Agricultural Economics Research Review
Vol. 30 (Conference Number) 2017 pp 241-256
DOI: 10.5958/0974-0279.2017.00038.6

Biotechnology for Farmers Welfare and Poverty Reduction: Technologies, Impact and Policy Framework

N. Chandrasekhara Rao*

Institute of Economic Growth, Delhi-110 007

Abstract

Tools of biotechnology provide the chances of infusing a new round of technology into the agricultural sector of developing countries, for raising farmers income and for accelerating poverty reduction. This paper has examined the nature and adoption of biotechnologies, socio-economic impacts, regulatory frameworks and concerns for rising farm incomes, in a cross country perspective. The product development in biotech has been moving from just insect/herbicide resistance to breaking yield barriers, drought tolerance and quality enhancing traits; and just from three crops to 28 crops. Contrary to the standard narrative, the developing countries in 2016 accounted for a larger share of the area under genetically engineered (GE) crops. The public sector has been making inroads in developing biotech crops. Rigorous study of peer-reviewed literature shows that GE crop cultivation has increased yields and net income, reduced pesticide usage, and helped conserve tillage. On the downside are instances of resistance development in pink bollworm in India and in weeds to glyphosate in other countries. Harnessing biotechnologies necessitate enabling policies like legal framework for biosafety, labelling and transboundary movement in consonance with Cartagena Protocol. Continuing consolidation, driven by higher needs of investments is transforming the seed sector and raises concerns for small-farm agriculture through "tragedy of the anti-commons". The possible countervailing forces and ways to strengthen them have been discussed. The policy implications have been then drawn for utilization of opportunities in advancement of biotechnology for developing country agriculture.

Key words: Yield effect, selection bias, halo effect, employment, regulatory framework, IPRs, drought-tolerance, labelling, consolidation

JEL Classification: J4, K19, L1, O3, Q10, Q16

Introduction

Food crisis of 2007 brought back the 'classical development paradigm' which views agriculture as an engine of economic growth, industrialization and structural transformation and stresses on uni-modal strategy of modernizing the entire agricultural sector, including the smallholder sector rather than just the high-value segment (Durr, 2016). Many developing countries are passing through the "Schultz" stage, where rising agricultural incomes fall behind the rapidly growing non-farm incomes, exacerbating rural-urban disparities (Barrett *et al.,* 2010: 451). While China and India are the striking examples of this phenomenon, countries in Africa continue to be food insecure and East Asian countries suffer from large food imports (Otsuka, 2013: 7-8). Lack of modernization of agriculture is one of the reasons for 'middle income trap' that has been haunting countries like Brazil, Mexico, Malaysia, Argentina, South Africa, China and India (Eichengreen *et al.,* 2013; Armstrong and Westland, 2016).

The decline in agricultural productivity due to climate change is estimated to be to the tune of 10-38

* Author for correspondence
Email: raonch@gmail.com

per cent in individual crops by 2050 and spatial spread is likely to be adverse to developing countries and regions (Muller and Robertson, 2014; Rao, 2015). Further, the scope of agriculture is expanding in the world to cater to the rising demands in non-food applications like fuels, fine chemicals and other products (Zilberman *et al.,* 2013). Concerted efforts are needed to counter the reversal of secular decline in food prices after the 1990s in most countries of the world including India (Dev and Rao, 2010; Rao *et al.,* 2015). Apart from the level of prices, excessive volatility and spikes are one of the most critical economic and food security challenges (Swinnen and Riera, 2013). To sum-up, there is a pressing need to modernize small farm agriculture and raise agricultural productivity in view of the need to put back agriculture as engine of growth in line with 'classical development paradigm' as well as issues arising out of climate change, expanding role of agriculture to non-food requirements, raising food prices and price volatility. Then, the issue to be addressed is whether and how the rapidly diffusing biotechnologies can serve this purpose. We present a framework here to follow in this paper.

Conceptual Framework

Theoretically, there can be both positive and negative impacts of any technology, including agricultural technologies, which can both be direct and indirect. It is noteworthy that technology has impacts on adopters, non-adopters as well as on populations unrelated directly to the production process of the sector. However, the actual extent of these impacts is moderated by the available infrastructure, political, socioeconomic contexts of regions as well as the characteristics of the adopters along with asset distribution patterns (Adato *et al.,* 2007).

There is a consensus in the extant literature on poverty reducing effects of agricultural growth (Ahluwalia, 1978; Mellor, 2006). The experience of poverty reduction in poor agrarian societies reveals that raising the productivity of small-scale farming is the key requirement to overcome poverty, because the poor are concentrated in the rural areas and their livelihoods are based on agriculture (Lewis, 1954; Rao and Dev, 2010). Beyond the obvious effects, technologies can increase growth and employment opportunities in rural non-farm sector and thereby contribute to poverty reduction (Mellor, 2006). This in turn will have an upward pressure on wages. However, the poverty-reducing effects of technology depend on the nature of technology, nature of poverty, and type of institutions in the adopting region (de Janvry and Sadoulet, 2002).

Several studies have shown that seed-fertilizer technologies of the 1960s made a positive impact on agricultural growth, helped in diversifying to high-value crops, and made a dent on poverty in Asia and Latin America, while the African continent could not derive significant gains, for lack of necessary policy support and unavailability of improvements in crops of local interest (Hazell, 2009; Pingali, 2012). It is clear from Green Revolution experience that new agricultural technologies cannot be harnessed without enabling policy framework.

This paper looks, in a cross country perspective, at nature of biotechnologies and their diffusion patterns, provides a critical evaluation of the impact of the genetically engineered (GE) crops on farm incomes, analyses evolving regulatory frameworks, and examines consolidation in seed and agricultural biotechnology and emerging countervailing forces for smallholder agriculture. This paper does not go into the biosafety issues and remains confined to agronomic and socioeconomic impacts and policy-related issues.

Diffusion and Nature of Biotechnologies: Moving Frontiers

Standard narrative in development literature posits that predominantly multinational-developed biotechnologies will be tailor-made to the cultivation requirements of industrial agriculture of developed countries and the crops and traits of importance to resource-poor farmers in developing countries will be bypassed (Rao, 2004; Rao and Dev, 2009). However, the recent shifts in both technology development and adoption across developing countries allay these fears to some extent, though issues arising out of concentration in the seed industry continue to be of concern. These issues are dealt with later in this paper.

The foremost among the recent shifts is moving of technology frontiers from genetic engineering to gene editing (Hefferon and Herring, 2017), leaving out many of the unintended consequences of introducing a foreign gene through the development and adoption of SU (Sulfonyl urea) tolerant canola in USA. It uses a new gene editing method called CRISPR (Clustered Regularly Interspaced Short Palindromic Repeat). The past few years have witnessed a higher share of developing countries in the total area covered under the GE crops, viz. 54 per cent of the 185.1 million hectares (Table 1) and this contrasts with the early years of commercialization. Brazil, Argentina, India and China occupied nearly 85 per cent of the area under these crops in 2016.

Commercialized crops moving beyond four crops (soybean, maize, cotton and canola) and public sector, despite diminished funding and regulatory and IPR hurdles, moving ahead and bringing out GE products in several crops are further indicators of moving frontiers. The portfolio of technologies encompassed 28 crops in 2015 and all of them were being commercialized in different countries (Table 2). Most prominent among them are: drought-tolerant (DT) soybean in Argentina; DT- sugarcane in Indonesia; Bt brinjal in Bangladesh; Bt cotton in China, Pakistan, and India; virus-resistant (VT)- bean in Brazil; VT-potato and VT-papaya in Argentina; and VT-papaya, petunia, sweet pepper and poplar in China. There are approved events now that break yield barriers, afford protection against abiotic stresses like droughts and enhance quality of product (Figure 1). The DT- maize

Table 1. Country-wise area under genetically engineered crops and approved events in developing countries

Country	Total area under GE crops in Mha	Soybean		Maize		Cotton		Other crops with comercialised biotechnology
		Area in Mha	GM events commer-cialised (Numbers)	Area in Mha	GM events commer-cialised (Numbers)	Area in Mha	GM events commer-cialised (Numbers)	
Brazil	49.1	32.69 (96.5%)	5	15.67 (88%)	20	0.79 (79.3%)	12	Mosaic virus resistant bean; fast-growing eucalyptus
Argentina	23.8	18.7 (78%)	8	4.74 (97%)	29	0.38 (98%)	3	Drought-tolerant soybean; virus-resistant potato
India	10.8	-	-	-	-	10.8 (96%)	6	
China	2.8	-	-	-	-	2.8 (96%)	8	Virus resistant papaya, petunia, sweet pepper, poplar
Paraguay	3.52	3.21 (96%)	1	0.3 (44%)	4	0.01 (100%)	3	-
Pakistan	2.9	-	-	-	-	2.9 (97%)	2	-
S. Africa	2.7	0.5 (95%)	1	2.16 (90%)	9	0.009 (100%)	6	-
Uruguay	1.3	1.23 (98%)	5	0.06 (86%)	10	-	-	-
Bolivia	1.2	1.2 (91%)		-		-		-
Philippines	0.8	-		0.812 (65%)		-		-
Total	98.9	57.53	20	23.74	72	17.69	40	-

Source: James (2016)
Note: Figures within the parantheses represent adoption rates of GE crops

Table 2. Approved GE technologies (Events) in public and private domains

Sl No.	Crop	Public sector	Private sector	Total
1	Maize	0	148	148
2	Cotton	4	54	58
3	Potato	2	43	45
4	Canola	3	41	44
5	Soybean	0	34	34
6	Carnation	0	19	19
7	Tomato	3	8	11
8	Rice	4	3	7
9	Alfalfa	0	5	5
10	Papaya	4	0	4
11	Sugarcane	3	0	3
12	Chicory	0	3	3
13	Sugar beet	0	3	3
14	Tobacco	1	1	2
15	Poplar	2	0	2
16	Melon	0	2	2
17	Rose	0	2	2
18	Squash	0	2	2
19	Apple	0	2	2
20	Wheat	0	1	1
21	Flax	1	0	1
22	Petunia	1	0	1
23	Plum	1	0	1
24	Creeping bent grass	0	1	1
25	Bean	1	0	1
26	Sweet pepper	1	0	1
27	Eucalyptus	0	1	1
28	Brinjal	0	1	1
	Total	31	374	405

Source: isaaa.org

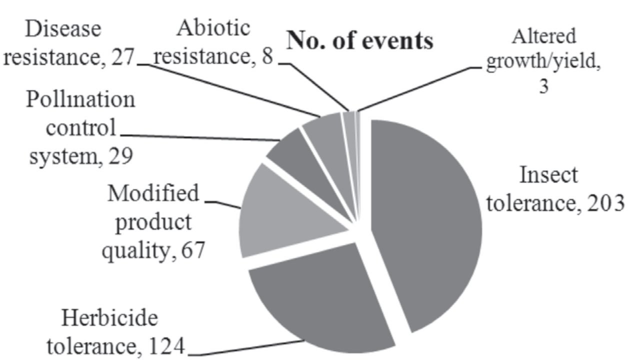

Figure 1. Commercialized genetically engineered (GE) traits
Source: isaaa.org

was commercialized and is grown in twelve lakh hectares in 2016 and the Water Efficient Maize for Africa (WEMA), donated by the private sector, is likely to be commercialized soon in Kenya. There has been a move towards GE food crops with white maize in S. Africa; non-browning apples, late blight resistant potato, sweet corn, sugar beet and papaya in USA; and Bt brinjal in Bangladesh. However, it is a matter of concern that private sector still has bulk of these new biotech crop products, despite some progress by the public sector.

Socio-Economic Impacts of Cultivation of GE Crops

Several rigorous research studies have focused on the agronomic, environmental and socio- economic impacts of GE crops, just as the debates and controversies have been leading to intense scrutiny of bio-safety related issues of agricultural biotechnologies. Both meta-analyses of studies on impacts (Table 3) and crop-wise individual studies (Table 4) show higher yields, lower pesticide-use and better net returns. Meta-analysis by Klumper and Qaim (2014) have found a 22 per cent yield increase associated with 68 per cent profit gain and 38 per cent reduction in pesticide expenditure. The longitudinal studies over the past 19 years show that GE crop cultivation created additional gains of US dollars 150 billion conserved biodiversity by saving cultivation of 152 Mha of land (Brookes and Barfoot, 2016; 2016a). Evidence from Tables 3 and 4 point to higher yield-gains in developing countries as pest attacks are not effectively controlled in the absence of these technologies. The causative mechanism can be expressed in a damage control framework, following Litchenberg and Zilberman (1986) as Equation 1:

$$Y = F(x)\,[1 - D\,(z, Bt; N)] \qquad \ldots(1)$$

where, Y is the effective crop yield, and $F(.)$ is the potential yield without insect/weed damage, which depends on variable inputs, x; $D(.)$ is the damage function determining the fraction of potential output being lost to insect pests; it can take values in the 0-1 interval; N is the exogenous pest pressure and can be reduced by either pesticide applications (z) or Bt technology adoption. Bt technology will reduce insecticide use, if farmers use lot of insecticides in conventional crop. On the other hand, this technology can help reaching potential yield $F(.)$ by reducing $D(.)$,

Table 3. Results of meta-analyses on performance of genetically engineered crops

Study	Number of studies covered	Region or crop	Yield gain over conventional	Profit over conventional	Costs over conventional	Pesticide cost over conventional
Klumper and Qaim (2014)	147	All crops	21.57%	68.21%	NS	-39.15%
		IR crops	24.85%	68.78%	5.24%	-43.43%
		HT crops	9.29%	NS	NS	-25.29%
Areal *et al*. (2013)	133	Developed countries	NS	16 Euros/ha		
		Developing countries	0.35 tonne/ha	188 Euros/ha		
		All countries	0.28 tonne/ha	166 Euros/ha	11 Euro/ha	
		Bt corn	0.55 tonne/ha	523 Euros/ha		
		Bt cotton	0.30 tonne/ha	84 Euros/ha		
		HT soybean	0.03 tonne/ha	16 Euros/ha	-25	
Hall *et al*. (2013)		All countries		66%	23%	
Finger *et al*. (2011)	177-maize	Maize- all countries	3.9%		-66.6%	
	454-cotton	Cotton-all countries	46.3%	86.3%		-48.2%
		India	50.8%	32.5%		-30.0%
		China	NS	-120%		-71.7%
		S. Africa	NS	114%		-51.7%
		Australia	NS			-22.0%
		USA	NS			NS
Gruere and Sengupta (2011)		Cotton	36.2%	58.1%	16%	42%
Carpenter (2010)	168	**Developed countries**				
		All crops	6%			
		Corn	7%			
		Cotton	7%			
		Soybean	7%			
		Developing countries				
		All crops	29%			
		Maize	85%			
		Cotton	30%			
		Soybean	21%			

Note: NS- indicates not significant.

if they were not using chemical insecticides for effective control of pests in the conventional crop. Similar finding of higher yield gains in the developing countries was observed in the case of weed control through use of GE crops by Brookes (2005) in Romania on herbicide- tolerant (HT) soybean (29-33% increase); Smale *et al.* (2012) in Bolivia on HT soybean (30% increase); and Kalaitzandonakes *et al.* (2015) on HT-maize in Kenya.

The positive yield effects have been noticed in all the Bt cotton growing countries, except in Australia, where the reduction in pesticide expenditure led to benefits by increasing gross margin to the tune of 79 Australian Dollars per hectare (Table 4). Apart from that, cultivating herbicide- tolerant soybean and sugar beet enabled the cultivators to raise another crop in the same field and additionally led to conservation of tillage (Marra *et al.,* 2004; Kniss, 2008), apart from

Table 4. Impacts of genetically engineered crops in different countries

Country	Studies	Crop/Trait	Percent change in		
			Physical yield	Pesticide/ Herbicide cost	Gross marginin monetary value
India	Kathage and Qaim 2012; Rao and Dev 2009	Bt cotton	32-47	-13 to -56	70-251
China	Pray *et al.* 2002	Bt cotton	19	-67	340
	Qiao 2015	Bt cotton	34	-50	NA
South Africa	Thirtle *et al.* 2003	Bt cotton	22	-36	28
Mexico	Traxler *et al*. 2003	Bt cotton	11	-77	12
Argentina	Qaim and de Janvry 2003	Bt cotton	33	-47	42
USA	Falck-Zepeda *et al*. 2000; Carpenter *et al*. 2002	Bt cotton	10	36	NA
Australia	Fitt 2003	Bt cotton	0	-48	NA
Argentina	Qaim and Traxler 2005	HT soybean	0	-42	9
United States	Marra *et al*. 2004	HT soybean	0	-33	-
Canada	Brewin and Malla 2012	Ht canola	10	-54	4
South Africa	Ghouse *et al*. 2009	Ht maize	85	79	440
		Bt maize	6	-41	124
Philippines	Yorobe and Quicoy 2012	Bt maize	34	-52	54
USA	Fernandez-Cornejo *et al.* 2005	Bt maize	9	NA	NA
USA	Kniss 2008	Bt sugarbeet	-	-68	-

Note: NA- Not available in the study.

enabling the farmers to spend time on non-farm activities through reduced time in weed management in soybean (Fernandez-Cornejo *et al.,* 2005; Qaim and Traxler, 2005).

Huge welfare gains from adoption of GE crops are shown to people of developing countries in the economy-wide models, despite trade barriers in the EU countries (Anderson *et al.,* 2008; Anderson, 2010). On the other hand, there are studies that show positive indirect effects of adopting GE crops. Bt cotton adoption in India increased household employment and income (Subramanian and Qaim, 2009), especially for the hired female workers (Subramanian and Qaim, 2010; Rao and Dev, 2009), as well as calorie intake (Kouser and Qaim, 2013). Adopting women farmers valued labour-saving benefit more in Bt corn grown in S. Africa, while men preferred yield-enhancing benefit, signaling gender perspectives in looking at new technologies (Ghouse *et al.,* 2016). Globally, the reduction in pesticide sprays is estimated to have saved 581.4 million kilograms (8.2% reduction) of active ingredient and the environmental impact associated with herbicide and insecticide use on these crops fell by 18.5 per cent (Brookes and Barfoot, 2016a).

On the downside, Bollgard II cotton in India developed resistance to pink bolloworm in western India (Fabrick *et al.,* 2014), while Bt cotton worked without resistance in China (Qaio, 2015) and USA (Carriere *et al.,* 2003). However, resistance to American bollworm continues in India and resistance to pink bollworm can be delayed by mixing refugia with biotech seeds (Kranthi, 2015). Weeds developed resistance in places where HT crops are grown and higher quantities of glyphosate are applied. NASEM (2016) has concluded that this is not because of GE crops *per se* and variations in applyied herbicides can prolong resistance.

Selection Bias

Higher yields and net returns in new technologies could be either due to technology effect or because better and motivated farmers self-select themselves for adoption. Therefore, isolating the technology effect by separating the confounding factors is critical in evaluating technologies, as otherwise ‘farmer effect’ can be wrongly attributed to technologies (Rao, 2013). Several studies have applied econometric tools to separate technology effect and found higher yields in insect-resistant cotton (Kathage and Qaim, 2012; Rao and Dev, 2009; Stone, 2011; Gruere and Sun, 2012; Morse *et al.,* 2012); herbicide tolerant soybean (Smale *et al.,* 2012; Fernadez-Cronejo *et al.,* 2002, 2005) and insect resistant maize (Yorobe and Smale, 2012). Further, using panel data models, Kouser and Qaim (2011) and Krishna and Qaim (2012) have shown that there were significant pesticide reductions in Bt cotton cultivation and that these are sustainable for adopters apart from helping the non-adopters with declined pest population, resulting in a *halo effect*. This corroborates research findings, on the benefits to non-adopters, in the realm of biological science reported in *Science* by Wu *et al.* (2008) in China, and Hutchison *et al.* (2010) and Carriere *et al.* (2003) in the USA.

Regulatory Framework as Policy Pre-requisite

Harnessing potential of biotechnologies is conditioned on putting in place an elaborate institutional mechanism to scrutinize technologies for biosafety, labelling, transboundary movement of GE foods in concurrence with Cartagena Protocol on Biosafety (CPB) and strengthening property rights through patent laws. This is a tall order for developing country governments and most of them, especially those in the African continent, are not equipped to do this, stoking fears of recurrence of the Green Revolution experience (of bypassing poor countries), though there has been some improvement in recent years. The countries with relatively stronger agricultural research capabilities are moving ahead in this trajectory and their regulatory frameworks have been analysed in this Section (Table 5). Countries having commercial and postcolonial ties to EU in Africa, the Middle East, South and Southeast Asia adopted more precautionary approach, while those having closer ties to USA, including most in the Western Hemisphere plus the Philippines have generally adopted a less precautionary approach (Herring and Paarlberg, 2016).

Overarching legal framework with exclusive personnel for regulation was put in place in very few countries like Brazil, S. Africa, and Mexico and very recently in the Philippines, while the same has been in the process in Argentina and India, as well as in Bangladesh and Pakistan. As could be seen from Table 5, either Ministry of Agriculture (Argentina, China, S. Africa) or Ministry of Science and Technology (Brazil, Mexico and the Philippines) handle this except in India where Environmental Ministry takes a final decision. Reforms to the framework in Brazil in 2008 making National Technical Commission on Biosafety (CTNBio) as the single agency for taking decisions on approvals quickened the process of harnessing technology and made it the leading GE crop cultivator, overtaking Argentina. To retain the edge, Argentina centralized all biotech related decision-making by forming an exclusive Biotechnology Directorate in the Ministry of Agriculture, Fisheries and Livestock since 2009 and further reformed in 2012 to take decisions within 24 months by reducing from 42 months (USDA, 2015).

Most countries take decisions on commercialization at the federal level, except in India and China. The Punjab Seed Council gave approvals to Bt cotton varieties in Pakistan until 2014 and there is uncertainty on the competent authority at the moment (Spielman *et al.,* 2015). In India, permissions from respective state governments are required to undertake trials since 2010 (Gupta, 2011) and only eight of them have allowed trials since then. The moratorium imposed in 2010 continues in India and probably subject to the verdict of a case in the Supreme Court. Mexico came out of an 11-year moratorium in 2009 and accelerated approvals since then. Though approvals have stopped after Bt cotton in China, there was a shift in policy in 2016, which was witnessed in Chinese government acquiring biotech major company, Syngenta that aimed at allaying fears of foreign domination in technology and pushing forward transgenic crops to overcome imports and legitimise widespread illegally grown GE maize and rice crops (Economist, 2016).

Development of biotechnological products in private domain is also conditioned on IPR protection either through UPOV (The Union for the Protection of New Varieties of Pulses) route or *sui generis* system. While Brazil, Argentina, China, S. Africa and Mexico joined UPOV 1978, India followed *sui generis* system and formulated Protection of Plant Varieties and Farmers Rights’ Act, 2011 to enable protection to

Table 5. Policy framework in selected developing countries

Regulatory issue	Arrangement in countries					
	Brazil	Argentina	India	China	S Africa	Mexico
Overarching law	Available	Not in place	Not in place	Not in place	Available	Available
Controlling ministry	Office of President (CNBS) & Ministry of S&T (CNBio)	Central food ministry	Ministry of envt&forests	Ministry of agriculture	Ministry of agriculture	Executive secretary nominated from Min of S&T and approved by President
Regulatory approach	Precautionary	Precautionary	Precautionary	Precautionary	Precautionary	Precautionary
Current stage of commerciali-zation	Outlook very positive with quick approvals after 2008	On the whole, quite positive. Approvals faster after 2012 change of policy	Moratorium from Feb, 2010 on approvals.Field trials, put on hold since early-2012, are revoked in 2013	Came to a standstill amid resistance	Process of approvals moving quickly	11-year moratorium ended in 2009. Now, approval process moving quickly
Purpose of harnessing agri-biotechnology	National development and exports	National development and exports	Domestic food security and exports	Domestic food security	Domestic food security and exports	Domestic food security
Separate permissions from provincial/ State governments	Not needed	Not needed	Need 'No objection certificate'	Needed	Not needed	Not needed
Approval of staked events	Treated as new events	Allows applications for transgenic combining two approved events without full analysis	Treated as new event, though the consisting events are approved	No clear policy	Treated as new events	Evaluates them as different than the parental one
Type of labelling law	Mandatory (process based)	Voluntary	Mandatory (Process based)	Mandatory (Process based)	Voluntary so far (Product based)	Voluntary
Labelling law	Mandatory labelling for >1%	No labelling regime. Does not differentiate GM &Non-GM	Ministry of consumer affairs, food and public distribution from 2013 for packaged form	Compulsory for soybean, maize, cotton, canola and tomato	By health ministry. Only when allergens or human/ animal proteins are present	No mandatory labelling. But, labelling of GM content of seeds
Enforcement of labelling	Not enforced	Not applicable	Not done presently	Enforced	Does not arise	Does not arise
UPOV Treaty, 1978	Joined in 1999	Joined in 1994	Not a member. But, enacted PPV&FR Act in consonance with UPOV '78	Joined in 1999	Joined in 1977	Joined in 1997
Patent laws	Not strong patents. Plant & animals not patentable. Microorganisms patentable with conditions	Strong protection to animals, plants, plant varieties, microorganisms, biological processes and genes	Microorganisms patentable	Patent law, 2008. Regulation on protection of new plant varieties, 1997.	NA	Strong protection to plants, plant varieties and microorganisms. Biological processes not patentable

Contd...

Table 5. Policy framework in selected developing countries — *Contd.*

Regulatory issue	Arrangement in countries					
	Brazil	Argentina	India	China	S Africa	Mexico
Cartagena Protocol	Ratified. But opposed to strict liability. Incoroporated precautionary principle	Signed, but not ratified	Ratified and a biosafety clearing house is set up in the ministry of envt and forests	Signed and ratified	Signed and ratified. Dept. of Agriculture, Forestry and Fisheries (DAFF) is looking instead of DEF	Signed and ratified
GE imports	Only GE events approved for commercial production can be imported. 0% tolerance for unapproved events	Does not differentiate GE & non-GE	Soybean oil from Brazil, Argentina and USA is allowed. Zero tolerance policy for unapproved events	LLP with 0% tolerance for unapproved events Permitted 10 events of soybean from USA, Brazil, Argentina and 17 events of GM corn	1% tolerance. But, processed product allowed. Only approved events allowed. 54 events in five crops- soybean, maize, cotton,canola & rice	Allowed under NAFTA. However, the imports should not be used for production but only for consumption. 2% level tolerance by The Secretariat of Agriculture, Livestock, Rural Development, Fisheries (SAGARPA)
Coexistence	Rules exist	No policy	No specific regulation	No rules	No rules	Biosafety law provision 90 established GEO free zones by SAGARPA
Traceability	No system	No official system	No system	No system	No system	No system
Animals	GE dairy cattle produced. Recombinant proteins in pipeline. Cloning done. No GE animals so far. Same regulatory framework	Transgenics in pipeline for growth hormones. Cloning allowed. Regulation same as agriculture	In its infancy. Two buffaloes are cloned successfully. No regulations on production or marketing of cloned animals	Transgenic animals being developed, but none are approved so far	No animals so far. Regulation is same	No GE animals or products. Covered under same regulatory framework as plants

Source: Compiled by the author

traditional knowledge by farmers. In the past few years, several African countries have joined UPOV and several others are in consultation to do so (Jefferson and Padmanabhan, 2016).

Labelling GE products has become a major issue of contention in recent times with demands for consumers choice. While Brazil, China and India follow the mandatory process based labelling methods, Argentina, South Africa and Mexico follow the voluntary product based method. Though there are divergent views on which of these two methods of labelling helps consumers make an informed decision, published academic research concludes that voluntary labelling serves the purpose better than mandatory labelling (Bansal and Gruere, 2012).

Most of the developing countries have signed and ratified Cartagena Protocol on Biosafety (CPB), except Argentina, though Brazil continues to have reservations about strict liability regime. The compliance to the CPB requires traceability arrangements on the source of GE product and also specific guidelines on coexistence of conventional, organic and GE crops (Bailey, 2002; Wilson *et al.,* 2008). None of the developing countries has the system for traceability and coexistence, except

Brazil which has put in place rules for coexistence (Table 5). Mexico is unique in that, the argument that the places of primary source of origin of crops should be left GE free, has forced them to keep GE free zones in some states. The issue of liability and compensation is another contentious matter which the developing countries will have to address in the years to come (Vigani and Olper, 2012). Free flow of crop products from developing countries would require harmonisation of GMO standards (de Faria and Wieck, 2015).

Consolidation in Agricultural Biotechnology and Countervailing Forces

The recent spate of mergers and acquisitions in the seed sector has raised serious concerns on improving small farm agriculture, especially in developing countries like India through rising seed prices (Bryant *et al.,* 2016). To mention the top three, these are: 130 billion USD merger of Dow and Dupont, 66 billion USD takeover of Monsanto by Bayer and 43 billion USD acquisition of Syngenta by China Chemical Corporation, all in the past two years. Even before these big ticket consolidations, "the big six" corporations collectively controlled more than 75 per cent of global agrochemical market, 63 per cent of the commercial seed market and almost three-fourths of R&D expenses in the seeds and pesticides sector and the sector has been witnessing transformation to oligopoly (Lianos *et al.,* 2016). These recent consolidations are continuation of long-term trend in the industry of agro-chemical companies taking over seed companies and likely to persist for some time to come (Rao, 2004; Lianos *et al.,* 2016; Howard, 2015), if the countervailing forces discussed below do not grow strong enough to counter the trend.

The public sector breeders quite often get stonewalled with patent hurdles in their effort to develop varieties even in orphan crops. The patent thickets create a situation referred to as 'tragedy of the anti-commons' by Heller and Eisenberg (1998), in which no one will be able to assemble a product overcoming the maze of patents and results in underuse of (or non-use) of resources. Golden rice is a classic example of this phenomenon, as its development was stalled for a long time to overcome the 40 odd patents from different owners (Jefferson and Padmanabhan, 2016). The challenge of ever rising share of the private sector in global food and agriculture R&D, that stood at 44 per cent in 2009, is another big concern, as private sector cannot compensate for the decline of public research in view of its focus on technology development while public universities and institutes continue to be the source of upstream research (Pardey *et al*., 2015). The private sector research however can have high social benefits (to farmers) relative to private benefits (to companies) (Figure 2) and can be utilized for the societal gains, with a clear understanding that public research can only create agricultural public goods (Dalrymple, 2008:350).

These disturbing developments mask another set of developments rising as countervailing forces to protect small farm agriculture. The locus of R&D expenditures in the world is now slowly shifting towards developing countries. In 2009, about 42 per cent of global R&D investment was done in the middle-income countries including China, Brazil, and India, though low income countries continue to have a miniscule of this total (Pardey *et al.,* 2015). Analyses of the changing landscape of biotechnology across developing countries show that they have realized the need to be pro-active to save resource-poor farmers through energizing public sector research. China, for example, acquired Switzerland based Syngenta at a price of 43 billion US dollars through its National Chemical Corporation.

Several developing countries like Brazil, Argentina, China, Philippines, Bangladesh, and Pakistan, have been ratcheting up public sector research in biotechnology and have brought out crop products in recent years. Not surprisingly, these crop products possess traits of importance to resource-poor farmers like drought-tolerance, examples of which are given earlier. Another significant positive development is in the realm of legal framework of property rights, whereby gene patents have either recently been invalidated (in USA and Australia) or likely to be done in the near future in many other countries. Also, subsequent to the Nagoya Protocol on access and benefit sharing, negotiations are underway in the Intergovernmental Committee to negotiate an international legal instrument to protect traditional knowledge and access and benefit sharing (Jefferson and Padmanabhan, 2016). In India, new 2013 patent guidelines, if enforced, might change the scenario away from strong patents (Ravi, 2013).

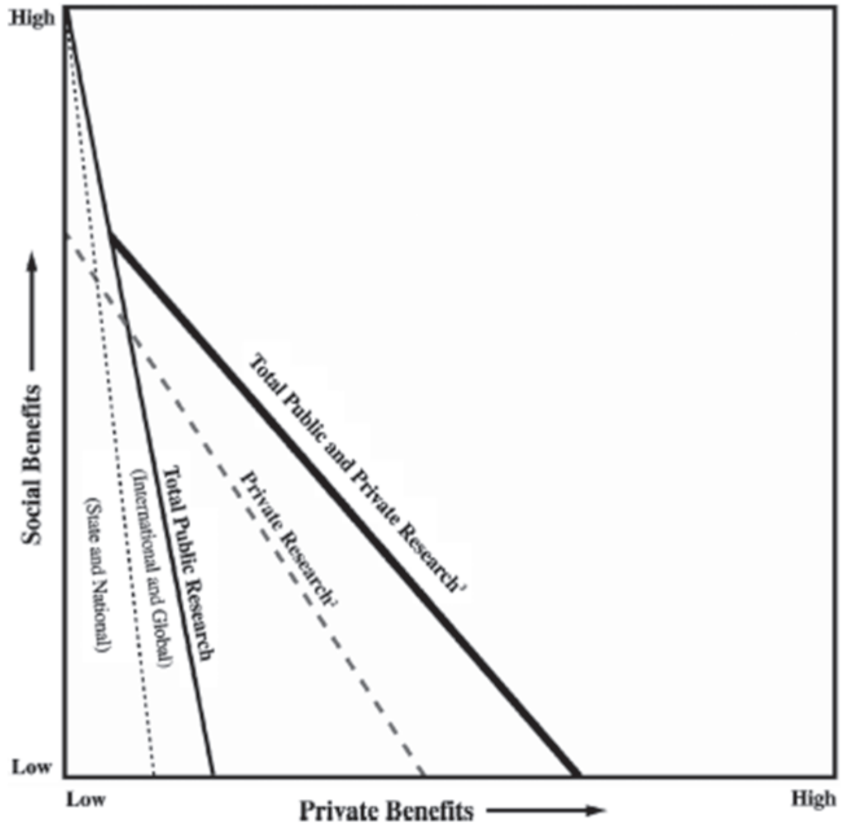

Figure 2. Hypothetical relationship between the social and private benefits from public and private research
Source: Dalrymple (2008)

Beyond IPR protection, stringent regulations through biosafety laws dampen research and product development by the public sector as well as small investors as happened in India and Argentina and this is referred to as 'IP-regulatory' complex (Graff and Zilberman, 2016). Despite not having patent protection, Bollgard I event of Monsanto enjoyed monopoly rights in India because of the arduous process of getting event approval leaving other companies dependent on Monsanto for seed development (Graff *et al.,* 2015).

Conclusions and Policy Implications

Any technology, including agricultural technologies, can in principle have both positive and negative impacts in varying degrees or only one of them in a certain magnitude. Empirical evidence in the specific socioeconomic, cultural and institutional milieu is necessary to evaluate technologies. This paper has examined the diffusion of genetically engineered crops in developing countries in a cross country comparative perspective in regard to their nature and adoption, impacts, necessary supplementary policies and challenges associated with developing oligopoly trends in the seed sector.

The pace of discovery in biological sciences has been rapid and biotechnologies are moving beyond genetic engineering and the first non-GE biotechnological crop using gene editing was released in 2016 in the form of sulfonylurea (SU)-tolerant canola (mustard) in the USA. Within the GE crops, technology has deepened to commercialize several (28) GE crops in place of just three crops earlier viz., soybean, maize and cotton and from single gene expressions like insect/herbicide resistance to second generation products like drought tolerance and improved quality attributes. The developing countries accounted for 54 per cent of the 185.1 Mha of area under these crops in 2016, negating fears that resource-poor farmers in these countries would not be benefited from these technologies.

Economic and agronomic impacts of GE crops have been rigorously studied, as the controversies on their utility continue. The peer-reviewed research findings suggest higher yields, higher net income and lower chemical use with conservation tillage. The most recent meta-analysis estimated 22 per cent yield gain associated with 39 per cent reduction in plant protection expenditure and 68 per cent higher net income. The longitudinal studies have shown that cultivation of these crops over the past 19 years has resulted in gains of 150 billion US Dollars to world agriculture. However, weeds developing resistance in some countries and pink bollworm becoming resistant to Bollgard II in India underline the need to combine agronomic measures for an effective pest management.

Technologies need supplementary policies to optimize social welfare. Very few of the developing countries could put a legal framework for biosafety and our study reveals that this is still a work in progress with inadequate efforts to create a professional body that allays the fears of consumers and arrives at decisions based on scientific data. The countries like Brazil and Argentina have been moving fast in diffusion of these technologies, as they could put this mechanism in place. India and China are yet to navigate this process, not to speak of the many low-income developing countries, especially from the African continent.

Ongoing consolidation, rapidly transforming the already concentrated industry into an oligopoly, raises serious concerns on the likely higher prices for seeds. It is likely to continue for some time to come, if countervailing forces do not grow strong enough in times to come. Foremost among these forces is the ratcheting up of public sector research by the national agricultural research system (NARS) in developing countries. Second is the recent trend of reversal of patent protection for DNA sequences that started with the Supreme Court verdict in *Association for Plant Pathology vs. Myriad Genetics* in the USA. However, it is premature to foresee the final outcome of this trend. The developing countries will gain by internalizing these technologies into their national agricultural research systems and invest more in both upstream and downstream research, besides proactively participating in the ongoing review process of negotiating international legal instruments for traditional knowledge.

The third countervailing force to overcome the asymmetric power of corporation in biotechnological research is to forge public private partnerships like in case of drought tolerant (DT) soybean in Argentina, DT-maize in Africa and several others. Innovative platforms like Public Intellectual Property Resources for Agriculture (PIPRA) established in the University of California, Davis and Africa Technology Foundation in Kenya show the way forward for the governments of developing countries to act in the interest of resource-poor farmers. It should not be forgotten that much of patented technology by companies has their origins from the upstream research done in public universities. Viewed from that angle, it becomes clear that science behind technologies and private sector domination need to be separated in taking decisions about their utilization. Excessive regulation or lack of regulatory mechanism has been stifling technologies developed by the public institutions and small companies that are of interest to developing country agriculture. The developing countries like India are likely to benefit more from engaging with development discourse on how to harness new opportunities arising out of rapid discoveries in biological sciences for raising incomes and welfare of rural populations with predominatly agriculture-based livelihoods.

References

Adato, M., Meinzen-Dick, R., Hazell, Peter and Haddad, Lawrence (2007) Integrating social and economic analyses to study impacts on livelihoods and poverty: Conceptual frameworks and research methods. In Michelle Adato and Ruth Meinzen-Dick (eds), *Agricultural Research, Livelihoods, and Poverty: Studies of Economic and Social Impacts in Six Countries,* Baltimore:Johns Hopkins University Press, pp. 20-55.

Armstrong, S and Westland, T., (2016) Escaping the Middle Income Trap. *East Asia Forum Blog*. Available at: http://www.eastasiaforum.org/2016/03/28/escaping-the-middle-income-trap/. Accessed on 10.4.2016.

Anderson, K., Valenzuela, E., and Jackson, L.A. (2008) Recent and prospective adoption of genetically modified cotton: A global CGE analysis of economic impacts. *Economic Development and Cultural Change,* **56**:265-296.

Anderson, K. (2010) Economic impacts of policies affecting crop biotechnology and trade. *New Biotechnology,* **27**(5):558-564.

Ahluwalia, M. S. (1978) Rural poverty and agricultural performance in India. *The Journal of Development Studies,* **14**: 298-323.

Areal, F. J., Riesgo, L., and Rodriguez-Cerezo, E. (2013) Economic and agronomic impact of comercialised GM crops: A meta-analysis. *Journal of Agricultural Science,* **151**: 7–33

Barrett, C, Carter, M.R., and Timmer, C.P. (2010) A Century-long perspective on agricultural development. *American Journal of Agricultural Economics,* **92**(32): 447-468.

Bailey, R. (2002) The looming trade war over plant biotechnology. *Cato Trade Policy Analysis.*18 August.

Bansal, S and Gruere, G. P. (2012) Implications of mandatory labeling of GM food in India: Evidence from the supply side. *Food Policy,* **37**(4): 467–472.

Brewin Derek G. and Malla, Stavroula (2012) The consequences of biotechnology:A broad view of the changes in the Canadian canola sector, 1969-2012. *AgBioForum,* **15**(3):257–275.

Brookes, G. (2005) The farm level impact of using RoundUp Ready soybeans in Romania. *AgBioForum,* **8**(4): 235–241.

Brookes, G and Barfoot, P. (2016) Global income and production impacts of using GM crop technology 1996–2014. *GM Crops & Food*, **7**(1), 38-77, DOI: 10.1080/21645698.2016.1176817. Available at:http://dx.doi.org/10.1080/21645698.2016.1176817.

Brookes, G and Barfoot, P. (2016a) Environmental impacts of genetically modified (GM) crop use 1996–2014: Impacts on pesticide use and carbon emissions. *GM Crops & Food*, 7:2, 84-116, DOI: 10.1080/21645698.2016.1192754. Available at: http://dx.doi.org/10.1080/21645698.2016.1192754.

Bryant, H., Maisashvili, A., Outlaw, J., Richardson, J. (2016) *Effects of Proposed Mergers and Acquisitions among Biotechnology Firms on Seed Prices*. Working Paper 16-2, Agricultural and Food Policy Center, Department of Agricutlural Economics, Texas A&M AgriLife Extension Sercie, Texas A&M University. Available at: http://www/af[c/tamu.edu/

Carpenter, J.E. (2010) Peer-reviewed surveys indicate positive impact of commercialized crops. *Nature Biotechnology,* **28**: 319-321.

Carpenter, J, Felsot, A., Goode, T., and Hamming, M. (2002). *Comparative Environmental Impacts of Biotechnology-derived and Traditional Soybean, Corn, and Cotton Crops*, Ames, IO, Council for Agricultural Science and Technology, 4 p

Carriere, Y, Ellers-Kirk, C., Sisterson, M., Antilla, L., Whitlow, M., Timothy, J.D., and Tabashinik, B.E. (2003) Long-term regional suppression of pink bollworm by *Bacillus thuringiensis* cotton. *Proceedings of the National Academy of Sciences,* **100** (4): 1519–1523.

Dalrymple, D.G. (2008) International agricultural research as a global public good: Concepts, the CGIAR experience, and policy issues. *Journal of International Development,* **20**: 347-379.

Dawe, D., R. Robertson and L. Unnevehr (2002) Golden rice: What role could it play in alleviation of vitamin A deficiency?" **27**: 541-560.

de Janvry, A., and Sadoulet, E. (2002) World poverty and the role of agricultural technology: Direct and indirect effects. *The Journal of Development Studies,* **38**(4):1–26.

de Faria, R. N., and Wieck, Christine (2015) Empirical evidence on the trade impact of asynchronous regulatory approval of new GMO events. *Food Policy,* **53**: 22-32.

Dev, S.Mahendra and Chandrasekhara Rao, N. (2010) Agricultural price policy, farm profitability and food security. *Economic and Political Weekly,* **45**(26&27): 174–182.

Durr, J. (2016). The political economy of agriculture for development today: the "small versus large" scale debate revisited. *Agricultural Economics,* **47**: 1-11.

Economist, The (2016). Gene Policy Transfer. *The Economist*, 23 April. Available at: http://www.economist.com/news/china/21697272-china-may-relax-its-almost-total-ban-growing-gm-food-gene-policy-transfer.

Eichengreen, B, Park, D., and Shin, K. (2013) *Growth Slowdown Redux: New Evidence on the Middle-Income Trap*. Working Paper No. 18673, National Bureau of Economic Research, Cambridge, USA.

Falck-Zepeda, J.B., Traxler, G., and Nelson, R.G. (2000). Surplus distribution from the introduction of a biotechnology innovation. *American Journal of Agricultural Economics,***82**(2):360–369.

Fabrick, J.A., *et al.* (2014). Alternative Splicing and Highly Variable Adherin Transcripts Assoicated with Field-Evolved Resistance of Pink Bollworm to Bt Cotton in India. *Plos One,* **9**(5): e97900-1-13.

Fernandez-Cornejo, J., and McBride, W.D. (2002) *Adoption of Bioegineered Crops.* Agricultural Economic Report NO.810, US Department of Agriculture.

Fernandez-Cornejo, Hendricks, C., and Mishra, A. (2005) Technology adoption and Off-Farm household income:The case of herbicide-tolerant soybeans. *Journal of Agricultural and Applied Economics*, **37**(2).

Finger, R., *et al.* (2011) A meta analysis on farm-level costs and benefits of GM crops. *Sustainability,* **3**: 743-762.

Fitt, Gary P. (2003) Implementation and impact of transgenic Bt cottons in Australia. *ICAC Recorder,* **21** (4): 14-19.

Ghouse, M., Piesse, J., Thirtle, C., and Poulton, C. (2009). Assessing the performance of GM Maize amongst stallholders in KwaZulu-Natal, South Africa. *AgBioForum,* **12**(1): 78-89.

Ghouse, M, Sengupta, D., Zambrano, P., and Falck-Zepeda, J. (2016). Genetically Modified: Less Drudgery for Her, More Maize for Him? Evidence from Smallholder Maize Farmers in South Africa. *World Development,* **83**: 27-38.

Graff, G. and Zilberman, D. (2016) How the 'IP-Regulatory' Complex Affects Incentives to Develop Socially Desirable Products from Agricultural Genomics. In E Marden, R N Godfrey and R Manion (eds.) *The Intellectual Property- Regulatory Complex: Overcoming Barriers to Innovation in Agricultural Genomics.* Vancouver: University of British Columbia Press.

Graff G, Hochman, G., Suntharlingam, C., and Zilberman, D. (2015) The Competing Policy Paradigms of Agricultural Biotechnology: Implications and Opportunities for Emerging and Developing Economies. *AgBioForum,* **18**(2):168-181.

Gruere, G., and Sengupta, D (2011) *Bt*cotton and farmer suicides in India: An evidence-based assessment. *The Journal of Development Studies,* **47** (2): 316–337.

Gruere, G and Sun, Y. (2012) *Measuring the Contribution of Bt Cotton Adoption to India's Cotton Yields Leap.* IFPRI Discussion Paper 01170, April, International Food Policy Research Institute, Washington,D.C.

Gupta, A. (2011). An evolving science-society contract in India: The search for legitimacy in anticipatory risk Governance. *Food Policy,* **36**: 736-741.

Hall, C., Knight, B., Ringrose, S., and Knox, O. (2013) *What have been the farm-level economic impacts of the global cultivation of GM crops? Systemic Review.* CEE review 11-002, Collaboration for Environmental Evidence Library. Available at: www.environmentalevidence.org/SR110.Accessed on15.11.2013.

Hazell, P.B.R. (2009) *The Asian Green Revolution.* IFPRI Discussion Paper No. 00911, International Food Policy Research Institute, Washington, D.C.

Hefferon, K.L., and Herring, Ronald J. (2017) The End of the GMO? Genome Editing, Gene Drives and New Frontiers of Plant Technology. *Review of Agrarian Studies,* **7**(1): 1-32.

Heller, M.A., and Eisenberg, R.S. (1998) Can Patents Deter Innovation? The Anticommons in Biomedical Research. *Science,* **280**: 698-701.

Herring, R.J. and Paarlberg, R. (2016). The Political Economy of Biotechnology, *Annual Review of Resource Economics,* 8.8.1-8.20. Available online at http://www.annualreviews.org/journal/resource.

Howard, P.H. (2015) Intellectual Property and Consolidation in the Seed Industry. *Crop Science*, **55** (2015): 1-7.

Hutchison, W.D. *et al. (*2010) Area wide suppression of European corn borer with *Bt* Maize reaps savings to non-*Bt*maize growers. *Science,* **330**: 222-225.

James, C. (2016) *Global Status of Commercialiased Biotech/GM Crops in 2012.* ISAAA Brief 51,International Service for the Acquisition of Agri-Biotech Applications.

Jefferson, D.J. and Padmanabhan, M.S. (2016) Recent Evolutions in Intellectual Property Frameworks for Agricultural Biotechnology: A Worldwide Survey, *Asian Biotechnology and Development Review*, **18**(1): 47-67.

Kalaitzandonakes, N., Kruse, J., and Gouse, M., (2015) The potential economic impacts of herbicide tolerant maize in developing countries: Review and Evidence from Kenya. *AgBioForum,* **18**(2): 221-238.

Kathage, J., and Qaim, Matin (2012) Economic impacts and impact dynamics of *Bt* (*Bacillus thuringiensis*) cottoninIndia. *Proceedings of the National Academy of Sciences,***109**(29):11652–11656.

Klumper, W., and Qaim, M. (2014) A Meta-Analysis of the Impacts of Genetically Modified Crops. *Plos-One,* 9(11, e111629): 1-7. Available at:http://journals.plos.org/plosone/article?id= 10.1371 /journal.pone.0111629

Kniss, A. (2008) Farm-scale analysis of glyphosate-resistant sugarbeet the year of commercial introduction in Wyoming. *International Weed Science Society Annual Meeting*.

Kouser, S., and Qaim, M. (2011) Impact of Bt Cotton on pesticide poisoning in smallholder agriculture: A panel data analysis. *Ecological Economics,* **70** (11): 2015-2013.

Kouser, S., and Qaim, M., (2013) Genetically modified crops and food security. *PLoS One*, open accessjournal, June.

Kranthi, K.R. (2015) Pink Bollworm Strikes Cotton Again. *Cotton Statistics and News,* No.35, December 1. Available at: http://www.cicr.org.in/pdf/Kranthi_art/Pinkbollworm.pdf.

Krishna, V., and Qaim, Matin (2012) Bt cotton and sustainability of pesticide reductions in India. *Agricutlural Systems,* **107**: 47-55.

Lewis, A. (1954) Economic development with unlimited supplies of labor. In M.Gersovitz (e*d*.) *Selected Economic Writings of W. Arthur Lewis,* New York University Press, 1983.

Lianos, I, Katalevsky, D. and Ivanov, Alexy (2016) The Global Seed Market, Competition Law and Intellectual Property Rights: Untying the Godian Knot. *Research Paper Series: 2/2016*, Centre for Law, Economics and Society, University of London.Available at www.ucl.ac.uk/cles/research- paper-series.Accessed on 10.09.2016.

Lichtenberg, E., and Zilberman, D. (1986) The econometrics of damage control:Why specification Matters. *American Journal of Agricultural Economics*, **68**: 261–273.

Marra, M.C., Piggott, N.E., and Carlson, G.A. (2004) *The net benefits, including convenience, of Roundup ready soybean: Results from a national survey.* Technical Bulletin 2004-3.(NSF Center for IPM, Raleigh, North Carolina, USA.

Mellor, J.W. (2006) Pro-poor Growth- The relation between agricultural growth and poverty reduction.In R. Radhakrishna,S. K. Rao, S. Mahendra Dev, and K. Subbarao (eds.) *India in a Globalising World: Some Aspects of Macroeconomy, Agriculture and Poverty,* (New Delhi: Academic Foundation).

Morse, S., Mannion, A.M., and Evans, C. (2012) Location, location, location: Presenting evidence for genetically modified crops. *Applied Geography,* **34**: 274–280.

Muller, C., and Robertson, R.D. (2014) Projecting future crop productivity for global economic modeling. *Agricultural Economics,* **45**: 37-50.

NASEM (The National Academies of Sciences, Engineering and Medicine) (2016) *Genetically Engineered Crops: Experiences and Prospects.* The National Academies Press, Washington, DC. Available at: www.nap.edu

Otuska, K. (2013) Food insecurity, income inequality, and the changing comparative advantage in world Agriculture. *Agricultural Economics,* **44**(2013): 7-18.

Pardey, P.G., Chan-Kang, C., Beddow, J.M., and Dehmer, S.P., (2015) Long-Run and Global R&D Funding Trajectories: The U.S. Farm Bill in a Changing Context. *American Journal of Agricultural Economics,* **97**(5): 1312-1323.

Pingali, P. (2012) Green Revolution: Impacts, limits and the path Ahead. *Proceedings of the National Academy of Sciences,* **109**(31): 12302–12308.

Pray, C.E., Huang, J.H.R., and Rozelle, Scott (2002) Five years of *Bt* cotton in China- the benefits Continue. *Plant Journal,* **31**: 423–30.

Qaim, Matin and Traxler, G. (2005) Roundup Ready soybeans in Argentina:Farm level and aggregate welfare effects. *AgriculturalEconomics*, **32**:73–86.

Qaim, Matin (2009) The economics of genetically modified crops. *Annual Review of Resource Economics,***1**: 665–693.

Qaim, Matin and Zilberman, D. (2003) Yield effects of genetically modified crops in developing countries. *Science,* **299**(5608): 900–902.

Qaim, Matin and de Janvry, A. (2003) Genetically modified crops, corporate pricing strategies, and farmers' adoption: The case of *Bt*cotton in Argentina. *American Journal of Agricultural Economics,* **85**(4): 814–828.

Qiao, Fangbin (2015) Fifteen Years of Bt Cotton in China: The Economic Impact and its Dynamics. *World Development,* **70**: 177-185.

Rao, N. Chandrasekhara (2004) Plant Biotechnology and the Emerging Scenario. *Review of Development and Change,* **9**(1): 69-92.

Rao, N.Chandrasekhara and Dev, S.Mahendra (2009) Biotechnology and Pro-Poor Agricultural Development. *Economic and Political Weekly,* **44**(52): 56–64

Rao, N.Chandrasekhara and Dev, S. Mahendra (2010) *Biotechnology in Indian Agriculture: Potential, Performance and Concerns.* New Delhi: Academic Foundation.

Rao, N.Chandrasekhara (2013) *Bt* Cotton Yields and Performance: Data and Methodological Issues. *Economic and Political Weekly,* **48**(33): 66–69.

Rao, N.Chandrasekhara, Pray, C.E., and Herring, R.J. (2015) Biotechnology for a Second Green Revolution in India: Socioeconomic, Political and Public Policy Issues. *AgBioForum,* **18**(2): 126-141.Available at www.agbioforum.org.

Rao, N.Chandrasekhara (2015) Disadvantaged Groups and Social Groups: Is There a Way Out? *Indian Journal of Agricultural Economics,* **70**(3): 438-449.

Ravi, B. (2013) Gene Patents in India: Gauging Policy by an Analysis of the Grants made by the Indian Patent

Office. *Journal of Intellectual Property Rights*, **18**(4): 323-329.

Smale, M., Zambrano, P., Paz-Ybarnegaray, R., and Fernandez-Montano, W. (2012) A case of resistance: Herbicide-tolerant soybeans in Bilivia. *AgBioForum,* **15**(2): 191–205.

Spielaman D, Nazli, H., Ma, A., Zambrano, P., and Zaidi, F. (2015) Technological Opportunity, Regulatory Uncertainty, and Bt Cotton in Pakistan. *AgBioForum*, **18**(1): 98-112.

Stone, G. (2011) Field *versus* farm in Warangal: *Bt*cotton, higher yields and larger questions. *World Development,* **39**(3): 387–398.

Subramanian, A., and Qaim, Matin (2009) Village-wide effects of agricultural biotechnology: The case of *Bt*cotton in India. *World Development*, **37**(1): 256–267.

Subramanian, A., and Qaim, Matin (2010):"The impact of *Bt*cotton on poor households in rural India", *The Journal of Development Studies*, **46**(2): 295–311.

Swinnen, J., and Riera, O. (2013) The global bio-economy. *Agricultural Economics,* **44**: 1-5.

Traxler, G., Godoy-Avila, S., Falck-Zepeda, J., and Espinoza-Arellano, J. (2003) Transgeniccotton in Mexico:A case study of the Comarca Lagunera. In N Kalaitzandonakes (ed) *The Economic and Environmental Impacts of Agbiotech*. New York: Kluwer.

Thirtle, C., Beyers, L., Ismael, Y., and Piesse, J. (2003) Can GM-technologies help the poor? The impact of *Bt* cotton in Makhathini Flats, Kwa Zulu-Natal. *World Development,* **31**(4):717–732.

USDA. (2015) *Argentina Annual Biotechnology Report, GAIN Report,* United States Department of Agriculture Foreign Agricultural Service.

Vigani, M., and Olper, A., (2012) International trade and endogenous standards: the case of GMO regulations. *World Trade Review,* **11**(3): 415-437.

Wilson, W.W., De Vuyst, E.A., Taylor, R.D., Koo, W.W., and Dahl, B.L., (2008) Implications of biotech traits with segregation costs and market segments: The case of Roundup Ready ® Wheat. *European Review of Agricultural Economics*, **35**(1): 51–73.

Wu, K.M., Lu, Y.H., Feng, H.Q., Jiang, Y.Y., and Zhao, J.H., (2008) Suppression of cotton bollworm in multiple crops in China in areas with *Bt* toxin-containing cotton. *Science,* **321**:1676–1678.

Yorobe, J.M., and Smale, M. (2012) Impacts of *Bt* maize on smallholder income in the Philippines. *AgBioForum,* **15**(2): 152–162.

Zilberman, D., Kim, E., Kirschner, S., Kaplan, S., and Reeves, J. (2013) Technology and the future bioeconomy. *Agricultural Economics,* **44**: 95-102.