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The Seed and Agricultural Biotechnology Industries in India

An Analysis of Industry Structure, Competition, and Policy Options

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ABSTRACT

Since the late 1980s, technological advances and policy reforms have opened up new opportunities for growth in India's seed and agricultural biotechnology industries. The impacts of such changes have been significant in India's cotton sector, but less so for the country's main cereal crops, where both yield and output growth rates have been relatively stagnant.

Some public policymakers and corporate decisionmakers are confident that the private sector will help reverse these trends, arguing that the right combination of new technological solutions and progressive policy reforms will unleash a significant increase in private investment in productivity-enhancing products and services.

The structure of India's seed and agbiotech industries, as well as the policies designed to support their growth, will be a significant determinant of this expected impact. This paper examines the structure of India's cereal seed and agbiotech industries, its potential effects on innovation and social welfare, and the policies that may improve both industry performance and the delivery of new technologies to resource-poor, small-scale farmers in India's cereal production systems.

We focus our analysis on indicators and scenarios within India's agricultural *innovation market* for improved seed and agricultural biotechnology products. This market includes firms engaged in the development, commercialization, and marketing of new seed-based technologies; it is characterized by a high level of knowledge intensity, relatively high levels of R&D investment, significant barriers to entry, significant levels of regulation, and relatively few products in the market. And it is within this market that factors such as strategic corporate behavior and public policy can affect the balance between a socially desirable rate of innovation, on the one hand, and a socially desirable distribution of the gains from innovation among consumers, farmers, and innovators, on the other hand.

Keywords: seed markets, agricultural biotechnology, industrial organization, cereal crops, India

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1. INTRODUCTION

Since the late 1980s, technological advances and policy reforms have opened up new opportunities for growth in India's seed and agricultural biotechnology industries. The impacts of such changes are well documented for India's cotton sector, where the introduction of cotton hybrids and insect-resistant transgenic traits by the private sector has contributed to increases in cultivated area, yield, and output, moving India from the world's third largest cotton importer in 2002–2003 to the second largest exporter in 2007–2008.

Less well documented are the effects of these technological advances and policy reforms on the major cereal crops cultivated in India, namely rice, wheat, and maize. Private investment in the research, development, and marketing of improved seed and seed technologies for these crops in India has lagged that of cotton. This is of concern to many because these crops are vital to national food security goals and because both yield and output growth rates for two such crops—rice and wheat—are relatively stagnant. Some public policymakers and corporate decisionmakers are confident that private investment in major cereal crops will reverse these trends. They argue that with the right combination of new technological solutions and progressive policy reforms, private firms can have a potentially large impact on the productivity and production of major cereals in India.

The structure of India's seed and agbiotech industries, as well as the policies designed to support their growth, will be a significant determinant of this expected impact. Factors such as strategic corporate behavior and public policy on innovation can affect the balance between a socially desirable rate of innovation, on the one hand, and a socially desirable distribution of the gains from innovation among consumers, farmers, and innovators, on the other hand. Although this topic is a focus of extensive inquiry in many industrialized countries, only a handful of researchers have recognized its importance in the context of Indian agriculture.

Thus, this paper examines the structure of India's cereal seed and agbiotech industries, its potential effects on innovation and social welfare, and policies that may improve both industry performance and the delivery of new technologies to resource-poor, small-scale farmers in India's cereal production systems. We frame this analysis by describing the seed companies, agbiotech firms, farmers, and consumers as agents within a specific segment of India's agricultural *innovation market*. This market segment focuses on the development, commercialization, multiplication, and marketing of technologies embodied in seed; it is characterized by a high level of knowledge intensity, relatively high levels of research and development (R&D) investment, significant barriers to entry, significant levels of regulation, and relatively few products in the market.

The paper continues as follows. Section 2 briefly examines the Indian seed and agbiotech industries, with an emphasis on history, structure, and policy in the innovation market. Section 3 discusses the data and data sources used in this paper. Section 4 discusses determinants and impediments to growth in India's seed and agbiotech industries, followed by a closer analysis focusing on rice, wheat, and maize seed in Section 5. Section 6 discusses policy dimensions of industry growth and examines alternative scenarios that may play out in the innovation market over the next decade. Concluding remarks are given in Section 7.

2. INDIA'S SEED AND AGBIOTECH INDUSTRIES

Basic Definitions

As a starting point, we need a definition of India's seed and agbiotech industries that sufficiently describes the unit of analysis covered in this study. Here, we are focusing specifically on that segment of the formal economy involving commercial entities engaged in the (a) breeding, multiplication, and distribution of seed and other planting material and (b) research, development, commercialization, and distribution of agricultural biotechnology applications, tools, and products, including (but not limited to) genetically modified crops and traits. The line between these two types of commercial entities is often indistinguishable. However, as will be described in more detail below, there is a distinct division within the industry between what might be described as the *downstream* segment, where firms multiply and distribute seed, and the *upstream* segment, where firms work with advanced scientific tools and materials.

Two caveats are worth noting here. First, this definition does not include small farmers engaged in seed saving, selection, and exchange, who account for an estimated 75 percent of India's total (formal and informal) seed market. Nor does this classification include the public seed production and distribution system—the National Seed Corporation, 13 state seed companies, and the State Farm Corporation of India—which accounts for 24 percent of the commercial seed market by volume. Rather, this definition focuses almost exclusively on the formal, commercial actors in India's seed market, which account for about 76 percent of the commercial seed market and 19 percent of the total seed market (Rabobank 2006). Second, although the introduction of genetically modified Bt cotton in India has driven much of the recent growth in the seed and agbiotech industries, the analysis here focuses primarily on cereal crops, where only a limited number of new technologies have been introduced. Although technologies such as hybrid maize or hybrid rice have made debuts in India—with significant success, in the case of hybrid maize—many technologies are still in the pipeline.

Historical Context

Until the 1980s, India's seed industry was largely the arena of public-sector organizations, namely the National Seed Corporation, the State Farm Corporation of India, state seed corporations, and state seed certification agencies. Policy reforms such as the New Policy on Seed Development (1988) and the economywide New Industrial Policy (1991) encouraged private-sector participation in higher-value segments of the seed market, first in vegetable hybrids, then with hybrids of sorghum and pearl millet, and more recently with hybrids of maize, cotton, and rice (Pal, Singh, and Morris 1998; Pray and Ramaswami 2001; Ramaswami 2002).

The Indian seed industry has grown in size and value over the last five decades. In 2008–2009, the Indian seed industry generated revenues of between US$1.3 billion and $1.5 billion[1] and was ranked the world's fifth largest seed market. It is currently estimated to be growing at an average rate of 12–13 percent per year (Rabobank 2006). A significant segment of that market includes companies with investments in agbiotech, both in the commercial sale of Bt cotton and in other crop–trait combinations that are still in the development and testing stages.

The shift from a state-dominated seed industry to a competitive private seed industry is most visible for hybrid crops because the biological properties of hybrids provide private firms with a greater ability to recoup their investments in cultivar improvement. In 2005, for example, an estimated 80 percent of commercial seed sales of pearl millet and sorghum were made by the private sector (Pray and Nagarajan 2009). Similarly, in 2003, an estimated 70 percent of hybrid maize seed was supplied by the private sector (Joshi et al. 2005; Nikhade 2003). Private-sector involvement in the seed industry is particularly significant when viewed as the proportion of total area cultivated under private hybrids:

[1] All dollars are US dollars.

private hybrids account for 90 percent of pearl millet area under cultivation, 80 percent of *kharif* sorghum, 60 percent of maize, and 6 percent of rice (Kumar 2010; Francis Kanoi 2009).

Despite this, the relatively recent development of a private seed industry in India has meant that for many staple crops, particularly rice and wheat, farmers are still making the transition from saved seed, seed exchanges with neighbors, or purchases from public seed suppliers to buying seed from private companies. Consequently, the seed industry for cereals is in the early stages of maturation. Recent policy reforms such as the Protection of Plant Varieties and Farmers' Rights Act (2001) and the (still pending) Seeds Bill are meant to further encourage the sector's maturation and private-sector participation.
Seed companies in the cereals business are still working to establish their market position and develop the infrastructure needed to supply products and services. In most cases, the depth and breadth of seed markets in India are fairly limited, such that firms generally do not face significantly high levels of competition. Despite this, the Indian seed industry is still very large—it hosts 410 regional or domestic seed firms and six multinational firms (Kumar 2010).

Key Industry Actors

Many firms in India's seed and agbiotech industries are descended from closely held family businesses, including some of the larger business conglomerates. Subsidiaries and joint ventures with foreign firms accounted for about 30 percent of all private seed industry research during 1998–1999 (Gadwal 2003). Mergers, acquisitions, joint ventures, and foreign direct investment have further diversified ownership in the last decade. Private firms in the Indian seed and agbiotech industry can be further classified into five categories based on their R&D capabilities, target markets, and ownership, as follows.

Technology Firms

These are firms from both India and foreign countries that provide traits and other technologies to Indian seed companies. For example, Mahyco-Monsanto Biotech, Arcadia Biosciences, Metahelix, and Avesthagen license their proprietary materials—including transgenic events—to seed firms in India. These companies may rely solely on technology licensing (for example, Mahyco-Monsanto Biotech), or they may conduct research and license technologies (for example, Arcadia Biosciences), or they may host combined portfolios of research, technology licensing, and relatively small-scale seed marketing operations (for example, Avesthagen and Metahelix).

Trading Firms

These are firms active in the downstream seed market that primarily operate in the areas of seed multiplication, distribution, and marketing of publicly developed crop varieties and hybrids. Examples include seed companies such as Harinath Seeds, Surya Seeds, and Sidhartha Seeds, among many others.

Small-Sized Seed Firms

These are firms active in the downstream market with operations in seed multiplication, distribution, and marketing, and often host small breeding programs to develop their own hybrids or to field-test publicly developed crop varieties and hybrids. They generally rely on technology accessed and transferred from other public or private sources, usually from domestic sources. Examples include companies such as Rasi Seeds and Nuziveedu Seeds, leaders in the Bt cotton seed market.

Medium-Sized Firms

These are firms engaged in seed multiplication, distribution, and marketing with limited, and somewhat variable, levels of R&D capacity usually in the form of proprietary crop breeding programs. While many of the firms in this category generally rely on technology transferred from other public or private sources and then introduce such technologies into their own breeding materials, some host more extensive research programs. Firms in this category may be independent companies, subsidiaries of larger domestic corporate interests, or companies with major equity investments from foreign corporate interests. Examples include Advanta, Shriram Bioseed, Devgen, and Mahyco.

Multinational Firms

These are firms active in the upstream technology market and the downstream seed market. This includes many of the *big six* multinational firms (BASF, Bayer CropScience, Dow Agrosciences, Pioneer Hi-Bred International,[2] Monsanto,[3] and Syngenta) that have (a) integrated interests in seed, agbiotech, and agrichemicals; (b) substantial levels of R&D capacity both in India and abroad; and/or (c) varying degrees of vertical integration that bring together upstream operations in product development (traits, chemicals) with downstream operations in product marketing (seed, chemicals). They operate directly in the Indian market, through wholly owned subsidiaries, through firms in which they hold an equity stake, and/or through licensees of their materials and technologies.

Since 2002 there has been an increase in the level of horizontal and vertical integration among seed, agbiotech, and agribusiness firms operating in India (see Tables A.1 and A.2 in the Appendix). Multinational firms have expanded their presence in the Indian seed sector through acquisitions, whereas domestic firms have leveraged technical alliances with foreign and domestic agbiotech companies and research institutions to access new technologies.[4] A study by Ramaswami (2002) finds that the technological advances and stronger intellectual property rights (IPRs) in recent years have attracted more private investment into agricultural R&D, resulting in a sizable private-sector presence in the seed market for many crops.

Much of this corporate strategic behavior has been driven by growth in the cotton seed segment of the market. A study of the cotton seed industry by Murugkar, Ramaswami, and Shelar (2006) finds that the rapid adoption of Bt cotton effectively eliminated those companies who were not marketing Bt cotton seed from the industry.

Yet despite these studies cataloging the contributions of India's private seed industry, the top 10 firms in India accounted for just 25 percent of the total volume of seed sold by the private sector in 2005 (Rabobank 2006). And in the major cereals segment of the market, strategic behavior has been far less significant, owing partly to the low-value, low-margin nature of the market and the relatively few technologies available to encourage innovation. Thus, there is still room to grow for both large and small firms, both foreign and domestic. This growth may be driven by the application of new technologies that address the diverse crops, farming systems, and agroecologies in India. Of equal importance, however, may be the application of new business models that address the varied nature of farmers themselves, particularly small-scale farmers, who account for 86 percent of India's rural population (India, Ministry of Statistics and Programme Implementation 2003).

Although there are contentions over where India's seed and agbiotech industries are headed, some industry experts and analysts offer an optimistic outlook on the future of India's seed and agbiotech industries. Gadwal (2003), for example, finds the greatest potential for growth in the application of modern biotechnology, provided that a more conducive regulatory system and closer public–private

[2] Pioneer Hi-Bred International is a subsidiary of Dupont and subsequently referred to here as referred to subsequently as Pioneer/Dupont or, as shorthand, Pioneer.

[3] Monsanto operates in India through several entities. Monsanto India Limited (MIL) is a subsidiary of the parent company and is the only publicly listed Monsanto company outside the United States. MIL markets maize seeds under the Dekalb® brand, as well as glyphosate herbicide under the Roundup® brand. Monsanto Holdings Private Limited (MHPL) is a 100 percent wholly owned subsidiary of Monsanto Company. Monsanto also owns a 26 percent stake in Mahyco, where the focus is on marketing cotton hybrid seeds with Monsanto's Bollgard® and Bollgard II® Bt cotton technologies, and on marketing vegetable hybrid seeds. Mahyco Monsanto Biotech (India) Limited (MMB) is a 50–50 joint venture between Mahyco and MHPL that markets Bollgard® and Bollgard II® Bt cotton technologies to other seed companies. See Monsanto Company (2010) for additional details.

[4] Interestingly all domestic companies in the top 10 bracket in 2009 had some technical collaboration either with a foreign technology–based company or national/international public-sector research organization.

cooperation are forthcoming. Rao and Dev (2009) echo that sentiment, but emphasize the need for a more active public-sector role to serve the needs of poorer farmers. Rao (2009), on the other hand, predicts that rapid growth will be driven by the private sector, primarily through the continued improvement of cotton, maize, and rice hybrids.

All of these optimistic outlooks hinge on the improvement of the current policy regime that governs the seed and agbiotech industries in India. In the last decade, the government has expanded its support to create a more enabling environment for private R&D efforts with initiatives such as the Genome Valley in Andhra Pradesh, specialized autonomous research institutions such as the National Agri-food Biotech Institute (NABI), the Indian Council on Agricultural Research (ICAR) National Agricultural Innovation Project (NAIP), and several other ventures. The government has also created incentives, such as a plant variety protection system to protect breeders' rights; permitting 100 percent foreign direct investment in health and agbiotech; single-window processing by the Department of Biotechnology (DBT) for large biotech projects involving foreign investments of $22 million or more; special benefits for public–private partnership projects; generous depreciation allowances for plants and machinery involved in agbiotech; and a three-year excise duty waiver on patented products (India, Department of Biotechnology 2007).

The question is whether these policies and incentives are sufficient to encourage growth and innovation in India's cereal seed and agbiotech industries, and whether such growth and innovation can improve productivity and welfare among resource-poor, small-scale farmers in India's cereal production systems. We examine these issues in more detail below.

3. DATA AND DATA SOURCES

In the case of Indian seed and agbiotech industries, there are limited data with which to characterize trends in industry structure and its impact on innovation and social welfare. This paper relies mainly on publicly available data on firms' market share and performance, field trials of genetically modified (GM) cultivars, and imports of GM seed and other planting materials. Data are extracted from a range of sources including peer-reviewed journal articles, government statistical reports, private databases, and documents from industry sources. A summary of the primary data sources is as follows.

Biospectrum-Able Survey

BioSpectrum, in collaboration with the Association of Biotechnology Led Enterprises (ABLE), has been conducting an annual biotechnology industry survey since 2003. The survey covers biotechnology applied to the pharmaceuticals, agricultural, industrial, services, and informatics sectors in India. For the agbiotech sector, the survey has focused only on GM seeds, molecular markers, and related products. The hybrid seed business has not been part of the survey focus. We use data from the survey to examine the growth and structure of the agbiotech industry in India.

Francis Kanoi Marketing Research Group

The Francis Kanoi Marketing Research Group conducted a survey-based study on rice cultivation and the rice seed market during 2008–2009 in India. The main objectives of the study were to estimate the demand potential for rice seed; identify various seed sources and their respective market shares; estimate the costs of cultivation of rice across various states and production zones; and estimate the market share of various companies in the hybrid rice seed market. The survey covered 11,076 rice farmers across 139 districts (those with more than 30,000 hectares under rice cultivation) in the 16 major rice-growing states in India for the 2008–2009 agricultural season.

IGMORIS (Various Years)

The Indian GMO Research Information System (IGMORIS) is a database on activities involving the use of genetically modified organisms and related products in India. The website has information on commercially approved GM events and Bt cotton hybrids since 2002, and data on field trials since 2006.

Key Informant Interviews

Information was gathered from a series of unstructured interviews held in 2008–2010 in several locations across India. Interviews were conducted with a range of persons knowledgeable about the seed and agbiotech industries in India, including corporate decisionmakers, private-sector researchers, public regulators, social science researchers, policy analysts, and biophysical scientists working in both public and private research units. Table 3.1 provides a breakdown of key informants by sector. Questions covered during the interviews were related to seed and agbiotech market opportunities in India (with specific reference to rice, wheat, and maize), R&D investment strategies and constraints, product delivery strategies and constraints, IPRs, technology forecasts and opportunities, and regulatory issues.

Table 3.1—Key informants interviewed, 2008–2010

Affiliation	Number
Private sector (managers, researchers, other)[a]	36
Public sector (regulators, researchers, other)[b]	35
Donors, nongovernmental organizations, charitable foundations, and others[c]	6
Total	77

Source: Authors.
Notes: [a] Includes representatives of industry associations.
[b] Includes researchers from the Consultative Group on International Agricultural Research.
[c] Includes representatives of donor agencies, international organizations, charitable foundations, and nongovernmental organizations.

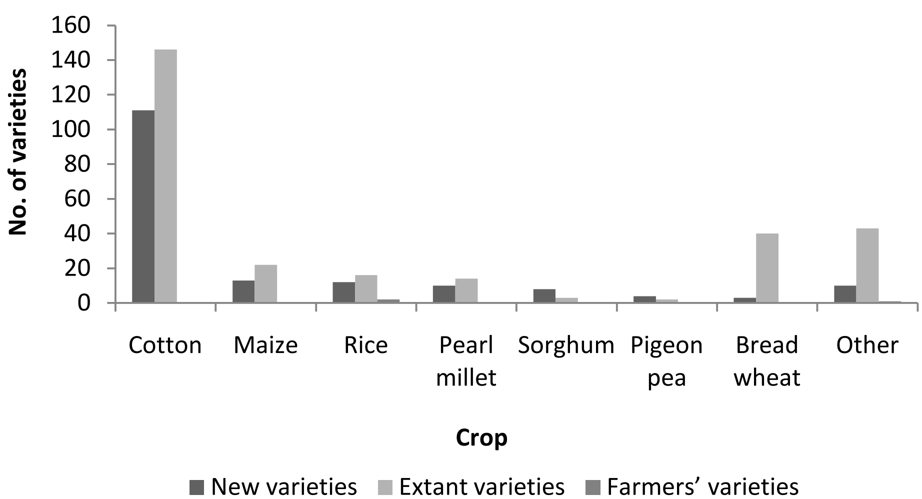
4. GROWTH IN INDIA'S SEED AND AGBIOTECH INDUSTRIES

Given the room for expansion in India's seed and agbiotech industries, we examine here the opportunities for and impediments to growth. We briefly examine India's IPR regime and its influence on innovation in the seed and agbiotech industries. We then examine the private sector's efforts to exploit agbiotech, a technology that has been a key driver behind the cotton seed sector's phenomenal growth and also a potential contributor to cereal improvement. We then discuss the policy and regulatory regime as a barrier to entry in the agricultural innovation market and its implications for the seed and agbiotech industries.

Intellectual Property Rights

Private firms operating in India's seed and agbiotech industries have recently begun to seek legal IPR protection for their innovative outputs under the 2001 Protection of Plant Varieties and Farmers' Rights (PPV&FR) Act. In 2008–2009, 64 percent of the 460 PPV applications received by the PPV&FR Authority were from the private sector, with the remaining 36 percent from public research organizations and farmers themselves. As shown in Figure 4.1, the crop-wise distribution of applications for PPV certification for novel varieties in 2008–2009 was concentrated in cotton (65 percent), followed by maize (8 percent), rice (7 percent), pearl millet (5 percent), sorghum (5 percent), and other crops (10 percent). The largest number of applications were submitted for crops where hybrids are most common, indicating that private hybrids dominate the agricultural innovation market.

Figure 4.1—Applications for registration of plant varieties in India under PPV&FR Act, 2008–2009



Source: PPV&FR Authority (2009).
Note: The term varieties used here includes hybrids.

Private firms in India's seed and agbiotech industries may next look to the country's Patents Act for protection of their intellectual property. Although the Patents Act of 1970 did not initially allow for patenting in the agricultural sector, this was reversed by amendments in 2002 and 2005 that made India's laws compliant with the Trade-related Aspects of Intellectual Property Rights (TRIPs) agreement. Microorganisms and any method of treatment for plants were made patentable with the 2002 amendment, although plants, animals, parts thereof, and essentially biological processes are still not patentable. These amendments may possibly pave the way for using patented genes from microorganisms while, in principle, exempting seeds, varieties, and species from patenting.

Legal IPRs have generally not played a role in crop improvement in India over the last several decades. Yet for maize and pearl millet, yields have increased significantly over time due to the combination of effective public hybrid breeding programs, biological IPRs conferred by hybridization that encouraged private-sector R&D investment in maize and pearl millet improvement, and policies that encouraged private investment in the seed industry (Kolady, Spielman, and Cavalieri 2010). Although the potential for hybridization in rice and wheat is far more limited than for maize and pearl millet (discussed in more detail below), the effects of strong legal IPRs, in addition to some form of biological IPRs for these crops, may be needed to encourage greater private investment in their improvement. In other words, a necessary condition for the replication of the maize/pearl millet experience with rice and wheat in India will require credible enforcement of legal IPRs through the certification of private varieties and hybrids and through the adjudication of infringement cases brought to the courts under the 2001 PPV&FR Act. And should transgenic options be explored, improvement in the regulatory system and credible application of the amended Patents Act are also necessary conditions.

Transgenic R&D Activity

Beyond the recent changes in India's IPR regime, an important indicator of growth is the extent to which India's seed and agbiotech industries are exploiting new research materials and conducting cutting-edge research. About 24 public-sector institutions are working on GM crop research targeting four genetic traits: pest and disease resistance; tolerance of the abiotic stresses such as drought and salinity; postharvest traits such as increased shelf life and delayed ripening; and improving protein and micronutrient content (Rabobank 2007). However, output from the GM technology pipeline in India has been driven by the private sector, which has a demonstrated capacity to move seed and seed technology products from discovery into product development and, ultimately, to delivery to farmers.

Here, we analyze data on transgenic planting material imports and transgenic field trials as proxies for progress through the GM technology pipeline. We use the data to calculate two measures—a mobility index and a biotech research intensity ratio—to provide further insights into the level of competition in the innovation market.

Note, however, that this analysis does not account for the current state of GM crop regulation in India. At present, cotton is the only crop for which GM varieties have been released for commercial application, and heated controversies have emerged over the GM regulatory regime. Until the issues underlying India's GM regulatory regime (discussed in more detail below) are resolved, the impact of GM technology on the agricultural innovation market is speculative at best.

Imports of Transgenic Planting Material

Since many firms import transgenic materials into India to research and develop GM crops, examination of import data can shed light on the level of activity in the seed and agbiotech industries. These data specifically capture activity in the upstream portion of the GM technology pipeline, where firms carry out discovery and development activities.[5]

Between 1997 and 2008, the private sector accounted for 85 percent of the 79 imports of transgenic research materials identified by Randhawa and Chhabra (2009) (Table 4.1). A firm-specific breakdown indicates that four firms were leaders in the importation of transgenic research materials—Monsanto, Bayer CropScience, Mahyco, and Syngenta (Figure 4.2). A crop- and firm-specific breakdown indicates that Monsanto is a leader in the import of transgenic research materials for soybean, maize, and cotton, Bayer CropScience for rice, vegetables, and rapeseed/mustard, and Mahyco for wheat and cotton.

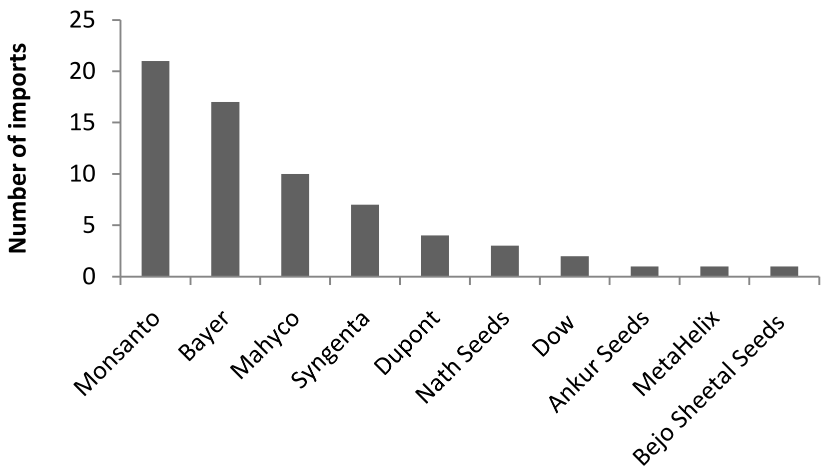
[5] Note, however, that the figures on importation of transgenic planting material discussed here does not account for all types of imported materials used in GM-related research, for example, biological material that is not seed material (e.g., plasmids) for which import permits are not required.

Table 4.1—Number of transgenic planting material imports, by crop and by sector in India, 1997-2008

Crop	Private sector (%)	Public sector (%)	Share of crop imports in total imports (%)
Cotton	22 (100)	0 (0)	28
Rice	13 (65)	7 (35)	25
Maize	18 (95)	1 (5)	24
Wheat	2 (100)	0 (0)	3
Rapeseed/mustard	5 (100)	0 (0)	6
Soybean	3 (100)	0 (0)	4
Vegetables	4 (100)	0 (0)	5
Chickpea	0 (0)	2 (100)	3
Potato	0 (0)	1 (100)	1
Tobacco	0 (0)	1 (100)	1

Source: Authors, based on data in Randhawa and Chhabra (2009).
Note: Figures in parentheses denote the sector-wise share of total imports for a particular crop.

Figure 4.2—Private importers of transgenic material in India, 1997–2008



Source: Authors, based on data from Randhawa and Chhabra (2009).

A further breakdown of the research materials import data from Randhawa and Chhabra (2009) shows that transgenic material imports have increased and expanded since 2006. Both the number of firms importing transgenic planting materials and the number of imports have increased. This suggests the possibility that more firms are becoming active in India's seed and agbiotech industries.

Field Trials

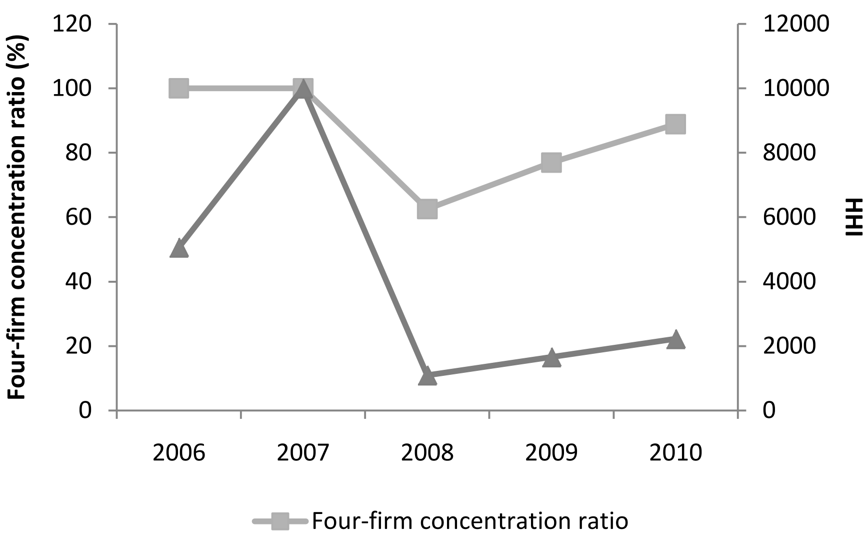
Field trials occur further downstream in the R&D process than the importation of transgenic research materials. Thus, an examination of GM field trial data provides more insight into the short-to-medium-term growth prospects in the seed and agbiotech industries. We calculate a four-firm *concentration (CR4) ratio* and a *Herfindahl-Hirschman index (HHI)* using the number of field trials conducted by firms to measure industry concentration and better understand the level of competition in India's agricultural innovation market.

The CR4 ratio measures the total market share held by the four largest firms in the industry. The HHI measures the size of firms in relation to the industry and is calculated as the sum of the squared market share of each firm in the industry. The HHI approaches zero when a market consists of a large number of firms of relatively equal size, and increases both as the number of firms in the market decreases and as the disparity in size between those firms increases. Because the HHI takes into account the relative size and distribution of the firms in a market, it is considered a more comprehensive and better indicator of concentration than the CR4 ratio (Rhoades 1995). Antitrust regulatory authorities use the HHI to examine whether a merger or acquisition is social-welfare enhancing: corporate acquisitory behavior that leads to an increase in the value of the HHI is not considered to be social-welfare enhancing (Dickson 1986).

Figure 4.3 presents the industry concentration in the seed and agbiotech industry based on field trials conducted between 2006 and 2009. Both the CR4 and HHI measures indicate that market concentration has dropped since 2007 as new firms have entered the market. The high CR4 and HHI values in 2006 and 2007 indicate that the number of firms conducting field trials during those years was very small (fewer than or equal to four).

The figure also illustrates why an HHI is a better indicator of concentration, as noted above. Although the number of firms conducting field trials is higher in 2006 (three firms) than in 2007 (one firm), the CR4 value remains constant at 100 percent. The reduction in the number of firms in 2007 is captured by the significant increase in the HHI value in 2007, suggesting that because a single firm conducted all the trials, the level of concentration was high in 2007.

Figure 4.3—Four-firm concentration ratio and Herfindahl-Hirschman index(HHI) based on firm-level field trial data in India, 2006-2009



Source: Authors, based on data from IGMORIS (various years).
Note: HHI denotes Herfindahl-Hirschman index.

The small number of firms involved in GM field trials in India is measured as a high level of concentration within the portion of the industry where R&D investments in agbiotech are highest. Moreover, when compared with benchmark values from the global and U.S. seed and agbiotech industries, these HHI and CR4 values suggest a high level of concentration. A crop-specific breakdown of GM field trials between 2006 and 2010 further reveals both a small number of active firms and similar levels of concentration (Table 4.2).

Table 4.2—Field trials in India, by crop and firm/organization, 2006–2010

Crop	2006	2007	2008	2009	2010	Total no. of firms conducting field trials	
						Private	Public
Cotton						4	1
		Mahyco	Dow	JK	Dow		
			JK[e]	Dow			
			Mahyco	CICR			
			Metahelix	Mahyco			
			CICR[f]				
Rice						3	2
	Mahyco	Mahyco	Bayer	Bayer	Pioneer		
	IARI[a]			Mahyco	Bayer		
	TNAU[b]						
Corn						4	0
	Monsanto		Monsanto	Monsanto	Dow		
					Syngenta		
				Pioneer	Monsanto		
					Pioneer		
				Dow			
Vegetables						4	3
	Sungro Seedsc	Mahyco	Sungro	Beejo Sheetal	IIHRg		
	Mahyco	Sungro Seeds	Avesthagen	Nunhems/Bayer	Nunhems India/Bayer		
	Nunhems/Bayer	UASd		UAS			
	IARI	TNAU					

Source: Authors, based on data from IGMORIS (various years).
[a] Indian Agricultural Research Institute; [b] Tamil Nadu Agricultural University; [c] Sungro Seeds, a part of the Barwale family of companies, which also owns Mahyco; [d] University of Agricultural Sciences; [e] JK Agri Genetics; [f] Central Institute of Cotton Research; [g] Indian Institute of Horticulture Research’ h Pioneer Hi-Bred International.

Public versus Private R&D Activity

The data on transgenic planting materials and field trials more closely reveal another angle on the seed and agbiotech industry. Specifically, the data indicate that the public sector accounts for a relatively larger proportion of field trials than imports of transgenic planting material. Key informants interviewed for this study suggest that the public sector’s GM research programs are working with a relatively narrow base of traits, conducting research on traits that tend to be unproven and earlier in the development stages, and testing a relatively larger number of products based on this narrow base. The private sector, on the other hand, is applying to field-test traits that have already been in wide use in other countries, indicating a high likelihood that such traits would eventually be commercialized. Given the limited capacity of public organizations to commercialize their research and the private sector’s comparative advantage in this activity, this suggests that the public sector’s contribution to the GM technology pipeline is limited when compared with that of the private sector.

Mergers, Acquisitions, and Licensing

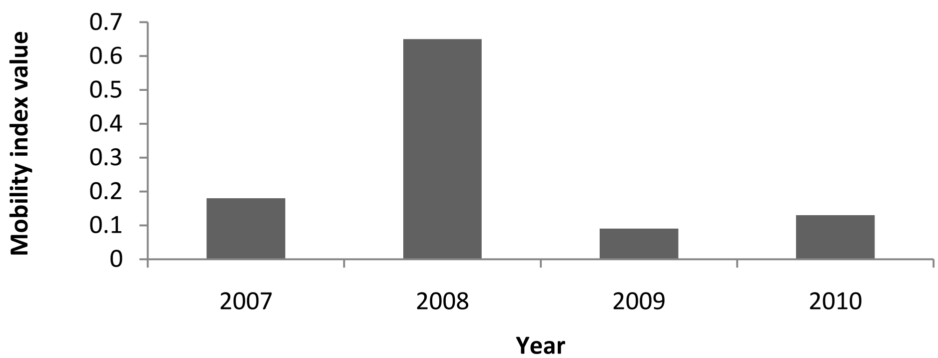
Corporate acquisitory behavior is a useful indicator to further characterize the seed and agbiotech industries in India. Increases in acquisitory behavior within a competitive market or among competing firms often reflect a growth of value in the industry. Firms use mergers, acquisitions, licensing agreements, and technical collaborations to increase the efficiency of their operations, secure valuable intellectual property, launch new products, break into new markets, or integrate related operations. Horizontal integration—the integration of similar economic activities under the control of a single firm—is a commonly used corporate strategy aimed at increasing firm-level efficiency by reducing R&D costs, realizing economies of scale and scope, and minimizing regulatory costs. Vertical integration—the integration of related economic activities in a given supply chain—aims at increasing firm-level efficiency by exploiting asset complementarities, protecting intellectual property, or increasing revenues through direct sales (Shi, Stiegert, and Chavas 2010; Whinston 2006).

Table A.1 in the Appendix summarizes the key mergers and acquisitions in India's seed and agbiotech industries. The table suggests that India has not experienced the same intensity of activity seen in the global and U.S. seed and agbiotech industries during the 1990s, where large firms such as Pioneer/Dupont and Monsanto acquired firms with elite breeding materials, branded seed names, and proprietary technology assets (see, for example, Brennan et al. 2005; Fernandez-Cornejo 2004; and Fulton and Giannakas 2001). Although some mergers and acquisitions in India have occurred, firms have largely relied on licensing agreements to integrate upstream technology development activities with downstream seed production and marketing, most significantly in the Bt cotton segment of the market.

One way of gaining insight into the effects of corporate acquisitory behavior on India's seed and agbiotech industries is to examine changes in industry leadership. Following Brennan et al. (2005), we calculated a *mobility index* using the field trial data described above. The mobility index measures changes in firm leadership within a position, as, for example, when a firm introduces a new product that allows it to capture a greater share of the market. In the seed and agbiotech industries, firm leadership may also be extrapolated from the introduction of new products for testing, that is, prior to their release in the market. In this context, the mobility index is a prognosis of what market leadership may look like given the current status of the GM technology pipeline.

The estimated mobility indexes calculated here are based on field trial data for 2007–2010 and are shown in Figure 4.4. The increase in the mobility index in 2008 reflects the entry of firms such as Dow AgroSciences and Avesthagen into the field trials for the first time in India. This resulted in a significant reduction in Mahyco's relative share in the number of field trials conducted after 2007, prior to which Mahyco was the only company conducting field trials. However, the mobility index drops again in 2009 and 2010, suggesting that few firms—either new or existing—are entering the innovation market with new GM products for field testing.

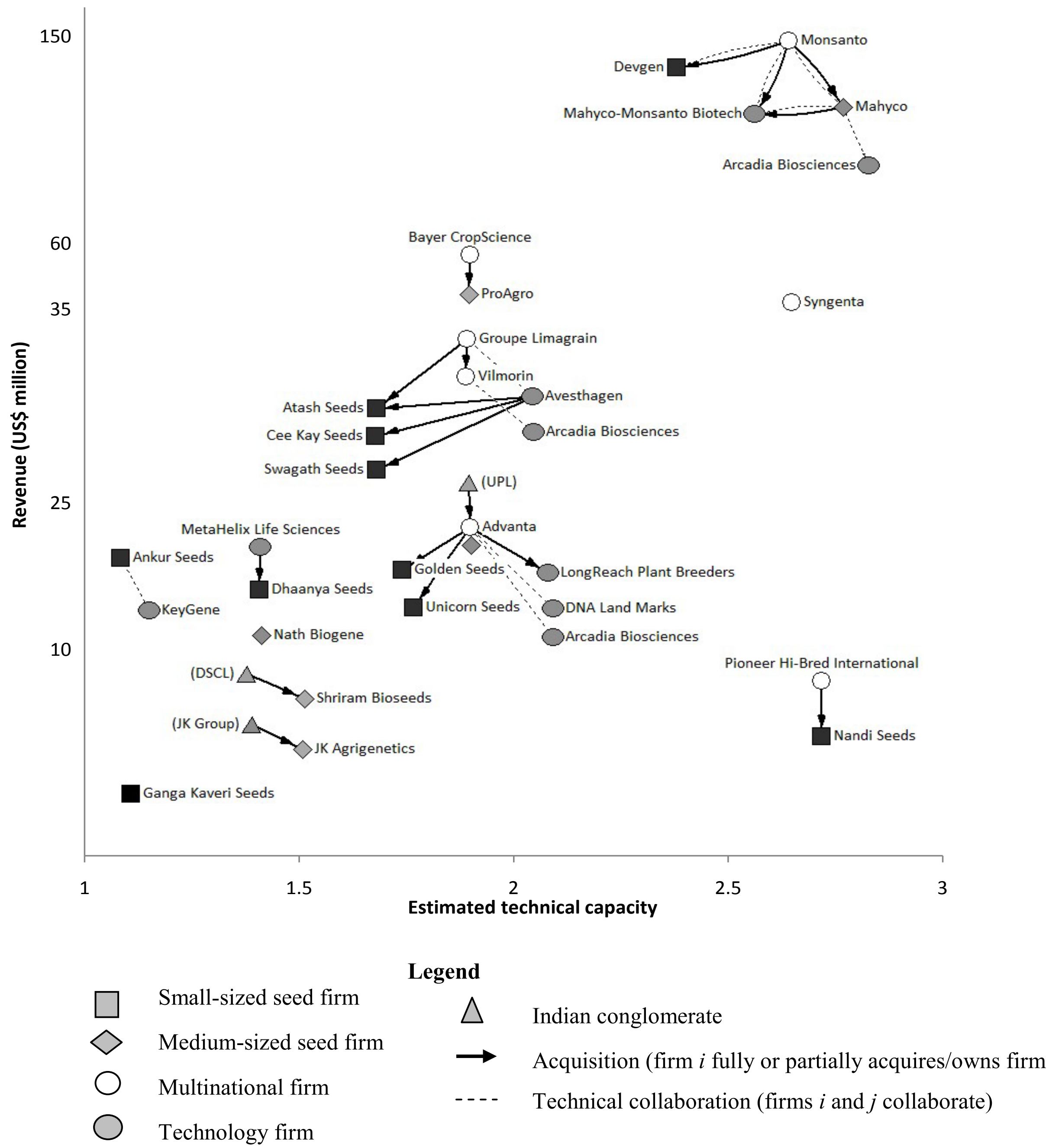
Figure 4.4—Mobility indexes for India's seed and agbiotech industries, 2007–2010



Source: Authors.

Figure 4.5 provides an illustration of India's seed and agbiotech industries based on data from Table A.1 in the Appendix and using a descriptive method of visualization introduced by Howard (2009). The figure is not an exhaustive representation of the industry, nor does it capture the extensive licensing of Mahyco-Monsanto Biotech's Bt trait to cotton seed companies. However, the figure does provide a useful representation of the industry by demonstrating the high level of fragmentation, the leadership of several large companies, and the small number of mergers or acquisitions. When compared with the far more intricate visualizations of the global seed industry developed by Howard, it is clear that there is still potential for growth, expansion, and maturation in the Indian seed and agbiotech industries.

Figure 4.5—Strategic acquisitions and technical collaborations in the Indian seed and agbiotech industries 2001–2009, for cereals only



Source: Authors.
Note: The figure only captures firms and activities in the seed and agbiotech industries in India relevant to cereals. The mapping of firms against revenue and technical capacity is approximate and for illustrative purposes only. See Tables A.1 and A.2 in the annex for further details. Advanta is denoted both as a medium-sized seed firm and a multinational firm owing to its unique status as an Indian multinational seed firm.

Policies, Regulation, and Barriers to Entry

The current level of concentration in India's seed and agbiotech industries noted above results partly from barriers to entry that inhibit innovation at the cutting edge. The major constraints are largely related to the high costs and time delays associated with regulatory approval for GM crops, uncertainty about IPR enforcement, and uncertainty in the regulatory approval process. Experiences with Bt cotton, GM mustard, and Bt eggplant are illustrative of the problems.

In the case of Bt cotton, pre-approval regulatory costs incurred by Mahyco-Monsanto Biotech (MMB) for Bt cotton during 1996-2001 were estimated at $1.8 million (Pray, Bengali, and Ramaswami 2005). That figure likely does not include the costs of data gathered for regulatory approval processes in the United States and other countries that were referred to in the Indian regulatory filings. Herbicide-tolerant mustard, which reached the advanced stages of India's regulatory process in 2002–2003, required that its developers (Pro-Agro in collaboration with PGS, a Belgian company) spend between $4 million and $5 million on regulatory approval, followed by another $0.1 million of additional testing requested by the Genetic Engineering Approval Committee (GEAC) in 2003. The uncertainty surrounding the process, alongside changes in the ownership of the firms involved, forced the developers to abandon the venture (Pray, Bengali, and Ramaswami 2005). Similarly, Bt eggplant reached the advanced stages of India's regulatory process in 2009, only to become the subject of a moratorium on its release in 2010.

Even though wide disparity exists between estimates of regulatory costs between the private and public sectors, experiences in India to date suggest that the current regulatory system is a source of significant uncertainty for the seed and agbiotech industries. The majority of corporate decisionmakers interviewed for this study indicated that regulatory uncertainty will negatively influence their willingness to participate in the Indian seed and agbiotech market.

Part of the problem is that the current regulatory system is spread across multiple ministries—the Ministry of Science and Technology, the Ministry of Agriculture, and the Ministry of Environment and Forests. Whereas the entire process of product development and field trials is conducted under the supervision of the first two ministries, the final approval for commercialization is with the third ministry, which heads the GEAC. The National Biotech Development Strategy developed in 2007 and the National Biotechnology Regulatory Authority of India (NBRAI) Bill developed in 2009 address this complexity.

Ideally, if the NBRAI Bill passes into law, it would address many of the issues emerging from the current regulatory regime. Provisions in the NBRAI Bill aim at streamlining the regulation of research, transport, import, manufacture, and use of organisms and products of modern biotechnology and for matters connected to biotechnology. There are also provisions to create a single-window approach to biotechnology regulation, which would be implemented under the Ministry of Science and Technology through the Biotechnology Regulatory Authority, which itself would be governed by an Inter-Ministerial Advisory Board and a Biotechnology Advisory Council.

However, such policies and bodies are only part of the solution. There is also a need for more and higher-quality data on agbiotech research in India to improve the efficiency and effectiveness of the regulatory system. At present, the Indian GMO Research Information System (IGMORIS) provides information with its publicly accessible database that covers such topics as the status of field trial applications and the number of commercially approved GM varieties, both by crop and by inventor. However, data on patents relevant to food and agriculture are not readily available to the public and are much harder to access. This type of information is critical to understanding how well the regulatory system works, where the bottlenecks are, and what technologies are on the horizon for India, among other things.

There is also a need for new regulations to encourage the rapid commercialization of public research. To that end, the government formed the National Innovation Council in 2010 with an initial corpus fund of 10 billion INR (approximately $218 million) to encourage innovation, with plans to gradually increase the sum to 50 billion INR (approximately $1.09 billion), with a major portion of the fund coming from the private sector (see NIC 2010). The council is mandated to develop an Indian model of innovation that focuses on inclusive growth and creating an appropriate system conducive to fostering inclusive innovation.

In addition, the Parliament is currently reviewing a proposed Protection and Utilization of Publicly Funded Intellectual Property Bill, 2008, or the Innovation Bill. The bill includes provisions to facilitate public, private, and public–private partnerships around technological innovation; create nationally integrated annual science and technology plans; codify and consolidate laws protecting confidentiality, trade secrets, and innovation; create fiscal incentives and tax breaks for innovative activities; and establish special innovation zones (SIZs) and an electronic exchange for trading in innovation. Relatedly, some policymakers have signaled their willingness to encourage innovation, particularly with respect to GM crop R&D, by opening the seed sector to 100 percent foreign direct investment, subject to the usual condition that the companies have to comply with national laws regarding development and commercialization of genetically modified organisms.

Indicators of Growth Potential

These data on the GM technology pipeline, IPRs, industry concentration, acquisitory behavior, and entry barriers provide useful indicators of India's agricultural innovation market and its growth potential. First, the private sector accounts for a relatively larger proportion of IPR applications, imports, and field trials than the public sector, all of which indicate strong market leadership from the private sector. Second, the GM technology pipeline is relatively limited in both the public and private sectors, as evidenced by the small number of transgenic material imports and GM field trials. Third, the agbiotech portion of the industry is highly concentrated around the top four firms, all of which are either multinational firms, subsidiaries of multinational firms, or domestic firms in which multinational firms hold an equity position. Fourth, the innovation market has not experienced significant levels of acquisitory behavior or significant changes in leadership. Finally, the barriers to entry that stem from uncertainty in the regulatory system may be significant enough to discourage investment.

5. INDUSTRY STRUCTURE AND INNOVATION IN THE RICE, WHEAT, AND MAIZE SEED MARKETS

In this section, we examine these issues on a crop-specific basis by identifying the opportunities for, and impediments to, growth for the three major cereal crops in India—rice, wheat, and maize.

India's Rice Seed Sector

Rice is the most important food crop in India in terms of cultivated area, production, and consumption. Of the 2.4 million metric tons of rice seed used in 2008–2009 in India, 51 percent was purchased (Francis Kanoi 2009). This is somewhat counter to the common perception that rice, a self-pollinated crop, is largely cultivated with farmer-saved seed (Table 5.1).

Table 5.1—Characteristics of the Indian rice seed market, 2008–2009

Indicator	Inbred varieties	Hybrids	
		Public	Private
Percentage of farmers using	93.7	0.2	6.1
Percentage of area under	93.8	0.3	5.9
Seed rate (kilograms/hectare)	56.0	11.0	13.0
Seeds used ('000 metric tons)	2,321.8	1.4	33.7
Quantity of seeds purchased ('000 metric tons)	1,174.5	1.4	33.7
Market value (US$ millions)	489.0	3.7	131.5
Yield (metric ton/hectare)	4.3	6.6	5.2
Average satisfaction level among farmers[a]	2.9	3.6	3.3

Source: Francis Kanoi (2009).
Notes: [a] Fully satisfied = 4, moderately satisfied = 3, not very satisfied = 2, and not at all satisfied = 1.

Still, the formal rice seed market is largely concentrated around the high-volume, low-margin varietal end of the business and is not what might be termed *cutting edge* in the seed industry. Until the recent introduction of hybrid rice, few private firms supplied the market with proprietary seed technologies for rice.

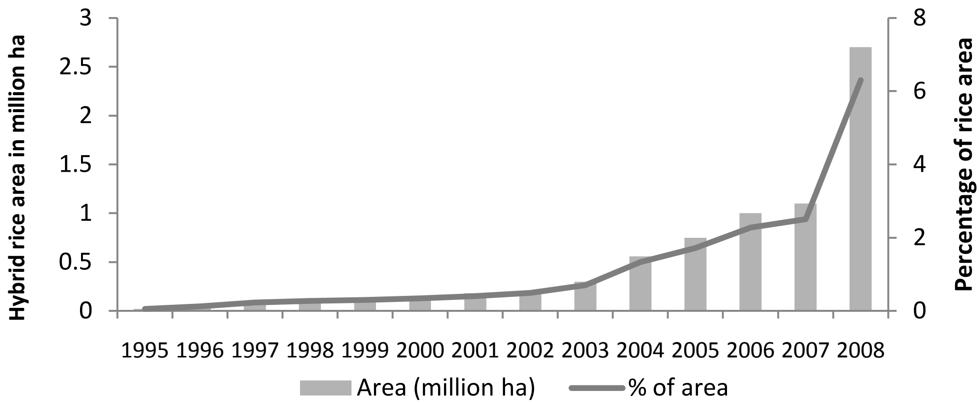
Despite the high proportion of purchased seed and a relatively high seed replacement rate (25 percent in 2006 according to Seednet [2007]), the compound annual growth rate of rice yields fell from 2.3 percent during 1968–1988 to 1.6 percent in 1989–2008 (Kolady, Spielman, and Cavalieri 2010). To address this decline in yield growth, the Government of India launched The National Food Security Mission in 2007, with the aim of increasing annual rice production by 10 million metric tons by the end of the Eleventh Plan period (2011–2012). Increasing the adoption rate of better-performing varieties and hybrids was a key strategy identified under the program (NFSM 2007).

In fact, the government's aim is to increase the area under hybrid rice cultivation to 25 percent of all rice-cultivated area by 2015. Hybrid rice accounted for less than 6 percent of India's 44 million hectares under rice cultivation as of 2008–2009 (Figure 5.1). The poor performance on this front is largely attributable to hybrid rice's rocky start following its first release in 1994 for irrigated rice-rice and rice-wheat systems in southern and northern India. Farmers in Andhra Pradesh, Tamil Nadu, and Karnataka cited inconsistent yield performance, low grain quality, high susceptibility to pests, and other factors that led to significant levels of rejection and disadoption (Janaiah 2002).[6]

6 The slow adoption of hybrid rice in India stands in contrast to the experience in China, where approximately 65 percent of rice area under is hybrid. This has been explained in a number of ways including the larger research investment of the Chinese government, the ability of the Chinese government to support and require adoption of hybrids, and the overall better quality and

In the last several years, the adoption of hybrid rice in India appears to be gathering momentum. Since 2005, the proportion of area under hybrid rice has grown at a rate of about 40 percent per year, albeit from a low base (Figure 5.1). This has occurred most markedly in six northern and eastern states of India where rice yields are low relative to the national average. In those states, private hybrids account for more than 95 percent of area under hybrid rice cultivation (Baig 2009; Francis Kanoi 2009; Nirmala and Viraktamath 2008).

Figure 5.1—Area under hybrid rice cultivation in India, 1995–2008



Source: Authors' calculations based on Baig (2009) and Francis Kanoi (2009).

Forty-two rice hybrids have been released for commercial cultivation in India (Baig 2009). This includes 28 hybrids from the public sector and 14 from the private sector, including two particularly popular hybrids (Arize 6444 from Bayer and PHB 71 from Pioneer/Dupont, both of which are more than 10 years old). In addition to these officially released hybrids, many more truthfully labeled private hybrids are also available in the market, suggesting that more than 100 rice hybrids are currently in circulation in India (Kumar 2008), although experts interviewed for this study suggest that many of these hybrids are imitations and copycats of the popular commercial hybrids. But regardless of the origin of the seed, the figures indicate that the hybrid rice seed industry is a decidedly private-sector venture (Table 5.2). It is because of this fact that we focus on hybrid rice here to provide context for later analysis of industry structure and composition.

Table 5.2—Hybrid rice seed market in selected states, 2008–2009, India

Region, state	% of cultivated rice area under hybrids		Hybrid seed market size ('000 metric tons)		Hybrid seed market value (US$ millions)[a]	
	Public	Private	Public	Private	Public	Private
East						
Bihar	-	8	-	4.00	-	17.01
Jharkhand	-	7	-	2.00	-	8.15
North						
Uttar Pradesh	-	29	-	23.00	-	98.59
Punjab	2	6	1.00	2.00	1.83	6.06
Haryana	3	20	0.40	2.00	1.16	7.66
Uttaranchal	1	1	0.02	0.02	0.09	0.09
West						
Maharashtra	-	3	-	0.48	-	1.67
India	*0.3*	*5.9*	*1.42*	*33.5*	*3.08*	*139.24*

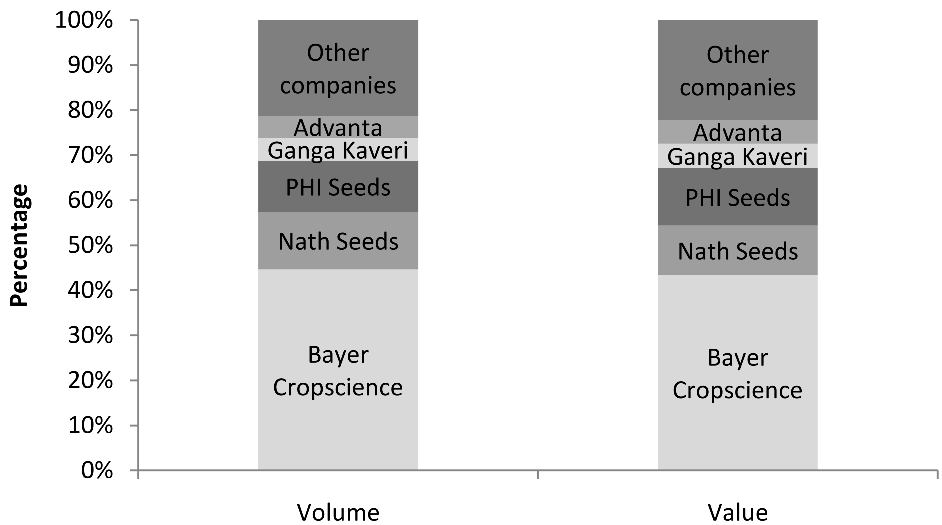
Source: Authors' calculations based on data from Francis Kanoi (2009).
Notes: [a] 1 USD = 43.2 INR in 2008.

yield of Chinese rice hybrids (Li, Xin, and Yuan 2010).

The size of the Indian hybrid rice market during 2008–2009 was estimated at about 35,000 metric tons with a total value of $142 million (Francis Kanoi 2009). Although there are no complete estimates for the number of companies marketing hybrid rice seed, Kumar (2008) and Nirmala and Viraktamath (2008) put the figure at between 30 and 60. Several of these firms are investing heavily in R&D to improve yield performance, reduce yield variability, and improve grain quality. Many other firms are investing in the expansion of their marketing and distribution networks (Baig 2009; Francis Kanoi 2009; Nirmala and Viraktamath 2008).

Examination of the hybrid rice seed market suggests that this sector of the seed industry in India is fairly concentrated at present. The four leading firms in the market include two multinational companies (Bayer CropScience and Pioneer/Dupont) and two domestic firms (Nath Seeds and Ganga Kaveri Seeds) (Figure 5.2). The CR4 ratios calculated using sales data during 2008–2009 are 74 percent by volume and 73 percent by value. The Herfindahl-Hirschman indexes are similarly high (2,312 by volume and 2,196 by value) and reflect the dominance of Bayer CropScience (with about 43 percent of the market) within the *top four* bracket. It is likely that this concentration reflects the hybrid rice seed market is still in the earliest stages of development. Private R&D investments in proprietary rice hybrids only began in earnest during the last 10 years in India, resulting in a fairly limited number of good-quality and well-adapted private hybrids on the market. Experts interviewed for this study indicate that overall, private-sector investment in hybrid rice R&D is on the order of $6 million to $12 million per year at present, with an equal amount going into GM rice R&D.

Figure 5.2—Structure of India's hybrid rice seed market by volume and value, 2008–2009



Source: Authors' calculations, based on data from Francis Kanoi (2009).

Another angle on industry concentration is to examine imports of transgenic material for rice as a predictor of firm-level R&D effort in the rice market. The private sector accounted for 65 percent of the 20 imports of transgenic material for rice during 1997–2008 (see Table A.3 in the Appendix). Almost half of those imports were attributable to Mahyco (23 percent) and Bayer CropScience (23 percent). Meanwhile, only a small number of GM field trials have been conducted in rice in India. The private sector accounted for five of the seven field trials conducted during 2006–2009 (Table 4.2), with Mahyco accounting for three and Bayer CropScience for two.

The small number of imports of transgenic material and even smaller number of field trials make it difficult to predict how this segment of the rice seed sector will develop. However, given the importance of insect resistance along with the extensive track record with this trait in cotton in India and other crops throughout the world, it seems likely that it will be a high priority. The multinational companies and Indian companies with technology arrangements with the multinationals or technology suppliers should be positioned to participate in the GM market should the Indian regulatory system choose to approve these crops. Given the wide availability of Bt from a number of sources, it is possible that companies that are successful in the Indian market may build on the quality and value of their germplasm base.

As is the case in the rest of the world, the public sector is conducting substantially less research than the private sector on GM rice, at least as indicated by the transgenic material imports and field trials. The breakdown of transgenic material imports also suggests a different R&D focus between sectors, with private firms working more on insect resistance and herbicide resistance traits, and the public sector working more on less-proven technologies such as disease resistance and nutritional enhancement traits.

There are several implications emerging from these trends in hybrid and GM rice development in India. The two lead firms, Bayer Crop Science and Pioneer/Dupont, are likely to continue to be strong competitors in the expanding hybrid rice market. As the industry evolves and should GM traits for rice move into commercialization, the other multinationals as well as companies that have technology access from agreements with the multinationals or other technology providers should be well positioned to compete in the Indian market. Indian seed companies that have developed capacity for working with transgenics (perhaps through their experience with Bt cotton) and that are active in the retail seed market should be able to compete on their own or in collaboration with the multinationals through strategic alliances, mergers, and acquisitions.

However, duplication of the Bt hybrid cotton experience seems unlikely. MMB, as the only technology provider during the first four years following commercial release, leveraged its first-mover advantage by sublicensing the technology to independent seed companies. Since the potential hybrid rice market is substantially larger and the number of research-driven seed companies and technology providers is large, the opportunity for a single technology provider to dominate the technology-licensing market is much less likely. Additionally, the IPR situation is becoming less restrictive as first-generation patents on various technologies begin to expire. Therefore, the GM hybrid rice market will likely evolve on the basis of interplatform competition based on extensive sublicensing among competitors.

Having said this, the uncertainties of India's regulatory framework for GM crops leave open the question of whether GM rice will ever be commercialized and, if commercialized, who the first movers might be. Moreover, if the uncertainties persist, this may provide late entrants with sufficient time to catch up with the technology and market leaders. Research investment by the seed companies for the Indian rice seed market may end if no realistic possibility of a clear pathway for commercialization of GM rice exists.

Further, public-sector organizations could also successfully introduce GM rice with traits such as disease resistance or nutritional enhancement that could further increase the interplatform competition and provide opportunities for gene bundling/stacking and product differentiation in the GM rice seed market. Unfortunately, the record of public-sector research organizations developing GM crops has been extremely poor throughout the world, and we have little reason to expect a high level of success in India given the low level of funding and limited capacity of public research in this area. Since vertical integration through mergers and acquisitions is limited in the Indian context, the extent of bundling and stacking of genes will depend heavily on the scope of IPRs held by the innovator and the licensing terms.

In short, the extent of competition in the upstream technology market will depend heavily on private investment for crops and areas other than rice, the timing of commercialization of competing technologies in India, and the performance of the technology platforms. The extent of competition in the downstream seed market will depend on the timing of commercialization, the performance of the technology platforms, the terms under which technologies are licensed, the scope of patent protection, and the ownership of elite germplasm.

India’s Wheat Seed Sector

Wheat is the second most important food crop in India in terms of production and consumption. As of 2009, wheat was cultivated on more than 28.4 million hectares in India. The low seed replacement rate of 18 percent in 2006 indicates that the commercial segment of the wheat seed market is small (Seednet 2007). The total market size for wheat seed was estimated at 3.2 million metric tons in 1998–1999, of which saved seeds accounted for almost 90 percent.

The compound annual growth rate of wheat yield fell from 3.8 percent during 1968–1988 to 1.5 percent during 1989–2008 (Kolady, Spielman, and Cavalieri 2010). As in the case of rice, reversing this trend is a major priority of public-sector agricultural research in India. The government aims to achieve this by investing more in R&D, developing better-performing cultivars, and encouraging farmer adoption of improved varieties, especially in regions which were bypassed by the Green Revolution (NFSM 2007).

Unlike rice, technological solutions such as hybrid wheat and GM wheat are in early stages, such that yield improvement efforts are still driven by public-sector breeding programs. The lack of success of hybrid wheat to date—for example, the weak heterosis found in hybrid wheat and the difficulties in producing hybrid seed—has limited private-sector interest in wheat seed. Moreover, the absence of policy solutions, such as the enforcement of plant variety protection for wheat, has further limited private-sector interest. As a result, research programs conducted by the Directorate of Wheat Research (DWR), various state agricultural universities, and international centers (CIMMYT) continue to provide most of India’s improved wheat varieties. For example, the DWR wheat program from its inception in 1965 through 2007 released 344 wheat varieties for cultivation under different production conditions in all the six wheat-growing zones (India, Directorate of Wheat Research 2010).

Mahyco, the sole producer of commercial hybrid wheat seed in India, introduced a wheat hybrid in 2001. By 2005, hybrid wheat was being cultivated in six states, although the adoption rate of hybrid wheat remained extremely low—an estimated 0.09 percent of cultivated area in 2005 (Zehr 2001; Matuschke, Mishra, and Qaim 2007).

Unlike GM maize and soybean, GM wheat has not met with much success. The benefits of GM traits in wheat would be similar to those in other crops, but sensitivity about acceptance issues given wheat’s importance as a food crop and in global trade has restricted R&D on GM wheat. That said, greater private investment in GM wheat may hinge on the development of hybrid wheat, since the biological IPRs inherent in hybrid wheat could provide an attractive platform for delivering GM technologies where legal IPR mechanisms are lacking or ineffective. This may even occur without significant yield advantages conferred by heterosis, so long as the gains resulting from the GM trait provide farmers with a significant yield gain or cost reduction advantage.

Mahyco imported transgenic planting materials for nematode resistance and herbicide tolerance in wheat in 2003 and 2007, respectively. However, currently no field trials are under way for wheat in India. Companies such as Monsanto, Syngenta, and BASF have recently activated research programs on GM wheat in the United States after several years of inactivity. Given that all of these large firms have a presence in India, it will be possible for them to transfer readily available transgenic events to selected Indian wheat cultivars in the future. Meanwhile, donors are currently funding public–private partnerships that provide access to technology to Indian seed companies for GM approaches of improving abiotic stress tolerance of wheat for poor and small wheat growers in India.

Still, prospects for wheat improvement in India remain poor. Improvement will be limited to publicly supported breeding programs. This is a problem that India shares with the rest of the world. In the absence of scientific breakthroughs that improve feasibility of economically viable hybrid wheat or enthusiasm for GM traits in wheat, it is unlikely that the private sector will invest in a meaningful way. Limited resources for public improvement of wheat have been a constraint on the rate of yield improvement in the crop, and farmers will likely shift to other crops (such as maize) if wheat improvement remains limited.

India's Maize Seed Sector

Maize seed is, in most countries, the most attractive segment for the private sector. Hybrid maize exhibits a high level of heterosis, a favorable reproductive ratio (seed produced to planting rate), and a biological form of IP protection, and it provides a favorable platform for biotechnology (established enabling technology, sequenced genome, diploid)—all contributing to the profitable nature of this crop for seed companies. Private companies invest in excess of $2.5 billion annually for maize improvement globally.

Maize is the third most important food crop in India. Currently about 49 percent of maize harvested is used for poultry feed, 12 percent for animal feed, 25 percent for food, 13 percent for starch and industrial purposes, and 1 percent for seed (Financial Express 2008). In 2008–2009, maize was cultivated on approximately 8.3 million hectares of land, 60 percent of which was accounted for by hybrids (Kumar 2010). More than 50 percent of the R&D effort for maize in India is carried out by the private sector, which supplied 70 percent of all maize hybrid seed in 2003 (Nikhade 2003; Joshi et al. 2005). Unlike in the case of rice and wheat, the compound annual growth rate of maize yield increased from 0.9 percent during 1968–1988 to 2.6 percent during 1989–2008.

Although the maize seed market is small at the moment (about $200−$250 million, according to Rao (2009)), we have several reasons to think that it might grow considerably larger. First, it is reasonable to predict that the area devoted to maize for feed is likely to increase with increased consumption of poultry and dairy resulting from income growth across India (Gulati and Dixon 2008).

Second, there are several relatively *quick wins* to increasing maize yields and output. Because only 60 percent of the current maize acreage is allocated to hybrids, there is considerable room for growth of hybrid acreage. Much of the hybrid acreage is based on the cultivation of three-way hybrids, and a shift to single-cross hybrids could deliver higher yield and more value. Moreover, because the current planting rate for maize in India is about 50,000 seeds per hectare, increasing planting rates could increase yields.

Third, although GM maize has not been approved for sale in India, there is extensive potential in several proven genes (including insect resistance and herbicide tolerance) that have been successful in other maize-producing countries in the developing world. Many of the multinational firms involved in India's seed industry have considerable ability to leverage R&D from other similar regions in which they operate (for example, Brazil). Further, the likelihood of GM maize successfully navigating India's regulatory process might be higher than that of other crops because maize is less sensitive to most Indian consumers' concerns because it is viewed as a feed crop that is only marginally important to national food security or biodiversity (unlike rice or eggplant, where debates over genetic modification are heated).

All of these factors suggest a much larger maize seed market and one that, given a clear path to market for transgenics, would justify increased interest in the Indian market by the private seed sector. R&D efforts are under way to develop GM maize in India (see Table A.4 in the Appendix). Unlike in the case of rice, where both the public and private sectors are conducting R&D, most of the R&D efforts in GM maize are carried out by the private sector. Of the 19 imports of maize transgenic materials that occurred during 1997–2008, 18 were attributable to the private sector. Monsanto accounted for about 60 percent of the private-sector imports, followed by Syngenta (11 percent), Pioneer/Dupont (11 percent), Dow AgroSciences (6 percent), Mahyco (6 percent), and Metahelix (6 percent) (Randhawa and Chhabra 2009). These imports were primarily for insect resistance and herbicide resistance traits. Monsanto also dominates field trials of transgenics by accounting for three of the five trials conducted, followed by Pioneer/Dupont and Dow AgroSciences with one apiece.

Even though the participation of the public sector is negligible in GM maize research, the presence of four competing technology providers in field trials provides an opportunity for interplatform competition. As in the case of rice, competition in the upstream technology market will be driven by the timing of commercialization and the performance of technology platforms, whereas competition in the downstream seed market will depend on additional factors such as the terms and conditions of licensing agreements, the scope of patent protection, the ownership of elite germplasm, and the regulatory process.

6. DISCUSSION: ALTERNATIVE INTERPRETATIONS AND FUTURE SCENARIOS

Limited data, nascent growth, and uncertainty are all constraints on how we interpret the analysis provided above. To be sure, the analysis opens the door for several different interpretations of the current and future status of India's seed and agbiotech industries. In this section, we examine these interpretations and build future scenarios for these industries and for the agricultural innovation market more generally.

Appropriate Roles for the Public and Private Sectors

The findings above suggest that technological innovation in India's seed and agbiotech industries is primarily a private-sector phenomenon. However, the private sector's participation is largely limited to seed technologies that are embedded in hybrids, and GM technologies remain a relatively small component of the private sector's R&D investment portfolio (apart from cotton). Still, the technological *edge* in India's agricultural innovation market is clearly being led by the private sector.

Findings also suggest that the public sector's current contribution to India's seed and agbiotech industries, GM technology pipeline, and wider innovation market is insufficient. National and international research organizations play an important role in varietal rice and wheat improvement and hybrid parent line development, but their contributions are limited by a range of factors. These include the basic incentive structure wherein public researchers are not encouraged to rapidly release viable technology products, gain familiarity with the process of commercializing regulated products, and build ties to other actors (including private firms) that can assist in the development and delivery of products. These factors also include other common concerns with public sector performance: bureaucracy, red tape, limited capacity to manage complex contracts, and political interference.

The public research system's marginal status is exacerbated by the fact that many private firms do not need public materials for their GM R&D programs. Rather, private firms can obtain material, as well as food and environmental safety dossiers, from parallel programs in other developing or industrialized countries. The absence of public-sector participation may limit the amount of R&D on those crops and traits that hold little interest for the private sector, such as, for example, open-/self-pollinated cereal crops such as rice and wheat. Having said that, there is evidence to suggest that the private sector is willing to invest in R&D for such crops, provided that they can develop technologies (for example, hybrid and/or GM rice or wheat) that also increase their ability to appropriate a share of the gains from innovation.

The proposed Indian Innovation Bill (2008) and Seed Bill (2004) are both steps in the right direction. Ideally, they will allocate the public sector to a more effective regulatory role that encourages private R&D, reduce transaction costs and information asymmetries in the commercialization of new cultivars, and accelerate the movement of materials and technology from the public sector to the private sector. The timely enactment of these bills and the effective implementation will be a key to the future of India's innovation market, particularly in the long term.

Regulatory Uncertainty and Technology Pipelines

The extent to which the private sector invests in crop improvement and R&D for cereal crops will depend partly on a reduction in the uncertainty that clouds India's seed and agbiotech industries, according to the findings. The figures shown earlier suggest that many firms with agbiotech R&D capacity may have not yet entered the Indian market—especially the seed market for cereals—at a significant level. At best, they are testing the waters with investments in Bt cotton, hybrid maize, and hybrid rice. From a policy angle, this reflects persistent concerns with India's weak IPR regime, uncertain regulatory environment, and inefficient market infrastructure. From a technical angle, this reflects uncertainty over the development of good rice hybrids, viable wheat hybrids, and other technologies that increase appropriability for the private sector. As a result, and based on the findings above, there is a clear indication that the GM and wider technology pipeline in India is fairly limited and narrow, despite the R&D investments in cotton, rice, and maize hybrids.

The 2001 PPV&FR Act could play a role in addressing corporate concerns over IPR protection, although the Authority's capacity to live up to its mission depends on the courts' ability to adjudicate fairly on infringement cases. And promulgation of the proposed NBRAI Act will be critical to lifting this cloud of regulatory uncertainty and widening the technology pipeline.

Data, Information, and Analysis

Additional consideration should also be given to the need for more data, information, and analysis to improve the quality of discourse and decisionmaking on both public policies and corporate strategies. There is a clear need for a publicly accessible clearinghouse or database that integrates information on applications for, ownership of, and issuances of patents, PPVs, field-testing permits, and commercialization approvals. Use of this database would help corporate managers, public regulators, policymakers, and researchers make informed and evidence-based decisions about innovation, competition, private profits, and social welfare. The U.S. Department of Agriculture's Agricultural Biotechnology Database (USDA-ERS 2010), among others, provides a useful model.

Industry Concentration and Market Power

A narrow technology pipeline, reticent private investment, and regulatory uncertainty raise the issue of whether the firms currently operating in India are enjoying uncompetitive levels of market power. Although the findings presented earlier suggest a degree of concentration in India's seed and agbiotech industries, there is no immediate suggestion that such concentration has led to significant exercising of market power by any one or set of firms. For example, studies of India's cotton seed market do not provide evidence of farmer or consumer welfare losses owing to private firms' involvement in the introduction of either cotton hybrids or Bt cotton (Rao and Dev 2009; Qaim et al. 2006; Murugkar, Ramaswami, and Shelar 2006; Qaim 2003). In fact, the Indian seed and agbiotech industry might be viewed as a still-emerging sector and attribute the current levels of concentration to insufficient market development, limited participation of firms with significant R&D capacity, and inadequate exploitation of available technologies, both GM and non-GM.

If the growth potential of India's agricultural innovation market is to be realized, we might actually expect a greater level of acquisitory behavior in its seed and agbiotech industries. This was the case in the global seed and agbiotech industry during the 1990s, when mergers, acquisitions, and licensing agreements were all part of the rapid acceleration of investment in the sector unleashed by the prospects of agbiotech. This has not yet happened in India. However, there is a possibility of seeing more acquisitory behavior in the near future if both foreign and domestic firms recognize the potential in India's relatively large markets for rice and maize seed, and if there is greater clarity on the enforcement of the intellectual property and regulatory regimes pertaining to cultivar improvement and agbiotech.

The moderate levels of industry concentration and the potential for growth should not reduce the need to remain vigilant over anticompetitive practices. The constant monitoring and occasional prosecution of anticompetitive practices in the U.S. seed and agbiotech industries stands as one of several models for India as the industry develops. India's Competition Act of 2007[7] is a step in the right direction, and its careful application to the agricultural innovation market is critical to ensuring both innovation and competition in the industry without the unwieldy impacts of price controls and other market distortions.

7 The 2007 amendment of the Competition Act of 2002 empowers the Competition Commission to act as the market regulator for anticompetitive conduct to protect the interest of consumers. The act prohibits any agreement between enterprises relating to the production, supply, distribution, storage, acquisition, or control of goods or provision of services that causes or is likely to cause an appreciable adverse effect on competition.

Future Scenarios

Several scenarios may play out in India over the coming decade, with implications for both the rate of innovation and the distribution of welfare resulting from new agricultural technologies. Here are some of the more likely scenarios.

The Fragmentation Scenario

If the Indian seed and agbiotech industries continue to operate as they are today, the industry will remain fairly fragmented with a mix of small seed traders, medium-sized firms, and a few foreign firms addressing crops like hybrid maize and hybrid rice. Each will claim its own niche, rely on hybrids to protect their IP, or survive on the multiplication and distribution of public breeding materials. Yet the seed business will be plagued with spurious seeds and *me-too* copies, and the industry will be unable to capture the synergies that emerge from R&D investment, mergers, acquisitions, licensing, and other strategies that bring together expertise, capital, IP, and market share. Few firms will be motivated to explore new technological opportunities, especially if events like the Bt eggplant moratorium continue to disincentivize investment. Ultimately, the strategic behavior needed to accelerate the rate of innovation will not occur so long as the firms with good research capacity, breeding materials, or distribution networks are undervalued.

The Protection Scenario

An alternative scenario is that which has proven effective with Bt cotton—rapid innovation through widespread dissemination of a single set of viable technologies and protection of IP through biological mechanisms (hybrids) and legal mechanisms (licensing). Here, the agbiotech firm (MMB) licensed its Bt gene to mainly domestic firms with quality breeding materials and good distribution networks (Rasi Seeds, Nath Seeds, and so forth). This strategy tends to provide the technology firm with a strong first-mover advantage. Interestingly, this approach drove out some small seed traders and smaller firms and encouraged industry consolidation. In spite of this, the cotton seed sector retains a good deal of competition and is still dominated by Indian companies. Although foreign companies have not dominated the cottonseed business, the primary technology in the form of Bt insect resistance was available as a spillover of research aimed at cottonseed markets in developed countries. This strategy also requires strong forms of IP protection; that, in India's cotton sector, has thus far played out in the form of a near-exclusive use of cotton hybrids but may gain further support from the PPV&FR Authority.

The Maize Scenario

Maize has a special status in the global seed and agbiotech industry, and it is likely that this special status will be carried into India in the near future. First, maize—hybrid maize—is an attractive investment because of the relative ease with which firms can appropriate their R&D investments with the biological IPRs conferred by hybridization. Second, maize is attractive because of the potential spillovers generated by high and sustained levels of global R&D investment in the crop, given that most of the global leaders in the crop science industry have major R&D investments in maize and own valuable assets such as well-established breeding programs, high-quality genetic materials, expertise in molecular biology, and experience with regulatory processes. Third, maize is largely a feed crop in India: as GM maize technologies move into the pipeline, maize may not generate the same level of heated debate that food crops such as eggplant or rice do. Ultimately, foreign investment in maize by multinational companies in India, either through subsidiaries or joint venture partners, could result in rapid growth in the hybrid maize seed market. But the availability of, and government openness to, acquisitions of Indian seed companies by foreign firms may determine how this market develops.[8]

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[8] Despite India's policy allowing foreign direct investment in the agbiotech sector, recent experience in South Africa illustrates how such investments can be inhibited. Pioneer/Dupont, saw its bid for Pannar Seeds, a regional seed company operating in southern and eastern Africa, blocked over concerns about anticompetitiveness in the maize seed market. The matter

The Rice Scenario

Rice is a far more sensitive crop to the Indian public, and efforts to explore new technological opportunities are likely to be slow-going in the short term. Nonetheless, the existence of foreign and domestic investment in rice hybrids indicates that there is underexploited potential in the rice sector. With better breeding materials (both public and private) and stronger enforcement of IP protection, hybrid rice could take off rapidly in India. The success of hybrid rice in the next 20 years will be the most important factor in the development of the rice seed industry. Given the size of India's rice market, improved rice hybrids and the resulting adoption could set off a flurry of strategic behavior as firms compete to develop rice hybrids through R&D investment and technology licensing, acquire local marketing and sales outlets, and establish their competitive edge in the market. If hybrid rice gains acceptance, private firms may seize the chance to use hybrids as a platform for GM-based improvements, such as, for example, insect resistance, drought resistance, and nitrogen use efficiency.

The Wheat Scenario

The scenario for wheat is much more problematic. The most optimistic assumptions for widespread adoption of hybrid wheat are that it will be 10 to 20 years off. Therefore, the wheat seed business is likely to remain largely a varietal business with little interest from the private sector. R&D expenditures will remain a fraction of those for cotton, rice, and maize. Public development of wheat varieties will continue as in the past; however, the benefits from additional investment may not be realized. A scenario in which wheat yields grow more rapidly may require a substantial increase in public R&D investment; more investment from the international research system in breeding, biotechnology, and crop management to accelerate technical progress and improve productivity; and the enforcement of IPRs for wheat under the PPV&FR Act.

The Transformation Scenario

The extent of innovation and competition in the upstream technology market will depend heavily on the time required to commercialize competing technologies, the performance of those technologies in the product development stage, and spillover from R&D conducted in other countries. Innovation and competition in the downstream seed market will depend not only on commercialization times, product performance, and spillovers, but also on the terms and conditions of licensing agreements, the scope of patent protection, the ownership of elite germplasm, and the design of appropriate business models for the Indian market. Transformative—even revolutionary—technology platforms may be particularly important in this scenario, especially for reaching small-scale, resource-poor farmers in India's more marginal agroecologies. Hybrids—starting first with maize, then rice, and eventually wheat—may be one such platform. By offering firms the ability to appropriate a portion of the gains from innovation, hybrid rice provides a stepping stone for private investment in other crop improvement technologies embedded in the hybrids, including transgenic technologies for drought tolerance, salinity tolerance, and insect resistance.

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is still pending in appeals (Gillam 2010).

7. CONCLUSION

Whereas the yield and output of rice, wheat, and maize have grown dramatically in India since the Green Revolution that began in the 1960s, the rate of yield gain for these crops is now falling. This has raised concerns among policymakers, many of whom are looking to revitalize the contribution of science, technology, and innovation to agricultural sector growth. But unlike in the Green Revolution, it is the private sector that may contribute to growth in coming years. India's seed and agbiotech industries possess both the technological and financial resources to open new opportunities for India's farmers.

However, India's seed and agbiotech industries are still at a relatively nascent stage of development, and there are questions about whether the industries and the policies that govern them can optimize this contribution. There are also concerns that the millions of small-scale, resource-poor farmers in India will be bypassed by the private sector altogether.

The available evidence suggests that several elements must come together before the private sector's contribution to both innovation and social welfare can be realized in India. First is continued public investment in *push* mechanisms that lower the costs of R&D and promote spillovers from public R&D into the private sector. However, additional investment is also needed in *pull* mechanisms that increase the expected returns to R&D by improving market conditions, particularly for those crops, traits, and technologies that are most relevant to small-scale, resource-poor farmers in India.

The public sector's contribution to private research and to the commercialization of new technologies can be strengthened through new policies and incentives that encourage innovation. Regulatory uncertainties clouding agbiotech and GM crop improvement in India need to be resolved in order to widen the technology pipeline and give companies the confidence to invest. More data, information, and analysis must be provided in the public domain on IPR applications, ownership, and issuances so that decisionmakers can act more strategically in the innovation market and make corrections as it evolves. Finally, anticompetitiveness issues notwithstanding, there is unexploited potential for much more acquisitory behavior in the seed and agbiotech industries that encourages horizontal and vertical integration, and encourages firms to increase their production efficiency.

There are several possible scenarios for the future of India's seed and agbiotech industries. The baseline scenario—the status quo—is a low-innovation situation in which these industries remain a fragmented mix of small domestic firms and large foreign firms relying on hybrids to protect their intellectual property, or surviving on the multiplication and distribution of public breeding materials. The more optimistic scenario is a high-innovation situation in which firms develop business models based on maize, rice, and possibly even wheat hybrids that offer smallholders a range of technological solutions to different agroecological constraints throughout India. The latter scenario likely holds greater promise for agricultural productivity growth in India than the status quo scenario. However, significant policy reforms will be needed to make it into a reality.

APPENDIX: SUPPLEMENTARY TABLES

Table A.1—Mergers, acquisitions, and alliances in the Indian seed and agbiotech industry, 2001–2011

Company (parent)	Estimated revenue from seed and agbiotech sales US$ millions	Estimated technological capacity 1 = low; 2 = medium; 3 = high	Notes
Advanta (UPL) Group[a]	$104 globally[a] $23 in India	2	The UPL group of companies acquired Advanta in 2005; Advanta is India's first multinational seed company.
Advanta		2	Advanta holds 9% of the hybrid rice market (total market valued at ~$100–150 million) and 10% of the maize market (total market valued at ~$280 million).
Golden Seeds			Acquired in 2007; working in vegetable seeds, with a major presence in cauliflower, tomato, gourds, and okra.
Pacific Seeds Australia			Acquired in 2007; primarily geared to crops and traits for the Australian and ex-India market in Asia.
Unicorn Seeds			Acquired in 2008; working in vegetable seeds.
Garrison and Townsend[b]	$11 globally		Acquired in 2008; working in sorghum seed in the U.S. market.
Groupe Limagrain (U.S. sunflower only)			Advanta purchased Groupe Limagrain's U.S.-based sunflower business in 2008.
Technical collaborations			
DNA Landmarks		3	A unit of BASF. Primarily a technology supplier, DNA Landmarks began collaborating with Advanta on marker-assisted breeding for vegetable crops in 2009.
Arcadia Biosciences		3	Arcadia Biosciences licensed its nitrogen-use efficiency and salt tolerance GM technologies for sorghum to Advanta in 2009.
LongReach Plant Breeders		3	Primarily a wheat seed breeding company in Australia; involved in a technology joint venture with Syngenta since 2008.

Sources: [a] Advanta (2008); Asia Pacific Seed Association, various documents; authors' estimates. Figures from Advanta (2008) are for 2007 and include revenues from animal feeds marketed by Nutrifeed, a subsidiary of Advanta.
Source: [b] Forbes (2007); figures are for 2007.

Table A.1—Continued

Company (parent)	Estimated revenue from seed and agbiotech sales US$ millions	Estimated technological capacity 1 = low; 2 = medium; 3 = high	Notes
Groupe Limagrain[c]	$1,834 globally $57 in Asia	2	Leading global wheat seed company; fourth largest seed company worldwide.
Groupe Limagrain	na	2	
Vilmorin	na	2	Vilmorin is Groupe Limagrain's wheat seed company.
Avesthagen[d]	$8		Primarily a technology supplier in India; owns several small seed companies. Strategic alliance with Groupe Limagrain began in 2010.
Swagath Seeds	na		Working primarily in seed for field crops. Acquired by Avesthagen in 2006.
Cee Kay Seeds	na		Working primarily in vegetable seed.
Atash Seeds	na		Owned by Vilmorin (51%) and Avesthagen (49%) as of 2009.
Technical collaborations			
Arcadia Biosciences	—		Arcadia Biosciences licensed its water efficiency technology for wheat in 2011.
Bayer CropScience Group[e]	$700 globally $62 in India	2	
ProAgro	na	2	Acquired in 1999; working in rice, cotton, pearl millet, maize, and sorghum.
Nunhems	na	2	Acquired in 2002; working in vegetable seed.

Source: [c] Limagrain (2010). Figures are for 2009–2010.

Source: [d] Money Control (2010). Figures are for 2009–2010.

Sources: [e] Bayer (2010). Figures are for 2010; BioSpectrum (2010); authors' estimates.
Note: "na" denotes that data are not available.

Table A.1—Continued

Company (parent)	Estimated revenue from seed and agbiotech sales US$ millions	Estimated technological capacity 1 = low; 2 = medium; 3 = high	Notes
Monsanto-Mahyco Group[f]	$7,600 globally	3	Monsanto's global revenue on seeds and traits in 2010 is estimated at $7.6 billion.
Monsanto India[g]	$55 in India	3	Working in maize under the DeKalb brand in India.
Mahyco[f]	$67 in India	2	Monsanto purchased a 26% share of Mahyco in 1998.
Mahyco-Monsanto Biotech	$20–30 in India	3	Mahyco-Monsanto Biotech is a 50–50 joint venture formed to license Bt cotton traits.
Devgen[h]	29 million globally < $5 in India	2	Devgen acquired Monsanto's hybrid rice, sunflower, sorghum, pearl millet business in India in exchange for $25 million in equity in 2007.
Technical collaborations			
Arcadia Biosciences	—	3	Arcadia Biosciences entered into a technology agreement with Mahyco on its abiotic stress–tolerant genes for rice in India in 2008.
Pioneer/Dupont Group[i]		3	
Pioneer Hi-Bred International/Pioneer Overseas Corporation	$5,300 globally $5–10 in India	3	Pioneer Hi-Bred International operates in India through its Indian subsidiary.
Nandi Seeds	na		Acquired in 2009; working primarily in cotton seed.
Nagaijuna Seeds	na		Acquired in 2009; working with cotton germplasm.
Technical collaborations			
Arcadia Biosciences	—	3	Arcadia Biosciences has a technology agreement with Pioneer Hi-Bred International for its nitrogen-use efficiency traits for maize worldwide, including India.

Sources: [f] BioSpectrum (2010), including only GM seeds, molecular markers, and related products; the value of seed sales are not included; authors' estimates.

Source: [g] Economic Times (2011). Includes revenues from all sources, in addition to seed and agbiotech products.

Sources: [h] Devegen (2010). Figures are for 2009–2010.

Sources: [i] Dupont (2011); authors' estimates.

Table A.1—Continued

Company (parent)	Estimated revenue from seed and agbiotech sales US$ millions	Estimated technological capacity 1 = low; 2 = medium; 3 = high	Notes
Syngenta Seeds Group[j]	$2,865 globally < $50 in India	3	Working primarily in maize and rice seed.
Syngenta India			
Technology collaborations			
LongReach Plant Breeders	Na		Engaged in a joint venture on wheat improvement technology with Advanta.
Metahelix Group[k]		1.5	
Metahelix Life Sciences	< $25	1.5	
Dhaanya Seeds	na		Metahelix markets its Bt cotton hybrids through Dhaanya Seeds, acquired in 2002.
Ankur Seeds[k]	$22	1	Working in rice, maize, cotton, and vegetable seed. Cotton and vegetable seed provide primary source of revenue. Involved in technology alliance since 2009 with KeyGene, a company specializing in molecular breeding, to improve Ankur's field crops breeding program.
Shriram Bioseed Genetics India[k]	$10	1.5	Subsidiary of DCM Shriram Consolidated Ltd. group of companies. Acquired Bioseed equity in 2002 with 100% in 2008.

Sources: [j] Syngenta (2010). Figures are for 2010; authors' estimates.

Source: [k] BioSpectrum (2010). Figures are for 2009–2010.

Table A.1—Continued

Company (parent)	Estimated revenue from seed and agbiotech sales US$ millions	Estimated technological capacity 1 = low; 2 = medium; 3 = high	Notes
JK Agri Genetics[k]	$7	1.5	Subsidiary of JK group of companies.
Vibha Seeds[l]	$5–10	1	Working in maize, rice, cotton, and vegetable seed. Revenue primarily from cotton and vegetable seed. Maize and rice seed revenue estimated at < $1 million. Involved in a technical collaboration since 2007 with the Australian Center for Plant Functional Genomics focusing on abiotic stress tolerance.
Nath Bio-Gene[k]	$17	1.5	Working in maize, rice, cotton, and vegetable seed. Maize and rice seed revenue estimated at < $3 million. Involved in collaboration with a Chinese company on hybrid rice.
Ganga Kaveri Seeds[l]	~$5	1	Working in rice, maize, cotton, sorghum, and pearl millet seed.
Rasi Seeds[k]	$75	1	Working in rice, maize, cotton, sorghum, and vegetable seed. Rice and maize revenue estimated < $5 million.
Naziveedu Seeds[k]	$100	1	Subsidiary of NSL group of companies. Working in rice, cotton, maize, vegetable, and other seed. Rice and maize revenue estimated at < $10 million.
Krishidhan Seeds[k]	$27	1	Working in rice, maize, cotton, vegetable, and other seed. Rice and maize revenue estimated < $3 million. Engaged in a technical collaboration since 2008 with Dutch biotech company Proteios International BV to develop molecular markers and DNA detection technologies for cotton.
Ajeet Seeds[k]	$21	1	Working in rice, maize, wheat, cotton, vegetable, and other seed. Rice, maize, and wheat revenues estimated < $3 million.

Source: [k] BioSpectrum (2010).

Source: [l] Authors' estimates.

Table A.2—Leading seed and agbiotech firms in India

Company/group	Investments in			Investments in agbiotech for				
	Crop protection chemicals	Conventional seed	Agricultural biotechnology (seeds and traits)	Rice	Wheat	Maize	Vegetables	Cotton
Advanta (UPL) Group		√	√	√		√	√	√
Groupe Limagrain		√	√	√	√	√	√	√
Bayer CropScience	√	√	√	√		√	√	√
Monsanto-Mahyco Group	√	√	√	√	√	√	√	√
Pioneer/Dupont Group	√	√	√	√		√		√
Syngenta Seeds Group	√	√	√	√		√	√	√
Metahelix Group		√	√	√		√	√	√
Ankur Seeds		√	√[a]	√	√	√	√	√
Shriram Bioseeds		√	√	√		√	√	√
JK Agri Genetics		√	√	√		√	√	√
Vibha Seeds		√	√	√	√	√	√	√
Nath Bio-Gene		√	√	√		√	√	√
Ganga Kaveri Seeds		√	√[a]	√		√		√
Rasi Seeds		√	√[a]	√		√		√
Nuziveedu Seeds		√	√[a]	√	√	√	√	√
Krishidhan Seeds		√	√[a]	√	√	√	√	√
Ajeet Seeds		√	√[a]	√	√	√	√	√

Source: Authors, compiled from corporate documents.
Note: [a] Denotes firm with Bt cotton products on the market but limited GM research and development capacity.

Table A.3—Import details of rice transgenic materials in India, 1997–2008

Year	Trait	Country of import	Importing organization
1997	High nutritional value	Philippines	JNU, New Delhi
1998	Herbicide resistance (HR)	United States	CCMB, Hyderabad
1999	Insect resistance (IR)	—	Monsanto Genetics Pvt. Ltd., Jalna
1999	IR	United Kingdom	Proagro-PGS Ltd., Gurgaon
2000	IR and HR	Belgium	Hybrid Rice International, Gurgaon
2001	Bacterial pathogen *Xanthomonas oryzae* resistance and insect resistance	Switzerland	DRR, Hyderabad
2001	Beta carotene biosynthesis in seeds	Switzerland	DRR, Hyderabad
2002	IR and glufosinate ammonium herbicide resistance	Belgium	Hybrid Rice International
2002	Bacterial pathogen *Xanthomonas oryzae* resistance	Philippines	Mahyco, Hyderabad
2003	Beta carotene biosynthesis in seeds	Vietnam	DRR, Hyderabad
2003	Nematode resistance	Germany	Mahyco, Mumbai
2005	Beta carotene biosynthesis in seeds	United States	IARI, New Delhi
2006	IR	China	Nath Seeds Ltd., Aurangabad
2007	IR and glufosinate ammonium herbicide resistance	Belgium	Bayer Bioscience Pvt. Ltd., New Delhi
2007	HR	United States	Mahyco, Mumbai
2008	IR and glufosinate ammonium herbicide resistance	Belgium	Bayer Bioscience Pvt. Ltd., New Delhi
2008	Improved nutrition	Philippines	Rice Research Station, West Bengal
2008	IR	China	Pioneer Overseas Corp., Hyderabad
2008	Improved nutrition	United States	Pioneer Hi-Bred International Inc.

Source: Randhawa and Chhabra (2009).

Table A.4—Imports of transgenic material for maize to India, 1997–2008

Year	Trait	Country of import	Importing organization
1998	Insect resistance (IR)	United States	Mahyco, New Delhi
2001	IR	United States	Syngenta Pvt. Ltd., Pune
2003	Herbicide resistance (HR)	South Africa	Monsanto Genetics India Ltd., Mumbai
2005	IR	United States	Monsanto Genetics India Ltd., Mumbai
2005	IR	Philippines	Monsanto Genetics India Ltd., Mumbai
2005	IR	Philippines	Monsanto Genetics India Ltd., Mumbai
2006	IR	Philippines	Monsanto Genetics India Ltd., Mumbai
2006	IR and HR	South Africa	Monsanto Genetics India Ltd., Mumbai
2006	HR	South Africa	Monsanto Genetics India Ltd., Mumbai
2007	HR	South Africa	Metahelix Life Sciences, Bangalore
2007	HR	Philippines	Monsanto Genetics India Ltd., Mumbai
2007	HR	United States	Monsanto Genetics India Ltd., Mumbai
2008	IR	United States	Monsanto Genetics India Ltd., Mumbai
2008	IR and HR	United States	Monsanto Genetics India Ltd., Mumbai
2008	HR	Philippines	Syngenta India Pvt. Ltd., Pune
2008	Reporter gene	United States	Dupont Seeds Pvt. Ltd.
2008	IR	United States	Dupont India Pvt. Ltd., Hyderabad
2008	IR	United States	Dow Agrosciences India Pvt. Ltd., Mumbai
2008	IR	United States	University of Agricultural Sciences, Bangalore

Source: Randhawa and Chhabra (2009).

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