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Globalization, the Rise of Biotechnology and Catching up in Agricultural Innovation: The Case of Bt Technology in India

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Abstract

The agricultural sector has played an important role in the provision of food, foreign exchange and sustainable energy to many developing countries. This sector, however, has not been considered as a driving force of innovation as compared to other productive sectors. However, recent economics and international business literature suggests that the agricultural sector (1) has become knowledge intensive with the rise of biotechnology (Bt); and (2) is a sector where firms in developing countries can play an important role in production and innovation due to their latent advantage in the context-specific or *in-situ* knowledge base. In this paper, we first present a conceptual framework that characterizes the knowledge required for successful agricultural innovation against the backdrop of globalization and rise of biotechnology. We then examine the case of diffusion of Bt cotton hybrids (*Bacillus thuringiensis*, an insect resistant seed technology) in India to illustrate the dynamics of knowledge creation and catching up by the local seed firms based on their interactions with global as well as other local firms. Our analysis reveals that the local firms with absorptive capacity, that is, the ability to effectively integrate location-specific (*in-situ* knowledge) and generic scientific knowledge (*global* knowledge) can catch up with global frontier technologies to gain significant domestic market shares.

Keywords: Globalization, Catching up, GMOs, Agricultural Biotechnology, Bt cotton India

JEL classification: O13, O31, O32, Q16

1. Introduction

The agricultural sector has played an important role in the development process by providing food, sustainable energy and foreign exchange to many developing countries. Despite these contributions, this sector has not been considered the driving force of innovation and technical change in improving productivity. Instead, this sector has, over the years, gained negative connotations of being 'low tech' and disassociated from the potentials of technological progress (Singer, 1950) as well as innovation (Pavitt, 1984), and has come to be considered as a symbol of 'underdevelopment'.

The recent rise of biotechnology has given a new technological trajectory to the agricultural sector. Against the backdrop of global integration, the agricultural sector is currently undergoing major changes, especially in the ways knowledge is created and diffused, which involves a diverse array of stakeholders at global and local levels. Much of the economics literature on global–local knowledge interactions within the innovation process has focused on cases from the manufacturing and services sector, while agriculture is less featured. In this article, we focus on technological catching up in the agricultural sector, examining changes in the way knowledge is created by interactions between global and local players, by looking at the case of Bacillus thuringiensis (henceforth Bt)[1] cotton, a genetically modified variety with built-in resistance to insects, in India.

India has huge agricultural potential, with the second-largest arable land area after the United States. India is the fifth-largest seed market in the world after the United States, China, France, Brazil and Canada that values at US$ 2000 million in the year 2012 (International Seed Federation, 2013). While India's acreage under cotton is the highest in the world (about 12 million hectares), its production volume still remains at number three globally. By the turn of the new millennium, a major problem in cotton production was the yield loss due to pests (bollworms) and the pesticide costs associated to deal with them. Subsequently, in 2002, Bt cotton, an insect resistant GM variety, was introduced in India by Mahyco, a domestic firm with its Bt technology licensed from a multinational firm, Monsanto, via a collaborative venture MMB (Mahyco Monsanto Biotech). Thereafter, numerous domestic firms in India were involved in the successful development and commercialization of Bt cotton hybrids.

The diffusion of Bt cotton in India was spectacular. Since its introduction in 2002 the area under Bt cotton grew from 0 to 95 per cent of the total cotton area by the year 2013 (Clive, 2013). With a significant contribution towards the decrease in the usage of pesticides for bollworm, the Bt insect resistance technology was a huge commercial success. Also a rapid increase in cotton yield, total production and exports can be noticed since the introduction of Bt cotton in India (see Figures A1 through A4 in the appendix).

[1] *Bacillus thuringiensis* is a soil bacterium that carries in its DNA a gene which produces a toxin for certain insect pests (cotton bollworm, Asian and European corn borers). By transfer of this gene into the plant DNA an automatic resistance is developed in the plant against such insect pests.

The case of Bt cotton in India clearly illustrates changes in the knowledge creation for agricultural innovation with the rise of biotechnology and increasing globalization of production. These changes have presented Indian firms with interesting and diverse pathways to catch up with the frontier technology. In this article, we try to answer the following questions. How did the Indian seed and agri-biotech firms catch up with this radical and frontier technology? What were their technology acquisition strategies? What role did the technology leader and multinational firm Monsanto play in the diffusion of this technology in India? What does the case of Bt cotton in India mean for local agri-biotech or seed firms' strategy elsewhere in other emerging countries in terms of catching up with global frontier technologies?

In order to answer these questions, we start by clarifying the following: first, the changing context of global–local knowledge interactions against the backdrop of increasing globalization and technological catching up; second, the nature of agricultural innovation processes, which is significantly different from that of the manufacturing sector; and third, the impact of the modern biotechnology on agricultural innovation processes. We develop a conceptual framework that characterizes the knowledge essential for agricultural innovation under the above themes. We then look at the case of India's Bt cotton seeds to analyse the catching-up process at firm level. Our analysis illustrates how the emergence of biotechnology and increased globalization not only contributed significantly to agricultural productivity, but also transformed the way in which knowledge is exchanged and created in a collaborative manner between the owner of global 'upstream' scientific knowledge (multinationals such as Monsanto) and the leaders of local 'downstream' *in-situ* knowledge (Indian seed firms).

The paper is organized as follows: in Section 2 a survey of the economics and international business literature is carried out to present the theoretical background on the processes of firm-level knowledge creation and technological catching up. We identify how these processes have changed with increased globalization and the rise of biotechnology. In the same section, we highlight the peculiarities of agricultural production and innovation processes, and present a conceptual framework that characterizes the knowledge involved in agricultural innovation process. In Section 3 we analyse in detail the different patterns of Bt technology diffusion in the Indian cotton seed market to draw some insights for firm strategy in catching up with frontier technologies. Finally, in Section 4, we conclude with our main findings from the case study analysis, and suggest possible directions of future research in this area.

2. Theoretical background and conceptual framework

2.1. Knowledge creation as a dynamic process

In the economics of innovation literature (Lundvall, 1992; Nelson and Rosenberg, 1993; Malerba, 2002), scholars have identified that the speed and trajectory of creation and diffusion of innovations is highly heterogeneous and dependent on the national and sectoral systems of innovation. While it is important to strengthen innovation systems at the national, regional and sectoral levels, these systems are now increasingly integrated into the global knowledge system. Globalization and subsequent interactions with outside actors introduced major changes into the processes of knowledge creation. For instance, the appropriation of knowledge through intellectual property rights (IPR) and its adoption through the TRIPS agreement became important institutions that transformed the way knowledge is transferred between actors (licenses and R&D collaboration).

Amin and Cohendet (2004) describe in detail the recent changes in the knowledge creation process that are significantly accentuated by the process of globalization (Iizuka, 2007). Amin and Cohendet (2004) consider that knowledge is no longer a pure public good because access is determined by the level of appropriation of knowledge. This does not mean that knowledge creation remains the solitary action of individual actors. Knowledge creation is, rather, a network phenomenon where actors interact with each other. It is true that individual gains from such interaction vary due to the variable degree of absorptive capacity (Cohen and Levinthal, 1990). The process of knowledge creation is becoming increasingly collaborative, where the producer of knowledge faces a specific structure of interaction among various agents at distinct levels.

Table 1 summarizes the changes that feature in the knowledge creation process as a result of globalization.

Table 1 Changes in the notion of knowledge and the knowledge creation process with increasing globalization

Before	**After**
Knowledge is simple accumulation of information and is a pure public good; it is not possible to exclude anyone from using it.	Knowledge is not a pure public good, and access to knowledge is variable.
Incentives for knowledge creation are not linked to its ownership (appropriability).	Incentives for knowledge creation are increasingly linked to its ownership.
Production of knowledge is often solitary.	Production of knowledge is not solitary; it happens in global production networks.
The producer of knowledge directly interacts with the market.	The producer of knowledge faces a specific structure of interaction among economic agents.
Agents have full capacity to understand existing knowledge.	There are differences in utilization of existing knowledge, depending upon absorptive capacities.

Source: Adapted from Iizuka (2007, based on Amin and Cohendet, 2004).

2.2. Alternative pathways for catching up in the global production processes

2.2.1. Changing role of producers in developing countries in global production

The literature on globalization of economic production demonstrates that the role of producers in developing economies has changed significantly. The global value chain (GVC) literature observes that the role of producers in emerging economies is gradually shifting from low-cost resource and service provision (human, natural and environmental) to less hierarchical, 'arm's-length' supply of products with possibility to upgrade its position in the GVC (Gereffi, 1994; Gereffi and Korezeniewicz, 1994; Humphrey and Schmitz, 2000, 2002a, 2002b; Gereffi and Kaplinsky, 2001; Kaplinsky and Morris, 2001). The global production network literature advances this point to state that producers in emerging economies now have a more equal standing to compete in coming up with the most efficient and productive solutions to delivery of necessary services (Ernst, 2001).

Similarly, in the international business literature, the role of subsidiaries is being reconsidered as a potential source of knowledge within a multinational enterprise's global knowledge network (Birkinshaw and Hood, 1998; Cantwell and Iammarino, 2003). In other words, industrial economics and international business literature suggest that actors in emerging economies are increasingly becoming knowledge collaborators and active partners of knowledge creation rather than passive users or implementers of knowledge.

Recent findings on global value chains (henceforth GVC) by OECD (2013) have also demonstrated the importance of 'knowledge-based capital' for upgrading producers' position in the GVC. 'Knowledge-based capital' is understood as tacit, operation- or organization-specific knowledge that others find difficult to replicate. While there are differences in types of upgrading (process, product, functional, chain and end-market), all types of upgrading require capacity building through conscious learning, interaction with other actors in GVC and beyond (Kaplinsky and Morris, 2001; Fernandez-Stark *et al*., 2011; OECD, 2013). Firms that have acquired knowledge-based capital in terms of access to complementary inputs and services can better position themselves in the GVC because they can 'glue' production processes and contribute significantly in maximizing gains from GVC (OECD, 2013; Kaplinsky and Morris, 2001). While knowledge plays a central role in increasing the profitability of a firm, investment in knowledge-based capital is difficult in the early phase of emerging economic activities due to non-excludability and high risk, which conventionally exist with regard to knowledge.

The complex nature of knowledge flows involving MNEs, one of the key players in GVC, is also observed with regard to IPR in emerging economies. For example, several studies have shown that the strength of the IPR regime influences MNEs' knowledge creation activities in emerging economies. International business literature reveals that technology transfer will be limited under a weak IPR regime because of less use of licensing (Yang and Maskus, 2001; Fisman and Foley, 2004). Other studies mention that MNEs are likely to engage directly in collaborative knowledge creation (R&D activities) with partner firms located in countries with a weak IPR regime to avoid IPR 'leakage' (Zhao, 2006; Griffith and Miller, 2011). The presence of absorptive capacity of local firms also influences MNEs' decision regarding knowledge collaboration with local firms (Alnuaimi *et al*., 2013). For a long time, the type of technology transfer that takes place between MNEs and local firms was believed to concentrate on the inexpensive manufacturing or customized products areas targeting local markets (Nandkumar and Srikanth, 2011); however, type of technology may not be the sole determinant. A recent study shows that MNEs' collaboration decisions are influenced by various factors, including the strength of the IPR regime, the capacity of local firms as well as the type of technology and the target market. All of the above suggest potential for local players to play an important role in global knowledge networks, especially if they are equipped with the absorptive capacity.

2.2.2. Catching up in global contexts: changing patterns of knowledge acquisition

In development studies, the term 'catching up' usually refers to closing the gap in technological capabilities, leading to increased domestic or export market shares (Abramovitz, 1986; Perez and Soete, 1988; Lim and Lee, 2001), or, in other words, the process in which firms learn quickly to narrow the gap or 'leapfrog' to the global technological level (Perez and Soete, 1988). Lim and Lee (2001), in the study based on six Korean industries (automobile, DRAM, machine tools, electronics, computers and mobile phones), identified three different patterns of 'catching up': 'path following', 'path skipping' and 'path creating'. 'Path following' is the pattern of learning that mostly concerns acquisition of knowledge through adaptation and imitation of existing technology and the processes of its creation; 'path skipping' is the pattern of learning that involves skipping a certain stage of technology development; and 'path creation' involves creating a new combination of knowledge to move the technology onto a slightly different trajectory. Their study highlights how different sectors choose different learning strategies by combining acquisition and creation of knowledge reflecting different industrial regimes. The catching-up process therefore involves integration of the existing knowledge base with that of the global advances in diverse pathways that may involve collaboration.

On the same lines, Prahalad and Mashelkar (2010), based on their study of successful Indian firms, identified different types of knowledge creation process with increased use of licensing in the context of globalization, giving more attention to the demand side. They identified diverse strategies of combining knowledge: first, creating customized solutions by combining the existing 'off-the-shelf' technologies via licensing (examples are Indian ICT firms such as Wipro, Infosys and TCS); second, creating new products by putting together existing technological components in a unique manner (for example, Computational Research Laboratories (CRL) coming up with the fourth-fastest computer with licensed technology); and third, addressing a new market segment with new products or services by selecting and integrating existing technologies (for example, Tata motors integrated various existing technologies[2] to produce a car, 'Nano', at a cost of $2000 addressing the low-income market segment). All these cases demonstrate that the scope of innovation is not limited to knowledge creation from scratch but increasingly involves combining existing knowledge in new ways to address new markets, such as the one emerging in India. The cases

[2] Tata Motors utilized the engine management system from German firm Bosch, styling and exterior design from Italian firm IDeA, lightweight steering shafts from Sona Koyo, controls for the seating system from American firm Johnson, the engine module from Japanese firm Toyo, heating, ventilating and air conditioning from German firm Behr, tougher tires from Indian firm MRF (Prahalad and Mashelkar, 2010).

demonstrated that local firms in emerging economies are increasingly capable of taking advantage of the opening of the 'windows of opportunity' in the innovation processes.

Against the backdrop of global integration of production processes a significant focus is placed on the emerging economies with a large domestic market (such as the BRICS – Brazil, Russia, India, China and South Africa), where the scope of knowledge-based capital is increasing and becoming critical for competitiveness. While these theoretical and empirical findings are important, many studies are based on the cases from the manufacturing sector. Our main aim in this article is to extend these arguments to the knowledge dynamics of technical change pertaining to the agricultural sector.

Agricultural innovation, like any other technological or industrial regime (as highlighted by Lim and Lee, 2001), demonstrates peculiar sectoral characteristics originating from the nature of the production processes, based on interactions between a diverse natural and highly localized combination of factors of production (climate, soil, water, plant varieties), let alone capital and labour. Furthermore, with the rise of biotechnology and the IPR regime became relevant for technological transfer in this sector. In the following section we explore the changes that the knowledge creation process has undergone in the agricultural sector.

2.3. Technical change in agriculture and globalization of the innovation process

2.3.1. Innovation in the agricultural sector

Agriculture has long been disassociated from technological development (Singer, 1950). This 'non-technological' nature of agriculture, along with the assumption that the sector has little scope for developing backward and forward linkages, led to the belief that this sector was a 'dead-end' along the path towards structural transformation and economic development. The idea accords with Pavitt (1984), who categorized agriculture as 'supplier dominant',[3] relying on the non-agricultural sector's innovation to increase its productivity. The major 'driving forces' for productivity-enhancing innovations in agriculture are considered to be similar to what Hirsch-Kreinsen *et al.*, (2005) claim as the key to the low-tech sector, that is, the ability to configure, adapt, transform, organize and design external knowledge emanating from the non-agricultural sector.

Hayami and Ruttan (1971) recognize technical change in agriculture as the outcome of a selection process involving endowed factors of production such as labour and land. They state that the high agricultural productivity of the developed countries is based on (a) the development of a non-agricultural sector capable of transmitting increased productivity to agriculture in the form of cheaper sources of power and plant

[3] We should consider the claims made by Pavitt (1984) with caution as his analysis was based on data from 1945 to 1979. This means that his description of technological activities in agriculture captures the situation before the biotech revolution when 'modern-science-based' knowledge was still evolving (also, even if such knowledge is noted, it was not considered as greatly influencing agricultural productivity).

nutrients (for example, tractors and chemical fertilizers) and (b) the capacity of a society to generate a continuous sequence of innovations that increases the demand for the inputs supplied by the industrial sector. Hayami and Ruttan (1971), therefore, asserted that agricultural innovation requires effective internalization of the technology developed by the non-agricultural sector, so that interaction is driven by locally endowed resources and science-based agriculture, which enable productivity to increase beyond natural endowed capacity.

Olmstead and Rhode (2008) paid attention to non-mechanical innovations in agriculture, in the form of new plant varieties and improved practices of production. They call the above 'biological innovations', which include organizational innovation, traditional knowledge and institutional arrangements for creating varietal improvement, herbicides and fertilizers. The success of biological innovations is strongly tied to their adaptation to the biosphere in which they are applied. Hence such innovations are inherently locally embedded and are highly location specific, subject to knowledge-based capital.

The above inference is critical on two accounts. First, biological innovations such as developing new plant varieties require adaptation to the local biosphere. For example, 'improved' variety by itself cannot increase yield if it is not adapted to the local climate, soil conditions and water availability; it needs to be accompanied by new farming practices. In other words, biological innovation is not simple implementation of scientific knowledge in a new context, but involves identifying the best combination that enables high yields through interactive learning in a trial-and-error manner. Second, the knowledge accumulated in agricultural innovation is often tacit and difficult to appropriate (Olmstead and Rhode, 2008: 10). Large parts of the agricultural knowledge base of this type are embedded (over the years) in diverse local contexts and institutions (i.e. traditions, community knowledge) in the form of 'routines'. Hence innovation in agriculture follows a particular pattern that involves actors from both the demand and supply sides, creating knowledge that is mainly tacit, locally specific and subject to constant and variable change (especially due to climate change).

Several case studies confirm this point of view. Bisang (2011) describes how agriculture is an 'open-sky' industry, which transforms selected seeds or animals into produce according to external environmental resources such as water (rain, irrigation, aquifers etc.), sunlight and cultivated land (which consists of minerals, bacteria, viruses, other living organisms, substrate etc.). It is common knowledge that plant varieties fail if they are not adapted to the local agro-ecology. Katz *et al.,* (2010) demonstrate that high variability and heterogeneity in productivity are increased in aquaculture due to interactions with the biosphere.

In sum, productivity in agriculture is highly location specific and, for this reason, it is important to understand that the innovation process here is conceptually different from that of the manufacturing sector (Bisang, 2011; Katz, 2006) because the same combination of factors of production (land and labour) may bring about different outcomes due to differences in environment and practices. The scope of localization or adaptation processes of upstream (generic and scientific) knowledge to a particular context and the dynamics associated with such integration are much broader and more critical for agriculture compared to other sectors.

Furthermore, the success of innovations in agriculture is determined by the configuration of both scientific knowledge at the global level and agro-ecological and knowledge of markets at the local level. While Olmstead and Rhode's (2008) study is convincing in introducing the role of 'biosphere' and 'biological innovations' into the agricultural production function, there are very few studies that examine the global (non-local)–local knowledge interactions between firms in coming up with such biological innovations.

2.3.2. The private sector and agricultural innovation

Investments in agricultural research have been dominated by the public sector (Pardey *et al*., 2006) and its R&D investments are still increasing (Shih and Wright, 2011). The dominance of the public sector in agricultural R&D is explained by the fact that the R&D output, high-yielding varieties, are public goods and the R&D is subject to 'market failures' because plant breeding faces the extreme case of durable-goods monopoly and appropriability problems (Timothy, 2001). Agricultural production is essentially a geographically dispersed activity, carried out in heterogeneous natural resource bases that evolve over time. These conditions make investment in knowledge unattractive for the private sector because of high risk and uncertainty, lack of scale effect and appropriability.

The rise of biotechnology and changing IPR regime in the sector changed the scenario, however. These changes created the condition in which the 'public-goods' nature of knowledge took a back seat, while appropriability is now technically feasible.[4] Upstream scientific knowledge became scalable as well as replicable via the transfer of genes. This enabled the entry and thriving success of large private firms such as Monsanto, DuPont and Syngenta in agricultural R&D. The rise of biotechnology associated with present-day agriculture, accompanied by a new set of institutions such as IPR, regulation and international standards, provided a different context for actors both private and public to interact in the innovation process.

2.4. From knowledge creation to innovation in agriculture: towards a framework of analysis

Productivity in agriculture is achieved either by improving yield per hectare or output per unit of labour. Each type of innovation, labour saving or land saving, contributes to overall productivity, but the association of innovation with combined productivity increase is often not clear-cut. This is because technologies that improve yield such as hybrid seeds necessitate more inputs (hybrid seeds require more water and

[4] Kranthi *et al.,* (2007) wrote 'Challenges in detecting GM crops' write 'World over, GMOs are detected reliably either by detecting DNA segments or specific proteins that are unique to the transgenic crop. DNA detection is primarily through PCR-based methods and protein detection is mainly through immunoassays such as enzyme-linked immunosorbent assay (ELISA) and lateral flow strip methods.'

fertilizers, and labour for harvesting), in turn affecting net returns.

Furthermore, yield is sensitive to both endogenous and exogenous changes surrounding the plant, such as sunlight, humidity, water and soil fertility. If all the exogenous parameters remain stable, yield is determined by the physiology of the plant, that is, its inherent genetic potential,[5] as well as newly introduced inputs. However, it is highly unlikely that the exogenous parameters remain stable every season.

In the past, yield improvements in a variety of crops were achieved by progressive farmers who, over time, accumulated the location-specific or *in-situ* knowledge (with efforts often spanning centuries) essential for varietal development. That is, the effort that goes into the selection of varieties with superior yield characteristics and with agro-ecological resilience is similar to that expended in building the knowledge-based capital in the context of the GVC literature which has been the key to successful future upgrading. However, the conventional mode of discovery, selection and preservation of superior germplasm was rudimentary and outcomes were often left to the mercy of nature, allowing the transformation to follow its own course over time. Moreover, the traditional or indigenous knowledge about the interaction of the new varieties with the local ecology, yield and seasonal variations in soil, climate, sunlight and pest incidence remained in tacit form.

In the case of the early 'Green Revolution', the new plant types that were developed had the capacity to respond to the application of fertilizers without lodging. Plant breeders and scientists altered the physiological and morphological characteristics of the plants, using scientific principles from microbiology and transitional plant sciences. The alterations were made in favour of higher yields, better germination, uniform growth characteristics, shorter production cycle and stable performance under changing agro-ecologies. This involved R&D in the laboratory and adaptation at the production site, observing yield responses of new crops, including photosensitivity, thermosensitivity and a range of atmospheric parameters; nevertheless, the performance of technology and new plant varieties was still highly dependent on the conditions of the local agro-ecology.

It is also important to recognize that, although the *prima facie* problem in agriculture is yield improvement, a package of technological solutions was needed to deal with dynamic and diverse productivity problems whose solutions come from various areas of complementary inputs as well as various practices (farm management techniques). The solutions for diseases (pathological), pests (entomological) and nutritional problems (physiological) were offered in the form of synthetic fertilizers, pesticides and herbicides. Improved yields have been mostly sourced from traditional plant sciences by continuous selection and breeding of new varieties.

The modern biotech breeding methods changed the above picture by enabling direct control and targeted manipulation of the genetic makeup (plant DNA) rather than

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[5] This is also referred to as strength of the germplasm to produce a level of output. Yield is a quantitative trait affected by multiple genes in a plant.

leaving this task to natural selection. Due to this new method, providing solutions became effective and less time consuming. Also the knowledge artefacts created by the modern methods are increasingly codified and transferable protocols. Therefore this high-end scientific knowledge is global in nature compared to past methods, which were tacit and *in situ*. The scientific component of the knowledge spectrum thus gradually evolved from being rudimentary to low-end scientific (low level of scientific complexity, e.g. plant sciences and conventional breeding) and finally to high-end scientific (high level of scientific complexity, e.g. genetics, biotech-aided breeding).

Global agri-biotech firms (as well as large public sector institutions, for example CGIAR) in general have a comparative advantage in the global scientific knowledge component as compared to local firms because they are more likely to possess the capital for R&D, have access to highly skilled resources and possess superior organizational capabilities. In this regard, Byerlee and Fischer (2002), while listing the complementary assets (knowledge and non-knowledge) of global and local firms in agri-biotech R&D, argue that local knowledge, strength of breeding programs and infrastructure, seed delivery system and market network are the assets of local firms, whereas upstream technology know-how, access to capital markets, economies of market size, skills in regulatory nuances and flexibility in decision making are the assets of global life science firms. They also argue that these assets are complementary for successful innovation, and therefore alliances and R&D collaboration between the global and local players are important for technological catching up.

While the success of agricultural innovation very much depends on global scientific knowledge, complementary *in-situ* knowledge is needed for localization of the technology. This knowledge is not only local in nature but also dynamic; that is, changes to the environment or agro-ecology are frequent, which means that the underlying knowledge base needs constant updating. The knowledge gathered in this respect can, however, be codified (for transfer). This codified knowledge; however, is relevant for only a short period of time. There is no guarantee that the codified knowledge at time t holds good at time $t + 1$. Moreover, physical presence or field data collection is needed to perceive, test, gather information, build and update this knowledge base from time to time. The need for constant updating, and the complexity and tacit nature of certain elements of this knowledge component, make its codification tricky.

Another type of *in-situ* knowledge is local market dynamics (local demand and elasticity of demand for a certain agricultural output, culture and behaviour of the society with respect to produce, production practices of farmers, and the dominant socio-economic characteristics of consumers).[6]This type of knowledge is essential for commercial success of an agricultural innovation and exhibits similar characteristics to agro-ecological knowledge: location specific, dynamic and tacit. Local firms and organizations have a latent advantage in this component because of the proximity to both agro-ecology and local markets.

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6 However, we do not analyse the dynamics of this component in this article.

The agricultural innovation therefore includes 'upstream knowledge', represented by generic tools, techniques and biological materials (including genes), and 'downstream knowledge', such as locally adaptable seed and plant varieties and agricultural practices. An agri-biotech firm can therefore innovate upstream part of the knowledge for the technology markets while working on downstream innovation in new seed varieties.[7] There are therefore two major demarcations in the modern agri-biotech product markets: (a) *generic* technology products such as events/genes, biological products, tools and processes; and (b) *in-situ* technology in the form of seed varieties and the accompanying tacit form of agricultural practices (Milind *et al*., 2006, 2007).

With advances in biotech research, the modern-day seed innovators need dynamic catching up with upstream scientific advancements at a global level. Downstream processes in the innovation involving the production of hybrid seeds always hinge on the local component of the knowledge (from now on *in-situ* knowledge). The *in-situ* knowledge therefore becomes critical for the successful adaptation of the innovations to the local ecological and market conditions. Combining these arguments, we propose the following:

a. Global scientific knowledge – molecular biology/genetics (high-end), conventional plant sciences (low-end) – global in nature

b. In-situ *knowledge – agro-ecology: climate, rainfall, soil; market: local food habits; demand patterns – local in nature*

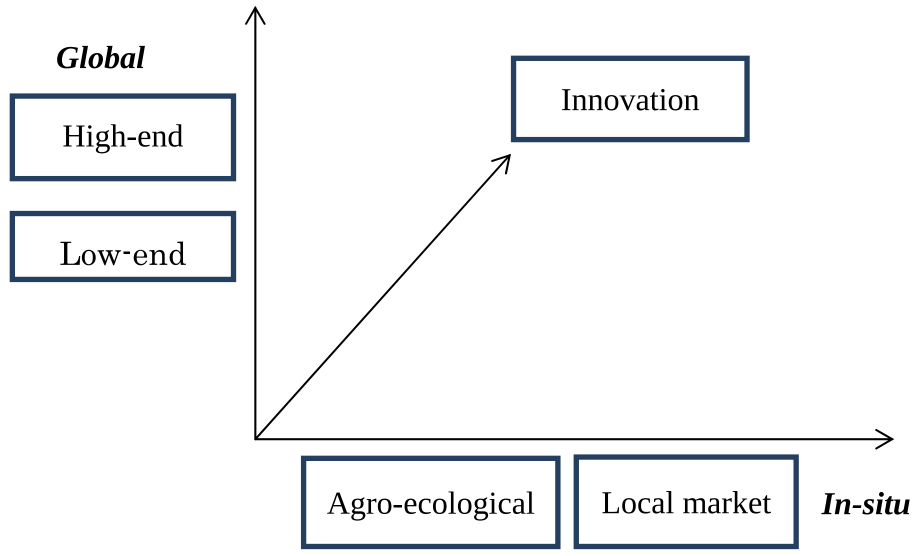

Figure 1 Characterization of Knowledge required for agricultural innovation by the authors

As can be seen from Figure 1, the upstream component of knowledge, which

[7] An agri-biotech firm that concentrates on upstream R&D (a science-based firm) will be selling biotech products, tools, protocols and biological material necessary for development (examples include markers that are resistant to antibiotics used in distinguishing the transformed cells from non-transformed plant cells).

is global in nature, has both high-end (genetics, molecular biology) and low-end (traditional plant sciences) components, whereas the *in-situ* component includes local agro-ecology and market dynamics. The advances in genetics and molecular biology (basic science in general) belong to the high-end scientific component; whereas the knowledge associated with conventional plant breeding and hybridization (non-biotech-aided breeding) belongs to the low-end scientific component. Similarly, with fast-changing climate and resource degradation, knowledge of the dynamics of local agro-ecology, changing food habits, socio-economic conditions and consumer preferences belong to *in-situ* knowledge. In this sense both the components are dynamic and complementary, and hold the key to success of agricultural innovation.

In the section to follow, we analyse the case of Bt technology in the cotton crop in India based on this general framework. We analyse the process of catching up of local seed firms with Bt technology. We also discuss the role of Monsanto, a global technology leader in this catching-up process. We then derive insights for both multinational and local firm strategies in catching-up.

We chose the case of Bt technology (cotton) in India for the following reasons: (1) the Indian hybrid seeds market has an active presence of both large multinational and medium-small domestic firms; (2) there is a competitive market structure in the hybrid seeds market for commercial crops and vegetables; (3) the dramatic speed of diffusion of Bt cotton hybrids in a decade; (4) the significant benefits observed in the productivity and production of cotton after the introduction of Bt cotton in India (see Figures A1 through A4 in the appendix).

3. The case of Bt cotton in India

3.1 Global and Indian seed industries and the entry of Bt cotton

3.1.1. Global seed industry

The global seed industry is worth $42 billion and, out of this, the global biotech seed market is estimated to account for $13.2 billion (Indian Seed Congress, 2011). The global seed industry is highly concentrated. The top three companies, Monsanto, DuPont and Syngenta, account for 43 percent of the world's seed market (ETC group, 2013; see Table 2). Also, the same top three companies accounted for 72 percent of utility patent applications in plant varieties and 44 percent of applications for plant variety protection (ETC group, 2013). These statistics indicate the leadership of global seed firms in both the upstream technology market (scientific knowledge base) and in the downstream seeds market.

The technology and seeds market show trends of high concentration (see Table 2). The increasing market concentration is also evident from the share of the top ten seed companies in the global seeds market, which increased from 40 percent in 2001 to 75 percent in 2011 (Indian Seed Congress, 2013). The increasing concentration is the result of mergers and acquisitions and cross-licensing between top players, primarily driven by the need to stay ahead in biotech[8] innovations. Above demonstrates the harsh competitions among seed firms in the global market.

Table 2 Top firms in the global seeds market in 2011

Rank	Firm	Sales in US$ million	% of global market share
1	Monsanto	8,953	26.0
2	DuPont Pioneer (USA)	6,261	18.2
3	Syngenta (Switzerland)	3,185	9.2
4	Vilmorin (Groupe Limagrain) (France)	1,670	4.8
5	WinField (Land O Lakes) (USA)	1,346 (est.)	3.9
6	KWS (Germany)	1,226	3.6
7	Bayer Crop science (Germany)	1,140	3.3
8	Dow Agro Sciences (USA)	1,074	3.1
9	Sakata (Japan)	548	1.6
10	Takii & Company (Japan)	548	1.6

Source: ETC Group communique, 2013

3.1.2. The Indian seed market and the entry of Bt cotton

The Indian seed market is the fifth largest after the US, China, France and Brazil. India also has the second-largest arable land area, after the US, accounting for 11.4 percent of world's total arable land (FAO). Since the early 1970s to the early 1990s, much of agricultural R&D in India had been carried out by the public sector (Indian Council for Agricultural Research: ICAR) and the private seed firms benefited a great deal from spillover from the public sector (Pray *et al*., 2001). While the private seed companies are by and large engaged in the high-value hybrids market (for example in cotton, sunflowers, maize and vegetables) the public sector institutions (ICAR, public research institutions, agricultural universities) concentrate on open pollinated varieties (OPVs) in grains, pulses and oil seeds.

Following the introduction of a liberal seed policy in 1988, which allowed for the importing of seed and planting materials of top varieties to make them available to Indian farmers, private sector investments in the seed sector have steadily increased from INR 417 million in 1987 to INR 6000 million in 2009 (Pray *et al.*, 2001; Milind *et al.*, 2006; Indian Seed Congress, 2013). This was accompanied by an increase in Indian firms' R&D investment, which rose from US$1.3 million (2005 US$) in 1984–85 to US$49.3 million (2005 US$) (Pray and Nagarajan, 2012). More recently the

[8] Agri-biotech innovations include molecular markers and related tools and techniques, genes/events, development/ regeneration protocols and hybrid seeds.

introduction of the Protection of Plant Varieties and Farmers' Rights Act, 2001 (PPV & FR Act, 2001) further boosted the private sector's confidence in the appropriability of innovations in the seed sector. These investments by Indian private seed firms are concentrated on developing hybrids in cash crops and vegetables.

Table 3 Top Agri-biotech firms operating in India: Compiled from ABLE-Biospectrum Biotech Industry survey, 2012 *

		Revenues in US$ million (conversion INR 60.5= US$ 1)		
Ranking	**Firm**	**2011–12**	**2010–11**	**2009–10**
1	Nuziveedu Seeds	123.18	100.86	78.85
2	Rasi Seeds	64.81	61.49	59.32
3	Ankur Seeds	53.74	41.34	18.11
4	Mahyco	51.92	59.36	51.59
5	Krishidhan Seeds	28.74	45.66	22.03
6	Nath Seeds	14.88	4.55	3.65
7	JK Agri Genetics	8.38	5.32	5.37
8	Mavens Biotech	7.53	9.28	7.86
9	Excel Industries	1.81	2.01	1.36
10	Metahelix	0.77	0.11	0.99

*These rankings to a large extent reflect firm performance in Bt cotton hybrids since only firms in the Bt cotton market and other biotech products such as molecular markers are seen as agri-biotech firms in the ABLE- Biospectrum survey.

As a result, the Indian seed market grew in value terms from US$ 1538 million in 1994–95 to US$ 5336 million in 2003–04 (Pray and Nagarajan, 2014). It has also grown to become an increasingly competitive market, with numerous local and multinational firms[9] competing in markets for cotton, corn and vegetable seeds (Milind *et al.*, 2006). Among the private firms operating in India, the major domestic firms include Nuziveedu Seeds, Rasi Seeds and Mahyco, among others (see Table 4). As of 2011, Nuziveedu has the largest share in the hybrid seed market in India (23 percent), out of which Bt cotton hybrids make the largest contribution to its revenues (Nuziveedu's website).

Table 4 Hybrids in selected field crops by public and private sector in India

[9] Monsanto, Syngenta, DuPont Pioneer, Bayer crop sciences among others have their presence in the Indian hybrids market.

Crop	Up to 2001–02		2002–03 to 2009–10		Total		Share of private sector hybrids (%)
	Private	**Public**	**Private**	**Public**	**Private**	**Public**	
Cotton	150	15	43	10	193	25	88.5
Maize	67	3	36	25	103	28	78.6
Paddy	12	4	11	15	23	19	54.8
Wheat	-	-	3	0	3	0	100
Pearl millet	60	6	22	7	82	13	86.3
Sorghum	41	5	12	8	53	13	80.3
Sunflower	35	6	13	10	48	16	75

Source: Singh and Chand, 2011

With the advent of Bt technology in India, the number of local firms engaged in agri-biotech R&D has increased and there are about 64 agri-biotech firms performing R&D of genetically modified seeds. Among these 64 firms, 37 engage in the sale of Bt cotton hybrids (*IGMORIS* database). The agri-biotech segment of the biotech industry saw a healthy growth in the last decade, and this growth comes mainly from the sales of Bt cotton seeds in the domestic market (see Figure 2).

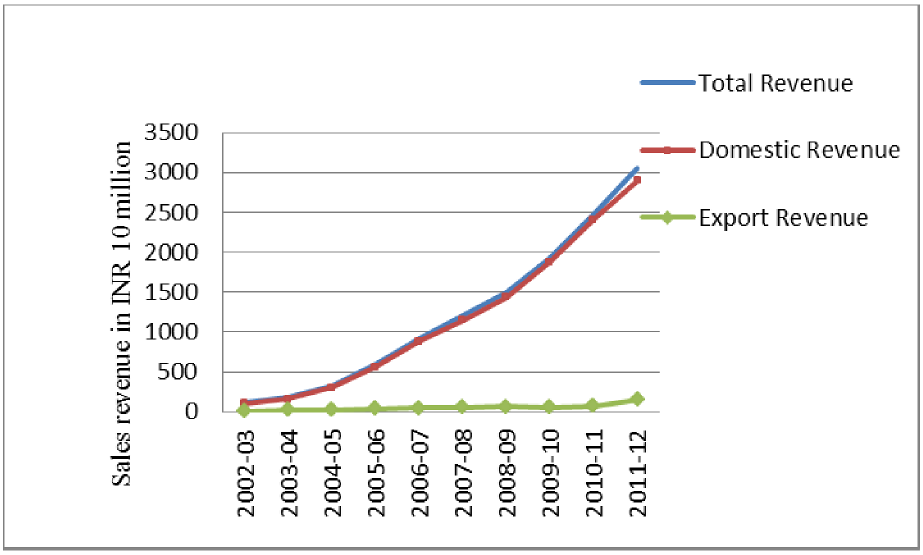

Figure 2 Growth of agri-biotech industry in India (GM seeds, molecular markers and related products only); Authors' compilation from ABLE-Biospectrum Biotech industry surveys 2002–2012.

As far as cotton is concerned, India has the largest cotton-growing area in the world (approximately 12 million hectares). Cotton is an important cash crop that constitutes about 60 percent of the total share of hybrid seeds segment in the Indian seed market (Indian Seed Congress, 2013). R&D and innovation in the cotton hybrids is dominated by the private sector (see Table 4).

However, by the start of the new millennium, cotton suffered from lower yields as compared to countries like the US and China, and the problem of pests was very serious. On the demand side, low uptake of hybrids and low-performing open pollinated varieties (OPVs) were causing distress among cotton farmers. On the supply side, by 2001–02 (Singh and Chand, 2011) the private seed firms that were active in cotton R&D commercialized 150 hybrids, whereas the public sector hybrids released 15. Nevertheless, farmers were facing yield losses and rising costs due to pests. In these circumstances, a local firm, Mahyco, while partnering with the multinational Monsanto, introduced in 2002 the first ever insect-resistant Bt cotton under the brand name of Bollgard.

Monsanto licensed its gene Cry1A to Mahyco, which in turn incorporated the gene into its hybrid MECH 1. Bollgard was approved for commercial release in two phases: first in 2002 for the central and southern zones, followed by its approval for the northern zone in 2005. With the commercial success of Bollgard the demand for Bt cotton hybrids increased rapidly (Milind *et al*, 2007). Local firms wanted to take advantage of this growing demand. Monsanto and Mahyco Biotech (MMB), a 50:50 joint venture of Monsanto and Mahyco, started sublicensing the Bt gene (event MON531) to local firms.

The speed of diffusion of Bt cotton was spectacular, as its planted area increased from less than 10 percent of the total cotton area in 2004 to more than 95 percent in 2013 (Choudhary and Gaur, 2010; Clive, 2013). The adoption of Bt cotton had contributed to increased economic returns in following manner: first, it reduced yield loss from bollworms by effective pest resistance in combination with increased yield due to hybrid vigour; second, it reduced the cost of spraying pesticide against bollworms. A combination of these measures created the net yield effect.[10] Furthermore, reduction in use of pesticide is believed to have contributed to reducing the negative externalities of pesticide sprays. A majority of economic studies evaluating the aggregate impact of Bt cotton show an increase in the yield and profits alongside the increase in costs (Ramani and Thutupalli, 2014).

Despite this seemingly positive impact of Bt cotton, different views exist on its benefits. Some studies cast doubt on whether or not the Bt technology is the actual source of increase in aggregate yields in cotton especially after the year 2002–03 (Guerer *et al*., 2011). Moreover, the higher cost of Bt hybrids as compared with conventional hybrids has fuelled debate on net returns. There are continuing debates on possible adverse ecological impact of GM crops in general although the evidence for the same is missing. More than anything else, the introduction of Bt technology can be clearly seen as a radical innovation that has kick-started not only a technology paradigm shift but also the GM crops controversy in India.

3.1.3. The science behind Bt cotton and global–local knowledge interactions

The nature of technological solutions changed significantly as a result of scientific advances in molecular biology, genomics, proteomics and the introduction of techniques such as polymer chain reaction, recombinant DNA and marker-assisted breeding. These new techniques have enabled the development of genetically modified

[10] Qaim *et al*., (2006) explain the economic benefits from Bt cotton technology in similar lines.

crops (GM crops[11]). GM crops are created by manipulating the DNA of crops, applying advanced molecular biology and genetic engineering techniques to favour desirable traits, such as insect resistance, drought resistance, herbicide tolerance and quality enhancement.

The development of a GM plant variety involves 5 major technical steps. They are 1. Isolation of the gene of interest 2. Gene Transfer 3. Regeneration 4. Hybridization for agronomic fit 5. Regulatory testing (see Table A1 of the appendix for a detailed explanation of the step by step process). The process of developing a Bt cotton hybrid therefore starts with the isolation of the gene of interest from *Bacillus thuringiensis*. This is followed by transfer of this external gene trait to target plant cells/tissue. The next stage involves regeneration of the plant cells containing the desirable gene trait into a plant (vegetative propagation or tissue culture) and verification of gene expression in the resultant plant. After regeneration and verification, the plants go through the hybridization process to incorporate the agronomic fitness (backcrossing). The final stage involves greenhouse (small-scale) and field trials (medium- to large-scale) to collect data for regulatory purposes on safety issues.

Introduction of genetic engineering techniques in the development of new plant varieties has kick started new dynamics in the global seed industry. The new techniques have enabled the scientists to break down the knowledge creation and innovation processes into steps, where different actors can manage each step. The emergence of these techniques took place against the backdrop of globalization of the production system where the production process is broken down into segments along the global production chain connecting actors at global as well as local levels. In such a context, local actors with a sufficient knowledge base, technological efforts and absorptive capacity are considered to play an increasingly critical role in the production process. This is also true in the case of agricultural innovation especially in the development of new plant varieties. The unique feature in the case of Indian Bt cotton seed firms is its variation on what constitutes the absorptive capacity to catch up, namely, the combination of *in situ* knowledge base and type of technological efforts.

With a large arable land area and low uptake of hybrid seeds, the Indian seeds market has a huge margin to grow. Cotton, among other crops, is a cash crop with huge market potential especially in the light of the new Bt technology. Both global and local players entered the cotton hybrids market in the new context of production segmentation, with strategic options for knowledge acquisition and learning. For instance, firms were able to choose strategically from the following options: whether, first, to develop the GM seed from scratch, that is, start with the identification of source genetic material and work from there; and, second, to skip the initial stages of development (isolation, transfer and regeneration); or to license the commercially approved event[12] (the genetic materials with favourable traits that are transferred to the

[11] The crops whose DNA is altered by inserting an exogenous gene (from other species) into its native genome are popularly known as genetically modified crops (GM crops).

[12] The occurrence of a genetic material in the cell structure of a target plant that exhibits the desired traits is usually termed an ‘event’. Events are usually IP protected and are licensed to the hybrid seed producers for backcrossing into their elite cultivars.

seeds) for backcrossing into their elite parental lines.

As far as local seed firms are concerned, their strategic choice was as follows: they could choose to stay in conventional hybridization of seeds or to engage in implementing biotechnology techniques; if they decide to do the latter, they have further choices to make on how to obtain and build technological/absorptive capabilities – from scratch, license, joint venture, alliances, building the capability in house, and in collaboration with MNEs or domestic firms or the public sector entities. Both scientific and *in-situ* knowledge are required in order to create high-performing seeds. The unique nature of agricultural/biological innovation created an opportunity for domestic players to leverage their *in-situ* (agro-ecological or agronomic) knowledge base while accessing upstream knowledge from global partners.

3.2 Strategies played by firms in the technology market

Monsanto created a 50:50 venture firm MMB (Mahyco Monsanto Biotech) in collaboration with a local firm, Mahyco (Maharashtra Hybrid Seeds Corporation) in order to diffuse its Bt gene/event MON531 in the growing Indian hybrids market. Mahyco introduced India's first Bt hybrid cotton called Bollgard, which incorporated Monsanto's MON531.

Other Indian firms reacted to the rapid success of Bollgard and, given the untapped market of Bt cotton hybrids, started sublicensing MMB's event MON531. In 2006, JK Agri Genetics, which started in 1989 with high-yielding varieties in field crops and moved to cotton hybrids, developed a Bt event called event I (Cry1Ac gene) in collaboration with BREF Biotech of the Indian Institute of Technology, Kharaghpur. In the same year, while Monsanto introduced its stacked gene[13] event MON15985, Nath Seeds, a local seed firm established in 1979, introduced its GFM event. Nath seeds initially licensed the Cry1Ac gene from the Chinese Academy of Sciences and further developed its own stacked gene event.

In 2008, purely public sector institutions (CICS, UAS Dharwad) gained commercial approval of their indigenously developed event Truncated Cry1Ac (along with the hybrids and open pollinated varieties) based on this event. [14] Later in the year 2009, Metahelix Life Sciences obtained commercial approval for its indigenously developed Cry1C event Metahelix 9124. A list of approved events by the genetic engineering appraisal committee of India is given in Table 5. By May 2012, six GM events and more than 1128 Bt cotton hybrids (based on the six events) gained permission to be planted across the three agro-ecological cotton zones[15] of India (GEAC, 2013).

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[13] A stacked gene is a combination of genes responsible for providing the desired trait in the plant. For example, Cry1Ac+Cry2Ab of Bt.

[14] The approval of this event is subject to controversy as traces of contamination (from Monsanto's event) seem to have appeared in its gene construct. http://www.thehindu.com/todays-paper/tp-national/panel-finds-lapses-in-development-of-first-indigenous-bt-cotton/article4215389.ece.

[15] North: Punjab, Rajasthan, Haryana; Central: Gujarat, Madhya Pradesh, Maharashtra; South: Andhra Pradesh, Karnataka, Tamil Nadu.

Table 5 Commercially approved Bt cotton events in India; Compiled from GEAC, 2013

Year	*Gene/event name*	*Type of firm*	*Strategy for developing Bt cotton hybrid*	*Type of partnership*
2002	Monsanto Cry1Ac; MON 531	Multinational	In-house R&D	None
2006	JK Agri Genetics indigenously developed Cry1Ac; Event I	Local	Alliance with IIT, Kharaghpur	R&D Collaboration of local private and public sector players
2006	Nath Seeds Cry1Ac+Cry1Ab; GFM	Local	License from Chinese Academy of Sciences	Indigenous development from licensed technology
2006	Monsanto Cry1Ac+Cry2Ab; MON 15985	Multinational	In-house R&D	None firm
2008	UAS Dharwad & CICS Event Truncated Cry1Ac	Public sector	In-house R&D	Between public sector institutions
2009	Metahelix 9124 Cry1C	Local	In-house R&D	None

It is interesting to note that Metahelix is the only local firm that developed its GM event via in-house R&D, while the majority of local firms opted to collaborate with other firms for accessing knowledge. Re-engineering of existing commercial genes by local firms played a crucial role in the development of Bt genes.[16] Since a large proportion of upstream knowledge is codified and transferable, re-engineering was plausible.

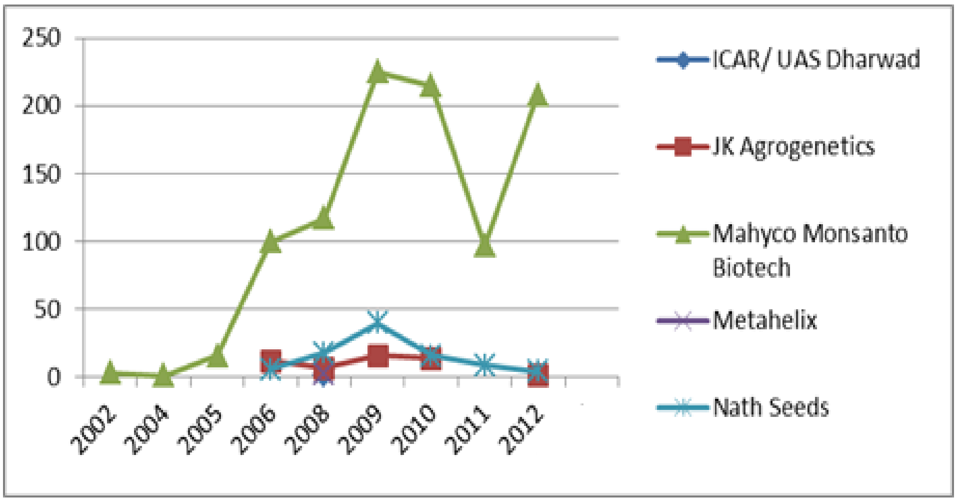

Figure 3 Firms in the technology market (Bt events) and the number of approved hybrids, approved year on year, based on their events; compiled from GEAC (2013)

[16] By JK Agro and Nath Seeds, excerpt from the focus group discussion on 'Status of Bt cotton R&D in India', held in December 2011, Agri Biotech Foundation India at NG Ranga Agricultural University, Hyderabad, India.

3.3 Strategies played by Indian firms in developing the Bt hybrid seeds

With the initial success of the technology and the hybrids incorporating the technology, domestic firms have significantly increased their investment in Bt cotton to acquire the technology in various ways. The initial market success of Mahyco's Bollgard prompted local firms to sublicense MMB's event MON531 and incorporate it into their best-performing hybrids. As a result, MMB enjoyed first-comer advantage in the technology market in India. Currently, MMB dominates the market for technology (via sublicensing of the single and stacked gene events to local firms; see Figure 3). In fact, 982 out of 1128 commercially approved Bt cotton hybrid seeds in India use Monsanto's events (see Figure 3).

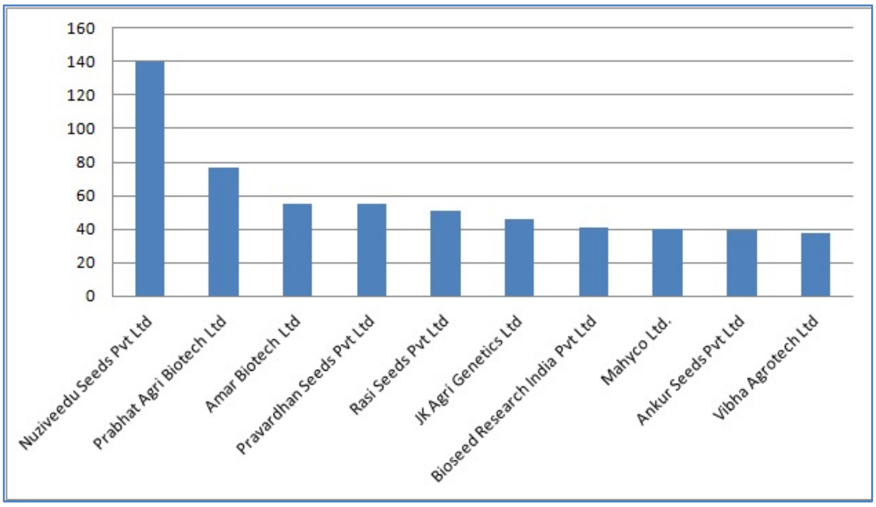

Figure 4 Top firms and the total number of Bt cotton hybrids commercialized by them in the year 2012; compiled from GEAC (2013)

While the technology (event) market is dominated by MMB, the hybrid seeds market is dominated by local firms, including Nuziveedu Seeds, Rasi Seeds and Mahyco (see Table 6 and Figure 4). The local seed firms enjoyed almost 100 percent of the market share by 2008. As early as 2000, the Indian seed firms developed the *in-situ* knowledge base that is critical for verifying the agronomic fit of the hybrids with the local agro-ecology (Pray *et al*., 2014). In fact Nuziveedu Seeds enjoyed market leadership in non-Bt or conventional cotton hybrids (through its superior hybrids Banni and Mallika) that were developed in house before the entry of Bt technology into India. By sublicensing the Bt event from MMB, Nuziveedu then introduced the Bt versions of the same hybrids. Thus, to utilize the existing competence, in terms of both the *in-situ* knowledge base and expertise in developing conventional hybrid seed markets (Pray and Nagarajan, 2014), a majority of local firms including Nuziveedu chose to sublicense MMB's gene to successfully integrate the 'generic' and 'high-end scientific' knowledge into their best-performing hybrids by backcrossing.

Table 6 Top firms in the Bt cotton hybrid market in India: Compiled from the ABLE-Biospectrum Biotech Industry Survey 2013

Rank	Firm	Type of the firm	Revenues in 2012–13 (INR million)
1	Nuziveedu Seeds	Domestic firm	7781.3
2	Ankur Seeds	Domestic firm	3410.0
3	Mahyco	Domestic firm	2460.0
4	Rasi Seeds	Domestic firm	2290.0
5	Krishidhan Seeds	Domestic firm	1998.1

3.4 Applying the framework

A diverse spectrum of strategies followed by key players in the Bt technology market (events) are shown in Table 5. Domestic firms such as JK Agri Genetics developed their event based on Monsanto's Cry1Ac in collaboration with a public institution, BREF Biotech, part of the Indian Institute of Technology, Kharaghpur. On the other hand, Metahelix Life Sciences developed an event based on the gene Cry1C via in-house R&D. Nath Seeds developed a new event of stacked genes, a combination of two genes, Cry1Ac and Cry1Ab, after licensing the single gene event (Cry1Ac) from the Chinese Academy of Sciences. Nath Seeds also developed new events of stacked genes by combining Cry 1 Ac and Cry1 Ab. It is interesting to note that a majority of local firms were able to produce Bt genes/events by acquiring generic knowledge via forming alliances with external actors except for Metahelix, which developed its GM event via in-house R&D.

The strategies taken by firms in catching up with the upstream as well as downstream knowledge components demonstrate the diversity in available pathways (see fig 5). At the same time there are common features across the firms' strategies that bring out the complementary of upstream and downstream knowledge for successful outcomes. Indeed, the different strategies to access upstream (generic scientific) knowledge are observed as follows: (a) alliance for R&D (Nath Seeds, JK Agri Genetics); (b) licensing or sub-licensing (a majority of local seed firms); (c) in-house R&D (Metahelix Life Sciences) and (d) joint venture (MMB by Mahyco). While a majority of the firms acquired the technology through collaborating with external actors, enabling them either to 'skip' some development steps or to 'create' new combinations of development.

Similar strategies are applied for building downstream knowledge. These were applied for producing quality seeds and in scale, the strategies are: (a) backcrossing of Bt events into hybrids developed in-house (b) a joint venture such as the setting up of MMB by Monsanto ; and (c) Mergers & Acquisitions - such as the acquisition of Prabhat Agri Biotech, Pravardhan Seeds and Yaaganti Seeds by Nuziveedu Seeds.[17]

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[17] The acquisitions are driven by the strength of maize and cotton hybrids of these firms in diverse markets.
http://www.nuziveeduseeds.com/customer-reach/subsidiary-and-associate-companys-distribution-network/

As can be seen in figure 5, the strategies adopted for catching up with upstream and downstream components by local firms as well as Monsanto can be mapped onto the matrix[18]. Also the two pathways collaboration or developing in-house of these knowledge components can be traced for all the firms involved in the development and commercialization of Bt cotton hybrids. For instance Nuziveedu seeds applied the collaboration strategy for acquisition of technology (upstream) where as it backcrossed the acquired technology into commercially successful hybrids developed either in-house (like Banni and Mallika) or those acquired through M&As. Metahelix developed its Bt cotton hybrids based on in-house efforts.

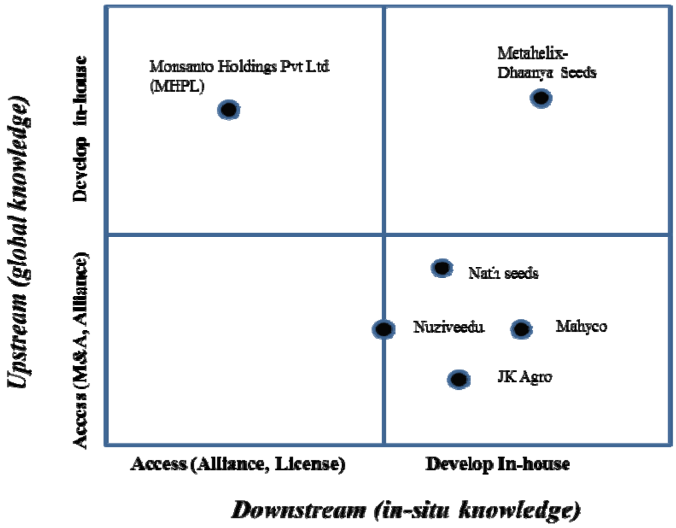

Figure 5 Mapping of firm strategies to produce Bt cotton hybrids

If we apply the aforementioned three types of ‘catching up’ – path following, path skipping and path creating as put forth by Lim and Lee (2001) to the case of Bt cotton, it is possible to say that the majority of firms adopted a stage-skipping strategy by sublicensing the technology. The stage-skipping strategy nevertheless requires well-established conventional plant-breeding capabilities for regeneration and verification. This means that only the firms with established low-end scientific capabilities (hybridization and basic biotech knowledge base) and higher levels of *in-situ* knowledge (local climate, soil conditions and market) can adopt the stage-skipping strategy. The rapid adaption and diffusion of Bt technology also meant the rapid scaling up of local firms in certain facets of upstream generic and scientific knowledge those are required for commercial success as well as regulatory purposes.

[18] Given the complexity involved in mapping the strategies of all Bt cotton seed firms, only the strategies of firms with commercially approved GM cotton events, as well as Nuziveedu Seeds, which has the largest market share in Bt cotton hybrids, is mapped. However, all firm strategies fit well into one of the regions of the matrix.
MMB (Mahyco Monsanto Biotech) does not appear in the matrix since it does not (on its own) produce or market any Bt cotton hybrids. MMB sub-licenses Monsanto’s events to the local firms.
Nuziveedu falls on the line since it developed Bt cotton hybrids from its own basket as well as from the hybrid lines of acquired local firms (see Footnote 17).

Though a majority of local seed firms adopted the stage-skipping strategy, few firms adopted the path-following pattern. For instance, JK Agri Genetics developed its event based on Cry1Ac in collaboration with a public institution BREF Biotech, of IIT Kharaghpur, from which it developed its own Bt hybrids. Metahelix Life Sciences, on the other hand, developed an event based on the gene Cry1C via in-house R&D.[19] This shows that Metahelix chose to create its own pathway. Nath Seeds adopted a similar 'path-creating' pattern by placing on the market its hybrids based on stacked genes (a combination of two genes, Cry1Ac and Cry1Ab) developed in collaboration with the Chinese Academy of Sciences.

The catching-up story of Indian firms in Bt cotton therefore illustrates a spectrum of patterns as illustrated by Lim and Lee (2001) by technological regimes. The comparison of how these domestic firms acquired both upstream and *in-situ* knowledge components illustrates the presence of diverse pathways in the 'catching-up process' in agricultural innovation, especially after the introduction of biotechnology.

The successful catching up of local Indian firms with Bt technology goes beyond just obtaining high-performing Bt cotton seeds through adapting genes from multinationals. For the seeds to carry good-quality features, these firms needed to have capacity to re-engineer in order to develop hybrids. Therefore what is different about the 'catching-up' process of Bt cotton is the critical role played by the local firms' strength in their low-end scientific and *in-situ* knowledge.

Monsanto, a multinational firm, has its strengths in the upstream (biotech) knowledge for developing the events, while Indian firms, such as Nuziveedu Seeds, Prabhat Agri Biotech, Amar Biotech, Mahyco and Rasi Seeds, among others, are strong in the downstream knowledge and capabilities for creating viable hybrids for distinctive agro-ecological zones in India. In fact, the world's first F1 cotton hybrid based on male sterility was developed by Mahyco in 1979. Even though Monsanto had advanced technological capability, demonstrated through its events, creation of good-quality hybrid seeds needs knowledge of successfully adapting innovations to the local agro-ecology. In this sense, the alliance of Mahyco and Monsanto was a natural outcome. Also collaboration for Monsanto was a *sine qua non* for penetration into the Indian GM seeds market since its technology, the Bt event, can be successfully demonstrated only when combined with high-performing hybrids.

The limitation of Monsanto's capability to dominate the seeds market on its own despite its strength in upstream scientific knowledge is clearly evident. MHPL (Monsanto Holdings Private Limited), which markets Paras Brahma Bt hybrids developed by Monsanto's own subsidiary, has lost competitive ground in the Indian market to the hybrids of other local firms including Mahyco. In fact, the Indian firm Nuziveedu Seeds has the highest market share in India, while Bt cotton hybrids were created based on a sublicensed technology from Monsanto Mahyco Biotech (MMB) (see table 6). What makes even more convincing the critical role played by local

[19] Metahelix markets its Bt hybrids via its own subsidiary, Dhaanya Seeds.
http://www.dhaanya.com/aboutus.html

producers is the fact that Nuziveedu Seeds' market share of Bt cotton hybrids is higher than that of the seeds produced by Mahyco a close partner of Monsanto, confirming the latent comparative advantage of Nuziveedu's in-situ knowledge base.

This comparison of Monsanto (standing on its own as Monsanto Holdings Private Limited – MHPL's Paras Brahma hybrids) and Nuziveedu Seeds in the Bt cotton hybrid seeds market reveals that the local firms are still able to compete with global giants in Indian cotton seeds market despite globalization of production and existing gap in upstream knowledge. Given the variable agro-ecological conditions that exist in the vast cotton-growing zones in India the local firms are able to strategically leverage their strengths in *in-situ* knowledge to develop their market competence.

At a broader level, the strategies played by the Indian seed firms confirm the transformation of the process of agricultural innovation, the diversity of pathways in catching up via integration of external and internal knowledge, through various means of collaboration such as licensing, joint ventures with MNEs, M&As of local firms and forming R&D alliances with public sector entities. Moreover, the catching-up process of Indian firms in Bt technology demonstrated the three patterns of 'catching-up' pathways as specified by Lim and Lee (2001) are applicable to understand firms' strategic choice. More importantly, the case validates our characterization of the knowledge involved in modern day agricultural innovation.

We see that, with the paradigm shift in the technology (agri-biotechnology with its genetic engineering techniques), new opportunities came up for local firms in the catching-up process as they become part of global production. Fragmentation of knowledge creation along the value chain and improved access to knowledge via the IPR system allowed domestic firms with high levels of absorptive capacity to catch up quickly by combining different types of knowledge through effective strategies. In the case of Bt cotton in India, local firms with established competence in the *in-situ* knowledge and conventional plant breeding techniques (seen as a proxy for absorptive capacity) were able to catch up quickly and enhance their competitiveness in the cotton seeds market. The gaps in the knowledge for foreign multinationals as well as local firms are being bridged via technology transfers, joint ventures and M&A's to increase returns from upstream technology as well as downstream seed markets.

In sum, it is evident from the analysis of the diffusion of Bt technology in India that global & upstream and local & downstream knowledge are complementary, and joint efforts for vertical integration are critical for successful outcomes in the agri-biotech industry. Furthermore, the case demonstrates that, even though collaborative efforts are necessary at the global–local level, there are various routes (strategies) which firms can take to reach the ultimate goal of increasing returns from the frontier technologies.

4 Conclusion

In this article, we have described the dynamics of knowledge creation and diffusion required for agricultural innovation and the role of producers in developing countries in the context of globalization and the rise of biotechnology. The literature review demonstrated that the knowledge creation process is now more collaborative and shaped by the distinctive configuration of networks that each entity has. The increasing integration of production processes at the global level also enhances the above trend of knowledge being increasingly shaped by interaction among global and local actors. Here, the rise of new technology paradigms, followed by the new set of institutions such as intellectual property rights (IPR), influences the diverse ways in which knowledge is accessed and configured for potential market gain.

While agricultural production, which relies heavily on agro-ecological conditions (temperature, climate, soil) remains unchanged, the rise of biotechnology has altered the conventional scientific approach for finding solutions for better yields. The case of Indian Bt cotton has clearly highlighted such changes. Today, the process of agricultural innovation is strongly punctuated by biotech R&D, which is configured in diverse and distinctive ways. Each firm can choose different strategic options, considering its strength in the knowledge base constituted by global scientific and *in-situ* components, to identify its preferred areas of investment. The diversity of innovation strategies presented in our case is analogous to the three types of catching up, as explained by Lim and Lee (2001).

To conclude, in an era of increased globalization, after the biotech revolution, with proliferation of institutions such as IPR, knowledge is increasingly accessible, in principle, to the wider population to improve productivity. While this increasing access holds true, studies focusing on the manufacturing sector have indicated that just adapting foreign technology is not enough to bring about the success of the innovation process in the catching-up countries. The imported upstream knowledge has to accompany the development of indigenous capabilities that enables appropriate selection and combination of local factors of production. We find an analogy in the case of the agricultural sector, but with its own unique features.

In our case, the absorptive capacity of local seed firms as seen through their *in-situ* and low-end scientific capabilities (evident via commercially successful non-Bt or conventional hybrids) played an important role. As well as the strengths in the knowledge base, identifying the right strategy to combine external and internal knowledge to acquire the global frontier technologies, for example Bt technology, is also important. The case clearly demonstrates the importance of complementarity between the upstream and downstream knowledge components, and that the knowledge flow can be bi-directional or circular, with global–local interactions between leaders of *in-situ* knowledge and global scientific knowledge. This has implications for vertical integration, M&As of large agri-biotech firms as well as local seed firms.

Our conclusions about knowledge creation and diffusion in the modern-day agricultural sector are in contrast with the linear or top–down models that are applicable to the Green Revolution period where much of the innovations were diffused internationally by public sector entities. Our findings are more in line with the recent understanding of international organizations working towards agricultural innovation and development (e.g. World Bank, 2012) that advocate a participatory approach and public-private partnerships for innovation generation. We claim, however, that a focus on both top–down and bottom–up knowledge interaction is needed for successful knowledge creation and diffusion, especially in agriculture. Of course this model relies on levels of absorptive capacity of local actors, which is critical in identifying an appropriate configuration of knowledge for the local context. Such a capacity, an agro-ecosystems management of location-specific knowledge with effective integration of global knowledge, is increasingly necessary in view of climate change, resource degradation and growing sustainability concerns.

Finally, we admit that there are the following limitations of our case study of Bt cotton hybrids. First, this is a cash crop and not a food crop; hence the generalization cannot be freely extended to innovations in food crops, which can have different dynamics because of their importance in the agricultural markets of emerging countries. As with the influence of industrial regimes and the nature of technologies in the catching-up process (Lim and Lee, 2001), we understand that open pollinated varieties and non-GM hybrids may have different dynamics in the global–local knowledge interactions. Also it is difficult to draw parallels with other cash crops and country contexts since the diffusion of agri-biotech innovations and the catching-up dynamics for GM crops across countries remain understudied. The same is true with respect to other non-transgene technologies. These shortcomings could be taken into consideration for future research.

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Appendix

Table A1 Major steps involved in the development of a GM plant variety

1. The isolation of the gene of interest responsible for a desired trait, i.e. insect resistance in the case of Bt from the source (micro-organism).
2. The gene of interest is then inserted into the native DNA of a vector (usually a soil bacterium called *Agro-bacterium Tumefaciens*); the process is popularly known as agro-bacterium-facilitated gene transfer.
3. The vector is then used as a means to transfer the desired genetic material into the target plant cells (alternative non-vector methods include gene transfer via a gene gun, micro injection).
4. The plant cells that took up the gene of interest are carefully selected for regeneration of the whole plant. Plant regeneration usually involves the methods of tissue culture or biotech breeding procedures.
5. The regeneration process is followed by the verification of the new plant characteristics for desired traits.
6. Laboratory and greenhouse-level environmental and biosafety tests are carried out.
7. The desired plant is then crossed with a local cultivar that has proven superior agronomic performance (usually by backcrossing).
8. All the desired genetic characteristics (both superior agronomic performance and GM traits) thus finally appear in the next generation plants.
9. Performance testing, environmental and biosafety tests are further carried out in field settings for obtaining commercial approval from the regulatory agency.

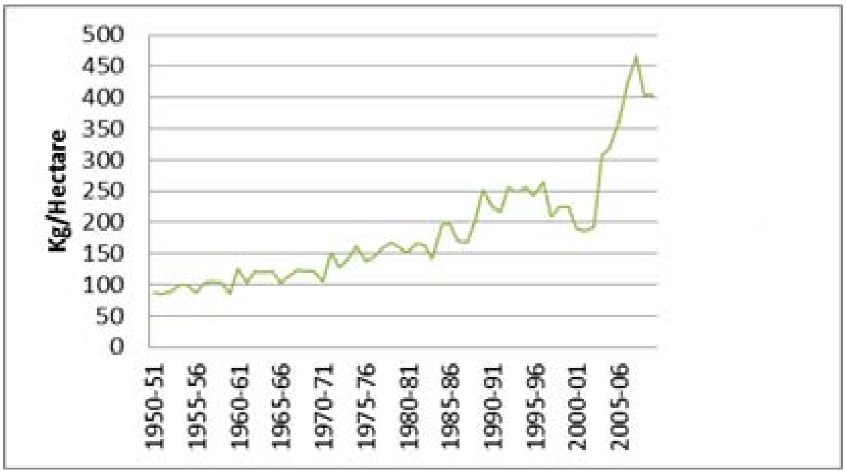

Figure A1 India's cotton yield in kg/hectare ; A clear jump is apparent starting in 2002–03 is evident (Source: Production, Supply and Distribution (PS&D) online database of USDA)

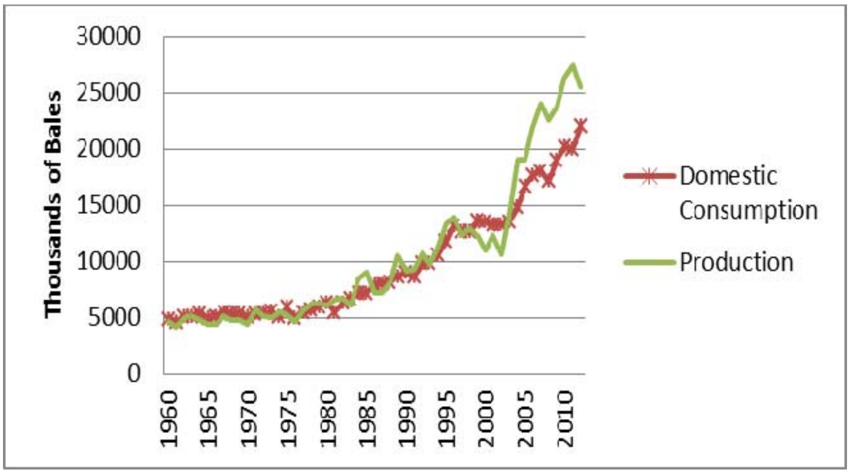

Figure A2 India's cotton: production and domestic consumption in thousands of bales (480 lb). A clear jump in the total production and consumption can be seen from the year 2002 (Source: Production, Supply and Distribution (PS&D) online database of USDA)

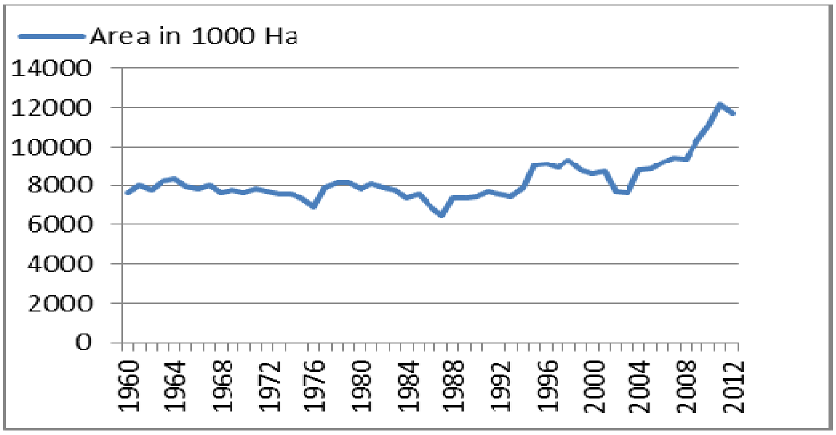

Figure A3 India's cotton: total harvested area in thousands of hectares (Source: Production, Supply and Distribution (PS&D) online database of USDA)

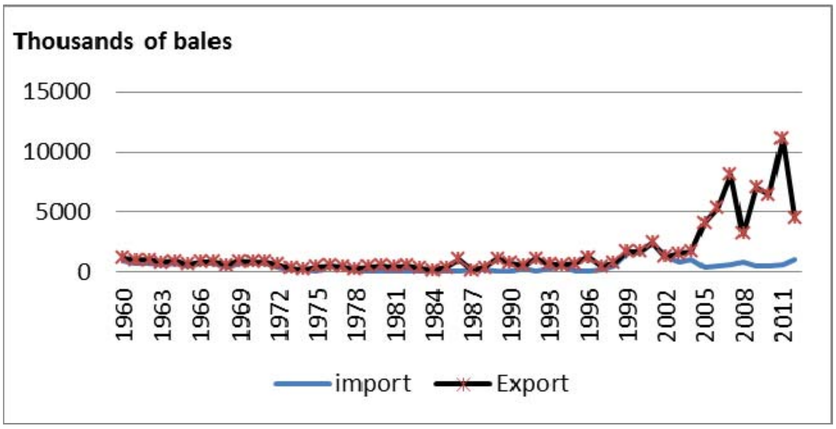

Figure A4 India's cotton scenario: export and import statistics (Source: Production, Supply and Distribution (PS&D) online database of USDA)

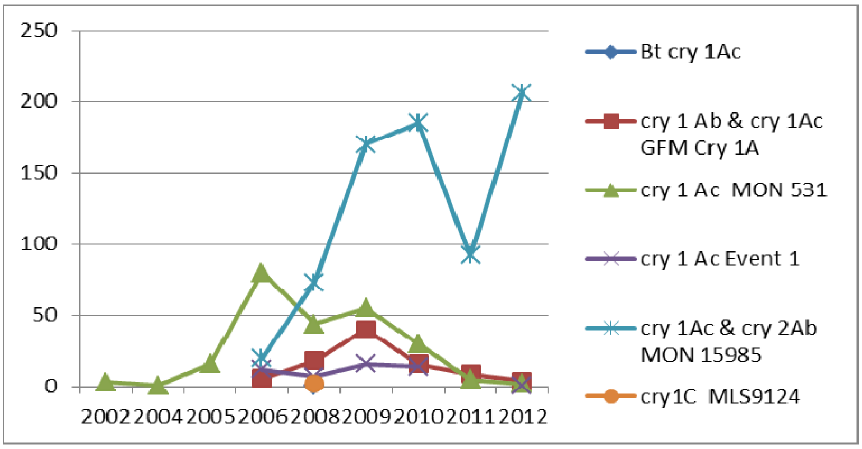

Figure A5 Annual growth of event-specific cotton hybrids (Source: List of commercially released varieties of Bt cotton hybrids up to May 2012, GEAC)

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