Food Policy 45 (2014) 88–100

Contents lists available at ScienceDirect

Food Policy

journal homepage: www.elsevier.com/locate/foodpol

The seed and agricultural biotechnology industries in India: An analysis of industry structure, competition, and policy options

David J. Spielman [a,*], Deepthi E. Kolady [b], Anthony Cavalieri [a], N. Chandrasekhara Rao [c]

[a] International Food Policy Research Institute, 2033 K St. NW, Washington, DC 20006, USA
[b] College of Agriculture and Life Sciences, Cornell University, Ithaca, NY 14852, USA
[c] Agricultural Economics Research Unit, Institute of Economic Growth, University of Delhi Enclave, North Campus, Delhi 110007, India

ARTICLE INFO

Article history:
Received 24 October 2012
Received in revised form 31 December 2013
Accepted 11 January 2014

Keywords:
Seed markets
Agricultural biotechnology
Industrial organization
Food staple crops
India

ABSTRACT

Since the late 1980s, technological advances and policy reforms have created new opportunities for private-sector investment in India's seed and agricultural biotechnology industries. These changes have had a significant impact on cotton yields and output in India, but less so for rice and wheat—the country's main cereal staples—for which yield growth rates are tending toward stagnation. This analysis examines the structures of these industries, their potential effects on competition and innovation, and the policies that may improve both industry performance and the delivery of new productivity-enhancing technologies to India's cereal production systems. Our findings suggest that more substantive policy reforms are needed to encourage further innovation, reduce regulatory uncertainty, and encourage firm- and industry-level growth, while continued public spending on agricultural research is needed to support technological change.

Introduction

Rice and wheat weigh heavily in the calculus underlying India's food policy discourse. For a majority of the 876 million people in India's rural population—69% of the country's total population—these major cereals represent an important source of employment, income, and subsistence. Across the entire population, these staples provide more than 54% of total caloric energy to the average diet, and more than 70% to the poorest expenditure decile (Dubey and Thorat, 2011; Birthal et al., 2011). For reasons such as these, the country's policymakers place high priority on maintaining low food prices for its urban and rural poor through continuous growth in cereal yields and output.

This food security imperative has motivated numerous government interventions in cereal improvement since the 1950s, most notably the public investments in infrastructure and research that doubled the yield and output of rice and wheat between 1965 and 1985 (Hazell, 2010; Fan et al., 2008; Fan, 2003). The latest intervention—the 2007 National Food Security Mission (NFSM)—similarly seeks to boost production of major cereals through improvements in farming practices, accelerated adoption of modern technologies, and adoption of resource conservation practices (NFSM, 2007).

This latest intervention is both timely and urgent because yield growth rates for India's major cereals have shown a downward trend toward stagnation since the mid-1980s (Rada, 2013; Ganesh-Kumar et al., 2012). Yield growth rates across India's 44 million hectares under rice cultivation have dropped to less than 2%—well below the 3% growth rates that were achieved during the early 1980s. Similarly, yield growth rates across India's 28 million hectares under wheat cultivation have dropped to less than 1%, far below the 4% growth rates achieved during the early 1980s. By all accounts, yield growth in India will have to come from improving allocative efficiency and technological progress, and not from expansion into new agricultural land.

Although cereal supply projections do not suggest an impending Malthusian crisis for India (Ganesh-Kumar et al., 2012), they do indicate the need for urgent investment in cereal productivity improvement. But while public expenditures on agricultural research have doubled since the mid-1990s (Pal et al., 2012), there are still concerns about the ability of this spending to reinvigorate cereal yield growth rates and reach India's cereal systems—the majority of which are populated by small-scale farmers with widely varying access to competitive markets for inputs, technologies, and outputs.

Some policymakers engaged in India's food policy discourse have recently argued that the private sector is poised to bridge this investment gap. Since the late 1980s, technological advances and policy reforms have provided new growth opportunities in India's

* Corresponding author. Tel.: +1 202 862 8137.
E-mail addresses: d.spielman@cgiar.org (D.J. Spielman), dek28@cornell.edu (D.E. Kolady), tonycavalieri@msn.com (A. Cavalieri), chandra@iegindia.org (N.C. Rao).

http://dx.doi.org/10.1016/j.foodpol.2014.01.001
0306-9192/

seed and agricultural biotechnology (agbiotech) industries that opened the door for the private sector to take a leading role in boosting agricultural productivity growth. The impacts of these changes are well documented for India's cotton sector, where the introduction of hybrids and insect-resistant transgenic traits have contributed to increases in cultivated area, yield, output, and exports and, consequently, to welfare improvements among cotton farmers (Gruere and Sun, 2012; Kathage and Qaim, 2012).

Less documented are the impacts of similar technological advances and policy reforms on India's major cereal crops. Private investment in the research, development, and marketing of improved cultivars and seed-based technologies for rice and wheat in India has lagged that of cotton. Nonetheless, some public policymakers—alongside a number of major corporate players—are confident that private investment in major cereal crops will reverse the trend. They argue that with the right signals, private firms will invest in a manner that accelerates both yield and output growth for major cereals across India (Gadwal, 2003; Rao and Dev, 2009; Rao, 2009).

This optimism hinges partly on signs that the policy regime is increasingly favorable to the private sector. Stronger plant variety protection rights, greater openness to foreign investment in agbiotech, new tax incentives, and novel high-tech initiatives such as the Genome Valley in Andhra Pradesh are all signs that private investment in cultivar improvement are welcome. 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 the industries' responses will help reverse the downward trend of cereal yield growth rates.

This paper attempts to shed new light on this question in two ways. First, the paper highlights the importance of studying relationships between science, innovation, industry structure, and growth along lines first set forth by Schumpeter (1934). While the paper does not introduce a new theory of Schumpeterian innovation, it does provide a novel application of the theory to developing-country agriculture and knowledge-intensive agroindustrialization which is still a nascent literature due to the small size of agroindustry in many developing countries, insufficient interest in such analysis, or simple data limitations. Second, the paper integrates data from several primary and secondary sources to compile a unique dataset that allows us to explore relationships between science, innovation, industry structure, and growth in the context of Indian agriculture.

The paper proceeds as follows. Section 'Conceptual framework' constructs a conceptual framework that ties together innovation, competition, and public policy in developing-country agriculture. Section 'Data and data sources' details the data used in this study. Section 'Industry characterization' examines the players, structures, and policies governing the seed and agbiotech industries in India. Section 'Key findings' discusses the study's findings, and section 'Policy recommendations' provides policy recommendations. Concluding remarks are offered in section 'Conclusion'.

Conceptual framework

Many developing countries face a significant challenge in integrating the private sector into national efforts to accelerate agricultural productivity growth while simultaneously protecting the welfare of farmers and consumers. Nonetheless, private sector integration is of increasing interest among public policymakers, corporate decisionmakers, and civil society, and among researchers studying the rapidly growing complexity of food and agricultural systems in developing countries, particularly in Asia (Reardon et al., 2012). These systems are often characterized by intricate networks of value chains in which farmers, firms, entrepreneurs, and intermediaries engage in relatively sophisticated webs of production, processing, and marketing activities (Reardon and Timmer, 2012). The sheer complexity of these networks requires a better theoretical framing and more robust analytical approaches to understand the impacts of change on farmers, consumers, and firms. This challenge is particularly relevant in those segments of the value chain where science, technology and innovation play a central role in driving change. Such is the case with the research, development, and delivery of improved cultivars—the physical embodiment of plant science and molecular biology that aims to enhance the productive powers of cultivated crop varieties (Pingali and Traxler, 2002; Byerlee and Fischer, 2002). Whereas earlier technological shifts in developing-country agriculture have been largely driven by public investment in science and technology, new opportunities to combine plant breeding and advanced biotechnology have brought private investment into the industry during the last two decades (Spielman, 2007). This raises the issue of how the gains from technological change are distributed across a more complicated landscape involving farmers, firms, and government.

An analysis of these issues might begin with Schumpeter (1934), who posited that technological change results from innovation undertaken by large firms that, through temporary monopolies or other forms of market power, can appropriate the gains from innovation—albeit with short-term consequences for social welfare. In the long run, technological change and economic growth result from continuous entry and exit of entrepreneurs who innovate on production processes and secure advantages that force the exit of older, obsolete firms (that is, "creative destruction") from the market.

An extension of the Schumpeterian system into empirical analysis requires a framework that can illustrate the complex—and often endogenous—relationships between innovation, market structure, and economic institutions designed to promote or impede innovation and productivity growth. For example, the literature on new empirical industrial organization offer insight into the relationship between innovation and competition in the agricultural sector, paying close attention to how alternative policies influence this relationship, and concerning itself with the measurement of research and development (R&D) investment trends, firm size, industry concentration, barriers to market entry, strategic corporate behavior, cost efficiency, and welfare outcomes (Azzam, 1997; Appelbaum, 1979, 1982; Schroeter, 1988; Wann and Sexton, 1992; Azzam and Pagoulatos, 1990; Schroeter and Azzam, 1991; Chen and Lent, 1992; Sexton, 2000). Similarly, the literature on new institutional economics offers perspective on how emergent rules and norms can overcome market imperfections and reduce transactions costs in the agricultural sector to improve the efficiency with which goods and services are exchanged (Kherallah and Kirsten, 2002; Kydd and Dorward, 2004; Dorward et al., 2004; Fafchamps, 2005). Together, these perspectives are useful in characterizing the structure and performance of knowledge-intensive industries where high levels of capital investment, technical proficiency, intellectual property rights, vertical integration of production, and other attributes are significant barriers to entry and can raise issues for competition, innovation and efficiency.

Based on these ideas, our underlying conceptual framework is as follows. First, we assume that technological change initially occurs within innovation markets, or markets that typically exist prior to the development of actual goods or services that can be exchanged in a market, and is characterized by (1) significant levels of knowledge intensity that require sizable investment in R&D, and (2) barriers to entry associated with both fixed production and regulatory costs (Brennan et al., 2005). In many developing countries, innovation markets in the agriculture sector may include firms that exhibit a wide range of technological capability and exchange scientific information, materials, and personnel through a variety of mechanisms—market-based exchanges, technical collaborations, joint ventures, mergers, and acquisitions.

Second, we assume that technological change advances from innovation markets to product markets, or markets where embodiments of technology are exchanged in the form of goods and services. In these markets, firms sell products embodying novel technologies to end-users who, in the context of developing-country agriculture, are often highly dispersed, small-scale, resource-poor farmers with varying levels of capacity to participate in these product markets.

Third, we assume that the government—the social planner that aims to achieve the best possible outcomes for all parties—intervenes in these markets to simultaneously encourage innovation, inhibit anticompetitive behavior among firms, and increase the participation of end-users in a competitive market. This balancing act requires that government has sufficient evidence with which to make policies and investments that address outcome variables of interest, such as productivity growth and welfare improvement. Sufficient evidence requires, at a minimum, (1) characterization of the heterogeneity among firms in the innovation and product markets, (2) characterization of industry structure and conduct, and (3) an analytical sense of how public policies and regulations influence innovation, competition, and other outcome variables.

Finally, we assume that this body of evidence can be used to construct alternative scenarios in which industry attributes, strategic corporate behavior, and public policy affect the balance between a socially desirable rate of innovation, on the one hand, and the development of a competitive market for products and services that embody innovation, on the other hand. A better understanding of how policies influence an industry's structure and conduct, and how these resulting attributes contribute to (or hinder) innovation and productivity growth can, in turn, improve both industry performance and the delivery of new technologies in developing-country agriculture.

Another way of illustrating this conceptual framework is to examine the "failures" that inhibit private-sector innovation for food staple crops in developing countries (Naseem et al., 2010). A classic example is the market failure that occurs with the development of improved cultivars for crops of marginal commercial value, such as self-pollinating varieties of rice and wheat. Because farmers can replant saved seed of self-pollinating varieties—thereby capturing the gains to innovation embodied in the seed—and because firms may not be able to prevent this through legal or technological means, the profit-maximizing firm will optimally choose not to invest in cultivar improvement at a socially desirable level. This results in a chronic undersupply of improved cultivars in the market, thus requiring public-sector intervention in the market, typically through the financing and management of plant-breeding programs and agricultural extension services.

While such market failures exist for many crops in many countries, institutional arrangements can emerge to improve the governance of innovation and reallocate some of the gains from innovation to the innovators themselves. IPRs are an example of such an institution, as they provide innovators with a time-bound monopoly on an innovation and a means of recouping their investments in R&D. IPRs, such as biological patents and plant variety protection certificates, aim to reduce the transaction costs associated with contested claims over the rights to innovation rents, while simultaneously incentivizing innovative behavior. Similarly, quality assurance systems for planting materials (for instance, seed certification or truth-in-labeling) are institutions designed to address information asymmetries resulting from the inability of farmers to make *ex ante* assessments of seed quality when such information is known only by the seller (Tripp and Louwaars, 1997). But where these types of legal institutions do not sufficiently facilitate knowledge exchanges, other institutions may also emerge. Examples include vertical integration of an agricultural supply chain—from seed supply to output sales—by a single company to protect the IPRs of technologies used throughout the chain.

Yet even functional markets and conducive institutions can be an insufficient means of incentivizing innovation. Higher-order systemic failures result from the inability of agents engaged in the knowledge production process to learn about each other, identify areas of complementarity and synergy, build and sustain trust through interpersonal or organizational relationships, communicate and exchange ideas effectively, or respond to leadership. Systemic failure also impedes processes of knowledge exchanges and can further exacerbate knowledge production (Hall et al., 1998; Spielman, 2006).

Using this broad conceptual framework, consider the following criteria with which to evaluate the growth and evolution of seed and agbiotech industries in India. First, how do market signals and public policies incentivize innovation in the seed and agbiotech industries? Second, how do these signals and policies influence the structure and conduct of these industries? Third, what are the growth and development implications of the emerging scenarios for these industries? We use these criteria to examine India's seed and agbiotech industries in the following sections.

Data and data sources

The main sources of data and information for this study are as follows.

BioSpectrum-ABLE survey: BioSpectrum (2010), 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 data used here focused only on genetically modified (GM) seeds, molecular markers, and related products.

Francis Kanoi Marketing Research Group: In 2008–09, the Francis Kanoi Marketing Research Group conducted a survey-based study on rice cultivation and the rice seed market in India. The study's main objectives 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 in the 16 major rice-growing states in India for the 2008–09 agricultural season.

IGMORIS (various years): The Indian GMO Research Information System (IGMORIS, 2010) is a database on activities involving the use of genetically modified organisms (GMOs) and related products in India. The website contains information on commercially approved GM events and insect-resistant *Bacillus thuringiensis* (Bt) cotton since 2002, and data on GM field trials since 2006.

Key informant interviews: In 2008–10, we gathered information from a series of unstructured interviews with 77 experts equally representing India's public and private sectors (Table 1). The interview questions were related to cereal seed and agbiotech market opportunities in India, R&D investment strategies and constraints, product delivery strategies and constraints, IPRs, technology forecasts and opportunities, and regulatory issues.

Industry characterization

In keeping with the conceptual framework set forth earlier, this analysis provides an initial characterization of (1) the heterogeneity among firms in the innovation and product markets, (2) the

Table 1
Key informants interviewed, 2008–10. *Source:* Authors.

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

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.

structure and conduct of the Indian seed and agbiotech industries, and (3) the public policies and regulations that influence innovation and competition.

The Indian seed and agbiotech industries

India's evolving seed and agbiotech industries are a segment of the formal economy involving commercial entities engaged in the (1) breeding, multiplication, and distribution of cereal seed and other planting material and (2) research, development, commercialization, and distribution of agbiotech applications, tools, and products, including GM cereal crops and traits. The line between these two types of commercial entities is often indistinguishable. However, there is a distinct division within the industry between what might be described as the downstream segment where firms compete in product markets by multiplying, distributing, and marketing improved seed, and the upstream segment where firms compete in the innovation market to develop technologies using advanced scientific tools and materials.

Private firms operating in the seed and agbiotech industries—in both the innovation market and the product market—represent a small but expanding part of India's total seed market. India's seed market can be divided into (1) an informal market accounting for an estimated 75% of all seed transactions, based primarily on farmers saving, selecting, and exchanging seed, and (2) a formal market accounting for the remaining 25% of all seed transactions, which is the primary focus of this paper. Within this formal market, state-owned seed production holds a 24% share—primarily through the National Seed Corporation, 13 state seed companies, and the State Farm Corporation of India—while private firms hold a 76% share (Rabobank, 2006).

Until the 1980s, India's seed industry was largely the arena of public-sector organizations. At that time, policy reforms, such as the New Policy on Seed Development (1988) and the economy-wide New Industrial Policy (1991), encouraged private-sector participation in higher-value segments of the seed market. These reforms led to an expansion of private investment in the breeding and marketing of hybrids of sorghum and pearl millet during the mid-1980s, maize in the early 1990s, cotton in the early 2000s, and rice in the mid-2000s (Pal et al., 1998; Pray and Ramaswami, 2001; Ramaswami, 2002; Joshi et al., 2005).

The Indian seed industry has grown in size and value over the last five decades. In 2008–09, the industry generated revenues of US$1.3–$1.5 billion and was ranked the world's fifth largest seed market, though serving primarily domestic demand and not export markets. It is currently estimated to be growing at an average rate of 12–13% per year, attributable to a combination of factors, including both the intensification of production and the expansion of acreage for certain crops where seed is largely purchased—that is, maize and cotton, as well as an increasing proportion of farmers who purchase, rather than save, seed (Rabobank, 2006). The industry hosts 410 regional or domestic seed firms and 6 multinational firms (Kumar, 2010). Despite these indicators of growth, the industry's top 10 firms accounted for just 25% of the total volume of seed sold by the private sector in 2005 (Rabobank, 2006).

The shift from a state-dominated seed industry to a competitive, privately led 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% of commercial seed sales of pearl millet and sorghum originated from the private sector (Pray and Nagarajan, 2009). Similarly, in 2003, an estimated 70% 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 measured as the proportion of total area cultivated under private hybrids: private hybrids accounted for 90% of pearl millet area under cultivation, 80% of *kharif* sorghum, and 60% of maize as of the late 1990s (Kumar, 2010; Francis Kanoi, 2009).

This shift to a competitive private seed industry is also visible with respect to GM crops. Private firms are the primary actors in the innovation and product markets for insect-resistant (Bt) cotton since it was commercialized in India in 2002. Although activity around GM crop development continues in India's innovation market, the market for other GM crops and traits remains at a standstill since the 2010 moratorium on the commercial release of Bt brinjal (Rao, 2010). Further, research on transgenics came to a virtual halt with stalled permission for GM field trials since April, 2012 as a fallout of the judicial process in the Supreme Court.

The relatively recent development of a private seed industry in India has meant that for many staple crops, 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 is in the early stages of maturation, particularly with respect to cereals. Seed companies in the cereals business are still working to establish their market position, strengthen their R&D capacity, and develop the infrastructure needed to supply quality products and services.

Industry actors

Private firms in the Indian seed and agbiotech industries can be classified into five categories based on their R&D capabilities, sales revenues, and sales volumes, as follows.

Technology firms are suppliers of traits, transgenic events, and other technologies that are accessed from both India and foreign countries and provided to Indian seed companies. These firms generally do not have their own seed production and marketing operations, but specialize in licensing their products to other, more downstream firms. Examples include Mahyco-Monsanto Biotech, Arcadia Biosciences, Metahelix, and Avesthagen. *Trading companies* are firms that multiply, distribute, and market publicly developed crop varieties and hybrids, and generally have no in-house R&D capacity. Examples include Harinath Seeds, Surya Seeds, and Sidhartha Seeds. *Small-sized seed firms* are similar to trading companies but often augment their production and marketing activities with small breeding programs that rely on technology accessed from other (usually domestic) public or private sources to develop hybrids and varieties that are sold under the firm's brand. Examples include Rasi Seeds and Nuziveedu Seeds, both of which are leaders in India's Bt cotton seed market.

Medium-sized seed firms are larger than their smaller-sized counterparts in terms of sales revenues and volumes, but are also distinct in that they manage higher levels of R&D capacity, usually in the form of proprietary crop-breeding programs that combine in-house R&D expertise with technologies from other public and private sources. Examples include Advanta, Shriram Bioseed, Devgen, and Mahyco. *Multinational firms* are larger, highly integrated enterprises with interests in: (1) seed, agbiotech, and agrichemicals; (2) substantial levels of R&D capacity both in India and abroad; and/or (3) varying degrees of vertical integration that bring together upstream operations in product development (traits, chemicals) with downstream operations in product marketing (seed, chemicals). Examples include many of the "big six" multinational firms: BASF, Bayer CropScience, Dow Agrosciences, Dupont, Monsanto, and Syngenta.

Ownership patterns among these firms range from closely held family businesses in the case of many small- and medium-scale seed firms, to wholly owned subsidiaries of India's large industrial family-owned conglomerates, to businesses capitalized by both domestic and foreign investment in the case of the multinational firms. These firms interact in the innovation and product markets through mechanisms ranging from licensing agreements to mergers, acquisitions, technical collaborations, and joint ventures.

Prior studies suggest that activity in both markets and integration across the markets have increased since changes in policy took effect in the early 1990s. For example, Ramaswami (2002) reports an increase in private investment in agricultural R&D during the 1990s that is primarily attributable to technological advances and stronger IPRs, resulting in a sizable private-sector presence in the seed market for many crops. Gadwal (2003) attributes approximately 30% of all R&D conducted by the private seed sector during 1998–99 to subsidiaries of, and joint ventures with, foreign firms. Relatedly, Murugkar et al. (2006) attribute much of the strategic behavior among firms in the seed industry to growth in the cotton seed segment of the market, and to Bt cotton in particular.

Cereal crops and markets

For major cereals, however, strategic behavior and research investment have 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 large and small foreign and domestic firms. Growth may be driven by new technologies developed to address India's diversity of crops, farming systems, and agroecologies, or by new business models that address the varied nature of farmers themselves, particularly small-scale farmers. We examine these issues in detail throughout the remainder of this analysis.

Rice

Rice is India's most important food crop in terms of cultivated area, production, and consumption. Despite its importance, rice's compound annual yield growth fell from 2.3% during 1968–88 to 1.6% during 1989–2008 (Kolady et al., 2012). Food policy experts generally agree that achieving similar rates will require a continuous flow of new technologies, combined with better management of resources, inputs, and policy incentives.

Of the 2.4 million metric tons of rice seed used in 2008–09 in India, 51% 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. In fact, many farmers prefer to purchase seed to switch into new varieties or to ensure better purity and germination rates than their own saved seed.

The formal rice seed market operates primarily through large-input supply firms and progressive farmers producing improved seed developed by public research organizations. This is effectively the high-volume, low-margin varietal end of the business, and is not a particularly lucrative investment for the private sector.

In fact, few private firms supplied the market with their own proprietary seed technologies for rice, such as rice hybrids. As of 2008–09, hybrid rice accounted for less than 6% of India's 44 million hectares under rice cultivation—a far cry from the NSFM's 2015 target of 25%. But in spite of the poor performance of early-generation hybrids (Janaiah, 2002), the adoption of hybrid rice in India appears to be gathering some momentum. Since 2005, the proportion of area under hybrid rice cultivation has grown at a rate of about 40% per year, 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% of area under hybrid rice cultivation (Baig, 2009; Francis Kanoi, 2009; Nirmala and Viraktamath, 2008). Forty-two rice hybrids have been released for commercial cultivation in India (Baig, 2009), including 28 hybrids from the public sector and 14 from the private sector, with 2 of the most popular originating from Bayer CropScience and Pioneer Hi-Bred International. In addition to these officially released hybrids, many more truthfully labeled private hybrids are available in the market, suggesting that more than 100 rice hybrids are currently in circulation in India (Kumar, 2008) and that the hybrid rice seed industry is a decidedly private-sector venture.

The size of the Indian hybrid rice market during 2008–09 was estimated at about 35,000 metric tons with a total value of US$142 million (Francis Kanoi, 2009). Although estimates for the number of firms marketing hybrid rice seed are incomplete, current estimates are between 30 and 60 firms (Kumar, 2008; Nirmala and Viraktamath, 2008). Several of these firms are investing heavily in R&D to increase and stabilize yield, improve grain quality, and enhance marketing and distribution networks. Although private R&D investment in hybrid rice only began 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, R&D investments are US$6–$12 million per year, with an equal amount going into GM rice R&D.

Wheat

While India's second most important food crop bears some similarities to rice, it also has distinct differences. Like rice, wheat's compound annual yield growth fell from 3.8% during 1968–88 to 1.5% during 1989–2008 (Kolady et al., 2012), attracting similar attention in India's food security discourse. But unlike rice, purchased wheat seed represents a much smaller fraction of the market—just 10% in 1998–99, though data suggest this portion grew to 18% by 2006 (Seednet, 2007), indicating emerging commercial potential. Like rice, few private firms supply the wheat seed market with proprietary seed technologies, although many large firms operate at the high-volume, low-margin varietal end of the business. Unlike rice, technological solutions, such as hybrid wheat and GM wheat, are in the early stages of development.[1]

Maize

Though far less important than rice or wheat to India's food security, maize is increasingly important to its livestock and poultry feed industries (Gulati and Dixon, 2008). The crop's compound annual yield growth rate increased from 0.9% during 1968–88 to 2.6% during 1989–2008, much of which is likely attributable to the cultivation of high-yielding maize hybrids that provide a biological form of IPR. Together, these factors provide private seed firms a profitable business model and the incentive to aggressively market their products. In the late 2000s, hybrids accounted for an estimated 60% of area under maize cultivation (Kumar, 2010), and the maize seed market was valued at about US$200–$250 million

[1] 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 it adoption rate remained extremely low—an estimated 0.09% of cultivated area in 2005 (Matuschke et al., 2007).

(Rao, 2009). During this period, more than 50% of maize R&D activity and 70% of maize seed sales were directly attributable to the private sector (Nikhade, 2003; Joshi et al., 2005).

Key findings

This section examines the structure and conduct of India's seed and agbiotech industries based on measurements of market power, competition, and strategic behavior. It then explores key policies that have influenced the industries' recent evolution, and discusses emerging scenarios and their implications for innovation, competition, and growth.

Industry structure and conduct

Although approvals for other GM crops have not been forthcoming since the first forays into Bt cotton, India's seed and agbiotech industries have continued to conduct research through the acquisition of new research materials and development of new products. Here, we analyze data on two indicators of this private investment—imports of transgenic planting materials and transgenic field trials—as proxies for the structure of the innovation market. We use the data to calculate two measures—a mobility index and an agbiotech research intensity ratio—to provide insights into the level of competition in the innovation market.

Imports of transgenic planting materials

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.

Between 1997 and 2008, the private sector accounted for 85% of the 79 imports of transgenic research materials identified by Randhawa and Chhabra (2009). As shown in Table 2, four groups of firms were leaders in the importation of transgenic research materials—Monsanto-Mahyco, Bayer, Syngenta, and Pioneer (Dupont) (see Table 3 for details on each group of firms). A crop- and firm-specific breakdown indicates that Monsanto-Mahyco Group was the leader in the import of transgenic research materials for cotton, maize, and wheat, while Monsanto-Mahyco Group and Bayer Group share this leadership position for rice.

A further breakdown of the research materials import data from Randhawa and Chhabra (2009) shows increases since 2006 in the number of both firms importing transgenic planting materials and the number of imports. Furthermore, imports by the four leading groups of firms have increased since 2004, although their share of total imports decreased from nearly 100% to slightly more than 80%. This suggests an increase in both innovative activity in the industry and the number of firms active in the industry.

Field trials

Field trials occur further downstream in the R&D process than the importation of transgenic research materials, but are still pre-market indicators of concentration within an industry. Here, an examination of GM field trial data from 2006 to 2010 provides insight into the short-to-medium-term structure and growth prospects of the seed and agbiotech industries. The Monsanto-Mahyco and Bayer groups conducted the largest number of field trials in the initial years (2006–08), although with the entry by other firms into field trials in 2009–10, industry concentration decreased (Table 3). These trends are necessarily reflected in the CR4 ratio and HH index calculated in Table 3. Although these measures rely on relatively small numbers of field trials, they are useful when benchmarking against the global and US seed and agbiotech industries, where corresponding CR4 ratios and HH indexes suggest a much lower level of concentration (for example, Brennan et al., 2005; Fernandez-Cornejo, 2004).

Public versus private R&D activity

The data on transgenic planting materials and field trials indicate that the public sector accounts for a relatively larger proportion of field trials than imports of transgenic planting materials. Key informants 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 higher 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 to the private sector.

Table 2
Private imports of transgenic material in India by importer and type, 1997–2008. *Source:* Authors, based on data from Randhawa and Chhabra (2009).

Year	Imports by type of importer			Private-sector imports by importer				
	Private-sector firms	Public research organizations	Total	Monsanto-Mahyco Group	Bayer Group	Syngenta Group	Pioneer (Dupont) Group	All other private
1997	2	1	3	0	2	0	0	0
1998	4	1	4	4	0	0	0	0
1999	6	0	6	3	3	0	0	0
2000	3	0	3	1	1	0	0	1
2001	3	4	7	0	1	2	0	0
2002	4	1	5	1	0	0	0	3
2003	4	1	5	3	0	1	0	0
2004	0	0	0	0	0	0	0	0
2005	8	2	10	3	1	3	0	1
2006	11	0	11	6	2	0	0	3
2007	6	0	6	4	1	0	0	1
2008	16	2	18	5	4	1	4	2
Total	67	12	78	30	15	7	4	11
Share of total[a]	85	16	100	45	22	10	6	16

Note:
[a] Share totals may add to more than 100 due to rounding.

Table 3
Mergers, acquisitions, and alliances in the Indian seed and agbiotech industries, 2001–11. *Source:* Authors.

Company/group (parent company)	Estimated technological capacity c. 2009[a] 1 = low; 2 = medium; 3 = high	Estimated revenue from seed and agbiotech sales c. 2009[b] US$ millions	Remarks[c]
Monsanto-Mahyco Group	3	\$7600 globally \$150 in India	*Key firms:* Monsanto India, Mahyco; *Joint ventures:* Mahyco-Monsanto Biotech (MMB); *Acquisitions:* Emergent Genetics, Devgen; *Technical collaborations:* Arcadia Biosciences
Pioneer (Dupont) Group	3	\$5300 globally \$5–\$10 in India	Key firms: Pioneer Hi-Bred International; *Acquisitions:* Nandi Seeds, Nagarjuna Seeds; *Technical collaborations:* Arcadia Biosciences
Syngenta Group	3	\$2865 globally <\$50 in India	*Key firm:* Syngenta India; *Technical collaboration:* LongReach Plant Breeders
Advanta (UPL) Group	2	\$104 globally \$23 in India	*Key firm:* Advanta; *Acquisitions:* Golden Seeds, Pacific Seeds Australia, Unicorn Seeds, Groupe Limagrain,[d] Garrison and Townsend; *Technical collaborations:* DNA Landmarks (BASF), Arcadia Biosciences, LongReach Plant Breeders
Limagrain Group	2	\$1834 globally \$57 in Asia	*Key firms:* Groupe Limagrain, Vilmorin, Avesthagen; *Acquisitions:* Avesthagen, Swagath Seeds, Cee Kay Seeds, Atash Seeds; *Technical collaborations:* Arcadia Biosciences
Bayer Group	2	\$700 globally \$62 in India	*Key firm:* Bayer CropScience; *Acquisitions:* ProAgro, Nunhems
Metahelix	1.5	<\$25 in India	
Shriram Bioseed	1.5	\$10 in India	Subsidiary of DCM Shriram Consolidated group of companies. *Technical collaboration:* KeyGene
JK Agri Genetics	1.5	\$7 in India	Subsidiary of JK group of companies
Nath Biogene	1.5	\$17 in India	*Technical collaboration:* Biocentury
Vibha Seeds	1	\$5–\$10 in India	*Technical collaboration:* Australian Center for Plant Functional Genomics
Ankur Seeds	1	\$22 in India	
Ganga Kaveri Seeds	1	~\$5 in India	
Rasi Seeds	1	\$75 in India	
Naziveedu Seeds	1	\$100 in India	Subsidiary of NSL group of companies
Krishidhan Seeds	1	\$27 in India	*Technical collaboration:* Proteios International
Ajeet Seeds	1	\$21 in India	

Notes:
[a] Technological capacity measures are based on authors' estimates from key informant interviews and analysis of industry and corporate information.
[b] Based on corporate annual reports and industry reports. See Spielman et al. (2011) for details.
[c] Includes the key seed and agbiotech firms in each group, joint ventures, acquisitions, and major technical collaborations with other private firms.
[d] U.S. sunflower business only.

Intellectual property rights

Evidence suggests that private seed firms have responded to IPR incentives laid out in the Plant Varieties and Farmers' Rights (PPV&FR) Act of 2001, the establishment of the PPV&FR Authority in 2005, and the commencement of varietal registration application processing in 2007 (Kolady et al., 2012; Mrinalini, 2011). In 2008–09, 64% of the 460 protection of plant variety (PPV) applications received by the PPV&FR Authority originated from the private sector, with the remaining 36% from public research organizations and farmers themselves. As shown in Fig. 1, the crop-wise distribution of applications for PPV certification for novel varieties in 2008–09 was concentrated in cotton, followed by the major and minor cereal crops. The largest number of applications were submitted for crops where hybrids are most common, indicating that private hybrids dominate the agricultural innovation market.

Private firms in India's seed and agbiotech industries may next look to the country's Patents Act for protection of their IPR. 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 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 et al., 2012). Although the potential for hybridization in rice and wheat is far more limited than for maize and pearl millet, 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. 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.

Strategic behavior

Increases in acquisitory behavior within a competitive market or among competing firms often reflect a growth of value in an industry. Firms use mergers, acquisitions, licensing agreements, and technical collaborations to increase the efficiency of their operations, secure valuable intellectual property (IP), 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 common corporate strategy to increase 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 IP, or increasing revenues through direct sales.

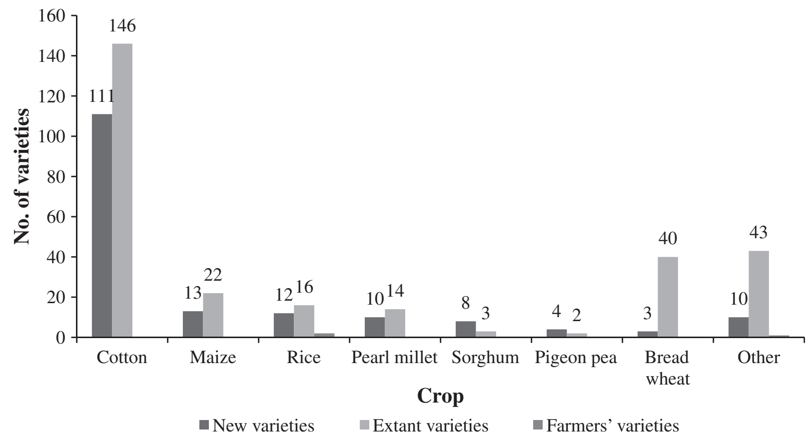

Fig. 1. Applications for plant variety registration under the PPV&FR Act, 2008–09. *Source:* PPV&FR Authority (2009).

Table 4
Firm-level field trial data, India, 2006–10. *Source:* Authors, based on data from IGMORIS (various years).

Year	Monsanto-Mahyco Group	Bayer Group	Syngenta Group	Pioneer (Dupont) Group	Dow Group	All other private	Total	CR4 ratio (%)	HH index (0–1)	Mobility index (0–2)
2006	7	2	0	0	0	0	9	100	0.65	
2007	5	0	0	0	0	0	5	100	1.00	0.10
2008	3	1	0	0	1	3	8	100	0.22	0.47
2009	3	2	0	1	4	3	13	92	0.21	0.10
2010	1	3	1	2	2	0	9	89	0.23	0.12
Total	19	8	1	3	7	6	44			
Share of total	43	18	2	7	16	14	100			

Note: HH = Herfindahl–Hirschman; CR4 = four-firm concentration ratio.

Although there have been several mergers and acquisitions in India's seed and agbiotech industries, evidence from Spielman et al. (2011) suggests that India has not experienced the same intensity of activity seen in the global seed and agbiotech industries during the 1990s, where large firms acquired smaller firms with elite breeding materials, respected brands, and proprietary technology assets (Brennan et al., 2005; Fernandez-Cornejo, 2004; Fulton and Giannakas, 2001). Although India has witnessed several mergers and acquisitions, most firms have instead relied largely 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. We follow Brennan et al. (2005) to construct a mobility index that takes on values ranging from zero (when there is no change in any company's share in the market) to two (when one monopolist is replaced by another in the market).[2]

In the seed and agbiotech industries, company 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 mobility indexes calculated here are based on field trial data for 2007–10 and are shown in Table 4. The increase in the mobility index in 2008 reflects the entry of such firms 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.

Finally, by mapping licensing agreements, technical partnerships, and acquisitory behavior against both firm revenues and technological capacity—based on insights from key informant interviews and corporate documents—we can develop a more complete picture of corporate strategic behavior in India's seed and agbiotech industries (Table 3). At present, evidence suggests that these industries are characterized by a fairly high level of fragmentation, leadership of several large companies, and a very low level of strategic behavior across firms. Large clusters revolve around the Monsanto-Mahyco, Limagrain, and Advanta groups, with smaller clusters around Bayer, Pioneer, and several others. For each firm or groups of firms, there are relatively few technical partnerships, joint ventures, mergers, or acquisitions in play within the industry. This suggests a low level of value in strategic activities aimed at securing market share through the access to IP or other assets that are key to securing a competitive advantage in a rapidly growing industry. In short, there is still potential for growth, expansion, and maturation in the Indian seed and agbiotech industries.

Public policies and regulations

Public policies in India have provided mixed signals to private investors in the innovation and product markets. The most

[2] We construct a mobility index as follows. Let the market share of firm i at time t be denoted as $m_{i,t}$. We define the mobility index to be $M_t = \sum_{i=1}^{n}(m_{i,t} - m_{i,t-1})^2$ which takes on values ranging from zero (when there is no change in any firm's share in the market) to two (when one monopolist is replaced by another in the market). See Cable (1997) for further details on its construction and use.

significant and supportive policy shifts are the promulgation of the 2001 PPV&FR Act and the approval of genetically modified Bt cotton in 2002. These policies signal India's openness to private investors by, respectively, ensuring that innovators would be allowed to recoup their research investments in cultivar improvement, and encouraging R&D at the technological frontier. However, a third policy shift—the 2010 moratorium on the commercial release of Bt brinjal—effectively dampened these innovation incentives.

The realization of this potential—and expansion beyond the current level of concentration—will likely occur when firms can overcome barriers to entry that currently inhibit innovation at the cutting edge. The major barriers are largely related to the high costs, time delays, and uncertainty associated with regulatory approval for GM crops and IPR enforcement for private cultivars. Uncertainty in the current regulatory system is probably the greatest constraint for India's seed and agbiotech industries. The majority of corporate decisionmakers interviewed for this study indicated that regulatory uncertainty will negatively influence their willingness to invest. Although the National Biotech Development Strategy of 2007 and the National Biotechnology Regulatory Authority of India (NBRAI) Bill of 2009 aim to streamline regulatory agencies and processes, the uncertainty is persistent and largely unaddressed to date.

This uncertainty is likely exacerbated by the slow progress on moving the 2004 Seed Bill through Parliament to (presumably) improve the innovation incentives facing seed companies. Of less concern to key informants, however, is the 2007 amendment of the Competition Act of 2002, which empowers India's 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. Limited application to the seed and agbiotech industries suggests that the full force of this act remains to be deployed.

Analytical results

Several interesting results emerge from these findings.

Rice

Findings suggest that there is scope for rapid expansion in the seed industry that would be led by hybrids, which, in turn, could provide a platform for GM rice technologies. Examination of the hybrid rice seed market suggests that this segment of the seed industry in India is fairly concentrated at present. The four leading firms include two multinational companies and two domestic firms (Fig. 2). The CR4 ratios calculated using sales data during 2008–2009 are 74% by volume and 73% by value, with Bayer Group holding about 43% of the market value.

Another angle on industry concentration is measurement of transgenic material imports for rice as a predictor of firm-level R&D effort in the rice market. The private sector accounted for 13 of the 20 imports of transgenic materials for rice during 1997–2008. Almost half of those imports were attributable to Monsanto-Mahyco Group (23%) and Bayer Group (23%). GM field trials serve as a similar predictor, and measurements show that only five of the seven GM field trials for rice conducted in India were attributable to the private sector in 2006–09 (Table 4).

This concentration suggests that the market is still in its earliest stages of development. Moreover, the small number of imports of transgenic materials, and even smaller number of field trials, make it difficult to predict how the GM segment of the rice seed market will develop. Certainly, Indian researchers recognize that GM traits, such as insect resistance, are critical to accelerating rice

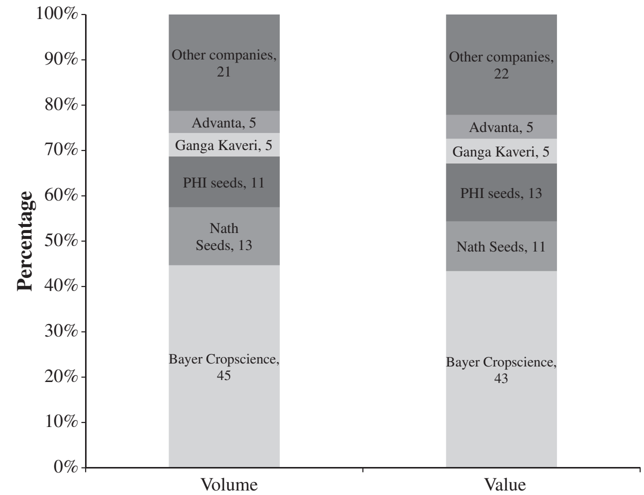

Fig. 2. Structure of India's hybrid rice seed market by volume and value, 2008–2009. *Source:* Authors' calculations, based on data from Francis Kanoi (2009). PHI denotes Pioneer Hi-Bred International.

productivity growth, just as they are aware that such traits as Bt are available from a wide variety of sources both domestically and internationally. However, the uncertainty overshadowing agbiotech in India is a likely disincentive to continued investment in this area.

Several implications emerge from this analysis. First, the two leading firms, Bayer and Pioneer (Dupont), are likely to continue to be strong competitors in the expanding hybrid rice market. As the industry evolves, if GM traits for rice move into commercialization, many other firms with access to agbiotech tools and materials—both multinational and domestic—could be well positioned to compete. 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 enter the GM hybrid rice market either on their own or in collaboration with the multinationals through strategic alliances, mergers, and acquisitions. Evolution in this direction would be markedly different from the Bt hybrid cotton experience, which, to date, has revolved around only technology providers.

Despite this, uncertainties in India's regulatory framework leave open the question of whether GM rice will ever be commercialized and, if commercialized, who the first movers might be. Private R&D investments in GM rice may drop off quickly if a clear pathway to commercialization is not realistic.

Wheat

The generally poor performance of hybrid wheat to date—for example, weak hybrid vigor and difficulties in producing hybrid seed—has limited private investment. Moreover, the absence of strong policy solutions, such as the enforcement of plant variety protection for wheat, is likely a limiting factor. As a result, public research programs conducted by the Directorate of Wheat Research, state agricultural universities, and international centers continue to provide most of India's improved wheat varieties.

Unlike GM cotton, maize, and soybeans, 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. However, if yield growth rates continue to stagnate, if GM wheat is commercialized elsewhere in the world, and if the regulatory uncertainty is addressed in India, then India may also consider exploring these new technological opportunities.

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 hybrid vigor, 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 for improving abiotic stress tolerance of wheat for poor and small wheat growers in India.

Still, prospects for wheat improvement in India (and the rest of the world) remain limited, and will be largely reliant on public breeding programs. In the absence of scientific breakthroughs that improve the 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. As a result, farmers will likely shift to other crops, such as maize.

Maize

It is reasonable to predict that the area devoted to maize for feed is likely to increase with greater consumption of poultry and dairy resulting from income growth across India. There are several relatively "quick wins" to increasing maize yields and output. Because only 60% 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.

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.

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. Most of the R&D efforts in GM maize are carried out by the private sector, and of the 19 imports of maize transgenic materials that occurred during 1997–2008, all but one was attributable to the private sector. Monsanto accounted for the majority with 12 imports, followed by the Syngenta and Pioneer (Dupont) groups (two each). These imports were primarily for insect- and herbicide-resistant traits. Monsanto also dominates field trials of transgenics by accounting for three of the five trials conducted, followed by Pioneer Hi-Bred International 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.

Policy recommendations

Limited data, nascent growth, and uncertainty are all constraints on interpretation of this analysis. 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. This section examines these interpretations and suggests several policy options.

Appropriate roles for the public and private sectors

The findings 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).

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 limited. National and international research organizations play an important role in varietal rice and wheat improvement and hybrid parent line development, but their contributions are constrained 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, or collaborate with other actors (including private firms) who can assist in the development and delivery of products. Other constraints include common concerns with public-sector performance, such as tedious bureaucratic processes, limited management capacity, 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, they 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 crops and traits that hold little interest for the private sector, particularly rice and wheat. Nevertheless, there is evidence to suggest that the private sector is willing to invest in R&D for such crops, provided that it can develop technologies (for example, hybrid rice or wheat) that also increases its ability to appropriate a share of the gains from innovation.

Regulatory uncertainty and technology pipelines

The extent to which the private sector invests in innovation and product markets for cereal crops will depend partly on reducing the uncertainty that characterizes agbiotech in India. Figs. 1 and 2 suggest that many firms with agbiotech R&D capacity 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 until regulatory uncertainties are resolved, and until the IPR regime is tested. From a technical angle, this reflects uncertainty about the development of viable rice and wheat hybrids and other technologies that increase appropriability for the private sector. As a result, there is a clear indication that the technology pipeline for cereal crops in India remains fairly narrow, limiting the range of products that might be expected in the medium term.

The 2001 PPV&FR Act could play a role in addressing corporate concerns over IPR protection, although the PPV&FR Authority's capacity to live up to its mission depends on the courts' ability to adjudicate fairly on infringement cases. Also, 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

There is a clear need for a publicly accessible clearinghouse or database that integrates information on applications for, ownership of, and issuances of patents, plant variety protection certificates, field-testing permits, and commercialization approvals. 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. While IGMORIS plays an important role in providing public access to data on field trial application status and commercially approved GM varieties, additional data on patents relevant to food and agriculture are needed. 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. Use of this information could help corporate managers, public regulators, policymakers, and researchers make informed and evidence-based decisions about innovation, competition, private profits, and social welfare.[3]

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 indicate 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 et al., 2006; Qaim, 2003). In fact, India's seed and agbiotech industries might be viewed as a still-emerging sector with the current levels of concentration attributable 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 industries 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. Although this has not yet happened in India, there is a possibility of increasing 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 IPR 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 continually scan for the presence of anticompetitive practices. India's Competition Act of 2007 is a step in this direction, and its careful application to the innovation and product markets is critical to ensuring both innovation and competition in the industry without the unwieldy impacts of price controls and other market distortions.

Future scenarios

With this in mind, several scenarios may play out in India over the coming decade, with implications for innovation, competition, and yield growth for the major cereals.

The fragmentation scenario

If the Indian seed and agbiotech industries continue to operate as they are today, they will remain fairly fragmented with a mix of small seed traders, medium-sized firms, and a few foreign firms addressing the major cereal crops. Each will claim its own niche, rely on hybrids to protect its IP, or survive on the multiplication and distribution of public breeding materials. The seed industry will be plagued with spurious seeds and pirated copies, and will depend on the public sector's slow rate of innovation. The industry will forgo synergies that emerge from R&D investment, mergers, acquisitions, licensing, and other strategies that bring together expertise, capital, and IP. Few firms will be motivated to explore new technological opportunities, especially if public and government attitudes toward agbiotech 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 competition scenario

An alternative scenario 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 technology firm licensed its Bt gene to mainly domestic firms with quality breeding materials and good distribution networks. This strategy tends to provide the technology firm with a high degree of market power in the upstream segment through its strong first-mover advantage, while stimulating vibrant competition among seed firms that license the technology and introduce it into their own cultivars. This strategy also leads to some level of consolidation by driving out small seed traders and smaller firms that cannot afford the licensed technology.

The competitive growth scenario

Growth in the seed and agbiotech industries could easily be led by the expansion of private investment in maize and rice hybrids. The biological IPRs conferred by hybridization provide firms with a mechanism to appropriate their R&D investments. Maize offers additional benefits because of the potential use of spillovers from high and sustained levels of global R&D investment in the crop that includes well-established breeding programs, high-quality genetic materials, expertise in molecular biology, and experience with regulatory processes. Ultimately, a mix of domestic and foreign investment in maize and rice hybrids through technical partnerships, joint ventures, mergers, and acquisitions could result in rapid growth in India's seed and agbiotech industries. This scenario is deeply dependent on government support for agbiotech, foreign direct investment, and improved R&D incentives.

[3] See USDA (2010) for a potentially useful model.

The transformation scenario

Innovation and competition in the downstream seed market will depend on commercialization times, product performance, and spillovers, as well as 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 technology platforms may be particularly important in this scenario, especially for reaching small-scale, resource-poor farmers in India's more marginal agroecologies. One such platform may be hybrids—starting first with maize, then rice, and eventually even wheat. 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.

Conclusion

An optimistic outlook might suggest a transition from fragmentation to a competitive growth scenario that is led by an expansion of private investment in maize and rice hybrids. This outlook assumes little progress will be made on changing current public attitudes and regulatory uncertainties surrounding GM crops and technologies. If progress is not made, then the consolidation and transformation scenarios are effectively ruled out. And this means that the rate of growth for rice and wheat yields in India may continue to stagnate, leading to continued concerns among policymakers and other stakeholders in the food policy discourse. If the private sector is expected to contribute to yield growth for food staples in coming years, then significant reforms are needed to strengthen the rules and regulations governing India's seed and agbiotech industries. These industries are still in a relatively nascent stage of development, as are the markets they serve.

The evidence suggests that several elements must converge before the private sector's contribution to both innovation and productivity growth can be realized in India's cereal systems. For example, continued public investment is needed 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 technology commercialization can be strengthened through policies and incentives that encourage innovation. Regulatory uncertainties clouding agbiotech in India could be resolved to widen the technology pipeline and give companies the confidence to invest. More data, information, and analysis could 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 higher firm-level efficiency.

Acknowledgements

This paper was prepared as part of the Cereal Systems Initiative for South Asia, a project supported with funding from the U.S. Agency for International Development and the Bill and Melinda Gates Foundation. The authors acknowledge the many key informants who provided their time and insights to the research presented in this paper. The authors thank Madhavi Char for comments on previous versions of the paper; Patricia Zambrano, Julia Vivalo, and Andrea Pedolsky for their technical contributions; and Lorena Danessi and Deepa Sahrawat for administrative support. Any and all errors are the sole responsibility of the authors.

References

Appelbaum, E., 1979. Testing price taking behavior. J. Econ. 9 (3), 283–294.
Appelbaum, E., 1982. The estimation of the degree of oligopoly power. J. Econ. 19, 287–299.
Azzam, A., 1997. Measuring market power and cost-efficiency effects of industrial concentration. J. Ind. Econ. 45 (4), 377–386.
Azzam, A., Pagoulatos, E., 1990. Testing oligopolistic and oligopsonistic behavior: an application to the U.S. meat packing industry. J. Agric. Econ. 41 (3), 362–370.
Baig, S.U., 2009. Hybrid Rice Seed Scenario in India: Problems and Challenges. <www.apsaseed.org/docs/00b9aab6/ASC2009/SIG/HybridRice/Rice_India.pdf> (accessed 20.12.10).
BioSpectrum, 2010. A Fast Clip Growth for BioAgri. <http://biospectrumindia.ciol.com/content/BSTOP20/110061423.asp> (accessed 15.11.10).
Birthal, P.S., Joshi, P.K., Narayanan, A.V., 2011. Agricultural diversification in India: trends, contribution to growth, and small farmers' participation. In: Ferroni, M.A. (Ed.), Transforming Indian Agriculture—India 2040: Productivity, Markets, and Institutions. International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, AP, pp. 89–126.
Brennan, M., Pray, C., Naseem, A., Oehmke, J.F., 2005. An innovation market approach to analyzing impacts of mergers and acquisitions in the plant biotechnology industry. AgBioForum 8 (2/3), 89–99.
Byerlee, D., Fischer, K., 2002. Accessing modern science: policy and institutional options for agricultural biotechnology in developing countries. World Dev. 30 (6), 931–948.
Cable, J.R., 1997. Market share behavior and mobility: an analysis and time-series application notes. Rev. Econ. Stat. 79 (1), 136–141.
Chen, Z., Lent, R., 1992. Supply analysis in an oligopsony model. Am. J. Agric. Econ. 74 (4), 973–979.
Dorward, A., Kydd, J., Morrison, J., Urey, I., 2004. A policy agenda for pro-poor agricultural growth. World Dev. 32 (1), 73–89.
Dubey, A., Thorat, A., 2011. Agriculture Growth, Poverty and Nutrition. Paper Presented at the 2020 International Conference on "Leveraging Agriculture to Improve Nutrition and Health", Organized by the Indian Economics Association, the Tackling Agriculture-Nutrition Disconnect in India Initiative, and the International Food Policy Research Institute (IFPRI), New Delhi, India, February 10.
Fafchamps, M., 2005. Market Institutions in Sub-Saharan Africa. MIT Press, Cambridge, MA.
Fan, S., 2003. Agricultural research and urban poverty in India. Q. J. Int. Agric. 42 (1), 63–78.
Fan, S., Gulati, A., Thorat, S., 2008. Investment, subsidies and pro-poor growth in India. Agric. Econ. 39 (2), 163–170.
Fernandez-Cornejo, J., 2004. The seed industry in U.S. agriculture: an exploration of data and information on crop seed markets, regulation, industry structure, and research and development. Agric. Inform. Bull. 786, U.S. Department of Agriculture, Washington, DC.
Francis Kanoi (Francis Kanoi Marketing Research), 2009. A Study on Paddy in India: 2009. A Syndicated Report on Seeds. Francis Kanoi Marketing Research, Chennai. CD-ROM.
Fulton, M., Giannakas, K., 2001. Agricultural biotechnology and industry structure. AgBioForum 4 (2), 137–151.
Gadwal, V.R., 2003. The Indian seed industry: its history, current status, and future. Curr. Sci. India 84 (3), 399–406.
Ganesh-Kumar, A., Mehta, R., Pullabhotla, H., Prasad, S.K., Ganguly, K., Gulati, A., 2012. Demand and Supply of Cereals in India: 2010–2025. IFPRI Discussion Paper No. 01158. IFPRI, Washington, DC.
Gruere, G.P., Sun, Y., 2012. Measuring the Contribution of Bt Cotton Adoption to India's Cotton Yields Leap. IFPRI Discussion Paper No. 01170. IFPRI, Washington, DC.
Gulati, A., Dixon, J., 2008. Maize in Asia: Changing Markets and Incentives. Academic Foundation, New Delhi.
Hall, A., Sivamohan, M.V.K., Clark, N.G., Taylor, S., Bockett, G., 1998. Institutional developments in Indian agricultural research systems: emerging patterns of public and private sector activities. Sci. Technol. Dev. 16 (3), 51–76.
Hazell, P.B.R., 2010. The Asian green revolution. In: Spielman, D.J., Pandya-Lorch, R. (Eds.), Millions Fed: Proven Successes in Agricultural Development. IFPRI, Washington, DC.
IGMORIS (Indian GMO Research Information System), 2010. Indian GMO Research Information System. <http://igmoris.nic.in/> (accessed 15.09.10).
Janaiah, A., 2002. Hybrid rice for Indian farmers: myths and realities. Econ. Polit. Weekly 37 (42), 4319–4328.
Joshi, P.K., Singh, N.P., Singh, N.N., Gerpacio, R.V., Pingali, P.L., 2005. Maize in India: Production System, Constraints, and Research Priorities. CIMMYT, Mexico City, Mexico, DF.
Kathage, J., Qaim, M., 2012. Economic impacts and impact dynamics of Bt (*Bacillus thuringiensis*) cotton in India. Proc. Natl. Acad. Sci. 109 (29), 11652–11656.

Kherallah, M., Kirsten, J.F., 2002. The new institutional economics: applications for agricultural policy research in developing countries. Agrekon 41 (2), 110–133.
Kolady, D., Spielman, D.J., Cavalieri, A.J., 2012. Intellectual property rights, private investment in research, and productivity growth in Indian agriculture: a review of evidence and options. J. Agric. Econ. 63 (2), 361–384.
Kumar, I., 2008. Hybrid Rice—An Indian Perspective. <www.apsaseed.org/images/lovelypics/Documents/SCs/Hybrid%20rice_india.pdf> (accessed 20.09.10).
Kumar, S., 2010. Seed Production in India: Triumphs and Challenges in Field Crops. <http://nsai.co.in/Publication/upload/Dr%20sateesh%20kumar.pdf> (accessed 15.04.11).
Kydd, J., Dorward, A., 2004. Implications of market and coordination failures for rural development in least developed countries. J. Int. Dev. 16 (7), 951–970.
Matuschke, I., Mishra, R.R., Qaim, M., 2007. Adoption and impact of hybrid wheat in India. World Dev. 35 (8), 1422–1435.
Mrinalini, K., 2011. The Indian PPV&FR Act, 2001: historical and implementation perspectives. J. Intellect. Prop. Rig. 16 (2), 88–101.
Murugkar, M., Ramaswami, B., Shelar, M., 2006. Liberalization, Biotechnology, and the Private Sector: The Case of India's Cotton Seed Market. Discussion Paper 06-05. Indian Statistical Institute, New Delhi.
Naseem, A., Spielman, D.J., Omamo, S.W., 2010. Private-sector investment in R&D: a review of policy options to promote its growth in developing-country agriculture. Agribus 26 (1), 143–173.
NFSM (National Food Security Mission, India), 2007. NFSM Rice. <http://nfsm.gov.in/Default.aspx> (accessed 20.12.10).
Nikhade, G.T., 2003. Cereal Seeds in India. Paper Presented at the World Seed Congress 2003, Bangalore, June 7–11.
Nirmala, B., Viraktamath, B.C., 2008. Economics of Hybrid Rice Seed Production in India. <http://hrdc.irri.org/images/5thHybridRiceSymposiumPresentations/47.%20Nirmala_Economics%20of%20HR%20Seed%20Production%20in%20India.pdf> (accessed 20.04.11).
Pal, S., Singh, R.P., Morris, M.L., 1998. India. In: Morris, M.L. (Ed.), Maize Seed Industries in Developing Countries. Lynne Rienner, Boulder, CO.
Pal, S., Rahija, M., Beintema, N., 2012. India: Recent Developments in Agricultural Research. Agricultural Science and Technology Indicators (ASTI) Country Note. IFPRI/Indian Council of Agricultural Research, Washington, DC/New Delhi.
Pingali, P.L., Traxler, G., 2002. Changing locus of agricultural research: will the poor benefit from biotechnology and privatization trends? Food Policy 27 (3), 223–238.
PPV&FR Authority (Protection of Plant Varieties and Farmers' Rights Authority), 2009. Annual Report, 2008–09. India Ministry of Agriculture, New Delhi, India.
Pray, C.E., Nagarajan, L., 2009. Improving crops for arid lands: pearl millet and sorghum in India. In: Spielman, D.J., Pandya-Lorch, R. (Eds.), Millions Fed: Proven Successes in Agricultural Development. IFPRI, Washington, DC.
Pray, C.E., Ramaswami, B., 2001. Liberalization's impact on the Indian seed industry: competition, research, and impact on farmers. IFAMR 2 (3/4), 407–420.
Qaim, M., 2003. Bt cotton in India: field trial results and economic projections. World Dev. 31 (12), 2115–2127.
Qaim, M., Subramanian, A., Naik, G., Zilberman, D., 2006. Adoption of Bt cotton and impact variability: insights from India. Rev. Agric. Econ. 28 (1), 48–58.
Rabobank, 2006. Indian Seed Industry: Market Overview and Outlook. Industry Note 184-2006. Rabobank, Utrecht, The Netherlands.
Rada, N.E., 2013. Agricultural Growth in India: Examining the Post-Green Revolution Transition. Selected Paper Presented at the Joint Annual Meeting of the Agricultural and Applied Economics Association and Canadian Agricultural Economics Society, Washington, DC, August 4–6.
Ramaswami, B., 2002. Understanding the seed industry: contemporary trends and analytical issues. Indian J. Agric. Econ. 57 (3), 417–429.
Randhawa, G.J., Chhabra, R., 2009. Import and commercialization of transgenic crops: an Indian perspective. Asian Biotechnol. Dev. Rev. 11 (2), 115–130.
Rao, M.P., 2009. Indian seed industry status and future trends: field crops. NSAI Mag. 1 (1), 7–11.
Rao, C.K., 2010. Moratorium on Bt Brinjal: A Review of the Order of the Minister of Environment and Forests, Government of India. Foundation for Biotechnology Awareness, Bangalore.
Rao, N.C., Dev, S.M., 2009. Biotechnology and pro-poor agricultural development. Econ. Polit. Weekly 44 (52), 56–61.
Reardon, T., Timmer, C.P., 2012. The economics of the food system revolution. Annu. Rev. Resour. Econ. 4, 225–264.
Reardon, T., Chen, K., Minten, B., Adriano, L., 2012. The Quiet Revolution in Staple Food Value Chains. Asian Development Bank (ADB)/IFPRI, Manila/Washington, DC.
Schroeter, J.R., 1988. Estimating the degree of market power in the beef packing industry. Rev. Econ. Stat. 70 (1), 158–162.
Schroeter, J.R., Azzam, A., 1991. Marketing margins, market power, and price uncertainty. Am. J. Agric. Econ. 73 (4), 990–999.
Schumpeter, J.A., 1934. The Theory of Economic Development. An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle. 1961 Reprint. Harvard University Press, Cambridge.
Seednet, 2007. Seed Replacement Rates, 2007. <http://seednet.gov.in/Material/SRR-08.pdf> (accessed 02.05.10).
Sexton, R.J., 2000. Industrialization and consolidation in the U.S. food sector: implications for competition and welfare. Am. J. Agric. Econ. 82, 1087–1104.
Spielman, D.J., 2006. Systems of innovation: models, methods, and future directions. Innovation Strat. Today 2 (1), 55–66.
Spielman, D.J., 2007. Pro-poor agricultural biotechnology: can the international research system deliver the goods? Food Policy 32 (2), 189–204.
Spielman, D.J., Kolady, D., Cavalieri, A., Rao, N.C., 2011. The Seed and Agricultural Biotechnology Industries in India: An Analysis of Industry Structure, Competition, and Policy Options. IFPRI Discussion Paper 1103. IFPRI, Washington, DC.
Tripp, R., Louwaars, N., 1997. Seed regulation: choices on the road to reform. Food Policy 22 (5), 433–446.
USDA, 2010. Adoption of Genetically Engineered Crops in the U.S. (Data Set). <http://www.ers.usda.gov/Data/biotechcrops/> (accessed 15.04.11).
Wann, J.J., Sexton, R.J., 1992. Imperfect competition in multiproduct food industries with application to pear processing. Am. J. Agric. Econ. 74, 980–990.