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Biotechnology for a Second Green Revolution in India: Socioeconomic, Political, and Public Policy Issues

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Long-term stagnation in total factor productivity of major crops in Indian agriculture coupled with a price-incentive-based spurt in recent growth have been responsible for the reversal of secular decline in food prices achieved in earlier decades with the success of the Green Revolution. This article traces the demands for new technology in the country's agriculture, examines the promise of biotechnology and demystifies controversies surrounding these technologies, summarizes the articles in this special issue, and then analyzes the challenges of mainstreaming biotechnology in policy making. It argues that the problem is not so much the proprietary nature of these technologies, but excessive regulation that is stifling technology development and diffusion as well as driving out many small players and several useful applications. Science-based regulation has to be put in place and the ban (moratorium) on commercialization has to be revoked immediately. Reenergizing the public sector to accelerate investments in these technologies is the best remedy to address market failures and also to gain acceptability from the public. Political leadership has to make bold decisions with a vision of taking the sector forward, much like C. Subramaniam did in the 1960s to usher in the Green Revolution.

Key words: technology fatigue, framing GMOs, public choice, panel data models, private sector R&D, labeling, biotechnology regulatory authority.

Towards a Second Green Revolution

India's crop sector stagnated during the 1950s and early 1960s, but the country overcame the infamous syndrome of 'ship to mouth' of the Public Law 480 days of food aid dependence and moved to self-sufficiency in food with the Green Revolution (GR) that started in the mid-1960s. The benefits for the nation were improved food security, reduced malnourishment, and reduced poverty.[1]

These universal goals were achieved in India by unleashing the production potential of lands and reducing the cost of food, providing employment to the rural population, and encouraging non-farm activities such as agro-industries. Production of food grains catapulted to 260 million tonnes in the triennium ending (TE) 2013-14 (with a buffer stock of 62 million tonnes as of January 9, 2015), from 81 million tonnes in the TE 1965, when seed-fertilizer technologies were ushered into the country's agriculture. Foodgrain productivity per unit of land increased from 591 kilograms per hectare to 2,100 kilograms per hectare in the same period. This spectacular success in agriculture has been hailed as one of the best success stories of the GR in the world (Lipton, 2001), along with Latin America and Mexico.[2] One question for technology now is how to replicate these results in areas bypassed by technological changes in agriculture—much of Africa, for example—in order to lift people out of the vicious circle of poverty and malnourishment (Pingali, 2012). The second question is what new challenges facing global and Indian agriculture can be answered by similar deployment of modern science and genetics as the previous wave reaches limitations in the major food crops.

GR technologies reached a plateau by the end of the 1980s for many crops and regions. Technology fatigue has been identified as one of the two main reasons for the problems of India's agriculture,[3] which has been

1. *Datt and Ravallion (1998) estimated the effects of farm yield growth in rural India using data spanning the period 1958-1994 and found that higher real wages and higher farm yields reduced absolute poverty, and with the same elasticity. They also concluded that the long-run gains are far higher compared to short-run. de Janvry and Sadoulet (2002) also found significant positive impacts of technology on poverty reduction.*

2. *Some of the recent criticisms on biotechnology completely ignore this role of technology in achieving food security (e.g., Parliamentary Committee on Agriculture [GoI, 2012]).*

going through a difficult phase in recent times with declining rates of growth in agricultural productivity and profitability. Performance of the agriculture sector in terms of growth has slowed dramatically over time. The first decade of the new millennium witnessed a trend growth in production of 2.7% per annum, compared to a 3.4% per annum during the 1990s, and 4.7% per annum during the 1980s. However, a better indicator of farmer well-being is the growth in farmers' income. Sen and Bhatia (2004) in their analysis of farm household data of the Department of Economics and Statistics found that the returns to paid-out costs turned almost static during the 1990s with growth down to only 0.03% per annum, compared to a growth of 1.78% per annum during the 1980s. Though the growth in agriculture and farmer profitability improved in the first decade of the new millennium, the predominantly price-incentive-driven nature of this growth raises serious doubts over its sustainability in the absence of breakthrough technologies (Chand, 2014; World Bank, 2014).

This slowdown in yield growth is the crux of this malaise.[4] For example, there was no significant growth in the yields of food grains in the first decade of this century. The index of total factor productivity (TFP) in agriculture in India increased from 100 in 1961 to 170 in 2009; this performance is much lower than that in Brazil, China, and Indonesia, where the index went up from 100 to 270 during the same period (Lele, Agarwal, Timmer, & Goswami, 2011). The major issue regarding the profitability of smallholder farming is the fact that the long-term TFP growth (between 1980 and 2008) is estimated at only 0.28% per annum for traditional crops, much less than the rate of 1.77% for the agriculture sector as a whole (World Bank, 2014). The continued lackluster performance of the crop sector has resulted in lower *per capita* availability of food grains at 447 grams per day in the TE 2012 compared to 494 grams per day in the TE 1991. Most importantly, the profitability of farming and incomes of the farmers suffered in the process. The growing divergence—between sliding agricultural growth and booming growth in the economy as a whole—exacerbated rural-urban inequality. This trend lends credibility to the alleged discrimination between *bharat* representing the rural areas, where people depend directly and indirectly on agriculture for livelihood and *India*, where people expect to get productive jobs and income from the services sector and manufacturing.

Upon coming to power in 2004 on the back of nation-wide uproar over the declining fortunes of the farming community,[5] The Congress-led United Progressive Alliance (UPA) government faced the challenge of correcting the earlier strategy and reviving the agricultural sector. In the absence of breakthroughs in agricultural technology, the government has taken recourse to using available technologies and increasing input use so that food security is not jeopardized during the 11th five-year-plan period (Government of India [GoI], 2013). The support price mechanism has been used to sufficiently compensate farmers for this input intensification in the background of slowdown in the growth of land productivity (Dev & Rao, 2010, 2015). This is one of the main reasons for the recent spikes in prices of several commodities, apart from the supply-demand mismatch that persists despite this strategy of the government. The secular decline in the cost of food since the GR days has been reversed after GR technologies lost steam by the early 1990s. The issue of serious concern and anxiety is the fact that the rising prices of food in recent years may not subside like the earlier rise in 1973-74 and a 'new normal' might have been established. Some experts forecast that the rising trend will continue with heightened instability into the future in the absence of a technological breakthrough (Chand, 2008; Rosegrant, Tokgoz, & Bhadary, 2012). Though global food prices have been declining of late, the outlook for the next 10 years—according to the Organization for Economic Co-operation and Development (OECD)/Food and Agriculture Organization of the United Nations (FAO) Agricultural Outlook 2015-2024—forecasts the prices to remain at higher levels than in the preceding years of the 2007-08 price spike.

Growing Demand for New Technology

Unlike other parts of the world, such as Latin America and Africa, the scope to increase area under cultivation is almost ruled out in India. In fact, the area under cultivation can go down in the long run with increased demands for non-agricultural use for industrial purposes, housing the ever-increasing population, road-

3. *See GoI (2008) for a detailed analysis.*
4. *There seems to be wide agreement in identification of the major problem facing Indian agriculture as the stagnation or even decline in productivities in many crops. Recently, the World Bank (2014) has issued a country report entitled Republic of India: Accelerating Agricultural Growth, squarely addressing this issue.*
5. *The sector had grown at a mere 1.66% per annum during 1996-97 to 2004-2005 (Chand, Raju, & Pandey, 2007).*

ways, airways and other related infrastructure, resorts, and other such amenities. Further, there may be very limited chances of increasing area under irrigation,[6] as any increase in area under irrigation from current levels requires huge amounts of investments that might prove to be difficult, as well as heightened environmental concerns with dams. Nearly 60% of the total net cropped area of 140 million hectares is under rainfed cultivation.

The challenge, then, is to improve productivity, profitability, and sustainability of this limited agricultural land area. Soil and water health have been severely affected in the past few decades; the majority of the soils are either degraded with salinity, alkalinity, or acidity or eroded by wind.[7] Ground water availability has gone down in many regions of the country with utilization exceeding replenishment levels. Changes in rainfall pattern and rising temperatures coupled with extreme weather events resulting from climate change have become major threats to the agricultural sector of the country. The process of urbanization exacerbates the gulf between food production and consumption, leaving few hands to produce always increasing numbers of mouths. To face the reality, the country's agriculture—in exactly same acreage (140 million hectares of net cropped area or even less)—has to produce for a 50% increase in population by 2050, by which time it is expected to reach 1.65 billion people from the present level of 1.27 billion. Further, new technologies in agriculture have to produce more for the same unit of water, withstand climate change, overcome degraded lands to produce more, and cater to the fast-rising consumer concerns on food safety, apart from just increasing production. Therefore, new technologies like biotechnology are lifelines for the battered agriculture sector, as noted by the government in its 12th five-year-plan document:

> "… since significant breakthroughs in production technologies are required to cope with increasing stress, particularly for rainfed crops, it is necessary to remain abreast with latest advances in biotechnology. It is, therefore, time to put in place scientifically impeccable operational protocols and a regulatory mechanism to permit genetically modified organisms (GMOs) when they meet rigorous tests that can outweigh misgivings, while simultaneously noting that many feasible advances in biotechnology do not in fact involve GMOs" (GoI, 2013, p. 11).

Promise of Biotechnology for Agriculture

The opportunities arising from the genetic engineering (GE) of crops and other tools of biotechnology are expected to provide answers to the productivity problems of agriculture, environmental degradation, climate change, and sustainability. The availability of the tools of modern biotechnology is a major advancement of science that has the potential to revolutionarize the agriculture sector like *Mendellian* genetics did. At a macro level, experts predict the 21st century to be the century of biology, much like physics in the 18th and 19th centuries and chemistry in the 20th century.

The gene revolution technologies follow the GR technologies and go even further beyond them in that they transcend the barriers of species. In other words, they represent both continuity and change over the GR technologies. While the conventional plant-breeding (CPB) methods identify a variety or line (of the same crop) with a desired physical characteristic and cross it with the cultivated variety using breeding methods that have been used for generations to integrate the desired trait, tools of biotechnology enable identifying the gene/s[8] responsible for the trait in the same crop, different crop, microorganism, or animal and insert the gene or genes in the crop using different techniques.[9] The gene revolution technologies can be more precise, dramatic, and much faster than the CPB. Unlike the CPB methods that were central to the GR, the tools of biotechnology are all pervading in that they have been used to produce

6. *The area under irrigation has been stagnant for the last two decades. The increases in yield and production in the earlier era benefited from bringing new areas into cultivation mostly until 1960. Subsequently, the green revolution technologies have the luxury of increasing area under irrigation from 24.66m ha in 1960-61 to 49.87m ha in 1991-92. It has stagnated at this level.*

7. *National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur of the Indian Council of Agricultural Research (ICAR) in 2005 has found that an area of 146.82 million hectares is reported to be suffering from various kinds of land degradation. It includes water erosion (93.68 million ha), wind erosion (9.48 million ha), water logging/flooding (14.30 million ha), salinity/alkalinity (5.94 million ha), soil acidity (16.04 million ha), and complex problems (7.38 million ha; ICAR, 2005).*

8. *Initially, the techniques were developed to identify and insert genes. But now that a full-fledged branch of science in the name of functional genomics has come about with detailed information at the nucleotide level, things have become easier, and precision has increased. The genome sequences of several crops are now deciphered after the human genome sequencing project and that enables better understanding of the genes and their functions.*

a wide range of new pharmaceuticals and industrial products such as biofuel and improve crops, livestock, fisheries, and forestry, as well as several other applications that are likely to be known in the future.[10] Biotechnology encompasses a range of technologies that include gene manipulation and gene transfer, DNA typing and cloning of plants and animals, genomics and bioinformatics, marker-assisted selection, diagnostic procedures, micro propagation, tissue culture, cloning, artificial insemination, embryo transfer, and other technologies.[11] CRISPR (clustered regularly interspaced short palindromic repeat) is the latest game-changing technology among new biotechnologies. Genetic engineering (or genetic modification) is but a subset of modern biotechnology; there are many more techniques and technologies that can be harnessed if the field is approached from a scientific—rather than ideological—standpoint.[12]

Application of Biotechnology in Agriculture

The available commercialized biotechnological products target insect pests and weeds with insect-resistant (IR) and herbicide-tolerant (HT) traits. These are often referred to as the first generation of biotech crops. It will take some time before full development and commercialization of the second generation of biotech crops—varieties that tolerate abiotic stress like drought, floods, and salinity; that can improve quality of food by enhancing nutritional content like vitamins, minerals (like iron, zinc, etc.), proteins and amino acids; and varieties with increased yield potential. The GE of the second generation of crops is more complex since they involve more than one gene. However, there is a lot of progress in this arena and the world is likely to see some of them in the next few years. The development of drought-tolerant maize in the United States and Africa and submergence-tolerant rice—which is spreading in India using biotechnology tools but is not genetically modified (GM)—are indicators of progress towards abiotic stress resistance. The major problem in the application of biotechnology to these problems is, however, the stifling regulations using the precautionary principle, which excludes small private firms and the public sector from developing GM plants. Despite the limited number of commercialized crops, they made a huge difference to the agricultural sector with annual benefits to the tune of more than US$90 billion to the farmers in the world (James, 2012).

The cultivation of GE crops is proceeding in India with 11.6 million hectares planted with biotech cotton in 2014; this is often referred to as Bt cotton. In the world, GM crop area has grown at 6.6% per annum to reach 181.5 million hectares across 28 countries in 2014 from just 1.7 million hectares in 1996 in 13 crops—maize, soybean, cotton, canola (mustard), sugar beet, alfalfa, papaya, squash, tomato, poplar, sweet pepper, potato, and brinjal (James, 2014). The fact that 90% of the 18 million adopting farmers are smallholders and 53% of the total acreage is in developing countries indicates that the technology is amenable to small farmers in developing countries as much as for big farmers in developed countries. However, the widely adopted traits are too few; 57% include herbicide tolerance in soybean, maize, cotton, and canola, and 27% contain staked traits that include herbicide tolerance; the remainder employ insect resistance in the same crops. Apart from the leading multinational companies, there are many start-up companies bringing out new transgenes in crops and public-sector research institutions. Some of the crops in the advanced stage of trials in India are given in the Table 1. There are many more in different stages of field trials. Crop scientists believe that emergent technologies could change the face of Indian agriculture by boosting crop productivity and sustainability. This would be the second Green Revolution. A GE mustard hybrid—developed by a Deepak-Pental-led Delhi University research team—that is reported to increase yields by 20-30% is ready for commercialization.

9. *Horizontal gene transfer and antibiotic resistance raised some food-safety concerns because many first-generation GM crops were created using antibiotic-resistant marker genes. However, researchers have developed methods to eliminate antibiotic-resistant markers from genetically engineered plants. Several methods have been reported to create transformed plants that do not carry marker genes, for example co-transformation, transposable elements, site-specific recombination and intrachromosomal recombination (FAO, 2004). These methods would make the process much safer in future development of genetically engineered crops, animals, and microorganisms.*
10. *The varied technologies in the realm of biotechnology and their potential make them eminently suited to the development of not just cereal crops in irrigated areas, but also dry-land crops, fruits and vegetables, livestock, fisheries, and forestry. These developments can improve food security in India, which is witnessing a diet diversification from food grains to fruit and vegetables, milk, and livestock products. They can also be crucial in nutritional security apart from food security.*
11. *Please see Royal Society (2009) for details on the different approaches.*
12. *For a recent cataloguing and discussion of frontiers in biotechnology, see Ricroch and Hénard-Damave (2015).*

Table 1. Transgenic crops in advanced stage of trials with traits in India.

Crop	Company	Trait	Gene/event	Stage
Maize	Pioneer Overseas Corporation	Insect resistance and herbicide tolerance	*cry1F* and *cp4epsps* genes (Stacked events TC1507xNK603 [DAS-01507-1XMON-00603-60])	BRL-I 2nd year conducted in 2012
	Syngenta Biosciences Pvt. Ltd.	Insect resistance and herbicide tolerance	GA21 event (*cry1Ab&mepsps* genes)	BRL-I 2nd year conducted in 2011
	Pioneer Overseas Corporation	Insect resistance and herbicide tolerance	*cry1F&cp4epsps* and *PAT* genes [Stacked events TC1507xNK603 (DAS-01507-1XMON-00603-60]	BRL-I 2nd year conducted in 2011
	Pioneer Overseas Corporation	Insect resistance and herbicide tolerance	*cry1F* and *PAT* and *CP4EPS PS*genes [TC1507xNK603 (DAS-01507-1xMON-00603-6)]	BRL-I 2nd year conducted in 2010
	Dow AgroSciences India Pvt. Ltd.	Insect resistance	*cry1F* (event TC 1507) gene	BRL-I 2nd year conducted in 2010
	Monsanto India Ltd.	Insect resistance and herbicide tolerance	Stacked *cry2Ab2* and *cry1A.105* genes (Event MON 89034) *CP4EPSPS* genes (Event NK603)	BRL-I 2nd year conducted in 2010
	Monsanto India Ltd.	Insect resistance and herbicide tolerance	Stacked *cry2AB2* and *cryA.105* (MON89034) and *CP4EPSPS*	BRL-I 2nd year conducted in 2009
Mustard	University of Delhi (South Campus)	Male sterile, female inbred rice lines	*Barnase*, *barsar*, and *barg*enes [Events bn 3.6 (barnase line) and modbs 2.99 (barstar line)]	BRL-I 2nd year conducted in 2011
Cotton	Dow AgroSciences India Pvt. Ltd.	Insect resistance	*cry1Ac* and *cry1F* (WideStrike=Event 3006-210-23 and Event 281-24-236)	BRL-I 2nd year conducted in 2010
	JK Agri Genetics Ltd.	Insect resistance	*cr1Ac* (Event-1) and *cry1Ec* (Event-24)	BRL-I 2nd year conducted in 2010
	Maharashtra Hybrid Seeds Co. Ltd.	Insect resistance and herbicide tolerance	Stacked *cry1Ac* and *cry2Ab* (MON 15985) and *CP4EPSPS* (MON88913)	BRL-I 2nd year conducted in 2009
Brinjal	University of Agricultural Sciences, Dharwad	Insect resistance	*cry1Ac*	Seed multiplication conducted in 2009
	University of Agricultural Sciences, Dharwad	Insect resistance	*cry1Ac*	Multi location research trials completed in 2007
	Sungro Seeds Research Ltd.	Insect resistance	*cry1Ac*	Multi location research trials completed in 2007
	Tamil Nadu Agricultural University	Insect resistance	*cry1Ac*	Multi location research trials completed in 2007
Rice	MAHYCO	Insect resistance	*cry1Ac*	Multi location research trials completed in 2007
Okra	MAHYCO	Insect resistance	*cry1Ac*	Multi location research trials completed in 2007

Source: Rao (2013a)

Notes: 1. The Institutional Biosafety Committee (IBSC) evaluates the proposal for conducting a field trial and, if recommended by the IBSC, the applicant may submit the application to the Review Committee on Genetic Modification (RCGM). RCGM, functioning in the Department of Biotechnology, is the Regulatory Authority for Biosafety Research Level I (BRLI) trials. These trials are limited in size to no more than 1 acre (0.4 ha) per trial site location and a maximum cumulative total of 20 acres (8.1 ha) for all locations for each plant species/construct combination (e.g., one or more events originating from transformation of a plant species with the same genetic construct), per applicant, per crop season. 2. This list does not include the trials approved in 2014.

Demystifying Contentious Issues in Commercialization and Adoption

Biosafety. The development of novel GE crops has raised public safety concerns—both real and perceived—in an unprecedented scale, unlike their pharmaceutical counterparts that are also produced using GE. Billions of people have consumed GE soybean[13] and GE maize products that have come out of the 1.8 billion hectares of GE crops since first commercialization in 1996. There have been no verifiable reports of any adverse impact on human health or environmental damage, as concluded by reviews of the scientific research on GE crop safety by reputed organizations like Royal Society (2003), Nuffield Council on Bioethics (1999, 2004), Food and Agriculture Organization of the United Nations (FAO, 2004), World Bank (2007), World Health Organization (WHO, 2005), International Council for Science (ICSU, 2003), and European Commission (EC; 2010). The European Union conducted the most rigorous research on food safety and environmental concerns about GE products. From their research on environmental impact, food safety, coexistence of GM and non-GM crops and risk management strategies, the EC concluded that GM products are safe (EC, 2010, p. 16). In the EU's words,

> "the main conclusion to be drawn from the efforts of more than 130 research projects, covering a period of more than 25 years of research, and involving more than 500 independent research groups, is that biotechnology, and in particular GMOs, are not *per se* more risky than e.g., CPB technologies."

The controversies on safety continue to persist in part because groups with personal, economic, or ideological opposition to the technology actively campaign against using them. The transfer of genes from one plant to another is a natural process and happens in nature through several means. Biotechnology can make this transfer more precise and quicker and it allows scientists to use genes from other species of the same crop or use genes from bacteria. GM products are the most scrutinized new foods for safety and still there is no evidence to show that they are more harmful than any other conventionally bred crop products. In fact, thousands of people die annually in India as well as in other countries as a result of naturally occurring food allergies, which clearly are the real dangers more than the GE products.

GE crops face the allegation of bringing the terminator technologies—what are technically called genetic-use restriction technologies (GURT). The company owning the technology has publicly announced that they would not use the technologies due to the concerns of the public at large, and Indian regulations specifically forbid the use of the terminator gene in India. Biosafety, however, remains a potent political idea. State science in the field of biotechnology has been a target of opposition activists, e.g., there is a criticism that the data generated for commercialization are collected by the companies themselves, though this is not true. Despite evidence in international science and findings of state science in India, safety of 'GMOs' is continually attacked, and stringent regulatory mechanisms permeable to political influence remain in place, serving as chokepoints for blocking the release of new products (Herring, 2014). Such controversies in India reflect and contribute to the global rift in the international arena, segregating agricultural biotechnology from other applications of biotechnology in pharmaceuticals, industry, etc. Framed as GMOs, products of agricultural biotechnology are subject to a different set of standards than those confronting rDNA counterparts in pharmaceuticals and industry.

Biosafety and Bioproperty. Because biotech crops have been placed politically in a category of special risk compared to all other new cultivars, delays and uncertainties are inevitable in biosafety institutions. The uncertain investment climate in agriculture discourages investors in general and in developing countries in particular.[14] The modernization of agriculture with the 'high pay-off inputs'[15] and increasing monetization of the sector paved the way for the private sector to take initiatives to supply agricultural inputs especially seeds, fertilizers, and pesticides. The seed sector has particularly become attractive with ever-enlarging markets in the world as a whole and in India in particular among the developing countries.[16] As the private players embarked on efforts to bring in innovations by enlarging markets, they tried to enforce protection of their innovations through plant breeders' rights under the umbrella of UPOV initially, then later through the much more broad-based Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement as part of the World Trade Organization (WTO).

13. *Seventy-nine percent of the world's soybean was under GE soybean in 2014. The same for maize is 32%.*

14. *Nurkse (1953) for the first time demonstrated the difficulties of investments in underdeveloped countries.*

15. *Schultze (1964) argued for modernizing traditional agriculture with 'high-pay-off' inputs.*

16. *Pray, Ramaswami, and Kelly (2001) bring out this phenomenon very clearly.*

The stronger property-rights regime has further encouraged the sector to grow to a stage where most major innovations in the seed sector are now in the domain of the private sector, in contrast to the GR technologies that were the outcome of research in the public-sector research institutes of the Consultative Group on International Agricultural Research (CGIAR) and national agricultural research systems (NARS) of developed and developing countries. In this special issue, Ronald Herring vividly explains how the novel technologies are linked with the 'special risks' and framed as GMOs. The heightened regulatory procedures combined with the precautionary principle (arising out of this framing) have in fact driven out many small players from the agricultural biotechnology sector and act as entry barriers to many of them. Another article in this special issue by Graff, Hochman, Suntharlingam, and Zilberman explains how many promising technologies would have been commercialized but for the stifling nature of the biosafety regime; this is a major problem for technology development and adoption at present, not the private players *per se*. Further, it is wrong to assume that the seed and biotech companies appropriate all the benefits. Empirical evidence shows that the social benefits to farmers from private investment are high, as demonstrated in the article by Nagarajan, Pray, and Naseem. Ironically, opponents of biotechnology on the grounds of dominance of multinational corporations advocate stricter controls on the technology and actively delay processes of approval when they can, creating an advantage for the multinational life-science firms with deep pockets, connections, and political clout over potential domestic competitors.

Neglect of Agricultural Commons. Natural fallout of the primacy of private players in the seed sector is likely to be the neglect of crops and traits of importance to the resource-poor smallholder cultivators in developing countries (FAO, 2004; Naylor et al., 2004; Pray & Naseem, 2007; Rao & Dev, 2009; Spielman, Kolady, Cavalieri, & Rao, 2014; World Bank, 2007). For orphan crops (such as oilseeds, pulses, minor millets, fruits and vegetables of local taste), livestock diseases in tropical countries like India, and traits like drought or water stress tolerance, salinity resistance might not create big and profitable markets for companies. Even the issue of raising yield barriers is essentially a need of *developing* countries and may not create markets in *developed* countries, as they have already reached higher levels of yield in most of the crops. Consequently, markets might fail to induce development of technologies for the resource poor farmers in developing countries. Market failure would then necessitate state intervention through research from international and national public research institutions. The public sector needs to enter into public-private partnerships to utilize the proprietary technology to optimize social welfare. Though the standard narrative of market failure and private-sector domination still holds true on the whole, the landscape in agricultural biotechnology seems to be moving away from this narrative with recent developments such as drought-tolerant maize in the United States, drought-tolerant sugarcane in Indonesia, public-sector developed virus-resistant bean in Brazil, and Bt eggplant varieties in Bangladesh with a public-private partnership.

Bt Cotton. Despite adoption rates reaching more than 95% of cotton area and the area under cotton increasing to more than 30% of the previously highest area, controversies continue on the performance of Bt cotton. It is noteworthy that there were no controversies in Gujarat, where the adoption was very fast, and stealth seeds made available locally adapted hybrids early on. The controversies are mainly two-fold.[17] The first kind of controversy is the nuanced belief that the yield increases are not significant and that Bt cotton is only a minor factor, even where there were yield increases (Kuruganti, 2009; Stone, 2012). The other kind of controversy involves extreme claims, i.e., that Bt cotton cultivation leads to farmer suicides and the killing of cattle, sheep, and goats on grazing Bt cotton (Ho, 2010; Shiva, 2011). These later controversies are baseless and propagated to draw attention from transnational advocacy groups, as Ronald Herring explains in his article in this collection. The suicides of farmers were first reported in 1997 in Warangal of Andhra Pradesh and have continued since then. The cultivation of Bt cotton—first commercialized in 2002—has in fact mitigated the distress and is in no way responsible for suicides. Three articles in this collection, based on primary and secondary data, show that farmers using GM products get more economic benefits relative to costs. Smale (2012) reviewed the methodologies followed in the impact evaluation studies of Bt cotton across countries and concluded that it would be necessary to go beyond partial budgeting techniques and use sophisticated modeling techniques such as fixed-effects models with panel data. This has been done in

17. *Herring and Rao (2012) examined these arguments more in detail and synthesized evidence on the performance of Bt cotton in India.*

some of the articles in this special issue. Sadashivappa uses panel data collected from primary surveys at three points of time. Nagarajan, Pray, and Naseem analyzed primary data collected by Francis Kanoi with a large sample of more than 15,000 farmers in different cotton-growing states from the mid-1990s to the present.

Political, Public Policy, and Socioeconomic Issues in this Special Issue

The collection of articles in this special issue tries to address the foregoing issues in the Indian context. Apart from the keynote paper that focuses on politics around GE crops, it contains six articles that deal with public policy, socioeconomic impacts of Bt cotton, and impacts of the technologies on the horizon in the Indian context. The set of articles in this special issue are the revised papers that were initially presented at a conference entitled 'Biotechnology in Indian Agriculture: Potential, Performance, and Concerns' organized by the Centre for Economic and Social Studies in Hyderabad, India in January 2012. This section summarizes discussion at the conference, focusing mainly on the articles included in this collection, with a brief mention of other relevant issues from presentations that are not included in this special issue.

In the keynote paper—which set the tone for discussion at the conference—Ronald Herring examines the politics of science and the science of politics. A necessary condition for technological progress in agriculture is political support. New technologies are subject to the politics of risk and therefore to unique regulatory hurdles that block or slow innovation. Herring asks specifically: why is the science of agricultural biotechnology so vulnerable to politics? There is great political dispute surrounding assessment of 'performance, potential, and concerns' in biotechnology in India; any analysis of necessity begins with Bt cotton and works through the continuities and disjunctures of Bt brinjal. The essay focuses on the processes through which objective information that could inform understanding of performance and potential of agricultural biotechnology generally operates in social and political life. By all credible accounts, Bt cotton has been an agro-economic success. One can think of few innovations that have had such a powerful impact on the farm and in the aggregate in Indian agriculture. Yet, when India's second transgenic crop was up for commercialization in 2010, much of the opposition centered on a narrative of 'the failure of Bt cotton' as a reason for halting further development of agricultural biotechnology. That narrative of failure and catastrophe—prominently an epidemic of farmer suicides—is widely distributed globally and affects positions on agricultural biotechnology in other nations, as well as future prospects in India. The transgenic *brinjal* [*Solanum melongena*; eggplant/aubergine] carried the same Bt transgene [*cry1Ac*] used in early and dominant Bt cotton hybrids and promised parallel benefits through an IR trait.

Lessons from Bt cotton have been constructed as indicating two radically different trajectories for agricultural biotechnology. As the failure and catastrophe narrative is contradicted by the results of normal science, its persistence and power create a puzzle within the politics of science. Why is the factual story of agricultural biotechnology so vulnerable? Can political science tell us anything about this peculiar politics of science? The answer of necessity requires embedding Indian dynamics in the global politics around biotechnology and their associated networks of activism. Of special importance is the institutional structure that followed from creation of the very idea of a GMO. The framing of agricultural biotechnology as GMOs, separating crops from pharmaceutical and industrial biotechnologies, proved generative in a path-dependent way. There could, for example, be no mobilization for GMO-free zones or bans on GM food without the GMO. Nor could global soft law—the Cartagena Protocol—provide for institutions that give opponents of biotechnology power and influence disproportionate to their numbers. This construction of especially risky plants vulnerable to control by firms unresponsive to and dominant over the farming community was a joint production of international and Indian networks of activists. That framing cumulatively rendered the science of assessing biotechnology in India vulnerable to erroneous and frightening accounts that undermined prospects for agricultural progress.

Context and Public Policy Issues

At the conference that produced this collection, Praduman Kumar presented data that indicate the necessity of technological change in Indian agriculture. The paper utilized indices of TFP and movement with the factors responsible for different crops and regions and data on cost of cultivation of important crops for the period 1971 to 2005, as well as infrastructural variables for the same period. It estimated indices of TFP (using the Divisia-Tornquist method) and real cost of production (value of marginal product and the internal rates of return). The results suggested that the sustainability issue of the crop sector is fast emerging as a major challenge in India; it is more serious in the Eastern and Western regions of the country. The productivity growth attained in 1975-95 has not been sustained from 1996 to 2005 for a number of important crops and has posed a challenge to the researchers. The ecological problems have cropped-up in a large number of states. At the farm level, long-term changes in the biophysical environment have manifested in terms of declining TFP growth. Due to degradation problems, growth in TFP has not made headway across a substantial area for several crops in India. Public policies—such as investment in research, extension, education, and infrastructure—and natural agricultural resource management have been the major sources of TFP growth. In India, returns to research investment for crops are high. The returns to government investment in agricultural research have been estimated as 42%, which is quite a significant contribution to the national economy. The internal rate of return to research investments ranges from 18% to 39% across crops. The conclusion is that efforts need to be concentrated on accelerating growth in TFP while conserving natural resources and promoting ecological integrity of the agricultural system.

The private sector has invested large amounts in agricultural research with the advent of modern biotechnology and simultaneous strengthening of provisions in the intellectual-property regime through worldwide enforcement of the TRIPS-compliant intellectual property regimes in many countries. Devraj Arya and co-authors present the viewpoint of a private investor on how the technology is engineered towards higher productivity and sustainability (this paper is not included in this special issue). They argue that biotechnology can play a major role in sustainability of Indian agriculture through higher productivity with effective pest and weed management, which otherwise drag down yields in the country to a much lower level relative to several other countries and the world average. They contend that weed control did not receive the attention that is commensurate with the magnitude of its negative impact on productivity of crops, and now is the time to debate the necessity of HT crops. It was also argued that the research data on food and feed safety in plants with novel genes and their effects, generated in other countries, should be accepted as the basis of safety assessment without replication and loss of time. The most important rule change is simplifying regulatory procedures through bringing in the proposed Biotechnology Regulatory Authority of India bill that can put in place a comprehensive regulatory framework.

Public Policy

Bansal and Gruere assess the economic implications of introducing a strict mandatory labeling policy for GM food in India, as proposed in 2006, focusing on rice and brinjal (eggplant), two food products that would likely be the first affected. They find that GM food labeling would result in a specific market outcome for each of these products. Mandatory labeling would generate adjustment and implementation costs, but consumer benefits would not always be visible and would depend greatly on the degree of enforcement. Their analysis is based on the existing literature and qualitative surveys of the market chain actors for these two products. They find that market effects of labeling will be highly dependent on the types of product. In particular, the labeling of brinjal and rice is bound to create more significant consumer reactions than for the highly processed edible oils. Furthermore, labeling for these products may result in increased product differentiation, but at a different scope and for different purpose. More generally, products with informal marketing systems are at high risk of being mislabeled.

The presentation by Dominic Glover (not included in this special issue) in the conference made an attempt to work out some implications of a human-rights-based perspective on food security for the governance of transgenic crop technologies. It implies that cultivators should have access to improved (including GE) germplasm and should be empowered to try transgenic varieties freely, assess their qualities in local conditions, exchange their seeds, and carry out selective cross-breeding with other varieties. He goes on to explain how transgene contamination is not necessarily disastrous for crop biodiversity because farmers will continue to conserve and develop a range of crop varieties that suit their diverse needs. He suggests that non-governmental organizations (NGOs) and campaigners should think carefully about the nature of their chief concerns about GMOs in agriculture by concentrating not on transgressions but on the commodification of agriculture, corporate dominance, and the erosion of crop biodiversity and the consequent unsustainability of modern farming methods.

Gregory Graff, Gal Hochman, Chubashini Suntharlingam, and David Zilberman analyze the political economy of intellectual property and regulatory policies in agricultural biotechnology and implications for the role of public-sector crop genetic development. Science and technology policies that influence the innovation and adoption of agricultural biotechnologies include public funding of crop genetic research, intellectual property protections, and biosafety approvals of regulated crops. The political economy (or 'public choice') approach views policy decisions as behaviorally rational responses to the range of pressures and inducements—such as political connections, lobbying, political donations, endorsements, elections, and popular movements—arising from the different segments of society or interest groups. This article uses the political economy approach to show how and why—almost twenty years after the disruptive technology of GE was first commercially deployed in agriculture—policies in most countries have come to be aligned so as to favor the incumbents of agricultural input industries, such as agrochemicals and seeds, over the interests of almost all others in society, including farmers and consumers. Moreover, it is argued that it is consistent with the interests of these industries to allow public opinion of the technology to be negative or at least uncertain. This can be seen as a rational strategy to exploit the policy process to direct the technology in a manner that reinforces their incumbent economic interests and minimizes the technology's natural potential to disrupt them. Implications are then drawn for the potential role of public-sector research, technology transfer, and new entrepreneurial entrants in agricultural input markets to realize the broader economic potential of agricultural biotechnology.

They argue that the regulatory mechanism should regulate the product and not the method of introducing genetic variation. Because the paradigm of pesticide industry rules policy making, regulation does act as a strong entry barrier and discourages many potential innovations (Kolady & Herring, 2014). The case of Bt cotton in India is a good example where Mahyco-Monsanto Biotech Limited enjoyed something similar to a monopoly position from 2002 to 2006, though it did not have a patent at that time because others could not get their Bt traits approved. The authors argue that a middle path has to be followed, including increased funding of public-sector biotechnological research, need-based regulation based on the end product rather than the process, and strong intellectual property rights. This policy configuration will combine to realize the social welfare potential of biotechnology.

The Bt Cotton Experience and Its Impact

The tools of modern biotechnology have changed the research environment in the agriculture sector with many players in the private domain investing in developing need-based technologies for farming communities in developing countries. The article by Nagarajan, Pray, and Naseem analyzes the impact of private-sector research and development (R&D) and biotechnology on cotton productivity by using a big dataset of farm households to calculate internal rates of returns to firms as well as the economic rates of return to society.

Private seed firms in India have made an important investment in cotton breeding and biotechnology since the 1980s. These investments were based on public-sector research that developed practical methods of producing cotton hybrids and inbred lines that companies could use as the basis for their breeding programs. These investments paid off with a series of hybrids that has allowed proprietary hybrids to take over 33% of the area under cotton by 1998 and 56% by 2002. With the introduction of Bt hybrid cotton in 2002, proprietary hybrids moved up to 75% of the area in 2004 and 95% in 2009. These hybrids have an important impact on cotton productivity: average cotton yield data from the government were 552 kg/ha in 2013-14 compared with 302 kg/ha in 1998.

Though many micro-level studies have shown that Bt cotton led to important gains in yield as well as reductions in pesticide use, few studies have used large datasets for the entire country, and none of them have tried to sort out how much of the yield increases were due to the adoption of hybrids as opposed to the adoption of Bt. Pray, Nagarajan, and Naseem address this very significant gap in empirical literature by presenting their analysis utilizing the data from surveys of between 10,000 and 20,000 farmers per year in 1998, 2000, 2002, 2004, and 2010 that were collected by the Francis Kanoi Marketing, Planning Services Ltd. and fitting a multivariate panel regression model with time-fixed effects using ordinary least squares method. By comparing the mean yields of open-pollinated varieties (OPVs), public hybrids, private hybrids, and private Bt hybrids, it was found that private hybrids did provide a major increase over public hybrids and OPVs and that private hybrids with Bt yielded more than private hybrids without Bt. Regression analysis also shows that the adoption of Bt cotton reduces farmers' pesticide costs while the adoption of non-Bt hybrids is associated with higher pesticide costs.

The rough calculation of financial benefits to companies that invest in hybrid cotton research and incorporate Bt genes show internal rates of return of 21%. The economic rates of returns to society are much higher (in the range of 36-44%) since farmers and consumers capture most of the benefits from this research. This suggests that government programs to encourage private-sector R&D could have substantial payoffs not only for private firms, but also for the farming community and Indian society.

In a similar vein, Prakash Sadashivappa analyzes the development of benefits and the role of government seed-price interventions with the introduction of transgenic cotton. While previous research has analyzed the impacts of Bt cotton in India, most available studies are based on one or two years of data only. He analyzed the technology's performance over the first five years of adoption, using panel data with three rounds of observations. The study emphasizes the advantages of using panel data econometrics in improving our understanding of technology adoption and impacts.[18]

The results from a random-effects probit adoption model show that Bt technology is scale-neutral. Therefore, the common notion that transgenic crops are suitable only for rich and large-scale farmers is not confirmed under Indian conditions. However, farmers with more formal education and those with better knowledge and information about the technology are more likely to be among the early adopters, underlining the fact that structural constraints in rural society still need to be overcome. Net impacts on cotton yields and profits are analyzed using a fixed-effects panel model. The estimation results confirm yield- and profit-enhancing impacts of Bt cotton. While the panel data models result in somewhat lower net impacts than simple regressions with cross-section or pooled data, the results are still sizeable and highly significant: controlling for the non-random selection bias, the net yield gain of Bt technology is 28%, while the net profit gain is 55%. These findings confirm and extend previous studies on Bt cotton impacts in India and other developing countries, building on a unique dataset. Nonetheless, further research is needed on long-term aspects of transgenic crops, including economic, social, and environmental implications under different conditions. The panel data methodology applied here can be a foundation for future technology adoption and impact studies.

Technology diffusion and adoption in cotton cultivation varied among the Indian states; Gujarat is in the forefront. Lalitha and Viswanathan examine the emerging scenario in that state with regard to the seed and pesticide technology among the Bt cotton growers by analyzing the farmer use practices of these inputs. Gujarat has always been ahead of other states in adopting new seed technologies such as the high-yielding varieties (HYVs), hybrids, or the recent genetically modified hybrids. Use of newer technologies has also increased the need to use plant protection methods to save the crop from other pests, though the overall usage of pesticides has declined. According to the geographical perspective of diffusion of technology, effective diffusion does not take place unless there is some institution that makes the technology available near the potential adopter. In the case of Bt cotton technology, seed diffusion takes place through the channels of the seed companies, seed dealers, and fellow farmers. While the direct link between the companies and the farmers is very thin, the link between the seed dealers and the farmers is strong, as the seed dealers also stock other agricultural inputs and provide the much needed extension service, though to a limited extent. Hence, the farmers also solicit the seed dealer's opinion in the choice of inputs. Using information collected through structured questionnaires in the year 2007 and 2010, this article discusses the role of the seed dealers in the diffusion, choice, and use of seed and plant protection technology by the farmers. The gaps in the information extended to farmers are neither met by the government or private seed companies' extension workers nor by the seed dealers, potentially restricting the dividend from adoption of technology.

Impacts of Biotechnologies on the Horizon

Bt cotton has been the only GE crop approved for commercialization in India. It has, by many measures, been an agronomic and economic success. This success suggests that other crops could benefit from transgenic technology.

The area under maize has been increasing, continuously reaching nearly 9 million hectares in India and replacing some of the traditional dry land crops. However, the productivity of maize in India is one of the lowest among the maize-growing countries. The losses due to ineffective control of crop pests and weeds pose major challenge in shifting the production function to a higher level. The application of IR and HT transgenic technologies have to be viewed in this background. The article by Kalaitzandonakes, Kruse, and Gouse examines evidence from several developing countries and mainly focuses on Kenya to work out the market effects (supply, demand, and prices) of the introduction of the

18. Rao (2013b) examined in detail the methodological pitfalls in assessment of impacts of cultivating Bt cotton and methods employed in different studies to overcome them and concludes that the transgene significantly increased yield in cotton in India relative to other countries, even after isolating the farmer effect and input effects.

HT maize by using a synthetic partial equilibrium model with data from Production, Supply, and Distribution Database (PSD); US Department of Agriculture (USDA); and FAO.

A review of the evidence suggests that the aggregate economic impacts of HT maize would exceed those of Bt maize when used alone, and the aggregate economic impacts of HT/Bt maize stacks seem even higher. Market evidence from small- and medium-sized farms in the Philippines and South Africa supports such valuations. Data collected in 2009/10 in Hlabisa, South Africa suggests that all farmers in the sample who used biotech maize had shifted to either HT maize or HT/Bt stacks, and none reported using Bt hybrids despite significant adoption in previous years. Similarly, while Bt maize was first introduced in the Philippines in 2003 and its adoption increased gradually over the four following years, after the commercial introduction of HT and HT/Bt stacks in 2006, the adoption of Bt maize has waned. In 2009/10, only 2% of the total maize hectares in the Philippines were planted with Bt maize, 4% with HT maize, and 13% with HT/Bt stacks.

The authors hypothesize that the yield effects in Kenya can be significant in view of the poor weed management and consequent cost inefficiencies and yield losses. Experience from the use of HT maize in the Philippines and South America is still emerging, but it is encouraging and suggests that the technology can substitute for large amounts of capital and labor used in land preparation and weeding, thus reducing production costs and increasing yields. It should be possible to replicate or exceed such farm-level impacts in Kenya. Based on the analysis presented here, the aggregate economic impacts from such farm-level impacts could be large. The results of a partial equilibrium model in Kenya show that the aggregate economic impact of HT maize in Kenya would be significant even under conservative assumptions about the likely farm-level impacts.

Challenges of Factoring in Biotechnologies in Policy Making

Technologies do not work in isolation of the existing socioeconomic milieu, institutions, policy framework, and prevailing cultural and managerial attitudes of the population, apart from resource-related and climatic factors. The agricultural technologies are no exception to this fact, as GR experience has amply demonstrated.[19] The government formed several institutions in the mid-1960s—parastatals for fertilizer and seed production, Agricultural Prices Commission,[20] procurement agencies like the Food Corporation of India, buffer stock management organizations like the Central Warehousing Corporation—in addition to stepping up efforts in the creation of irrigation facilities. It has to be underlined that these measures are aimed at making optimum use of seed-fertilizer technologies to achieve food security and agricultural development, considered to be major national development goals at the time. However, a moot question is whether the country's government is willing to take similar wide-ranging policy measures required to take the plunge in harnessing biotechnology.[21]

Harnessing biotechnologies would most importantly require regulatory framework that allows commercialization of safe and useful technologies, while at the same time assuages the concerns of the consumers. While the discoveries in biology have made huge difference to the available inventory of technologies in the sphere of biotechnology, the regulatory mechanisms have not kept pace with the changes in technology and the demands of society, and therefore tensions have arisen out of this disjuncture.[22] There can be a sea change if the new Biotechnology Regulatory Authority of India (BRAI) comes into effect with sufficient manpower to assess the risks and with the power to make decisions regarding commercialization of biotech products. The BRAI bill—first prepared in 2009—was introduced in Lok Sabha in April 2013 and sent to the standing committee. It details an elaborate mechanism with three divisions for agriculture, human health and veterinary medicine, and industrial and environmental products. These divisions include risk-assessment units, product-ruling committees, environmental-appraisal panels, an inter-ministerial governance board, biotech advisory council, state-level bodies, and appellate tribunal. BRAI proposes to be governed by a five-member committee on a full-time basis. It could address many of the loopholes in the present system of regulation and

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19. *Unable to understand the role of technology as one of the several factors in production and profitability of farming, some critics blame Bt technology for the farm crisis. (e.g., Sainath, 2012).*
20. *Now referred to as the Commission for Agricultural Costs and Prices (CACP).*
21. *Rao and Dev (2009) discuss how public investments in biotechnology are important to assist with possible market failures with the biotechnologies, apart from providing an enabling environment to the private sector.*
22. *Kalaitzandonakes (2000) argues for institutional changes to make best use of biotechnologies.*

can go a long way in improving the enabling environment not only for agricultural biotechnology, but also for pharmaceutical and industrial biotechnology. However, the bill has been in Parliament for a long time without any certainty on when it can come out of the process. The same is the case with the Seeds Bill, which was first introduced in 2004. These delays lead us to the question of why these policies are not taken seriously or why there is such a huge time lag in passing these bills. Let us examine the background to this.

Agriculture No Longer Considered Central to National Development. The major problem now is that agricultural development itself is not central to the concerns of the policymakers, as the changing paradigms of development theory at the international level and certain developments in India relegate agriculture to an issue of secondary importance. The post-second-war literature on development theory emphasized the need for modernization of agriculture as a precondition for industrial growth, which then was regarded as the sole indicator of development of a country (e.g., Lewis, 1955; Schultz, 1964). However, the decline of development theory[23] and rise of post-modernist approaches combined with the rise of neoclassical economics have virtually robbed agriculture of its importance for national development projects throughout the world in general and developing countries in particular. The focus of development has been on export-oriented industrialization and service sectors.

The changing dynamics of electoral politics, the relatively small share of agriculture to national income, and declining proportion of people in the sector has reduced the political importance of agriculture in India. The changing dynamics of electoral politics indicate that now elections are fought with money from real estate dealers and industrialists rather than money from the landlords who financed the Parliament and Legislative Assembly members in the 1960s. The farming community is seen just as a group that has to be placated by means of some populist measures and a lot of rhetoric (Suri, 2006). The share of people in agriculture in the 1960s at 70% was far more than that in 2011, which stands at a little less than 50%. This fact alone naturally reduces the collective voice of agriculturists at the polls.

More striking than the decline in relative numbers of agriculturalists, is the decline in share of agriculture in the gross domestic product of the country, which has declined from 48.3% in 1960-61 to 18% in 2013-14. As a result, policymakers are likely to focus on service and manufacturing sectors to spike the aggregate growth rate of the economy. Further, there are arguments that the manufacturing sector has become independent of the growth of agriculture sector (Chandrasekhar, 2007), while some scholars have shown that poverty reduction does not depend on the development of agriculture (Panda, 2010). The new government under the National Democratic Alliance (NDA) regime seems to be focusing on manufacturing to take the economy to higher growth trajectory with the likes of the 'Make In India' campaign. The coalition politics after 1991 led to an enlarged role for the states, which eroded the center's authority. The controversies surrounding the entry into WTO reinforced the clamor for an enhanced role for states in policy formulation for agriculture, which is a state subject under constitution.[24] Returning to the case of agricultural biotechnology, the moratorium on Bt eggplant in 2010 was followed by executive instructions making it mandatory to obtain permission from state governments to allow field trials of transgenic crops. This is proving to be the major hurdle in approval for field trials. Judicial activism has spilled into the technological sphere also and has stalled approvals for field trials from April 2012 until the new government began permissions toward the end of 2014. All these developments at the international and national level reduce the salience of agriculture in policymaking and waning capability of the central government to propel technological change.

The most powerful of the causative factors with regard to resistance for harnessing biotechnology in agriculture seems to be the rise of civil society groups active since the onset of liberalizing reforms in 1991. They run an acrimonious campaign to 'drive out' biotechnology from India and usher in organic agriculture. The problem is best explained in the words of economist and former Prime Minister Dr. Manmohan Singh (2012, p. 908) in an interview with *Science*:

> "Biotechnology has enormous potential, and in due course of time we must make use of GE technologies to increase the productivity of our

23. *Streeten (1995) vividly captured this change. de Janvry (2010) decried the lack of grand theory for agricultural development.*

24. *This is diametrically opposed to the situation in the sixties when centrality in policy making facilitated policy making in favor of modernization of agriculture (see Anderson & Morrison, 1982, for role of central government).*

> agriculture. But there are NGOs, often funded from the United States and the Scandinavian countries, which are not fully appreciative of the development challenges that our country faces."

Farmer groups are much less powerful in India compared to countries like Brazil, Argentina, South Africa, and the United States. They are unable to force the government to make decisions that improve access to better technologies. Besides, many farmer organizations are focused on single crops or work only in one state and lack national presence. Their focus is typically subsidies on inputs, higher price supports, and loan waivers. Indian politicians attempt to increase their rural votes not through projects for technological innovation, but through more immediate, less risky, and more lucrative means such as bigger food rations, price supports for major grain crops, subsidizing agricultural inputs, and rural employment schemes. While these measures have the advantage of immediate results, patronage jobs, and bribery opportunities, support for biotechnologies invites controversy and outrage from the urban-based activist groups.

However, agricultural development has attracted renewed global attention in recent years after a number of economic, social, and environmental crises, especially the food crisis of 2008 (de Janvry, 2010). The crisis in Indian agriculture intensified by the beginning of the new millennium, and reviving agriculture topped the policy priorities after the 2004 national elections. The relentless campaigns by civil society groups, lack of visionary leadership on the part of political parties, and erosion of central authority restricted full commitment to harnessing biotechnology to agricultural development. There is precedence for this dilemma. The adoption of GR technologies and the associated supportive policy framework encountered opposition as well. Despite stiff opposition to the 'dangerous' seeds in the 1960s, visionary leader C. Subramaniam was able to think ahead and move the country forward. He wrote about the all-round resistance in 1964 to import HYV seeds in his memoirs:

> "The Agricultural Department members and senior scientists were all opposed. With the exception of a few voices, they all said 'No, it's too dangerous.' But, I heard those few voices, and that was all I needed" (Vietmeyer, 2004, p. 108).

Subramaniam's bold approach contains a lesson, and the results are there for everyone to see. Production and productivity increased dramatically, and the import bill diminished. Sooner or later the political leadership will have to come forward to make bold decisions for a revival in the country's agriculture through a second Green Revolution. The government will have to provide an enabling environment for the private sector to bring out useful products for the farmers and simultaneously invest more in public-sector research in biotechnology. The public-sector research on biotechnology now is very meager compared to China and Brazil, where NARS is strong. The regulatory framework has to be made more professional and responsive to the need for commercialization and the concerns of consumers about safety.

However, there is hope that in view of the accumulating evidence on the potential and performance of these technologies, as discussed in many of the articles in the this special issue of *AgBioForum*. Many countries (like Mexico, South Africa, and Brazil) that earlier had been very apprehensive have been recasting their policies. The present logjam in commercialization of agribiotech products in India calls for visionary leadership by policymakers to change biotech policy and regulation. The revival of interest in agriculture for development in light of rising food prices at the national and international levels and better alignment of regulatory frameworks to the scientific data is consistent with these objectives. This understanding of the need for agricultural productivity growth and the potential for biotechnology to contribute to it should enable policymakers to apply course correction in addressing regulatory issues in the foreseeable future. Serious knowledge gaps remain in the area of indirect and economy-wide effects of these technologies, and future research addressing them would be the key to better understanding and harnessing of biotechnologies. In this evolutionary learning process, dispassionate research into the nature, impacts, and policy-related lacunae will go a long way toward informing productive discourse and better policy.

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