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Impact of technology and policy on growth and instability of agricultural production: The case of cotton in India

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ABSTRACT

Cotton is a crop that underwent continuous technology and policy shifts over period of time, and thus is a test case through which one can examine the changes in the growth and associated instability. The major technology and policy changes cotton cultivation saw include the commercial hybrids' introduction in late 1960s, diffusion in 1970s and 80s supported by favourable public policy, emergence of new constraints in cotton cultivation in technological and institutional fronts in 1990s and introduction of genetically modified cotton during early years of the last decade. This study reveals that shifts in technology and policy are associated with distinct changes in major agricultural parameters like growth and instability of area, production and yield. National cotton production stagnated during pre-hybrid phase, exhibited significant and positive growth during the early hybrid phase ushered in by public sector, and showed stagnation again during the late hybrid phase. This was followed by significant positive growth during the Bt phase. This trend was in tandem with the trends in yield as well. The pattern of growth in area, production and yield was closely associated with instability also – generally low during the pre-hybrid phase, increased substantially during the early hybrid phase, but fell during the late hybrid phase and exacerbated during the Bt phase.

Historically, India was a major cotton economy. In 2010, cotton was cultivated over an area of 10.1 million ha (GoI 2011), by about 4-5 million farm households. Before the hybrid era, cotton cultivation was dominated by low yielding *desi* cotton varieties (*Gossypium arboreum* and *Gossypium herbaceum*) followed by American cotton (*Gossypium hirsutum)* varieties. These low yielding varieties were gradually replaced by hybrids since their introduction in late 1960s. The production of cotton increased with the widespread application of associated inputs like fertilizer, plant protection chemicals, irrigation, etc. Over years, the advantages of hybrids cultivation started dissipating and it exhibited signs of fatigue in increasing the yield. One of the major reasons was increased pest attack. The most economically important pest that infested cotton crop was the American bollworm (*Helicoverpa armigera*). Considering the damage potential, farmers had to maintain near zero tolerance against this pest. Cultivators resorted to heavy application of pesticides, thereby raising the cost of cultivation, polluting environment, deteriorating human and animal health, rising resistance, facilitating resurgence of minor pests and leaving residue in the food chain. This led to new management options like Integrated Pest Management (IPM) and later Insecticide Resistance Management (IRM) in cotton cultivation. Genetically modified Bt cotton hybrids, acting like a biological pesticide factory offering *in situ* resistance against the target pest was an alternative, cheaper and environmentally benign technological solution to the problem. Following the clearance of the Genetic Engineering Approval Committee of Ministry of Environment and Forests, many commercial Bt cotton hybrids were introduced in the market since 2002. These technological shifts had significant effect on growth and stability of cotton cultivation. Some of the earlier studies had analysed the growth and instability of Indian agriculture for various time periods (pre or post green revolution with or without different sub-periods), crop/crop groups and regions, and arrived at conforming and contradicting results regarding effects of the technological and/ or policy interventions. However, cotton is a crop which provides opportunity to examine these issues in a greater depth, as the crop has witnessed yet another (genetic) revolution (Bt technology). In this background, the present study focuses the behaviour of growth and instability of area, production and yield of cotton in India with respect to the technology and policy shifts.

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MATERIALS AND METHODS

The study uses secondary data pertaining to area, production and yield of cotton provided by various agencies, primarily by Ministry of Agriculture, Government of India. All those states having an area of more than one lakh ha as on 2009-10 have been selected for state level analysis.

The short term and long term effect of new technology on agricultural growth parameters can be totally different and therefore, analysing the impacts in various phases unmasks the overall effect concealed in a longer period analysis, particularly in those cases which are characterised by major technology and policy changes (Chand and Raju 2009). The major milestones in cotton cultivation was the introduction of the hybrids and associated spurt in cotton production during the early phase of hybrid diffusion, the subsequent yield fatigue and later introduction of genetically modified cotton. For analytical purposes only the crop improvement and marketing landmarks have been considered in phasing the study periods with an all India perspective. It may be noted that the area under hybrid cotton in Punjab, Haryana and Rajasthan till introduction of Bt cotton was less than four per cent, as open pollinated varieties – *desi* (indigenous) and *hirsutum* (American) under irrigated condition out-performed hybrids (Kairaon *et al.* 2000).

Accordingly, entire study period of about half a century has been divided, reflecting this continuum. They are: (1) pre-hybrid phase of 1960-61 to 1970-71 accounting for the period before introduction of the hybrids, (2) early hybrid phase reflecting the diffusion of hybrids in most states during 1971-72 to 1991-92, (3) late hybrid phase, characterized by yield fatigue and chronic pest infestation during 1992-93 to 2001-02 and (4) Bt hybrid phase 2002-03 to 2009-10.

In empirical studies, the usual techniques of estimating growth rates in sub-periods of a time series is to fit separate trend lines by ordinary least square (OLS) method to each sub-period of the series. In a few studies a composite regression equation *in lieu* of independent regression equations to represent different sub-periods is fitted in which intercept and slope dummies are used to estimate growth rates for different periods. This is equivalent to estimating separate regressions and yields the same growth rates (Goldar and Seth 1989). These trend lines are likely to be discontinuous, and therefore, can result in anomalies such as sub-period growth rates, which all exceed, or are less than the estimated growth rates for the period as a whole. Poirier (1976) suggested that these discontinuities between segments of piece-wise regression can be eliminated by imposing certain linear restrictions. Boyce (1986) demonstrated that in case of log-linear models, such an approach yields kinked exponential functions, and these estimates provide a better basis than conventional estimates of inter-temporal and cross-sectional growth rate comparisons. Kinked exponential growth rates with one, two or multiple kinks can be easily estimated with standard OLS regression packages by using composite independent variables. This methodology has been adopted by many researchers for estimating unbiased estimates in cases that include sub-period analysis (Goldar and Seth 1989; Saha and Swaminathan 1994). On this basis, this paper adopts the kinked exponential growth rate for estimating the growth rates during various continuous technology and policy phases.

Following Boyce's proposition of the general model for a time series for the period t = 1, ... , n with m number of sub-periods and m-1 number of kinks (K_i), where, $k_1,..,K_{m-1}$ represents the kinks and $D_1,...,D_m$ represents the sub-period dummy variables (D_j) which takes value 1 in j^{th} sub-period and 0 otherwise,

$$\ln Y_t = \alpha_1 + \beta_1\left(D_1 t + \sum_{j=2}^{m} D_j k_1\right) + \beta_2\left(D_2 t - \sum_{j=2}^{m} D_j k_1 + \sum_{j=3}^{m} D_j k_2\right) +$$

$$\ldots + \beta_i\left(D_i t - \sum_{j=i}^{m} D_j k_{i-1} + \sum_{j=i+1}^{m} D_j k_i\right) + \ldots + \beta_m\left(D_m t - D_m k_{m-1}\right) + \mu_t \qquad (1)$$

The model used for estimation is as follows:

$$\ln Y_t = \alpha_1 + \beta_1(D_1 t + D_2 k_1 + D_3 k_1 + D_4 k_1) + \beta_2(D_2 t - D_2 k_i - D_3 k_1 - D_4 k_1 + D_3 k_2 + D_4 k_2) + \beta_3(D_3 t - D_3 k_2 - D_4 k_2 + D_4 k_3) + \beta_4(D_4 t - D_4 k_3) + \mu_t \qquad (2)$$

The OLS estimates of β_1, β_2, β_3 and β_4 provides exponential growth rates for the four phases. There is a kink between the two trend lines, when successive coefficients are not equal. In our analysis the regressions were run using the triennium ending averages as the estimates were robust. For details of the method, see Boyce (1986).

The desired agricultural growth trajectory of an economy needs to increase agricultural production, while reducing the instability. This is obvious for several reasons - the most important ones are the reduction of production risk, stabilising producer price and farm income, and incentivising adoption of newer technologies. Some studies on instability in food production in India associated with the adoption of green revolution technology conclude that the instability in agricultural production has increased since adoption of the new technology (Mehra 1981, Ray 1983). However, Mahendradev (1987) reported positive, but marginal decline in instability in India's food production at All India level, and mixed results for the state level. Larson *et al.* (2004) concluded that the increase in food production in India since green revolution came at the cost of increasing instability in production and yield. On the contrary, Sharma *et al.* (2006) reported that that the production of individual crops and total food grains had become more stable during 1990s compared to 1980s. Chand and Raju (2009) observed that, the production of foodgrains and total crop sector was much more stable in recent periods, compared to the pre-green revolution and the first two decades of green revolution period.

The measures for estimating instability in a time series data need to satisfy two minimum properties. It needs to take care of the instability that may arise due to the secular trend and it should be comparable across data sets having different means. On this basis, the methodology proposed by Ray (1983) and used by various researchers like Mahendraev (1987) and Chand and Raju (2009) was employed to examine the instability of cotton production in India.

The instability index is calculated as follows:

$$\text{Instability index} = \text{Standard deviation of Ln}\left(\frac{Y_{t+1}}{Y_t}\right) \times 100 \quad (3)$$

where, Y is the area/ production/yield of cotton, t represents the current year, t+1 corresponds succeeding year. When there are no deviations from the trend, the ratio of Y_{t+1}/Y_t is constant and thus the standard deviation is zero. As the series fluctuates more, the ratio of Y_{t+1} and Y_t also fluctuates more, and standard deviation increases.

Cotton is a crop that assumed political and economic significance in Indian economy due to its sheer contribution towards employment generation, foreign exchange earnings and national income. It provides employment to 60 million people and 200 mandays/ha (Kairon *et al.* 2000). As on 2009-10, the cotton textile industry contributed to the extent of four per cent to the GDP, 14 % of industrial production and 14.2 % of export earnings (GoI 2011a). In this section a brief account of the major technology and policy development in case of cotton since independence is delineated under the four phases.

The pre-hybrid phase in cotton cultivation was focused on improving cotton production by area expansion, mainly through the programmes like "Grow More Cotton" and "Cotton Extension Schemes" of early 1950s (Kairon *et al.*). Through these concerted programmes, the area and production of cotton in India increased, *albeit* at a low pace. However, the gain in productivity was very low and it acted as a major hindrance in Indian cotton production. The technological intervention in case of cotton started with the introduction of All India Coordinated Cotton Improvement Programme (AICCIP) by Indian Council of Agricultural Research in 1967 (AICCIP 2009). These programmes started bearing its fruits by early 1970s (Ramasundaram *et al*. 2003).

One of the significant outcomes of the cotton research is the ushering in of the era of hybrids in cotton. Release of intra-*hirsutum* hybrid cotton H4 in 1970 paved the way to the hybrid cotton era, unique in the global cotton history; subsequently, several intra-hirsutum and inter specific (*G. hirsutum* × *G. barbadense*) and desi (*G. herbaceum* × *G. arboreum*) hybrids became successful in central and south zones. With the development of short duration and high yielding cultivars of wheat suitable for delayed planting, cotton - wheat rotation became the most prominent cropping system facilitated by irrigation, technology development, increased cropping intensity, and policy planning (Ramasundaram *et al.*, 2004). Another important landmark in cotton development was initiation of Intensive Cotton Development Programme in 1971-72 to improve production and productivity. Other major developments were in market front, which included establishment of Cotton Corporation of India (CCI) in early 1970s, monopoly procurement of cotton in some states like Maharashtra to ensure minimum guaranteed prices to the growers and declaration of support prices by Commission on Agricultural Costs and Prices for the basic varieties, viz. F 414/H-777(medium staple) and H-4 (long staple) of cotton (Ramasundaram *et al* 2005). The establishment of Central Institute of Cotton Research (CICR) in Nagpur in 1976 provided the research and development backup for many of these initiatives. In nutshell, the early hybrid phase, till the fag end of 1980s received favourable policy support in terms of research and development initiative and other support programmes.

The major development during the late hybrid phase was emergence of new constraints in cotton production, particularly from the entomological front. The hitherto monopoly of the public sector in the research front gave way to co-existence with private sector, particularly in the form of the seed and pesticide industries. Concerned with the need to enhance the cotton production through productivity gains, Government of India initiated Cotton Technology Mission by the end of the late 1990s. The basic objectives of the Mission were to increase the production and productivity of cotton by increasing the yield, farm income, domestic availability and exports by research and technology transfer, development of infrastructure and technology upgradation and modernization in processing sector (Sundaram *et al.* 1999). Another important development was in trade front in the form of coming into force the Agreement on Textiles and Clothes (ATC) in 1995 under the auspices of WTO agreements (Singh and Ramasundaram 2005). Cotton yield in India exhibited signs of fatigue by the end of this phase. One of the major problems that circumvented cotton production was the high incidence of the pest, cotton bollworm. None of the existing varieties could tolerate the infestation of this pest, and therefore farmers resorted to heavy application of pesticides, that severely affected the profitability of cotton production.

The most important development of this phase is development of the genetically modified cotton (Bt-Cotton) that could withstand the early attacks of cotton bollworm, thereby significantly reducing the pesticide cost and minimizing the yield loss. The technology package in this phase was provided by the private sector. Following the approval of the Genetic Engineering Approval Committee, many Bt cotton hybrids were introduced in the market. This technology was immediately adopted by the farmers, cutting across the farm size, cropping system and regions.

RESULTS AND DISCUSSION

Growth in area

The area under cotton has increased over years at all

India level- from 7.8 m ha in 1962-63 to about 9.7 m ha in 2009-10 (Triennium ending), accounting for about 7.2 % of net area sown (Table 1). Among the states, Maharashtra, Gujarat and Andhra Pradesh together accounted for more than three-fourths of total area under cotton as on 2009-10.

Analysing the area growth rates, it can be inferred that the area under cotton at all-India level increased at growth rate of 0.31% per year during the period of about half a century (1960-61 to 2009-09). However, as anticipated, these growth rates concealed the distinct trends in it. The area registered negative trend during the pre-hybrid phase and it remained almost static during the entire early hybrid phase. The late hybrid phase exhibited a spurt in area growth; but during the Bt phase, the area allocation did not show a marked change and the growth rate turned out to be statistically insignificant.

The state wise analysis provides more vivid account of the growth story. During the pre-hybrid phase, all states exhibited either a decreasing or an insignificant area growth. As noted earlier, this was a phase when *desi* cotton, under dry farming conditions, occupied most of the area under cotton (Table 2). Hybrids were introduced in late 1960s to break the yield barrier. By around 1996-97 (up to which official data on hybrid's area share is available), only about one third of total area could be brought under hybrids, and it varied widely across states. In case of Andhra Pradesh, Gujarat and Maharashtra, the hybrids occupied around 40% of area. On the other hand, in case of Punjab, Haryana and Rajasthan, the penetration of the hybrids was near absent. The cotton cultivation in these states was dominated by open pollinated varieties.

The introduction of hybrids could not arrest the declining trend of area under cotton, except in case of Andhra Pradesh and the irrigated tracts of Haryana, Punjab and Rajasthan. The area expansion of cotton in the irrigated tracts of north India has to be explained by the some factors other than the penetration of the hybrids, as hybrids were not cultivated in these states. The continued decline of the area under cotton in other states despite the introduction of the hybrid cotton might be because of the adverse income terms of trade against cotton compared to substitute crops that might have benefitted from green revolution technology and favourable public policy. Contrary to this, the area under cotton experienced a sudden expansion during the late hybrid phase—from 7.5 million hectares to 8.9 million hectares. This was contributed mainly by area growth in Andhra Pradesh, Gujarat and Maharashtra. During the late hybrid phase, these three states consolidated their position by accounting for more than two-third of the area under cotton.

Cotton crop is an entomologist's delight that it attracts a range of pests that no other crop does. The high incidence of pests and the subsequent high cost of plant protection increased after introduction of hybrids. The repeated crop failures brought about a reduction in the area of crop in some states, particularly in Tamil Nadu and Karnataka. In this context, introduction of Bt cotton emerged as the major watershed in cotton cultivation in India. Once the Bt cotton was officially approved for release, it diffused at a faster rate compared to hybrids during early 1970s. By around 2009-10, Bt cotton accounted for more than 70% of area under cotton in all the states (TE average, see Table 2). Though Bt hybrids fared well compared to conventional hybrids in terms of farm economics (Narayanamoorthy and Kalamkar 2006, Rao and Mahendra Dev 2010), this did not result in sharp increase of total area under cotton. Positive and significant area growth was observed only in case of Gujarat and Madhya Pradesh. The sharp area-increase under cotton during this period in Gujarat (from 1.6 million ha in 2000-01 to 2.4 million ha in 2009-10) could mask the area shrinkage in many other states, and contributed to increase in area at the national level (from 8.9 million ha to 9.7 million ha).

One major factor to be noted is the fast rate of expansion of cotton in irrigated belts of Punjab, Haryana and Rajasthan. As on 1970-71, these three states together accounted for around 0.9 million ha of area under cotton, but it almost touched 1.6 m ha by the end of 1990-91. All the three states exhibited positive trend during this phase. However, this trend started withering during the late hybrid phase, first exhibited in Punjab, by posting a growth rate of -3.5%.

Devastating attack by bollworm during mid-nineties inflicted severe crop losses leading to reduction in area of the crops. The growth rate in these three states exhibited mixed trends during Bt hybrid phase- the cotton area expanded in Punjab at a rate of 1.4%, but shrank in Haryana and Rajasthan at –3.3 and –7.3%, respectively. Another discernible fact is the continued shrinking of area under cotton in Karnataka and Tamil Nadu. These two southern states together accounted for about 1.3 million ha of area under cotton cultivation as on 1970-71, but it reduced to less than half by 2009-10. Continuous area decline was experienced by these two states during all the four phases. The area under cotton declined in these states mainly on account of crop substitution triggered by the comparative advantage of substitute crops, notably with the expansion irrigation. Increased pest attack worsened the economic performance of cotton *vis a vis* other crops. It is noteworthy that the sharpest rate of decline was observed during Bt phase (–4.7 and –7.6%, respectively).

Growth in production

The production of cotton in India expanded continuously over years. It increased from nearly 5.1 million bales in 1962-63 to almost 24 million bales by 2009-10, at an overall average growth rate of about 2.8% (Table 3). The major highlight is that the production growth, unlike area growth was more pervasive across states.

During the overall period, positive growth in production was widely experienced by all the states (with the exception of Tamil Nadu, which lost much of the area under cotton to

Table 1 Area under cotton in India and growth rate over various phases of technology and policy

States	Share of cotton area to net sown area (Per cent) 2009-10	Share of cotton area to total area under cotton (Per cent) 2009-10	Area ('000 hectares, Triennium Ending Average)						Compound growth rate (%)				
			1962 -63	1970-71	1980-81	1990-91	2000-01	2009-10	Pre Hybrid	Early Hybrid	Late Hybrid	Bt. Hybrid	Overall
Andhra Pradesh	14.68	14.48	343	313	404	644	1114	1333	–2.84***	4.29***	4.16***	0.78	3.30***
Gujarat	23.92	24.32	1712	1612	1682	1066	1604	2413	1.52	–2.55***	4.29***	4.93***	–0.03
Haryana	14.28	5.00		200	305	464	560	482	1.47	4.20***	1.90***	–3.31***	2.88***
Karnataka	4.39	4.51	1016	1021	1045	649	578	423	1.33	–2.73***	–1.80	–4.65**	–2.22***
Madhya Pradesh	4.08	6.03		688	626	582	494	622	–4.39***	–1.29***	–0.07	3.48***	–0.72***
Maharashtra	20.09	34.50	2652	2780	2549	2665	3177	3278	–1.44**	0.35	1.44***	-0.17	0.39***
Punjab	12.29	5.04		397	639	730	504	547	2.80	2.00***	–3.53***	1.42	0.49*
Rajasthan	2.62	4.39	210	241	382	396	579	372	1.96	2.65***	1.68	–7.32***	1.70***
Tamil Nadu	2.13	1.03	419	313	289	250	189	106	–5.13***	–0.74	–4.05***	–7.64***	–2.42***
India	7.24	100	7833	7644	7340	7493	8862	9651	–0.83	–0.03	1.59***	0.55	0.31***

Note: 1. The time coverage of the periods under consideration as below:
Pre-Hybrid – (1962/63 to 1970/71); Early Hybrid – (1971/72 to 1991/92); Late Hybrid – (1992/1993 to 2001/02); Bt. Hybrid – (2002/03 to 2009/10);Overall – (1962/63 to 2009/10)

2. ***, ** and * indicates significance at 1, 5 and 10 % levels of probability

3. For Punjab, Haryana and Madhya Pradesh the Pre Hybrid Phase represents the period of 1966/67 to 2009/10. The overall phase covers the period of 1966/67 to 2009/10

4. Compound growth rates based on triennium ending average

Sources: Agricultural Statistics at a Glance, various issues, GOI, New Delhi

Table 2 Coverage of hybrids, Bt cotton and irrigation in cotton in India over various phases of technology and policy

(Triennium ending average)

States	Irrigation coverage (Per cent)						Area under hybrid cotton (Per Cent)					Area under Bt cotton (Per cent)
	1962-63	1970-71	1980-81	1990-91	2000-01	2009-10	1962-63	1973-74	1980-81	1990-91	1996-97	2009-10
Andhra Pradesh		3.97	38.07	12.40	17.83	17.78		0.59	7.67	25.76	44.31	89.35
Gujarat		32.08	25.71	40.33	40.41	56.67		9.72	18.27	47.17	39.96	43.43
Haryana		94.92	98.27	99.51	99.46	99.60						78.32
Karnataka		3.72	7.69	24.10	16.09	17.18		0.97	4.98	55.96	61.84	49.94
Madhya Pradesh		1.50	7.70	22.98	36.48	42.55		0.30	5.17	23.47	56.02	83.22
Maharashtra		2.68	4.34	2.28	3.88	2.68		2.19	14.56	31.52	39.43	87.36
Punjab		98.45	98.17	99.47	99.60	99.94						87.76
Rajasthan		65.28	87.75	93.93	97.76	93.63			0.78			38.05
Tamil Nadu		32.49	48.05	36.36	36.17	30.51		5.72	7.26	3.46		62.71
India	13.17	16.95	29.77	33.69	33.23	35.73		3.18	11.14	26.93	32.90	71.47

Sources: Agricultural Statistics at a Glance, various issues, GOI, New Delhi; Fertilizer Statistics, various year issue, The Fertilizer Association of India, New Delhi; Directorate of Cotton Development, Mumbai, Government of India; Hand book of Statistics on Cotton Textiles Industry and ICMF Bulletin, The Indian Cotton Mills Federation & East India Cotton Association, Mumbai

Table 3 Production of cotton in India and growth rate over various phases of technology and policy

States	Share of cotton production to total production in India (%) 2009-10	Production (' 000 bales, Triennium ending average)						Growth rate (Per cent)				
		1962-63	1970-71	1980-81	1990-91	2000-01	2009-10	2009-Hybrid	Early Hybrid	Late Hybrid	Bt. Hybrid	Overall
Andhra Pradesh	13.43	140	92	516	869	1 593	3 429	2.19	10.28***	1.59	10.15***	7.39***
Gujarat	33.25	1 422	1 547	1 867	1 516	2 383	7 759	3.02	-0.53	4.75***	19.62***	2.40***
Haryana	8.02		350	613	1 061	1 187	1 890	4.06*	5.51***	0.06	7.95***	4.15***
Karnataka	3.61	419	367	647	836	832	837	3.12	2.86***	–3.56	1.90**	1.31***
Madhya Pradesh	3.56		310	270	387	364	859	–4.17	0.60	2.72***	11.58***	1.82***
Maharashtra	24.39	1 273	1 078	1 427	1 821	2 507	5 875	–3.35**	2.91***	3.62***	10.59***	2.94***
Punjab	8.35		834	1 246	2 160	915	2 215	3.82	3.78***	–6.36***	14.61***	1.86***
Rajasthan	3.76	157	184	479	835	887	830	6.56***	6.18***	–3.15***	2.65*	3.79***
Tamil Nadu	0.94	398	352	434	466	354	205	–2.39	1.40*	–6.15***	–4.51	–1.16***
India	100	5 095	5 258	7 539	10 003	11 114	24 061	0.89	2.95***	0.86	11.25***	2.79***

Notes: As in Table 1
Source: As in Table 1

other crops). However, the growth rates exhibited contrasting trends during various phases of technology and policy. The production almost stagnated during the pre-hybrid phase at around five million bales. However, it doubled during the early hybrid phase, at a growth rate of around three per cent per year, despite the stagnation in area growth as has been noticed from Table 1. But, this momentum could not be sustained during the late hybrid phase, wherein the production growth was only 0.9% per year. It may be noted that, this lower growth rate was realised despite the sharp area growth at 1.6%, pointing to negative yield growth during this period (as can be noted from Table 4). This stagnation in production experienced sudden reversal during the Bt-hybrid phase.

Compared to the variations in the area growth across states, the state level production growth exhibited more of a uniform pattern during each phase. During the pre-hybrid phase, the production growth was non-significant at national level, with all but two states registering insignificant and/or negative growth. The production growth was more prominent in the irrigated production systems of north India (Haryana and Rajasthan, in particular). During the early hybrid phase, the growth rate exhibited positive trend in all the states barring Gujarat which witnessed a sharp decline of area. On the contrary, the highest production growth during this phase

Table 4 Yield of cotton in India and growth rate over various phases of technology and policy

States	Yield (Kg/ha, Triennium Ending average)						Growth Rate (Per Cent)				
	1962-63	1970-71	1980-81	1990-91	2000-01	2009-10	Pre hybrid	Early hybrid	Late hybrid	Bt. hybrid	Overall
Andhra Pradesh	69	50	215	228	247	444	5.01*	6.09***	–2.69	9.42**	4.12***
Gujarat	141	163	188	242	251	546	1.55	1.91***	0.83	14.58***	2.45***
Haryana		299	342	387	362	668	2.79**	1.19***	–1.57***	11.06***	1.27***
Karnataka	70	61	112	212	244	337	1.75	5.74***	–1.90	6.84***	3.60***
Madhya Pradesh		77	73	113	126	235	0.002	1.92***	2.71***	8.15***	2.53***
Maharashtra	82	66	94	116	134	305	–1.97	2.56***	2.21**	10.73***	2.55***
Punjab		357	332	503	317	689	1.02	1.79***	–2.82*	13.05***	1.37***
Rajasthan	128	131	212	357	262	383	4.73***	3.42***	–4.59***	9.91***	2.08***
Tamil Nadu	162	190	248	286	319	330	2.78**	1.97***	–1.85*	3.49*	1.25***
India	111	117	178	227	213	424	1.82**	2.95***	–0.82	11.64***	2.51***

Notes: As in Table 1
Sources: As in Table 1

was recorded by Andhra Pradesh (10.3%) where large area was brought under hybrids and some area under irrigation during this period.

The late hybrid period was characterised by almost stagnant production at the national level. This was mainly due to stagnation in yield (as can be observed from Table 4). Contrary to the national trend, the three major cotton producing states increased the production from 4.2 to 6.5 million bales. The Bt hybrid phase reversed the cotton production trends from one of stagnation to acceleration. During this phase, the production of cotton increased from 11.1 to 24.1 million bales, at the rate of 11.3% per year. Positive growth was exhibited by all the states, except Tamil Nadu, where the area under cotton was found shrinking rapidly. Highest production increase during this phase was registered in case of Gujarat, where total production increased from 2.4 to 7.8 million bales at a growth rate of 19.6%. The production increase in case of Gujarat owes it to the series of check dams those came up recently in the state which could provide protective irrigation to cotton (Shah *et al.* 2009).

Growth in yield

During the pre-hybrid phase to the Bt hybrid phase, the yield of cotton increased from 111 kg/ ha to 424 kg/ha at a growth rate of 2.5% per year (Table 4). All the states exhibited positive and significant growth rate led by Andhra Pradesh with 4.1%. At national level, during the pre-hybrid phase, the yield increased from 111 kg/ ha to 117 kg/ha at a growth rate of 1.80%. The gradual spread of the cotton hybrids accompanied by intensive input use improved cotton yield to 227 kg/ ha by the end of the early hybrid phase at an annual growth rate of 3.0%. This period was characterised by an increase in area under irrigation also (Table 2). During the next phase, the area under irrigation did not show a marked increase. This slump in irrigation coverage coupled with the high incidence of pest and diseases might have resulted in decline of cotton yield to the level of 213 kg/ha at a growth rate of –0.8%. The Bt hybrid phase helped to achieve a sudden spurt in the yield to the level of about 424 kg/ha (with an impressive growth rate of 11.6% per year). This phase exhibited mild increase in irrigation coverage as well. Unlike the case of the conventional hybrids, the spread of the Bt cotton was at a much faster rate, cutting across the size, class and ecosystems. Bt hybrids, by virtue of size neutrality of technology, could break the lumpiness in investment requirement, and its cultivation could be undertaken with the same kind of input management as was in conventional hybrid. Therefore, there was no much need for skill upgradation as far as the farmers are concerned and additional capital investment was only for purchase of seeds.

During the pre-hybrid phase, the yield growth was significantly positive only in a few states. In fact, five out of the nine states registered negative or insignificant growth rate. On the other hand, once the hybrid cotton was released for cultivation, the yield increased significantly in all the states and the annual growth rate ranged between 1.2% in case of Haryana to 6.1 % in case of Andhra Pradesh. The yield also exhibited wider range –113 kg in case of Madhya Pradesh to 503 kg in case of Punjab.

The late hybrid phase did not sustain the tempo of yield growth, may be because of the higher base and the intensity of the biotic and abiotic stresses the phase faced. The growth rates were positive and significant only in case of Madhya Pradesh and parts of Maharashtra, where more area was brought under irrigation. The yield decline was sharp, particularly in Punjab, Haryana and Rajasthan mainly due to the emergence of pests and diseases. It became amply clear from the Table 3 and 4 that it was mainly due to the stagnation of yield in other states, notably in Punjab, that the total production at the national level suffered substantial reduction.

The yield decline reversed during the Bt phase, when all the cotton growing states posted positive and significant growth, led by Gujarat. Besides the three cotton producing states, the growth rates were also high in case of Haryana, Punjab and Rajasthan. The hitherto not favourable North Zone for hybrid cotton, after Bt hybrid introduction, underwent a total shift from *desi* and American cotton varieties to hybrids, as the Bt cotton was available only in hybrid form.

Instability

The instability indices exhibited clear trends across various phases of technology and policy (Table 5) regimes. The instability of area, production and yield was quite low during the pre-hybrid phase and it increased during the early hybrid phase. On the contrary, the late hybrid phase was characterised by sharp decline in instability. During Bt hybrid phase, the instability in production and yield increased compared to the previous phase, whereas that of the area posted a mild decline.

Instability in area

During the early hybrid period the instability in area at national level increased from 3.4 to 10.3 registering more than 200% increase. The late hybrid phase saw a 36% reduction in instability compared to the previous period with subsequent lowering in the Bt hybrid phase (by –8.8 % over the late hybrid phase). These results conformed to the trend at states also. The instability of area under cotton at state level ranged between 3.9 to 15 % during the pre-hybrid phase. With the introduction of hybrids, the area under the cotton exhibited changes, which resulted in high instability during early hybrid phase. The instability during this phase was more than the pre-hybrid phase for all the states. This was followed by a decline in area instability in late hybrid phase, in eight out of nine states barring Punjab. During the Bt phase, the area instability reduced at national level by around 14% (from 6.6 to 5.7%) while the states exhibited mixed trends, with four out of the nine registering decreased instability. It may be recalled that all the states exhibited increased instability during the early hybrid phase, which also witnessed technology introduction as in Bt phase.

Instability in production

In tandem with the area instability, the production instability also increased during the early hybrid phase at national level (by around 41%) and also across the states *sans* Karnataka. There was reduction in instability during the late hybrid phase at national level (from 16.78 to 14.15%) and across states except Haryana, Punjab and Rajasthan. It is discernible that the high instability in the early hybrid phase moderated during the late hybrid phase. This decline of production instability might be due to the expansion of modern input and provision of controlled irrigation that mitigated the fluctuations. By the end of early hybrid phase, almost one

Table 5 Instability of area, production and yield of cotton over various phases of technology and policy (%)

States	Area					Production					Yield				
	Pre hybrid	Early hybrid	Late hybrid	Bt hybrid	Overall	Pre hybrid	Early hybrid	Late hybrid	Bt hybrid	Overall	Pre hybrid	Early hybrid	Late hybrid	Bt hybrid	Overall
Andhra Pradesh	13.08	20.36	17.93	16.22	17.81	32.75	39.65	15.98	25.62	34.21	25.61	36.73	19.12	27.13	30.78
Gujarat	4.50	19.85	6.67	9.37	13.97	12.84	53.33	37.81	33.77	41.09	10.93	38.72	34.61	37.95	32.74
Haryana	14.96	10.26	8.10	10.38	11.00	0.12	17.33	31.78	23.60	0.22	7.86	18.88	36.00	20.38	23.54
Karnataka	4.73	18.84	15.90	24.82	17.55	30.73	29.92	24.87	39.94	31.55	29.29	19.07	19.55	18.28	21.75
Madhya Pradesh	4.56	6.56	4.32	3.30	6.07	26.10	32.74	29.17	18.23	29.77	28.78	30.50	26.78	17.66	28.72
Maharashtra	3.85	6.10	5.14	4.50	6.08	37.67	43.63	37.66	27.58	39.03	37.55	42.18	36.94	25.39	38.94
Punjab	5.26	10.77	17.02	8.84	12.19	6.54	20.90	38.48	19.46	23.53	5.19	24.86	36.66	15.78	23.81
Rajasthan	12.56	15.94	10.82	24.33	15.61	31.03	41.58	41.91	40.53	38.93	32.68	42.06	40.05	45.16	39.58
Tamil Nadu	13.42	18.08	10.54	21.60	20.31	21.75	32.30	12.34	21.50	31.71	9.62	16.77	14.17	20.45	16.50
India	3.40	10.29	6.58	5.69	8.04	11.87	16.78	14.15	18.24	16.62	11.45	17.33	10.96	19.10	16.00

Notes: 1. The time coverage of the periods under consideration as below:
Pre-hybrid – (1960/61 to 1970/71); Early Hybrid – (1971/72 to 1991/92); Late Hybrid – (1992/1993 to 2001/02); Bt. Hybrid – (2002/03 to 2009/10);Overall – (1960/61 to 2009/10)
2. For Punjab, Haryana and Madhya Pradesh the Pre Hybrid Phase represents the period of 1964/65 to 1970/71 and the overall phase covers the period of 1966/67 to 2008/09
Sources: As in Table 1

quarter of total crop area was under irrigation and almost 27% was under hybrids. However, by the end of late hybrid phase, almost one third of area was under irrigation and hybrids, dissipating the area instability with technological diffusion. On the other hand, Bt phase witnessed a spurt in instability by about 29%. The change in production instability across the states was not consistent during the Bt hybrid period (five out of nine states recording reduction in instability). It is noteworthy that production instability reduced in case of irrigated environments of Haryana, Punjab and Rajasthan.

Instability in yield

Similar trends are noted in case of yield also. Compared to the pre-hybrid phase, the early hybrid phase experienced increase in yield instability both at national level (from 11% to 17%) and at state levels too. This was followed by a reduction during the late hybrid phase by about 36% while instability declined in six out of nine states. Sharp increase in instability was observed in Haryana and Punjab due to drastic yield decline. It can be concluded that like area and production instabilities, the yield instability also moderated with technology deepening (hybrids and associated inputs). During the Bt phase, the yield instability reduced sharply, with about eight percentage points (from 11.0 to 19.1) increase at national level, but the states exhibited mixed trends. In nutshell, three kinds of changes were observed during this phase – declining trend in instability reversed in case of Andhra Pradesh, Gujarat, Rajasthan and Tamil Nadu; the declining instability in Madhya Pradesh and Maharashtra continued; Haryana and Punjab, showing consistently increasing yield instability during all the previous phases, posted reduced instability in Bt phase. In general, it can be concluded that the instability of area, production and yield increased during the early hybrid phase compared to the pre-hybrid phase, and the high instability during early hybrid phase got moderated with the wider diffusion of the hybrid and associated technologies. The increase in instability during the early hybrid phase is more or less uniform for all the states compared to the reduction in the instability during the late hybrid phase. The instability in general increased during the Bt phase compared to the late hybrid phase; however, there was no uniformity in instability increase across states as experienced at the time of introduction of the hybrids. In fact, in Haryana and Punjab, the yield instability declined by 43 and 57% respectively during Bt phase compared to the late hybrid phase with corresponding decline in production instability by 26 and 49 %. It may be remembered that in these two states cotton is entirely an irrigated crop.

Eventhough the introduction of the Bt cotton was a paradigm shift, compared to the introduction of hybrids, the instability changes during the Bt phase was not all pervasive as experienced during early hybrid phase, indicating that agrarian system has now become more robust to absorb the shocks of technological change. This could also be because of the fact that Bt cotton, but for the trait value embedded in the seed to prevent the damages by the target pest, warranted no change in management practices compared to its conventional (hybrid) counterpart. Hybrid was yield enhancing intervention through exploitation of heterosis or hybrid vigour without the paraphernalia in terms of better infrastructure, institutional mechanism, knowledge and skill management, etc., the Bt cotton had when introduced.

CONCLUSION

The impact of technology and policy on agricultural growth and instability has generated interest among academics and planners. It is argued that though the new technologies impact the growth positively, it would come at the cost of decreased stability. The present study analyses this issues in detail taking the case of cotton, and convincingly establishes that the introduction of newer technologies invariably increased the yield and instability in the initial phases of technology adoption as evident in case of early hybrid phase and Bt hybrid phase. The study also establishes that the instability in cotton production was not widely pervasive during the Bt phase compared to the early hybrid period, mainly because of the integration of the new technology in the already existing input management regime. In other words, if the technology can overcome the investment lumpiness assuming that there is no need for any management and skill upgradation, it would be accessible by large number of farmers and then instability would reduce. In case of Bt cotton, the increase in instability compared to the late hybrid period is definitely a matter of concern, but measures like provision for protective irrigation will bring down the yield instability.

The role of irrigation in raising the productivity and spiking the instability is clearly evident in Gujarat which could increase the cotton production at the rate of 20 % with a reduced instability during the Bt hybrid phase, when irrigation coverage increased from about 40 to 57 %. This clearly indicated that provision for protective irrigation would mitigate the technology induced instability even as increasing the mean productivity. Here also the irrigation technologies need to cross the barrier of lumpiness. While the lumpiness of irrigation technologies is an insurmountable problem for resource poor individuals, community approaches like check dams, watersheds and private water conservation mechanisms can stand in good stead in boosting rainfed cotton productivity as Gujarat has demonstrated.

The study calls for making the newer technology affordable and accessible to large number of cultivators so as to attain high growth with stability. This is important in view of the dominance of the small scale production system and weak institutional mechanisms like credit delivery. Development and spread of the high quality seeds at low cost is an urgent step towards this. Currently the seed requirement for hybrid cotton, Bt or conventional, is largely met through private seed production and delivery system. Ensuring an efficient seed delivery system would help to meet the surging demand for quality seed. In this context, contract farming and public-private partnership in quality seed production are important strategies.

There are considerable areas (resource poor shallow soil regions of central India and assured irrigated areas of Punjab, Haryana and Rajasthan) where varieties can give equally better performance on par with hybrids due to agroclimatic and edaphic reasons. Further, varieties do not require seed replacement every year and reduction of farmers' dependence on purchased seed would help in increasing the benefits of the technology by lowering production costs. Development of open pollinated Bt varieties may be an important step in this regard. It reduces small farmers' cost of production without reducing yields or quality. Bt varietal development may not be an attractive proposition for private sector and hence public sector biotech research needs address such specific needs.

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