parents, and selection of their offspring so that evolution is directed towards the production of seed varieties with desirable characteristics.

Cross-breeding can be performed at a basic level by relying purely on the observation of crop phenotype (i.e. the external appearance and performance of the plant). Plants are artificially crossed and then agronomists, who are skilled in plant observation, identify which are the best adapted varieties to select (e.g. varieties with higher yield). This procedure relies to a large extent on agronomists' tacit knowledge.

A more technologically advanced way to perform cross-breeding is to combine both phenotype and genotype information (the latter obtained from knowledge of the DNA structure of the plant). Genetic information is obtained through the use of advanced biotechnology tools, such as molecular markers which require knowledge of molecular biology and plant genetics, as well as specialized equipment. The combination between both codified and tacit knowledge of plants' agronomic characteristics (i.e. the physiological and metabolic characteristics of a plant) and codified knowledge about genetics allows breeders to significantly reduce the length of the breeding process, making it more precise and efficient. This is because genotype information allows breeders to anticipate and explain plants' phenotype (e.g. if we know which metabolic mechanism is involved in the way a plant's leaves are positioned we can identify the genes that are involved in that characteristic). Genomic selection is the most advanced biotechnology tool with in the cross-breeding approach, and is used by world leading firms. This technology requires high technological capabilities in molecular biology and genetics, as well as strong capabilities in crops´ agronomic characteristics.

Box 3: The cross breeding approach

Traditional breeding and marker assisted selection explains the bulk of seeds´ innovation and plant yields´ increase throughout the years. This approach has been successful in producing a variety of heat, drought, flood and disease tolerant traits in key crops such as beans, maize, rice, soy or wheat that have been developed and disseminated in developing countries. Every year, thousands of seeds improved using conventional breeding (nowadays typically assisted by molecular markers) are delivered to the market. Just to provide some examples of the last few years. Recently researchers from the National Forestry, Agriculture and Livestock Research Institute (INIFAP) in Mexico have developed a new variety of wheat that is more resistant to leaf rust (a disease), which will allow producers to reduce the use of fungicides. Another example comes from the Philippines-based International Rice Research Institute (IRRI) where scientists have developed a non-GM rice variety (through marker assisted selection) with high submergence-tolerance underwater and adapted them to different flood-prone areas of Laos, Bangladesh and India.

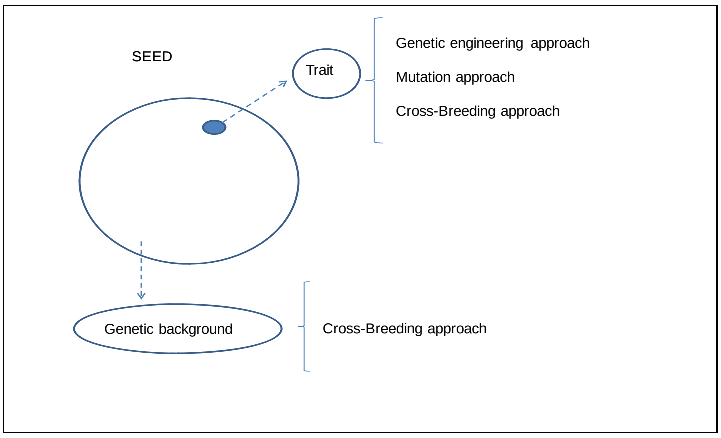
A worth-mentioning initiative to combat climate change is the Drought Tolerant Maize for Africa (DTMA) implemented by the International Maize and Wheat Improvement Center (CIMMYT) and the International Institute of Tropical Agriculture (IITA) that has disseminated 34 new drought-resistant maize varieties in 13 project countries—Angola, Benin, Ethiopia, Ghana, Kenya, Malawi, Mali, Mozambique, Nigeria, Tanzania, Uganda, Zambia, and Zimbabwe— between 2007 and 2011. In addition to drought resistance, seeds include other traits for enhancing their local adaptation, such as superior milling, cooking quality and resistance to regionally- diseases like maize streak virus, turcicum leaf blight or gray leaf spot. The project's main objective is to ensure the good harvest of small producers under reduced rainfall, an increasing concern in the region due to recurrent droughts, and in the meantime enhance food security for local communities.

Some novel varieties have for purpose to address health issues. For instance, not GMO tomatoes with high levels of antioxidants developed at the Oregon State University and other variety at the University of

Sao Paulo, which could prevent certain diseases such as cancer, heart attacks and degenerative diseases; a new variety of broccoli known as Beneforté, developed at the Institute of Food Research and the John Innes Centre using *conventional breeding techniques, which contains two to three times the level of the phytonutrient glucoraphanin as commercial varieties .*

It is important to note that genetic engineering and mutation approaches are dependent on the outputs of cross-breeding. This is because whilst genetic engineering and, mutation (and cross-breeding) approaches may be used to try and introduce specific traits to a plant variety (such as resistance to a particular herbicide or plant pest) all three require background germplasm (i.e. a seed variety) in which to either insert those traits using recombinant DNA-techniques in the case of genetic engineering approaches, or by trying to breed in the desired traits in the case of cross-breeding approaches (see Figure 2). However, only cross-breeding approaches can produce that background germplasm, such as a variety well suited to agricultural regions' agronomic and environmental conditions.

Figure 2: Seed improvement



Source: Own elaboration.

It is important also to point out that firms can choose one, or the other or – though resources are limited - all of the approaches at the same time, and that they can have different level of capabilities across different approaches. For instance, they can have world leading capabilities in the genetic engineering approach and basic capabilities in the cross breeding approach as it is the case of many dedicated biotech firms. The choice of one approach over the other does not assure superior capability or performance. The cases we analyse in the next section illustrate very well these points.

4. EXPLAINING DYNAMISM IN THE ARGENTINEAN SOYBEAN SEED MARKET AND IN SOY-BASED AGRICULTURAL PRODUCTION

In this section we analyse empirically the relative importance of each of the three innovation approaches summarised above for firms and markets in Argentina, focusing on the dynamism of the soybean seed industry, of soybean agricultural production, and case studies of individual firms. The section has two parts. In the first part we provide: a)a brief explanation as to why we chose to focus on the soybean sector and our approach to analysis (4.1); b) a description of the Argentinean seed market (4.2), and c) a description of how the transgenic seed market has been supported by the Argentinean government (4.3). In the second part, we analysed the data and information collected in the interviews. First, we analyse the contribution of each approach to the dynamism of the seed market in Argentina (4.4), second we analyse the contribution of each approach to profits and productivity gains of the soy bean sector (4.5), and third we analyse the evidence of the two cases, Bioceres and Don Mario.

4.1. Our approach to analysis

The soybean sector is interesting for several reasons. It is an important crop globally and is hugely important for Argentina's agricultural economy, constituting almost half of all Argentina's agricultural production by value, and 20% of total exports. Soy was the first crop in which transgenic seeds were commercialised, and transgenic varieties diffused very rapidly. Within five years or so after their introduction, GM soy varieties were planted on about 95% of soy fields, and the area devoted to soy production has expanded considerably, from about 6 million hectares in 1995/6 to 19 million hectares by 2009/10, which is about half Argentina's cultivated land area.[11]

The first part of our empirical analysis, on the dynamism of soybean seed innovation, is based on two types of archival data:

1) Registered plant varieties in the National Registry of Property of Varieties (RNPC). Plant breeders that wish to protect their varieties with the IPR system must apply for a registration in the RNCP. For each plant variety we have data about the name of the solicitor of the grant, the name of the breeder, the year when IPR was applied, the country of origin of the variety, the region of Argentina where the plant variety is best adapted and the type of variety   We use the latter category and the name of the variety to identify the technological approach used in the development of the plant variety.

2) Plant varieties certified by the National Seed Institute (INASE). In Argentina, as in other agricultural countries, seeds that are traded commercially have to be certified by a state agency which guarantees their genetic purity, identity and quality. The aim of the certifying system is to protect the buyer. We use this dataset so to establish which plant varieties registered under the RNCP have reached the market each year.

The second part of our empirical analysis, on the dynamism of soy-based agricultural production, is based on data produced by the Ministry of Agriculture covering the evolution of soy production, yields, the area under cultivation, and soy-bean prices. This data is used to estimate the relative contribution of transgenic and non-transgenic innovation to changes in the productivity of soybean farming over time.

We complement our analysis of the seed market and of soybean production with two case studies of Argentinean seed firm strategies. The choice of the cases was guided by two criteria: the firms´ importance in the soybean seed market and by the type of technological approach followed by the firms. For each case we interviewed managers of the seed companies as well as key informants within the seed industry and within agricultural research institutions.

Case 1 (Bioceres) is the sort of dedicated biotechnology firm that is typical of the domestic biotechnology industry in the advanced industrialised countries. It is a small R&D intensive firm, founded in 2001 with Argentinean capital and has about 30 employees. It is closely linked, through R&D agreements, to public research institutions and universities. The company focuses on the discovery and isolation of gene sequences. Its target is to develop traits. It has three patents in the US and exports technology to foreign multinationals.

Case 2 (Don Mario) is also an Argentinean firm, although it is beginning to operate in other countries too. Founded in 1980 it has 450 employees and follows a very different strategy to Bioceres in the

[11] Data from the UNCTAD database, the Argentine Institute of Statistics (INDEC) and the Argentine Ministry of Agriculture Livestock and Fisheries.

seed business. It is mainly involved in cross breeding. The company has its own breeding programmes and makes use of advanced biotechnology tools to develop plant varieties. Its main market is the soybean seed market. Currently, the firm has 40 per cent of the Argentinean soybean seed market and 25 per cent of the Latin American soybean seed market. It has opened subsidiaries in Brazil, Bolivia, Uruguay, Paraguay, and more recently in the USA.

4.2. The seed market in Argentina: importance and regulation

Public sector and commercial seed breeding activities started very early in Argentina. By the 1930´s there was already a relatively dynamic seed market in Argentina composed of both local private companies,[12] and public experimental stations (Gutierrez, 2006). Three decades later, foreign seed companies joined the local market, the first being Cargill in 1947 (Gutiérrez, 2006). Very shortly after, plant breeding started to be regulated in Argentina by laws that were designed to make the seed market more transparent and to protect farmers´ interests (new plant varieties had to be assessed and authorized prior to their diffusion in the market).By the 1970s, the seed market was sharply divided between foreign firms that focused on hybrid varieties (mostly corn), and local firms and public institutions that developed new plant varieties in non-hybrid plants (mostly wheat) (Gutiérrez and Penna, 2004). However, this division soon began to be blurred as local companies learned about hybridization.

Today, Argentina is the 9th largest seed market in the world, valued at 600 million dollars, and is the world's 11th largest seed exporter. Plant breeding is mostly performed by the private sector which has an annual turnover of 772 million dollars (ASA, 2012). There are about 40 seed companies which produce seed for a wide variety of crops. The market is dominated by three different kinds of players: MNCs, domestic companies and the National Institute of Agricultural Technology (INTA) which is the state agricultural research institution. INTA produces knowledge useful for the sector, which is then licensed to other firms, both domestic and foreign, who commercialize the seeds. Despite the importance of INTA for the seed market (e.g. it owns 50% of new varieties), this institution does not commercialise seeds itself.[13]

Although MNCs have gained a prominent role in the seed market, especially in the wake of the economic liberalization of the agricultural sector in the 1990s, domestic firms have developed strong capabilities in breeding technologies and have maintained a key role, together with INTA, at least for some crops. Local firms typically buy biotechnological events from, and sell domestic varieties to, MNCs, and compete with them in the final market, with leading positions for some crops such as soy (where two domestic companies Don Mario and Nidera have 60% of the market).

Argentina was an early adopter of intellectual property rights (IPR) for plant varieties, in the form of a plant variety protection regime that dates from 1973. That regime was revised in the early 1990s to be compatible with the international UPOV 1978 plant variety protection scheme.[14] Patent law in this country allows isolated gene sequences with known function, such as the novel genes introduced into transgenic seeds, to be patented. As with most other countries, with the exception of USA and Japan, Argentina does not allow the patenting of life forms (such as seed varieties) and/or genome (or genes), as found in nature.

[12] The first two Argentinean seed companies, Klein, Buck and Relmo were created in 1919 and 1930, and were dedicated to the improvement of wheat varieties.

[13] It is interesting to mention that INTA in this respect is different to its equivalent in Brazil, Embrapa, who is a company selling seeds to the final market.

[14] The Union International pour la Protection des Obtentions Végétales (UPOV) consists of a global agreement setting out a minimum standard for the protection of plant varieties.

4.3. Support for transgenic seed innovation

Since the early 1990s, successive Argentinean governments have provided strong support for agricultural biotechnology, and in particular for the development and commercialisation of genetically engineered seed varieties. Argentina established bio-safety regulations in 1991 and was the first Latin American country to do so. As the head of Argentina's biosafety approval system later explained a key reason for setting up the regulatory regime was that "…agriculture and agroindustry are the country's strongest economic sector and the new technology was seen as a means to increase production and therefore exports (Burachik and Traynor, 2002, p. 2).

Given that transgenic crops have subsequently been perceived as largely responsible for the rapid increases in oil seed and grain production, as noted in the introduction to this paper, transgenic seed innovation, and agricultural biotechnology more generally, feature prominently in government discussion about strategic priorities for the country. A ten year strategic plan developed by the Secretariat of Agriculture's Office of Biotechnology in 2005, viewed biotechnology as providing the main source of technological solutions for agricultural productivity growth, and stressed the importance of creating a favourable political and legal environment for the creation and development of biotechnology-based companies.[15] Both that plan, and other government documents on agricultural biotechnology usually acknowledge that there is more to plant biotechnology than genetic engineering.[16] Nevertheless, and inconsistently, the 10 year plan and other documents typically define modern biotechnology as involving recombinant DNA techniques (i.e. genetic engineering).[17] Furthermore, discussions about plant biotechnology are invariably focused, sometimes exclusively, on plant genetic engineering.[18] Unfortunately, there are no data on the level of public funding of R&D in agricultural biotechnology, nor on how such funding might be split between support for plant genetic engineering and other areas of agricultural biotechnology. We cannot therefore estimate the extent to which government support for transgenic seed innovation is reflected in financial support, or whether other technological options have also received government funding (though some indication emerges from the analysis of the cases).

One area where government policy does directly favour transgenic seed innovation, and in this case at the expense of other approaches to seed innovation, is in intellectual property. This is because Argentina's intellectual property framework sets up asymmetric levels of protection for transgenic seeds and seeds produced using non-transgenic methods. In particular, seeds produced using non-transgenic methods are covered only by national seed law, based on the international UPOV 1978 agreement. This provides seed breeders with a monopoly on the commercial use of their seed varieties, whilst allowing competing seed breeders to use protected varieties as an initial source of germplasm for the purpose of creating new varieties, without the need to seek permission or pay royalties. This long standing exemption (the 'breeders' exemption') from what would otherwise be monopoly commercial control by the original seed breeder is designed to promote innovation. It essentially recognizes the cumulative characteristic of knowledge and explicitly provides room for research spillovers. However, UPOV 1978, which was devised before the advent of genetic engineering, can at the same time, provide the chance for free riding others innovation outputs. The

[15]Secretaría de Agricultura, Ganadería, Pesca y Alimentos 2004, Plan Estratégico 2005-2015 para el Desarrollo de la. Biotecnología Agropecuaria

[16]Secretaría de Agricultura, Ganadería, Pesca y Alimentos 2004, Plan Estratégico 2005-2015 para el Desarrollo de la. Biotecnología Agropecuaria, p.5; Ministerio de Ciencia, Tecnología e Innovación Productiva (2010) BET - Boletín Estadístico Tecnológico: Biotecnología, N°4 diciembre-marzo de 2010, p. 3

[17]Secretaría de Agricultura, Ganadería, Pesca y Alimentos 2004, Plan Estratégico 2005-2015 para el Desarrollo de la. Biotecnología Agropecuaria, p. 7; Ministerio de Ciencia, Tecnología e Innovación Productiva (2010) BET - Boletín Estadístico Tecnológico: Biotecnología, N°4 diciembre-marzo de 2010, p. 2

[18]See, for example: Ministerio de Ciencia, Tecnología y Innovación Productiva (2010) Área Estratégica: Biotecnología. Temáticas y Líneas Prioridades Para Fondos Sectoriales, Section 2.1

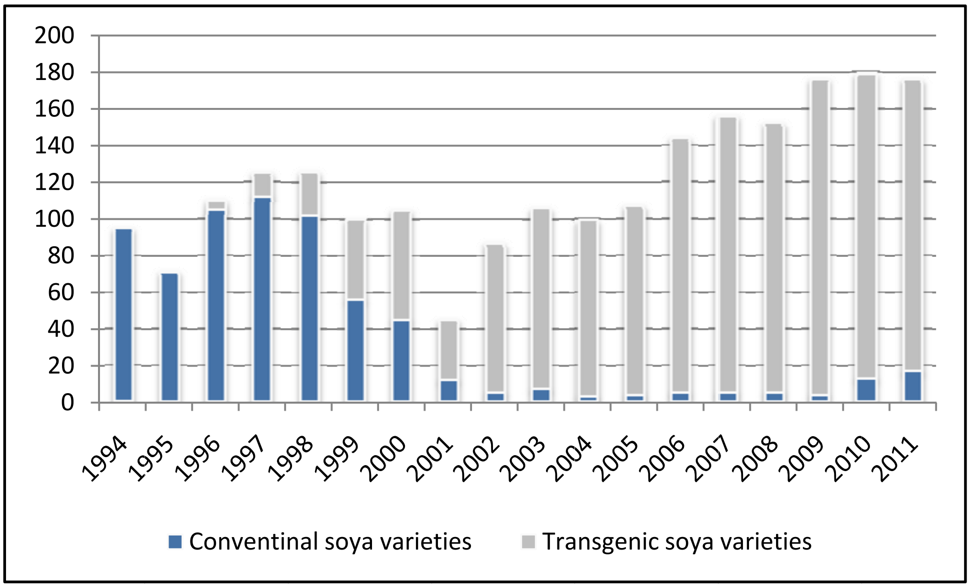
mere insertion of a few genes into an existing variety allowed the seed to be defined as a novel variety, which could then be marketed without the original licence holder's agreement. A later version of UPOV limited the ability of seed breeders to make minor changes, such as the insertion of a few genes, without paying a royalty to the original seed breeder, but Argentina has not updated its seed legislation along those lines.

Transgenic seeds, on the other hand, can also be protected by patents on the inserted genetic constructs. This means that unlike varieties produced using other technological approaches, transgenic seeds cannot be used as a basis for further improvement, without a license from their owner. Seed companies that have the capabilities to enter into the 'gene market' thus enjoy greater protection in terms of intellectual property and thus higher rents.

4.4. Innovation approaches and the dynamism of the soy seed market

We now explore the contribution of the different technological approaches to plant improvement outlined in section 3 to the dynamism of the soybean seed market. Figure 3 shows the number of *new* soy seed varieties commercialised each year between 1994 and 2011. We can see from the figure that the rate of innovation and the overall market expanded significantly – from 95 new soybean varieties introduced per year in 1994 to 176 new soybean varieties per year in 2011. This rise in the number of new soybean varieties offered and traded in the Argentinean market reflects the dynamic nature of innovation activity during that period. All plant varieties traded in the market have to be novel, and distinct from all other registered and traded varieties.

Figure 3: Soy seed varieties commercialized in Argentina between 1994 and 2011



Source: Own elaboration based on data from RNPC and INASE.

Figure 3 differentiates between new soybean varieties that have a genetically engineered trait that confers resistance to the herbicide glyphosate (commonly known, after the trade-mark name for Monsanto's glyphosate herbicide, as Roundup-Ready varieties), and those that do not have such a trait, and that are usually termed conventional or traditional varieties. Between 1997 and 2011, three new transgenic events related to soy were authorised in Argentina, the first in 1996 and the last two in 2011. However, only the first of those events was commercialised in Argentina before 2011, and therefore only varieties that incorporate that event appear in our data. We observe that since 1996, when herbicide-tolerant soybean varieties were first introduced commercially, the market share of transgenic varieties has increased steadily, from 5% in 1998 to 90% in 2011. Thus, the Argentinean soybean seed market turned into a transgenic soybean market.

That increase in the market share of transgenic varieties tells us little, however, about the relative contribution of the different technological approaches to soybean innovation. In order to shed some light on that question, Table 3 provides information on the novelty of the new varieties of soy introduced in Argentina between 1997 and 2011. Column 1 shows the number of new soybean varieties that were introduced in each year. Columns 2 and 3 distinguish between those new varieties those that did not incorporate the transgenic trait for glyphosate-resistance, and those that did. The former are soybean varieties whose novelty resides entirely in the fact that their germplasm has been modified in ways that do not include incorporation of the genetically engineered sequence that confers glyphosate resistance.[19] The latter are soybean varieties whose novelty may be either due only to the incorporation of the trait that confers glyphosate-resistance, or to both the introduction of that transgenic trait and to other modifications to the plants´ germplasm (as in the non-transgenic varieties).

Thus for non-transgenic varieties, plant innovation (and hence novelty) can be attributed entirely to cross-breeding and mutation approaches, but for the transgenic varieties, the relative contribution of the genetic engineering approach to novelty is less clear. We can, however, estimate that relative contribution taking into account the following considerations:

1. When the trait for glyphosate resistance first became available, in 1996, it began to be incorporated into the genetic background of existing Argentinean soybean seeds, via licensing agreements between Monsanto, and national firms active in the soybean market. Thus, at the beginning of the period beginning in 1996, a significant share of the novelty of the new varieties registered should be attributed to the transgenic approach (i.e., most new transgenic varieties registered during this period would might have been based on introducing the trait into *commercially existing* conventional germplasm).That proportion is unlikely to be 100%, however, because local firms would have continued to develop new conventional soy varieties at the same time, to which the herbicide tolerant trait would also have been added, and also because substantial efforts were made to cross bread the gene into the existing varieties.

2. At some point most existing commercial varieties would have been backcrossed with the gene sequence for herbicide tolerance. Therefore, innovative activity would have consisted of further improvements to those soybean varieties that already contained the glyphosate resistance trait. Thus, other technological approaches would have begun to be responsible for seed innovations in newly commercialized GM plant varieties.

3. We do not know how long it took for the majority of existing varieties to be backcrossed with the herbicide tolerant gene, but experts whom we interviewed argued that it took about 5 years for the trait to diffuse into local plant varieties, and it almost certainly went into the most popular varieties first. We also know that in 1994-1995 (two years prior to the introduction to the RR trait) 107 soybean varieties were commercially available in Argentina, and that it took five more years for a similar number of new herbicide tolerant varieties to be

[19] Just to provide one example a major innovation in 2010, was resistence to the fungus ´cancrodeltallo´ (o ´manchadelojo´) which had attacked the plant or roundworms affecting yields for over several years in the country. This innovation was obtained and introduced in the market by an Argentinean company, via classical cross breeding. In 2012, most new varieties that gained the market have this characteristic.

introduced into the Argentinean market (see Figure 3). Therefore, we can assume that the transgenic approach explained the bulk of transgenic plant innovations within that 5-year period. After that, other technological approaches are most likely to have been responsible for introducing novelties in the new transgenic soybean varieties subsequently commercialised.

Based on the above, we can create different scenarios about the share of novelty that should be attributed to transgenesis during the different periods. Table 1 presents a central projection in which, during the five year period 1997-2001, the transgenic innovation alone accounted for a 70% share of the novelty of the new seeds that were registered. After that period, we have assumed that the novelty of most new GM seeds were the product of local breeding programmes, but that transgenic innovation alone may still have accounted for a 10% share of the novelty of GM seeds subsequently commercialised in order to capture firms that were still backcrossing the glyphosate resistant trait into plant varieties that had *already* been released commercially.

Table 1: Analysis of the novelty of new varieties of soy introduced in the Argentinean market between 1997 and 2011

Years	**New soy varieties**			**Novelty of new GE varieties**		**Total novelty explained by the non-GE approaches**	**Innovation rate**
	Genetic engineered (GE) (1)	**Non -GE (2)**	**Total (3)=(1+2)**	**Explained by the GE approach (*) (4)**	**Explained by non-GE approaches (**) (5)**	**(6)=(2+5)**	**(7)=(4/(2+5))**
1997	8	16	24	6	2	18	0.33
1998	13	12	25	9	4	16	0.56
1999	20	10	30	14	6	16	0.87
2000	20	10	30	14	6	16	0.87
2001	0	1	1	0	0	1	0
2002	57	1	58	6	51	52	0.11
2003	33	4	37	3	30	34	0.08
2004	25	0	25	3	22	23	0.13
2005	12	1	13	1	11	12	0.08
2006	44	1	45	4	40	31	0.09
2007	26	0	26	3	23	23	0.13
2008	37	0	37	4	33	33	0.12
2009	54	44	98	5	49	93	0.05
2010	76	7	83	8	686	75	0.10
2011	29	5	34	3	26	31	0.09
Total 1P	61	49	110	43	18	67	
Total 2P	393	63	456	40	353	416	
TOTAL (1P + 2P)	454	112	566	83	371	483	0.17

Source: Own elaboration.

Notes:

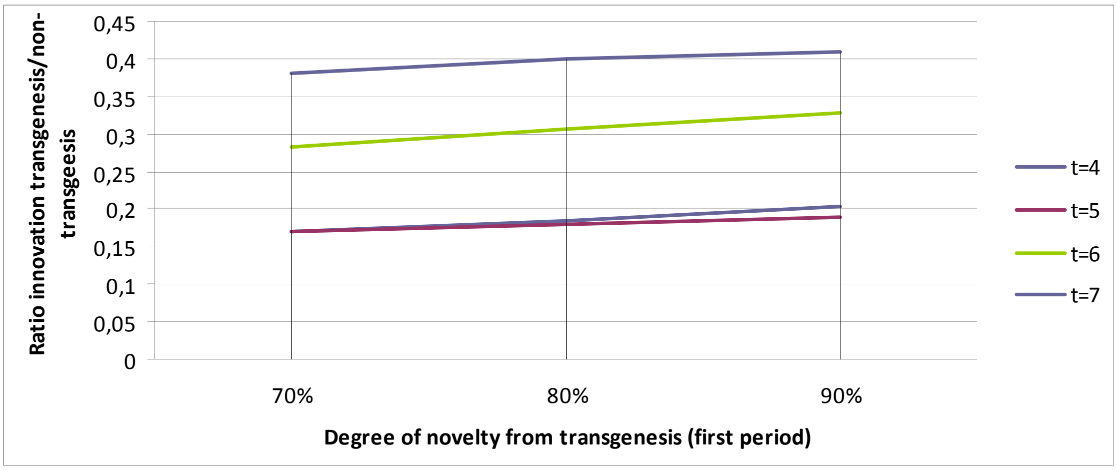
(*) Innovation in transgenesis is calculated as the number of new plant varieties that can be attributed to the innovation approach. We assume that the share is 90% in the period 1997-2001, and 10% in the period 2002-2011.

(**) Innovation from other approaches is calculated as the number of new plant varieties that can be attributed to non-transgenic approaches. We assume that the share is 10% in the period 1997-2001, and 90% in the period 2002-2011.

Under these assumptions Table 1 shows that out of the 566 innovative seed varieties that were introduced into the soy market in Argentina between 1997 and 2011, the share of the novelty attributed to the transgenic approach (expressed as numbers of new plant varieties) would have been 83, as compared to 483 attributed to the other approaches. In other words, only 14% of seed innovation over this period would be attributed to transgenic approaches. In this case the ratio of novelty attributed to the transgenic approach relative to other technological approaches is 0.17 (see Table 1, column 7).

Given uncertainty over our assumptions about the relative contribution of the herbicide tolerant trans-gene versus other changes to each new seed variety, we performed a sensitivity analysis by increasing the novelty attributed to the transgenic approach during the first period from 70% to 90% (since 100% is not likely to be a reasonable scenario) and extend the time period that took for the gene to be backcrossed from 5 to 7 years. Figure 4 depict different rates of innovation of genetic engineering approaches - calculated as in Column 7 Table 1, as the ratio between: (1) the novelty of new varieties explained by the GE approach and (2) the novelty of new varieties explained by non GE approaches – under different assumptions of novelty attributed to genetic engineering approaches during the first period (between 70% and 90%) and different assumptions regarding the time that took for the gene to be incorporated in the local varieties between 4 and 7 years. It is notable that in all circumstances the transgenic approach makes a less significant contribution to the rate of innovation that the non-transgenic approaches. The maximum contribution of the genetic engineering approach is under the very unrealistic assumptions that the contribution to novelty of the approach was 90% during the first period was 90% and that took 7 years for the gene to be pasted into all local varieties, and does not pass 50%.

Figure 4: Innovation rate in the soybean market in Argentina (1997-2011)



Source: Own elaboration.

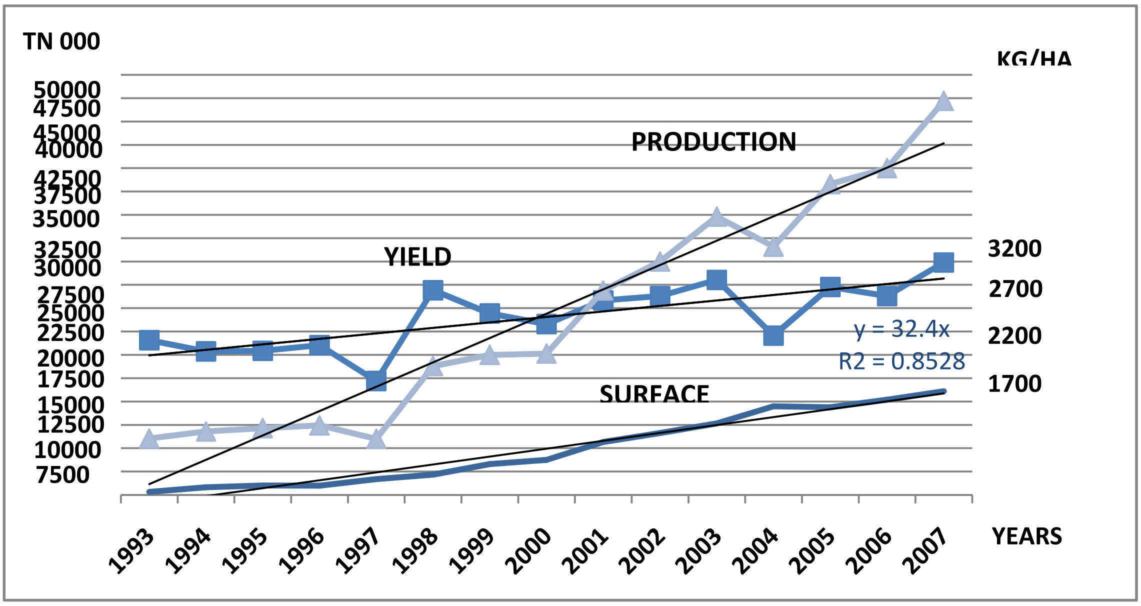
In summary, our data show clearly that between 1997 and 2011, which is the period of rapid diffusion of transgenic seeds in Argentina, in a country with one of the highest rates of adoption of this technology in the world, most of the dynamism of the seed market is not explained by transgenic technologies, but by innovations performed using other approaches.

4.5. Innovation approaches and productivity gains in soy production

So far we have focused on the proportion of soy seed innovations that can be attributed to transgenic approaches. However, this tells us nothing about the contribution of each type of innovation to agricultural performance. For example, the incorporation of the glyphosate resistant trans-gene into seed germplasm might have had a far more significant contribution to performance than a hundred innovations achieved using other approaches.

The performance of soy-production in Argentina, at least for certain metrics, has improved markedly since the early 1990s. Eight million tons of soy were produced in 1990 but by 2007 the figure was more than 47 million tons. Over the same period the area of land sown to soybean increased from 5 million hectares to 14 million hectares, but this constitutes only a 250% increase in the area planted with the crop, compared to a 400% increase in production. Farm profitability has also improved significantly over that period (see Figure 5). Some analysts give the impression that those gains can be attributed to the adoption of the herbicide resistant varieties of soy, in combination with the simultaneous adoption of no-till farming, without distinguishing between the effects of different technological approaches on improvements in the performance of soy production (Trigo, 2011). In the rest of this section we analyse the relative impact of the different technological approaches on the performance of the soy sector. Our evidence shows that transgenic seed innovation has only been responsible for a small proportion of the productivity gains in that sector.

Figure 5: Argentinean soy production and productivity evolution – 1993-2007.



Source: Own elaboration based on data from Ministry of Agriculture.

We know that the profitability of farmers depends entirely on two factors: yields (tonnes produced per hectare) and production costs, assuming fixed final prices for the crop. If we assume constant environmental conditions, increases in yields are related to three types of improvements: seed improvements, improvements in agronomic practices, and the combination of both. Production costs depend on the costs of inputs, and on the agronomic practices that are adopted, which affect the kinds and quantities of inputs necessary to produce the crop.

Existing studies on the economic effects of herbicide resistant soy production in Argentina (and in other countries) all agree that the introduction of varieties resistant to glyphosate has had no overall effect on yields, but that it has reduced production costs, largely because gylphosate is cheaper than the herbicides it has replaced. Penna and Lema (2003), the first authors to conduct a systematic study into the effects of the introduction of herbicide-resistant soy seeds on farm productivity argue that:

> "The main contribution of RR [glyphosate resistant] soy beans to the profitability of farms in Argentina lies on a more efficient control of weeds rather than in an increase of yields. This more efficient (though very contaminating) control of weeds has meant a reduction of farmers costs of between 15 and 17 US dollars per hectare, explained almost entirely because of the price difference in the herbicides utilised".

Qaim and Traxler (2005), in a study covering the period 1996-2001, also found that the main contribution of transgenic soy has been in weed control and a reduction in costs of production, mainly from lower herbicide costs. They estimate a reduction in costs of 21 US dollars per hectar on farms that used herbicide resistant soy compared to those that used conventional varieties.

Soy yields increased by a total of 23% in Argentina between 1997 and 2011, the period during which herbicide resistant soy varieties diffused to virtually all soy farms. Part of this yield increase will be explained by better performing seeds and part by better performing agronomic practices. Studies conducted in Argentina and the USA have sought to distinguish the effects on yields of genetic improvements from improvements in agronomic techniques. These estimate that 60% of yields gained over a period of time can be explained by genetic gains (Santos et al 2001). Given that the herbicide tolerant trait innovation itself does not increase yields,[20] the proportion of yield increases between 1997 and 2011 that can be attributed to genetic improvement will have been obtained by cross breeding and mutation based methods. Using the price obtained for soya in different periods, we can calculate the economic contribution of the genetic improvements in germplasm (obtained by cross breeding and intra-genic methods), and compare this with the economic contribution of transgenic methods in lowering costs of production.

Columns 2 to 4 in Table 2 show, respectively, the average land productivity in soy production per hectare between 1971 and 2011, grouped in periods of five years, the gains in yields over each period, and the extra tons produced per hectare as a result of those yield increases. Column 6 shows the extra tons produced per hectare as a result of yield increases that can be attributed to

[20] The diffusion of glyphosate resistant soy varieties is strongly associated with the adoption of 'no-till' methods of production. These involve using a machine to directly insert seeds into unploughed land containing the residue of the previous crop. The use of glyphosate tolerant seed facilitates no till practices because the broad spectrum herbicide helps discourage competition from other species. An important question therefore arises about the possible effects of no-till practices on costs and yields. Qaim and Traxler's analysis of the economic impacts of adopting herbicide resistant soya compared farmers' costs and outputs before and after adopting the herbicide tolerant seed. The authors note that many of the farmers switched to no-till practices once they started to use transgenic seed varieties. Their data on cost saving, included in the analysis here, therefore includes the potential saving obtained from using no-till techniques, which the authors ascribe to marginally lower machine running costs. They also note that yields were similar in both conventional systems (i.e. using conventional seed and conventional tillage techniques) and transgenic and in many cases no-till based production. Indeed Lema and Penna (2003) note that the adoption of no-till techniques has no effect on yields, at least in the short term. Nevertheless, some authors have noted that no-till techniques have facilitated the double cropping of soya with wheat, because the agronomic technique reduces the timer period between harvest of one crop and planting with another. In this sense, the adoption of transgenic soya may have indirectly had a significant impact on overall farm income (as opposed to income from soya production per se) if farmers have been able to double crop in circumstances when this was previously not possible.

improvements in seed germplasm which, as explained above, has been estimated to be 60% of the yield gain. Column 5 show the dollars gained per hectare due to increases in yields. Column 7 shows the dollar gains due to increases in yields that can be attributed to improvements in seed germplasm. Since herbicide tolerance does not itself improve yields, those dollar gains must have been obtained by non-transgenic improvements in germplasm.

As indicated in Table 2, this implies a monetary gain for producers in Argentina of 27.95 dollars per hectare over the period 1997-2001 that can be attributed to non-transgenic improvements in germplasm. This compares to a 20 dollar reduction in costs over the same period, due to the adoption during this period of varieties containing the herbicide resistant trans-gene, and the associated agronomic changes in practice that herbicide tolerance has enabled (in particular the substitution of herbicides that were traditionally used for glyphosate and non till practices – see note 19).

For the periods 2002-2006 and 2007-2011, we estimate a yield-related monetary gain per hectare for soy producers of 47.53 dollars and 12.87 dollars, respectively, which again can be attributed to improvements in germplasm obtained by non-transgenic technologies. Over those two periods there would have been no further cost reductions arising from adoption of seeds containing the herbicide resistant trans-gene because glyphosate tolerant varieties were already being used by virtually all soy producers (Trigo, 2010). The cost savings associated with adopting glyphosate resistant varieties were a one-off.

Over the 15 year period 1997-2011, we therefore estimate the accumulative monetary effect of gains in yields due to improvements in germplasm delivered by cross-breeding or intra-genic methods to be a 77.16 dollar increase in income per hectare. This compares to a reduction in production costs of about 20 dollars per hectare due to the lower costs of using glyphosate, made possible because of transgenic methods of seed innovation. Thus about 80% of the gains accruing to producers as a result of seed innovation over the last 15 years or so can be explained by non-transgenic approaches to improving seeds.

It is worth noting too that the increase in farm income as a result of those yield increases that can be attributed to (non-transgenic) seed innovation is qualitatively different from the cost savings that occur as a result of switching to cheaper herbicides that can be attributed to (transgenic) seed innovation. The former is an improvement that is of wider social value than the profitability and competitiveness of soy farming (because it is a permanent increase in grain production per unit of land). Even if we only consider the profitability and competitiveness of soy farming, it is a benefit that is likely to endure over time. The monetary value of those yield increases will of course vary with changes in the price of soybeans, but when measured as a proportion of farmers' income from soy sales the benefit of the yield increase to soy farming is permanent. The latter cost saving, on the other hand is of no social value beyond the profitability and competitiveness of soy farming and even then it may be temporary; it depends entirely on how input prices change. As Lema and Penna (2003) noted in their analysis of the adoption of transgenic soy in Argentina, if the fee for the use of the new seeds were $17/hectare, as in the United States, the difference between farmers' gross margins under the transgenic and conventional systems would disappear.

Table 2: Contribution of seed improvement technological approaches to agricultural performance

Years	Average productivity (tons per hectare) (1)	Gains			Gains explained by germoplasm improvements (60 %)		Costs reduction attributed to improvements by RR (dollars per hectare) (6)	Cultivated area (7)	Increases in cultivated area (8)	Increases inter period (9)
		In yields (2)	In tonnes per hectare (3)	In USD per hectare (3)	In yields (4)	In USD per hectare (5)				
1971/72-1974/75	1,46	10%	0,130		0,078			193,348	155	404%
1975/76-1980/81	1,96	34%	0,500		0,300			1332087,7	1331894	688859%
1981/82-1985/86	2,08	6%	0,120		0,072			2752261	1420173	107%
1986/87-1990/91	2,05	-1%	-0,030		-0,018			4314641	1562380	57%
1991/92-1995/96	2,13	4%	0,080	19,76	0,048	11,86		5529687	1215046	28%
1996/97-2000/01	2,26	6%	0,130	27,95	0,078	16,77	20,00	8113119	2583432	47%
2001/02-2005/06	2,59	15%	0,330	79,20	0,198	47,52		11177355	3064236	38%
2006/07-2010/11	2,64	2%	0,050	21,45	0,030	12,87		14006403	2829048	25%
1996/2011		23%	0,51	128,60	0,306	77,16	20,00	8476716	110%	
1981/1996		9%	0,17		0,102			4197599	192%	
1971/1981		44%	0,630		0,378			1332049	689263%	

Source: Own elaboration based on data from Ministry of Agriculture.

4.6. Innovation approaches and firm strategies

We now discuss the strategies adopted by two successful national seed firms active in the soy seed business, Bioceres and Don Mario. The two firms represent very different possible ways of participating in the seed business. Bioceres, unlike all other domestic seed firms in Argentina, is mostly focused on transgenic approaches to innovation. It has been very successful in discovering new genes which are then licensed to foreign companies. Don Mario, on the other hand, is exclusively oriented to the cross-breeding approach.

Case I - Bioceres: the transgenic approach

Bioceres was created in 2001 by a co-operative of 23 agriculture producers belonging to two important agricultural trade organisations, the Asociación Argentina de Productores en Siembra Directa and the Asociación Argentina de Consorcios Regionales de Experimentación Agrícola. The aim was to take advantage of the research on biotechnology that, at that time was being conducted within public institutions (INTA and Universities). The company created its own research lab, INDEAR in 2008. INDEAR is the result of a public-private alliance with Argentina's National Research Council (CONICET), and is fully dedicated to gene discovery. As one of the interviewees explained: "INDEAR has pursued the development of our own technological platform… it is an alternative to outsourcing R&D programmes in public institutions or universities. The goal was to generate our own transgenic seeds based on our own germplasm and package the product to sell it to the agriculture producers. We consider that this is the way to capture the innovation rent".

A year earlier in 2007, Bioceres had created a seed unit, following a technological agreement with INTA in which the public institution developed a wheat variety which was then commercialised by Bioceres. In other crops, the company buy transgenic events from MNCs and use them as part of the development of new seed varieties.

A major achievement of the company has been the granting of three patents by the US Patent and Trademark Office.[21] The first, based on collaboration between the firm, CONICET and the National University of Litoral, was for a gene enhancer that confers resistance to hydride stress and salinity, and which was subsequently licensed to the MNC Advanta. The second was for a gene enhancer that increases the expression level of genes in plant cells, and the third is for a gene which confers shorter life cycles and tolerance to oxidative stress.

At present, Bioceres cannot introduce its own genes into germplasm because of the costs of regulatory approval. For this reason, they continue to buy transgenic events from MNCs and backcross them in to their own seed varieties – mostly INTA varieties. One of the main problems they face concerns patenting, and complying with biosafety regulations, both of which are very demanding processes that require skills, time and resources which most small and medium companies do not have. They are developing alliances and subcontracting with international companies to help them with these processes, but our interviewees stressed that patenting and regulatory hurdles, as well as commercialisation, are still serious restrictions. This company thus has been successful in developing technology to be licensed to MNCs but, as a seed company, has not been successful in capturing a significant share of the domestic market, or any market -. They

[21] Genes in plant cells. The third one protects the gen Hahb-10, which confers transgenic plants shorter life cycles and tolerance to oxidative stress.

are therefore still very dependent on public funding for research and technology, since they are mostly dedicated to genes discovery, with their scale they do not have many varieties on their own (see Table 3).

Table 3: New varieties registered by Argentinean companies – 1979-2011

	Sunflower	Corn	Soy	Sorghum	Wheat
Total	721	1788	702	833	303
Enterprises					
Bioceres	1	1	**4**	3	8
Nidera	37	118	127	32	14
Don Mario	4		**117**		
Sursem-Relmó	21	58	41	5	1
Total	63	177	289	40	23

Source: Own elaboration based on data from INASE.

Case II - Don Mario: the cross-breeding approach

Don Mario is a family owned Argentinean company that has started to internationalise. It is dedicated largely to the development of soy seed varieties based on cross-breeding techniques. It began by adapting foreign varieties (mostly from the US) but now focuses on developing its own varieties. Don Mario purposively does not engage in the ´transgenic trajectory´, but not for knowledge capability or technological reasons, but rather because it is not large enough to afford the costs of meeting the bio-safety regulatory requirements involved in commercialising transgenic events.

Don Mario´s core business is in selling transgenic seeds. Its strategy is to develop well-adapted varieties using cross-breeding methods and to purchase genetic events from other companies (Monsanto in the case of soya) an incorporate these into its germplasm. In turn, the multinationals purchase the transgenic varieties from Don Mario. Multinational companies are perceived more as clients than as competitors.

The company performs cross breeding using an advanced level of capabilities. It has its own laboratory of molecular markers, created 5 years ago. It can therefore combine both phenotype and genotype selection in the development of their own plant varieties. The firm could upgrade its capabilities by adopting, for instance, genomic selection methods. However, researchers from the company explained that adopting genomic selection techniques (which would position Don Mario at a world leading level) is not advantageous in the soya business (unlike corn or sunflower), because it is difficult to recover the R&D costs of applying that technology to self-pollinated crop varieties such as soya because farmers can and do readily re-use self- pollinating seeds. To diminish that problem, Don Mario uses a system of ‘extended royalties’ that involve individual agreements with farmers who commit to buying new seeds each year in exchange for access to improved seeds every year, for an agreed period of time.

A key element for Don Mario strategy is positioning itself as a first mover, which is key for the self-pollinated seeds´ business. Don Mario´s strategy consists of possessing a wide spectrum of seed varieties that are suitable for different climate and soil conditions as well as resistant to pests. Thus, Don Mario attempts to be the first that cater to the market with the type of variety that is more suitable for the problems or agro-ecological conditions of each year and region.

Another key element in the strategy of Don Mario is the use of international expansion through foreign direct investment, as a way not only to gain market, but also to broaden up its germplasm and become aware of the agro-ecological problems and solutions from other regions. Don Mario has no patents, since it is not engaged in the genetic business. However, it is among the companies with the most varieties registered in the Argentinean market.

Examples of recent innovations by Don Mario include, Qmax a novel seed treatment system launched in 2011 designed to have more than 95% germination and 85% of force and incorporates a comprehensive treatment of Plenus, Syngenta. Another one is resistance to “frog eye spot” (a disease that can cause premature loss of leaves in the plants). According to INTA Marcos Juarez, Don Mario is the only company in the Argentinean market that already owns 70% of its portfolio resistant or moderately resistant to this disease that is very common in LAC, and the world.

Don Mario has expanded its business to other countries. The company has recently opened subsidiaries in Brazil (where it has 16% of soy market in the south), Uruguay (50% of the soy market), Paraguay, Bolivia and, and the USA. As a result, the company currently has one of the largest breeding programs in Latin America, and 25% of the certified soybean market in the region.

5. WHICH APPROACH TO DEVELOPING TECHNOLOGICAL CAPABILITIES?

In this section we now reflect on our empirical analysis, especially in terms of options for accumulating advanced technological capabilities. To begin, a number of points emerging from our empirical analysis are worth reiterating.

First, our case studies indicate that Argentinean seed firms currently recognise the potential of both transgenic and non-transgenic technology options for seed innovation, and are active in both areas. More importantly, the cases illustrate that these alternatives are not only technically feasible for the domestic seed industry, but that they all have involved the application of world-leading technological capabilities that exploit modern biotechnology. The potential benefits of performing with world leading capabilities (especially in terms of becoming innovative firms) are available in all the technology options.

Second, non-transgenic approaches have thus far been responsible for most of the seed innovations, and for the major part of the productivity improvements that have characterised soy agricultural production since the commercialisation of transgenic varieties in the late 1990s. Furthermore, of our two case studies of domestic firms, it has been the firm specialising in a non-transgenic approach that has proved to be commercially most successful, thus far, capturing market share and expanding into different countries. By contrast, the firm specialising in a transgenic approach (the only *domestic* firm that focuses on this approach) has yet to release its own technically successful technology commercially, largely for IPR and regulatory cost reasons and is therefore still dependent on public support.

Third, despite the plural approach adopted by the seed industry, and despite our strong evidence that it is non-transgenic approaches that have been far more successful thus far in explaining the performance of the seed and soy sector over the last 15 years, policy rhetoric focuses overwhelmingly on transgenic innovation options, and the need to support that trajectory. In terms of actual policy, intellectual property rules clearly favour innovators that adopt the transgenic approach. Why, then is that the case?

The promise of the transgenic option

Transgenic options for seed innovation might appear promising, and worth supporting with public resources and, say favourable intellectual property rules and other regulations by developing countries, for a number of reasons. The first of these, as we have already noted, is that it is frequently claimed or assumed that genetic engineering has already been the leading technology for improving seeds and seed and agricultural performance in many of the developing country jurisdictions where it has been adopted. Certainly, in some countries, including Argentina, studies indicate that GM crops have contributed to gains in farm income and productivity. A key review of Argentina's experience with planting GM crops by the agricultural economist Eduardo Trigo (2011), now a senior official in the Ministry of Science, Technology and Innovation, argues that the cumulative gross benefits for Argentina after15 years of adopting GM soybeans is US$ 3.5 billion as a result of estimated reductions in production costs. Trigo also claims that a staggering additional US$ 62billion of gross benefit can be attributed to the transgenic soy innovation because of an increase in the rate of expansion of the area planted to soya since transgenic varieties first became available in 1996.This involves the rather heroic assumption that transgenic soya alone was responsible for that increase in the rate of expansion of soy.[22] It also involve the even more heroic assumption that the entire gross economic value of the additional area sown with soya, measured as the price obtained from each harvest, can be attributed to the transgenic innovation - for example, that there is no need to take into account the foregone economic value of whatever agricultural practices were displaced, or that the economic value should not be shared between different aspects of soy production technologies, or even that there is no need to take into account the costs of production (that is the 62 billion figure is gross income, not net income, or profits!!)

Whatever the validity of such figures, to the best of our knowledge no one has tried to distinguish between the benefits arising from transgenic versus other seed innovation approaches since 1996, as we have attempted to do so on this paper. At least in our case, we find that benefits from reduced production costs as a result of the transgenic seed innovation are proportionately far less than the economic gains obtained by yield increasing innovations in non-transgenic techniques. In other words, one of the factors that might have prompted government support for transgenic seed innovation; namely the assumption that transgenic innovations are largely or even entirely responsible for the recent dynamism of the soy sector in Argentina, appears to be false.

A second reason why genetic engineering seed innovation options might appear promising and worth supporting is that the technology can be very beneficial for those firms – up to now mostly MNCs - in ways that were not available using older plant improvement techniques, at least under current regulations. This is for several reasons: (i) transgenic innovations benefit from the extension of patent laws to genetic sequences in ways that are not available with other plant innovations. In particular, intellectual

[22]Expansion may have been due to higher yields and thus profitability for example. Two INTA researchers in their analysis of soy in Argentina have suggested that "Due in part to genetic improvements the average yield surpasses 2.6 tons/hectare, making it possible to extend the agricultural border into marginal regions where edaphic and climatic conditions are less favorable" (Lema and Penna, 2003).

property rules for conventionally bred seed encourage further innovation by ensuring that conventional seed remains in part a public good, in the sense that anyone is free to use an existing variety as a basis for further improvement. That is not possible with transgenic varieties if, as is usually the case, the trans-gene has patent protection. In those cases, seed firms wishing to improve on a transgenic variety require a license from the patent holder, and so firms than own the genetic sequence gain a rent from not only the variety they have commercialised but each and every future variety based upon the original innovation – an option unavailable for firms specialising in other approaches to seed innovation. (ii) Transgenic seeds can be packaged with complementary assets (such as proprietary herbicides) that substantially increase the scope for extracting rents associated with sale of the seeds.(iii) Transgenic events are generic technologies that can be inserted into different varieties of the same crop, as well as different crops, and have worldwide applicability across different agro-ecological environments. This is an important reason why genetic engineering options provide more potential for firm profitability than other approaches because there are substantial possibilities for scale economies for firms selling this kind of innovation, and provides a reason for some companies to invest in the technology, though that is not a rationale for government support.

For developing country governments, the promise of highly profitable domestic seed firms specialising in transgenic seed innovation might be tantalising, but it is an option that in practice is unlikely to be available for all but the largest firms since the barriers to market entry are so high. The regulatory costs of commercialising transgenic seeds are formidable. Food safety and environmental bio-safety testing for transgenic seeds (which are not required for seeds created using cross-breeding or mutation approaches) can exceed by up to an order of magnitude the R&D costs. Estimates from other developing countries of the direct regulatory costs to firms seeking to gain a licence, i.e. the costs of providing the necessary data, range from 100,000 to 4 million dollars, depending on the jurisdiction and crop-event combination, and on whether there already exists, for example food safety or composition data, as a result of prior applications in other countries. Furthermore, whilst it is typically the case that R&D costs of a new technique decrease over time, sometimes quite substantially, regulatory costs are unlikely to decrease, and may well increase. The outlook for the structure of the transgenic seed industry is reminiscent of that for innovative pharmaceutical firms, where high regulatory costs have helped to create an oligarchic industrial structure. The strategies and experience of our case study firms back up these points. Thus, Don Mario, despite being a strongly innovative and science intensive firm is not interested in entering into the transgenic seed business because it lacks the scale and the financial resources to afford the regulatory costs involved. Although Bioceres is in the transgenic seed business, it faces problems complying with patenting and bio-safety regulations, and needs significant government support and alliances with much larger international companies to enable it to do so.

In addition to high market-entry costs there are a number of other reasons why, for developing country seed firms, the transgenic approach may be limited or risky. These include the fact that high regulatory costs mean that large markets are required to justify the development of novel traits. For firms interested in breeding crops grown for relatively smaller markets, transgenic technologies may not be commercially viable. In addition, concerns about potential, but difficult to predict, adverse effects of transgenic crops and food on biodiversity and/or human health have meant that markets for the products of transgenic plants do not currently exist in some jurisdictions, most notably in Europe. Likewise, some crops that are only used in human food stuffs, such as wheat and rice, currently have no potential market in transgenic forms; indeed the entire market for transgenic crop products is vulnerable to the discovery of future adverse negative effects in ways that are not anything like as risky for alternative approaches to seed innovation.

A third reason for why transgenic options for seed innovation might appear promising, and worth supporting, is that the technology is often assumed to represent the leading technological frontier in seed innovation. That, we have already argued, is largely an unexamined assumption, and one that we have shown to be misleading in so far as other approaches to seed innovation can, involve the development and application of world class capabilities based on modern biological knowledge, and evidently do so in practice in countries such as Argentina. The fact that the largest and most profitable global seed companies are involved in transgenic seed innovation, no doubt reinforces that assumption, but as have suggested above, the choice on the part of some of the major chemical MNEs to adopt that trajectory is perhaps largely an artefact of favourable IPRs, and market conditions, rather than technical opportunity.

A final reason as to why transgenic options for seed innovation can appear promising is future expectations of what the technology might achieve. In the early 1990s, advocates of the technology claimed, for example, that increased yields, tolerance of drought, more efficient use of fertilizers, and ability to produce drugs or other useful chemicals were all forthcoming. Such expectations have declined considerably in recent years because 25 years of investment and global effort have basically delivered only two single trait types, herbicide tolerance and pest resistance.[23] Furthermore, while these traits have helped to reduce uncertainty and costs, and have simplified management, they have had no overall effects on intrinsic yield.[24]

In summary, neither the relative performance of genetic engineering-based innovations in soya, nor the fact that the approach involves world-class capabilities appear to be good reasons to support the technology. Non genetic engineering-based approaches to seed innovation have demonstrated far superior performance, thus far, and also involve world-class technological capabilities. Furthermore, although there may be important opportunities for firms that specialise in genetic engineering of seeds, these are unlikely to be realised by any but the largest MNCs. For developing country firms, the only plausible option would be to license genetic engineering-based innovations to their far larger competitors to commercialise. In the end, only future, but highly uncertain, expectations of the technology appear to provide a rationale for strong State support of the development of domestic capabilities in seed genetic engineering, but possibly to the detriment of alternative, better performing, techniques.

[23]In Argentina between 1991 and 2011, 20 new traits obtained with transgenic technologies have been obtained, 15 for corn, 3 for cotton and 2 for soy. All of these traits incorporate three types of resistance: 1) resistance to glyphosate (or the some other herbicide), 2) tolerance to lepidóteros (a butterfly that harm corn and cotton), and stacked, which include both characteristics. During the same period 2720 new varieties for these crops obtained with the other approaches were registered, including different types of improvements of the type described in box 2 and 3.

[24]M. Qaim (2009). 'The Economics of Genetically Modified Crops', *Annual Review of Resource Economics*, 1, 665-93.

6. CONCLUSIONS

Our approach in this paper and our empirical findings have implications both for debates about the role of seed genetic engineering in agricultural development, and for policy debates about ‘catching up’ in seed innovation, as well as raising more general issues of relevance to the ‘catch up’ literature.

First, as regards debates about the role of seed genetic engineering in agricultural development, it is notable how analyses of the performance of genetically engineered crops are almost always conducted as if that was the only innovation for which information on benefits, costs and risks was needed; that is without reference to the performance of alternatives. Yet, perhaps the most important purpose of appraisal is to inform public and private decisions about the allocation of resources, and those kinds of decisions can and do involve choices between alternative technologies that fulfil the same goal, in this case better performing seeds. As such, for policy-makers and managers, faced with real options about which, amongst several different technology approaches to encourage and fund, the most useful kinds of appraisal are those that are conducted comparatively. To do otherwise means that efforts at appraisal are of limited use, and perhaps even misleading. In our case, of soy in Argentina, existing analyses of the performance of genetically engineered soy in isolation certainly indicate that the innovation has been beneficial, mainly by lowering production costs. Yet, our comparative analysis of the benefits of soy seed innovation indicates that most of the innovations that explain increases in farm productivity have been obtained by conventional breeding and mutation techniques; not genetic engineering. The question then is does it make sense to support genetic engineering approaches that, at least on soy, have had no effect on yields and relatively small effects on costs savings, at the expense of alternative seed innovation approaches that have been shown to substantially increase both yields and farm income?

In terms of policy debates about ‘catching up’ in seed innovation, we have advanced a number of argument and empirical findings that challenge the assumption that genetic engineering represents the leading technological frontier in seed innovation. In particular, not only have alternative technological approaches to soy seed innovation delivered more and better innovations, but they can all be performed using world-leading capabilities. In our case studies, the most successful Argentinean seed firm, in terms of a growing share of the soy market and expansion into the other two leading soy producers, Brazil and the USA, focuses on advanced cross breeding approaches. Furthermore, the option is available using cross-breeding and mutation approaches to innovate using very different levels of technological capability, whereas for genetic engineering, innovation is only possible for firms that have leading-edge capabilities. The option for market entry with less investment and less capabilities, and for subsequent learning is available with the alternative approaches in ways that are far more difficult for genetic engineering approaches.

‘Catching up’ strategies in the seed sector will involve trade-offs. Different seed innovation strategies may not be incompatible with one another, at least from a technical point of view(except where contamination of non-genetically engineered seeds or crops with trans-genes has implications for seed input and/or crop output markets). Nevertheless, financial resources are limited, and R&D and other forms of support for the development of capabilities in seed genetic engineering may mean fewer resources are available for alternative options, (unless the capabilities can be applied generically across innovation approaches).Why, for example should the Argentinean government fund INDEAR, the research laboratory of Bioceres that specialises in plant genetic engineering, and not genomic selection tools that could be used by all domestic seed companies, thus taking those firms closer to the frontier in cross breeding approaches to seed innovation? Or why not support research to provide genomic understanding of the soybean, a public good for the entire sector? There are tradeoffs involved in public resource allocation, and these should be informed by comparative benefit (and risk) analysis between technologies or technological options.

Also, certain regulatory rules, as we have seen in the Argentinean case, may favour one option at the expense of other technological approaches. At the very least, it may be important that catching up strategies in the seed sector encourage diversity and avoid an overemphasis on one technology, most notably, genetic engineering. This is an important issue for emerging countries that are setting up rules, institutions and providing strong financial and policy support to foster the development and diffusion of transgenic technologies, without considering in many cases and situations how these policies and support might be affecting alternative technologies.[25] If alternative non-transgenic approaches are also supported as part of catching up strategies in the seed sector, firms with different technological capabilities, financial resources and equipment can survive. These include small scale seed companies, companies that target what are currently niche markets, such as organic producers, as well as larger, more sophisticated producers who aim to develop seeds in a science-intensive manner. A far more diverse national seed industry is likely to develop and/or survive if diversity in technological approaches is maintained.

Finally, and more generally, we have argued that in the seed industry and probably other industries too, attention to the comparative performance of different innovation approaches and the wider implications of those different approaches for the development purposes of the country is critical. Industry leaders and global institutions might heavily favour one innovation approach, but that does not necessarily imply that this is the only direction towards which technological capabilities should be accumulated.

[25]There is evidence in these countries that, excitement about the potential of transgenesis is stimulating shifts in funding at public institutions to enhance intellectual capacity and infrastructure for molecular genetics and genomics research, which ironically often occurred at the expense of conventional plant breeding (Knight, 2003). This emphasis may have been temporarily necessary to establish the foundations for 21st century plant biology, but there is currently a growing recognition that increased investment in plant breeding capacity and translational research linking molecular methods with breeding objectives is necessary to fully realize the potential of recent advances in biotechnology and genomics (Guimarães and Kueneman, 2006; National Research Council, 2008).

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