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Abstract

Recent studies have analyzed the adoption of Bt cotton in the light of government seed price interventions. According to one view, reduction in seed prices enabled the farmers to buy seeds at lower prices and this resulted in the sudden surge in area under Bt cotton. The other view holds that seed price interventions had little impact on the adoption rates rather these interventions might have negative implications for the company to innovate in future. Which of the two views characterizes adoption of Bt cotton in India? Using three variations of dynamic logistic model, this paper analyzes the impact of certain economic factors like seed prices, technological development, cotton prices on the diffusion of Bt cotton in India. We used a panel data set covering 9 major cotton growing states and the over the years from 2002 to 2008 and found that although seed prices were significant in impacting the diffusion rates but its impact was limited. This study also sheds light on the significance of technological development in impacting the diffusion rates.

JEL Classification: O33, Q16

Key words: Diffusion, Bt cotton, Seed price interventions, Technology adoption, Technological development.

Introduction

Bt cotton is the first agricultural biotech crop that has been commercialized in India. Since its approval for commercial cultivation in 2002, there has been a considerable increase in the area under Bt cotton. The adoption of Bt cotton has been remarkable in India with around 168-fold increase between 2002-09.

Recent studies on Bt cotton have partitioned the welfare created by genetically modified (GM) crops among agricultural producers, consumers and innovating input firms (Moschini and Lapan, 2000). In these studies the market price of the technology is not questioned; it is assumed to be fixed at its current level. Given that most GM crops have been commercialized by private sector multinationals, however, there are fears that monopolistic market structure may prevail resulting in excessive prices being charged for Bt seeds, which may restrict technology access for resource poor farmers in developing countries (Lalitha, 2004). This concern has been expressed in the context of many developing countries and India decided to intervene in the pricing of Bt cotton seeds.

A US based firm Monsanto in collaboration with an Indian firm, Maharashtra Hybrid Seed Company (MAHYCO), released 3 Bt cotton hybrids for cultivation in India in March 2002. The release was with the approval of GEAC (Genetic Engineering Approval Committee). The domestic companies who licensed the Bt trait from Mahyco-Monsanto Biotech (MMB) paid a one-time license fee as well as royalty fee in order to avail the gene. In 2006, the government of Andhra Pradesh intervened to control seed prices and passed an ordinance directing MMB to reduce the price of 450 gm packet of Bollgard-I seeds from Rs 1600 to Rs 750. The other cotton growing states of India followed suit.

The literature has examined impact of seed prices on adoption of Bt cotton. There are two conflicting views regarding the impact of seed price intervention on adoption rates. According to one view, charging a lower price for Bt cotton seeds would not only make these seeds more accessible to farmers but may also increase profitability of firms (Qaim and Janvry, 2003). Motivated by the relatively low adoption rates in Argentina, Qaim and Janvry (2003) analyzed farmers willingness to pay (WTP) for Bt cotton seeds and the expected level of demand for the new technology under different pricing regimes. They found the demand for GM seeds to be price responsive, and the WTP to be much lower than the current market price of Bt seeds in Argentina. Hence, they argued that reducing the Bt cotton seed prices would not only increase farmers profits but would also be more profitable for the seed producing company.

In contrast to the above paper, analyzing adoption of Bt cotton in India in the light of government seed price interventions, Sadashivappa and Qaim (2009) find a high WTP (close to the official market price) for Bt cotton seeds in India. According to them, the take off phase for Bt cotton had already begun before 2006 and thus the government seed price interventions had little impact on aggregate Bt cotton adoption. Instead, seed price controls might reduce the incentive of the company to innovate in the future. Thus government interventions should be implemented after careful analysis of the long run implications of the policy on agricultural innovations.

This paper is motivated by the conflicting recommendations of the above two papers: while Qaim and Janvry are suggesting that seed price intervention in Argentina would result in increased adoption of Bt cotton, Sadashivappa and Qaim are arguing that the impact of price controls on aggregate technology adoption in India is relatively small. Which of the two views characterizes adoption of Bt cotton in India? More specifically, what has been the impact of seed price intervention on percentage area under Bt cotton in India? We attempt to address these questions.

Pray and Rao (2008) have attempted cost-benefit analysis of seed price controls in case of Bt cotton in India for the short term and long term scenarios. While one would expect welfare of the farmers to change positively in the short run as cost of production are reduced due to price controls, in the long run these price distorting policies might reduce corporate investments in research and innovation thereby delaying the supply of new technology to farmers. Using secondary data analysis and an economic surplus model they find that the short term benefits to farmers from the price controls seem to outweigh potential losses in the long run.

Qaim and Basu (2007) have analyzed farmers adoption decisions in response to pricing strategies of a foreign monopolist and a domestic supplier of conventional seeds. They show a positive correlation between the prices of GM and conventional seeds. By exploiting this strategic complementarity in the pricing of GM and conventional seeds they have evaluated a host of policy options in order to ensure wider coverage of GM seeds and also proper access to resource poor farmers.

Murugkar, Ramaswami and Shelar (2007) have discussed competition and monopoly in the cotton seed market. They mention two ways to access Bt hybrids, either a firm can license an already approved gene construct from a technology provider or can develop its own Bt gene by undertaking research and development. According to the paper, Bt related investment could be recouped easily if the firm follows the first route and these investments do not act as barriers to entry. Developing own Bt genes, on the other hand, is considerably more expensive. In 2006, two domestic seed companies JK Agri Genetics Ltd and Nath Seeds Ltd opted for the second route and got regulatory approval for their Bt cotton hybrids which incorporated non-Monsanto genes. The paper argues that the competition from alternative genes could have a serious impact on the seed price because the alternative gene providers could target a trait value lower than that fixed by MMB. Hence, although the price ceilings were supposedly directed at controlling (MMBs) monopoly pricing, they probably disadvantaged the alternative gene providers like JK Seeds Ltd and Nath Seeds Ltd even more (as it could discourage their incentive to innovate due to huge costs involved).

As shown in Figure 1, the adoption of Bt cotton technology had spread rapidly in India between 2002-09. Since its approval for commercial cultivation in 2002, there has been a considerable increase in the area under Bt cotton. In 2006, when the price controls were implemented, adoption rates recorded an increase of 192% over the previous year. The increase in area under Bt cotton was 63% in 2007and 23% in 2008.

After the initial approval of three hybrids, many more Bt cotton hybrids have been approved for cultivation in India. The initial hybrids contained the Bt gene *cry1Ac* owned by Monsanto which licensed the gene to MMB. In 2005, 20 Bollgard-I varieties were approved for cultivation by GEAC, some of which were specifically suited for agro-ecological conditions of the Northern zone. In May 2006, hybrids with stacked Bt genes, Bollgard II were approved for commercial release in the central and Northern zones. In the same year, JK Agri Genetics Ltd. and Nath Seeds Ltd also released their own approved events[1] of Bt cotton. Thus, the number of hybrids increased from 62 in 2006 to 131 in 2007 and further to 274 in 2008 (James C., 2008). Hence, the number of events as well as the number of cotton hybrids has all increased significantly since 2002. This can be considered as the technological development that has increased portfolio of choice for farmers. (i.e., from 4 hybrids in 2004 the number went up to 274 in 2008). Another important contribution of this study is to find effect of technological development (defined in terms of number of Bt hybrids approved for commercial cultivation) on the diffusion of Bt cotton in India. This aspect has not been examined by any of the previous research papers.

Two broad approaches have been used in the literature for analyzing spread of new agricultural technologies. One approach is to study adoption decision of farmers using contingent valuation surveys and estimate their willingness to pay for the new technology. A limitation of such an approach is that WTP expressed in surveys may not reflect the actual purchase behaviour. It is known that individual decisions can differ drastically between when they are hypothetical as in the contingent valuation study or when they involve a real purchase decision**.**

The other approach is to study diffusion of technology in terms of percentage area adopted under the new technology. This approach examines adoption paths of agricultural technologies and economic factors affecting them. Diffusion is the process by which a successful innovation

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1 An event refers to the unique DNA recombination event that took place in one plant cell, which was then used to generate entire transgenic plants. Every cell that successfully incorporates the gene of interest represents a unique event.

gradually becomes broadly used through adoption by firms and individuals (Jaffe et al., 2000). In this study, we use the second approach and analyze data on actual area under Bt cotton. It is a panel data study, which covers 9 major cotton growing states, viz. Punjab, Haryana, Rajasthan (Northern zone), Madhya Pradesh, Maharashtra and Gujarat (Central zone), and Andhra Pradesh, Karnataka and Tamil Nadu (southern zone) for the period 2002-08.

Using a dynamic logistic model, it estimates impact of factors like seed price intervention, technological development, price of cotton, etc., on the diffusion of Bt cotton in India. We are interested in finding whether and to what extent the government seed price interventions in 2006 have helped in increasing the diffusion rates. Another contribution of this research is finding effect of technological development on the diffusion rates. It also attempts to predict and compare diffusion paths under three alternative policy scenarios: no seed price intervention; seed price intervention; and a scenario where competition among alternative gene providers reduces the seed price to an intermediate level of Rs 1200. The results from the study offer insights into the economic determinants of diffusion of Bt cotton in India. The study has implications for both policy makers and the researchers. It will help policy makers in framing policies regarding seed prices and also procedures for approval of new hybrids. To the best of our knowledge, such a study has not been done for India.

The rest of the paper is organized as follows. The next section provides a background of government intervention in the form of introducing price controls in the Bt cotton seed market. This is followed by a description of the empirical motivation, methodology, description of the data, the estimation results and their interpretation, the comparative statics where we tried to trace adoption paths under three alternative scenarios and our conclusions and policy implications.

Price controls and government intervention

Cotton is a major cash crop of India. It is mainly grown in 9 states spread over three zones namely Northern zone (Punjab, Haryana and Rajasthan) Central zone (Madhya Pradesh, Gujarat Maharashtra) and Southern zone (Andhra Pradesh, Karnataka and Tamil Nadu). In 2002, Bt cotton hybrids were made commercially available to farmers in the central and southern zones of India. Realizing the potential of Bt-cotton, many Indian seed companies have shown interest in the technology and have sub-licensed it from MMB.

MMB dominated the market for cotton hybrids, either directly through selling hybrid seeds or indirectly through sub-licensing to private seed companies till 2005. The domestic companies who licensed Bt trait from MMB were required to pay a one-time license fee as well as royalty fee for availing a gene. This led to wider price differences between Bt and non-Bt hybrids. (In 2004, Bt hybrids cost $19 more per acre compared to non-Bt hybrids; Murugkar, Ramaswami and Shelar, 2007). Until 2006, the price for official Bt cotton seeds in India was around Rs 1600 per packet of 450 grams. Out of this, Rs 1250 was charged by MMB (Mahyco-Monsanto Biotech) as the trait value.

The debate on Bt cotton pricing began in late 2005 when South India Cotton Association urged the seed companies to lower their seed prices. The idea gained popularity among various farmer organizations which led the state of Andhra Pradesh to impose certain regulations targeted to control Bt cotton seed prices, so as to make the technology affordable and accessible to small and marginal farmers in the state. In January 2006, the government of Andhra Pradesh filed a case with the Monopolistic and Restrictive Trade Practices Commission (MRTPC) against MMB for indulging in monopolistic trade practices with unreasonably high prices and limited technical developments. Thereafter, MMB appealed to the Supreme Court and argued that the technology fee being charged was not for the sale of any goods but for the knowledge transfer to the sub licensees. In response to MRTPC Act imposed by the state of Andhra Pradesh, on May 11, 2006, MMB reduced the price for BG-I from Rs 1600 for a packet of 450 gm of seed to Rs 1200. The government of Andhra Pradesh felt that this was still too high a price, and in June 2006 further released an ordinance declaring that seed prices for Bt cotton seeds in the state would be capped at Rs 750 for a packet of 450 gm of seed (inclusive of technology fee). This pricing directive was soon adopted by other domestic firms such as Nath Seeds Ltd and JK Agri Genetics Ltd. The other states of India also adopted the same pricing.

Empirical motivation and methodology

Studies estimating diffusion path have shown that cumulative adoption path often behaves like an S-shaped curve. The underlying premise being that diffusion occurs through interpersonal contacts among a group of homogenous adopters. When a new technology is introduced, adoption increases slowly at first because initially only the most progressive and less risk averse adopt and then it increases more rapidly as information spreads to other producers and finally it slows when nearly all producers who find the technology profitable have adopted, the process reaches a stable ceiling. This produces the classic 'S-shaped' diffusion curve. The logistic function is often used to represent the S-shaped diffusion process for agricultural innovations for its relative simplicity.

The literature has considered broadly two kinds of diffusion models: static diffusion model(Griliches 1960) and dynamic diffusion model (Knudson 1991, Jarvis 1981, Fernandez-Cornejo 2002).The static diffusion models express diffusion path as a function of time and assume diffusion parameters to be constant over time. The dynamic diffusion models allow determinants of diffusion to change with time and therefore, may more accurately measure the rate of diffusion. For example, as the real price of an innovation decreases and stabilizes (as reflected in seed price reduction), the innovation becomes more attractive and is adopted more rapidly. While dynamic model could capture this change, a static model cannot. As a result of its flexible form, dynamic models enable researchers to study impact of changes in economic variables on the pattern of diffusion.

The dynamic logistic models could be either variable ceiling models or variable slope models. The variable ceiling logistic model defines ceiling level (maximum rate of adoption) as a function of exogenous factors believed to influence adoption. Knudson (1991) used this model to study diffusion of semi dwarf wheat varieties in the U.S. A limitation of the variable ceiling logistic model is that there is no guarantee that the ceiling will stay at theoretically justifiable levels. In contrast to this, the variable slope logistic model allows the diffusion rate instead of the maximum number of adopters to vary as a function of exogenous factors. This model has several advantages. In this model, the rate of acceptance (slope) can vary and even be negative, given the movement of exogenous factors. It also allows the direct use of certain exogenous variables on the diffusion rate, and ceiling levels can be set at a theoretically justifiable level (e.g., 100 percent or lower).

An innovation's profitability as compared with the traditional alternative is often regarded as the primary motivation behind adoption. This suggests that the widespread adoption of Bt cotton can be explained by its perceived profitability over the conventional cotton. The expected profitability from Bt cotton can be measured as the difference between the revenue and the cost associated with new technology. Thus, both seed prices and cotton prices could affect the rate of diffusion through affecting profitability of the technology. Besides prices of cotton and seed, technological development could affect rate of diffusion. Since all these factors are impacting the rate of diffusion rather than the ceiling, we use a variable slope dynamic logistic model for our purpose. The functional form used for this study is as follows:

$$P_{it} = \frac{K}{1 + e^{-(a+b(z)t}} \qquad (1)$$

The right hand side measures the proportion of the total acreage under cotton planted with Bt seeds. P_{it} denotes the percentage area under Bt cotton in state i at time t. K is the adoption ceiling representing the maximum rate of adoption in the long run equilibrium. The term t is a time trend, a represents the origin parameter and it captures the date of availability of Bt cotton and b represents the slope coefficient or rate of diffusion of Bt cotton. The z variable denotes economic variables that are influencing the rate of diffusion *(b)* of Bt cotton in India.

We keep the ceiling to be fixed with $K=100$ and allow the coefficient of diffusion (b) to be a function of exogenous factors like price of seed, technological development, price of cotton etc. We also assume the origin parameter a to be fixed.

The mathematical derivation of our regression equation is discussed below.

Equation (1) can be linearized to

$$\log(\frac{P_{it}}{K - P_{it}}) = a + b(z)t \qquad (2)$$

where $b = f(P_s, P_c, T)$

More specifically, b is assumed to be a linear function of seed prices, cotton prices and technological development.

$$b = \beta_1.P_{s_{it}} + \beta_2.p_{c_{it}} + \beta_3.T_{it} \qquad (3)$$

where P_s, p_c and T denote seed prices, cotton prices and technological development, respectively.

Plugging in (2) we get,

$$\log(\frac{P_{it}}{K - P_{it}}) = a + \beta_1.P_{s_{it}}.t + \beta_2.p_{c_{it}}.t + \beta_3.T_{it}.t + \mu \qquad (4)$$

We analyze three variations of the variable slope dynamic logistic model. Their specific functional form is given below and the motivation for using them would be explained later.

The first model introduces six year dummies (for the years 2003 to 2008) in order to see the year specific impact on the diffusion rates.

Model 1: Dynamic logistic model with year dummies

$$b = \beta_1.P_{s_{it}} + \beta_2.p_{c_{it}} + \beta_3.T_{it} + \beta_4.D_{03} + \beta_5.D_{04} + \beta_6.D_{05} + \beta_7.D_{06} + \beta_8.D_{07} + \beta_9.D_{08} \quad (5)$$

Plugging (5) in (2), we get

$$\log(\frac{P_{it}}{K - P_{it}}) = a + \beta_1.P_{s \cdot it}.t + \beta_2.p_{c_{it}}.t + \beta_3.T_{it}.t + \beta_4.D_{2003}.t + \beta_5.D_{2004}.t + \beta_6.D_{2005}.t$$
$$+ \beta_7.D_{2006}.t + \beta_{8.}D_{2007}.t + \mu \quad (6)$$

The term $\frac{P_{it}}{K - P_{it}}$ captures the actual to potential percentage area under Bt cotton. We are using number of hybrids of Bollgard-I approved for commercial cultivation in India as a proxy for technological development.

Model 2: Dynamic logistic model with two interaction dummies

Model 2 introduces two interaction terms, viz., $T_{05} = d_{05} * T$ (which is dummy for year 2005 * technological development) and $T_{06} = d_{06} * T$ (dummy for year 2006 * technological development*)* in the regression equation.

$$b = \beta_1.P_{s_{it}} + \beta_2.p_{c_{it}} + \beta_3.T_{it} + \beta_4.T_{05} + \beta_5.T_{06} + \beta_6.D_{04} + \beta_7.D_{05} + \beta_8.D_{06} + \beta_9.D_{07} \quad (7)$$

Putting (7) in (2), we get

$$\log(\frac{P_{it}}{K - P_{it}}) = a + \beta_1.P_{s \cdot it}.t + \beta_2.p_{c_{it}}.t + \beta_3.T_{it}.t + \beta_4.T_{05}.t + \beta_5.T_{06}.t + \beta_6.D_{2004}.t + \beta_7.D_{2005}.t$$
$$+ \beta_8.D_{2006}.t + \beta_9.D_{2007}.t + \mu \quad (8)$$

Model 3: Dynamic logistic model after dropping one interaction term

Model 3 is an extension of model 2 where we have dropped the interaction term, T_{06}.

$$\log(\frac{P_{it}}{K - P_{it}}) = a + \beta_1.P_{s \cdot it}.t + \beta_2.p_{c_{it}}.t + \beta_3.T_{it}.t + \beta_4.T_{05} + \beta_5.D_{2004} + \beta_6.D_{2005}$$
$$+ \beta_7.D_{2006} + \beta_8.D_{2007} + \mu \quad (9)$$

Econometric specification and data

For this study, the three models specified above are estimated using generalized least squares where our dependent variable is $\log(\frac{P_{it}}{K - P_{it}})$.

Here, P_{it} is (area under Bt cotton/area under cotton) *100. Data on area under Bt cotton is taken from ISAAA Brief 41, Global status of commercialized GM crops, Clive James (2009), and data on aggregate area under cotton cultivation is obtained from Cotton Corporation of India (CCI).

Table 1 presents percentage area under Bt cotton for 9 major states from 2002 to 2008. For the explanatory variable seed prices, we have used the price for a packet of 450 gms of Bt seed, Bollgard 1. Data on price of Bollgard-I is obtained from Internal Mahyco- Monsanto Biotech Estimates. (For some of the years, data represents an average rather than an exact price.) The second variable cotton prices $p_{c_{it}}$ are the average annual prices of cotton. More specifically, these are the average price of Kapas (raw cotton) for major varieties, which includes Bengal Desi, LRA, J-34, H-4, S-6 and DCH-32. Price of cotton is again taken from Handbook of Statistics, Cotton Corporation of India (CCI). CCI publishes average annual prices of kapas (raw cotton).

The variable T_{it} captures technological development, i.e., the number of hybrids of Bt cotton (Bollgard-I) approved for commercial cultivation in India. Data on the number of hybrids of Bollgard-I approved in India is taken from Indian GMO Research Information System (IGMORIS). It may be noted that this study captures technological development in terms of number of approved hybrids of Bollgard-I only, and does not include Bollgard II or other hybrids.

Table 3 illustrates that in year 2006, there was a one shot decline, from Rs.1600 to Rs.750, in the price of a packet of 450 gm of Bollgard -1 seeds for all three cotton growing zones of India. The common approach of introducing a dummy variable that takes value 0 for the pre-policy period and 1 in the post-policy period for analyzing such policy intervention is not appropriate for our case. Since the policy intervention changed seed prices in a one shot fashion, the variable, seed prices, itself works as a policy dummy. Thus in order to avoid muticollinearity problem between policy dummy and seed prices we are not introducing a separate policy dummy.

This is a panel data study. We conducted Hausman test to check whether fixed effect or random effect model is more appropriate for our purpose. Table 4 shows that the Hausman test statistic is insignificant. So we accept the null hypothesis that random effect model is appropriate in our case.

Model Estimation and Interpretation of Regression Results

Table 2 tabulates regression results of three dynamic logistic models using generalized least squares (GLS) techniques based on panel data. Column 2 presents the results pertaining to model 1. It is evident that the model provides a good fit to the data with an adjusted R-square of 0.82. Most of the variables are significant and have the expected signs. Note that coefficient of $P_{s_{it}}$ is significant at 11 percent level and has the expected negative sign. It implies that the diffusion rate (*b*) is negatively and significantly related to the price of the seed indicating that as seed prices decline the incentive to adopt Bt cotton increases. From (5) it also implies that a one unit decline in seed prices will lead to 0.038% increase in the diffusion rate. As discussed earlier, since there is no variability in the data on seed prices other than that caused by government intervention, seed prices themselves would act as policy dummy and the significance of this variable implies that the government seed price interventions in 2006 were successful in impacting the diffusion rate.

The rate of diffusion is positively and significantly related to cotton prices suggesting that as cotton prices rise the incentive to adopt Bt cotton increases. Further a unit increase in $p_{c_{it}}$ will lead to 0.041% increase in the rate of diffusion of Bt cotton. Similarly the coefficient for technological development ($T_{it}.t$) is significant at around 8 percent level and has the expected positive sign which again implies that as the number of hybrids approved of Bt cotton increases rate of diffusion also increases. In particular, a unit increase in T_{it} will lead to 0.34% increase in diffusion rates.

Column 2 of Table 2 also shows significance of various years on the diffusion rate. While years 2006 and 2007 are significant at around 11 percent, year 2005 is significant at around 6 percent and the value of the coefficient is much larger as compared to 2006 and 2007**.** This is an interesting result and suggests that some significant changes must have occurred in 2005 that had considerable impact on the diffusion rate and ultimately on the percentage area under Bt cotton

(P_{it}). It motivates us to look for the changes that may have had a significant impact on the diffusion of Bt cotton in India in year 2005. Around 20 new hybrids of Bollgard-I were introduced in year 2005 and among these some were specifically suited for agro-ecological conditions of the northern zone. Hence in order to see whether the increase in diffusion rates in 2005 and 2006 could be explained by technological development or not, we introduce 2 interaction terms, namely, T_{05} ($T_{05} = d_{05}*T$) and T_{06} ($T_{06} = d_{06}*T$) in Model 2.

From Column 3 of Table 2, it can be seen that model 2 also provides a good fit to the data with an adjusted R-square of 0.83. Here also all the coefficients have the expected signs. Technology coefficient (T_{it}) and price of cotton ($p_{c_{it}}$) are significant at 10 percent and 1 percent, respectively. But an important thing to note is that while the coefficient for the interaction term (T_{05}) is significant at around 12 percent, coefficient for d_{2005} (year dummy for 2005) is insignificant. This implies that the entire increase in the diffusion rates in 2005 is explained by Technological Development in 2005. Also note that both the coefficients for T_{06} and d_{2006} are insignificant. We check possibility of multicollinearity among these two variables by conducting an F test[2] for both variables individually. The results are presented in Table 5.

It can be seen from Table 5 that the coefficient for T_{06} is less significant than d_{2006}. Hence, in Model 3 we have dropped the interaction term T_{06}. The results of Model 3 are presented in Column 4 of Table 2. Interestingly, the coefficient of d_{2006} became significant in Model 3. In our final model, i.e., model 3, we find that while the price of the seed is significant at around 7 percent, technology coefficient is significant at around 5 percent. Also cotton prices are significant at 1 percent, and all three variables have the expected signs. The coefficient of seed prices in column 4 also suggests that a unit decline in seed prices will lead to 0.038% increase in the diffusion rates. Also a unit increase in technological development and cotton prices will lead to 0.36% and 0.039% increase in the diffusion rates, respectively. Thus, we find that the impact of technological development is stronger than the impact of seed prices. This result has important

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2 $F = \frac{(RSS - URSS)_m}{URSS_{n-k}}$; where m is number of restriction in the restricted model, n is number of observation, and k is number of parameters of the unrestricted model.

policy implications. Another interesting feature to note is that $d_{2006,}$ which was insignificant in the previous model is now significant at 10 percent. This again suggests that other than changes in seed prices, technological development, and cotton prices, something else happened in 2006 which impacted the diffusion rates and ultimately the percentage area under Bt cotton in India.

One possible factor could be the introduction of Bollgard II in the Northern, Central and Southern zones of India in 2006. Apart from Bollgard II, J.K Agri Genetics Ltd and Nath Seeds Ltd had also introduced some events which further increased portfolio of choice for farmers and may have led to an increase in the diffusion rates. Thus, the increase in the adoption of Bt cotton in 2006 cannot be attributed entirely to the seed price interventions of the government of India, approval of certain specific events and hybrids of Bt cotton (Bollgard II) may also have contributed to an increase in the adoption.

Using the estimated coefficients from Model 3, we estimate percentage area under Bt cotton *(*P_{it} *)*. Figure 2 plots the actual versus estimated area under Bt cotton for each state separately. Here the percentage area under Bt cotton is plotted on the vertical-axis and years are on the horizontal axis. These graphs depict that our Model 3 fits in quite well for almost all the states.

In order to compare the Goodness of fit of different models we have applied the criteria of 'Explained Variation' which is given by $\sum_{it}\left(\hat{P}_{it} - \overline{P_{it}}\right)^2$

where, $\hat{P}_{it}$ is the estimated percentage area under Bt cotton, and

$\overline{P_{it}}$ is the average of the estimated area under Bt cotton.

In terms of adjusted R- square, all the three models had similar values. However, model 3 has the highest explained variation amongst the three models.

From the results, it is clear that seed price interventions of the government were significant in impacting the diffusion rates at least in the short run. Our study also sheds light on the significance of technological development in impacting the diffusion rates. To examine the impact of seed price intervention, we have tried to trace diffusion path under three alternative scenarios.

Comparative Statics

Using the values of coefficients estimated in model 3, we will now do comparative statics to predict diffusion paths under different scenarios and compare them with the base scenario.

Scenario I: Base scenario

The base scenario is the estimated diffusion path using estimated coefficients and actual data on percentage area under Bt cotton.

Scenario II: No seed price intervention

Since the focus of this paper is on determining the effect of seed price intervention on the percentage area under Bt cotton, the second scenario traces diffusion path if the government had not intervened in seed prices, and the seed prices continued at the rate of Rs 1600 for a packet of 450 gm.

Another interesting scenario would be to allow competition among the gene providers bring down seed prices instead of government intervention doing it. Murugkar, Ramaswami and Shelar (2007) have argued that competition among alternative seed companies like J.K Agri Genetics Ltd and Nath Seeds Ltd would reduce the seed prices on its own. Due to this competition, seed prices may not go down drastically to Rs 750 but may take some intermediate value. To capture this possibility we consider the scenario, where seed prices are reduced from Rs1600 to Rs1200 in year 2006 and trace the diffusion path for this case.

Scenario III: Prices for Bt cotton seeds are brought down to Rs 1200 for a packet of 450 gm in 2006 and remain at that level.

To compare diffusion paths under alternative scenarios we are assuming that except for seed prices, the values for all other variables remain same as in the base scenario. To be able to do that, the implicit assumption is that variables are not interrelated. Although seed prices can affect incentives for developing new hybrids, it takes a fairly long time to develop new hybrids of any seed and thus it is reasonable to assume that this effect would not have manifested itself in the short run. Similarly since domestic cotton prices are influenced by the cotton prices in the world market, seed prices are unlikely to affect cotton prices over the period studied.

Figure 3 illustrates these comparisons. The gap between the blue and the pink line traces the change in the percentage area under Bt cotton due to seed price interventions. Thus, a substantial gap between the two lines indicates that seed price interventions were significant in impacting the adoption of Bt cotton in India at least in the short run for almost all states. However, the gap between the blue and the yellow line depicts the change in the percentage area if seed prices had been brought down due to market competition. We find that the diffusion path with seed prices at Rs1200 (since 2006) lies above the path of diffusion without interventions. This implies that competition among alternative gene providers would reduce the seed prices on its own rather than government doing it and would ultimately increase the adoption of Bt cotton. This has some policy implication which is discussed in the next section.

Conclusion

Using state level data for the period 2002-2008, this study analyzes impact of seed price interventions and technological development on diffusion of Bt cotton in India.

We have tried to examine whether and to what extent the government seed price interventions in 2006 have helped in increasing the diffusion rates. In the process we examine other factors such as technological development, cotton prices, etc. responsible for an increase in the diffusion rates of Bt cotton in India.

Using three variations of dynamic logistic model with variable slope coefficient, we found that the variables (seed prices, technological development and cotton prices) are significant and have the expected signs. The coefficient for seed prices is negative which implies that a decline in seed prices will lead to an increase in the diffusion rates. However, both technological developments as well as cotton prices are positively impacting the diffusion rates. Further the significance of our interaction term (T_{05}) implied that year *2005* is significant in impacting the diffusion rates of Bt cotton. This can be attributed to the introduction of around 20 new hybrids of Bollgard-I in year 2005. Among these some were specifically suited for agro-ecological conditions of the Northern zone.

We found that the coefficient of technological development was positive, significant and also larger in magnitude as compared to the seed price coefficient. This suggests that although seed price reductions were successful in increasing the diffusion rates over the period studied but its impact was limited. Also the dummy for the year 2006 was significant which implies that apart from seed prices, technological development and cotton prices, some other factors impacted the diffusion rates in 2006. There could be various reasons for this. One reason could be the introduction of Bollgard II in 2006 in the Northern, Central and Southern zones of India. Also, there were certain events introduced by J.K Agri Genetics Ltd and Nath Seeds Ltd which also increased the portfolio of choice for farmers and may have led to an increase in the diffusion rates. Thus, the increase in percentage area under Bt cotton in 2006 cannot be attributed entirely to seed price interventions of the government rather certain other factors like approval of some specific events and hybrids (Bollgard II) of Bt cotton would have led to an increase in the adoption of Bt cotton in India.

Our results provide inputs for the government policy by quantifying the effect of government seed price intervention on diffusion rates. Further they suggest that the impact of government seed price reductions was limited hence, government should look for other policies which would enhance the diffusion rates and improve overall welfare. One could be simplifying the process of approval of Bt hybrids. Lalita, Pray and Ramaswami (2008) have discussed that our current regulatory framework for approval of Bt hybrids is very complex and time consuming and it has acted as an entry barrier for new genes. Hence, in order to streamline the process of approval of Bt hybrids and to ensure technological development government should further simplify the procedure of approval of Bt hybrids. This will ensure the benefits not only to the farmers in terms of greater portfolio of choices which will increase the diffusion rates but also for the company as it will protect their interests to innovate in the future. Also, simplification of our regulatory procedure would encourage new seed companies to come in which would enforce competition among them. This competition among alternative gene providers could reduce the seed prices on its own (rather than the government doing it) and could ultimately increase the diffusion rates.

Acknowledgements

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Table1 : Percentage adoption of Bt cotton in 9 major states from 2002 to 2008.

State	2002	2003	2004	2005	2006	2007	2008
Maharashtra	0.89	1.08	7.04	21.1	59.2	90.1	99.9
Andhra Pradesh	0.99	1.19	6.66	27.10	85.3	95.7	98.14
Gujarat	0.61	2.18	6.4	7.8	19.6	37.4	56.2
Madhya Pradesh	0.36	2.19	13.8	23.5	48.5	79.3	94.6
Northern Zone (Punjab, Haryana and Rajasthan)				3.72	14.4	47.8	69.1
Karnataka	0.27	1.27	3.45	7.26	22.4	36.06	61.5
Tamil Nadu	2.35	6.79	3.87	19.2	45	58.8	75

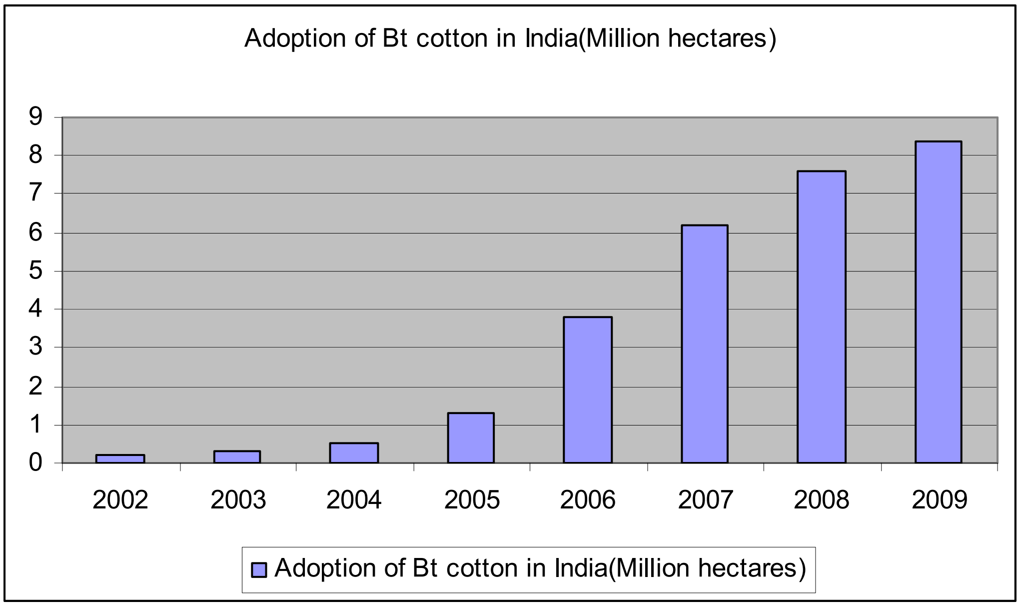
Source: Computed using data from ISAAA brief 41 and Cotton Corporation of India.

Table2. Estimation results of 3 different models for 9 states from 2002-08.

Dependent variable:	*Log*$(P_{it}/K-P_{it})$	*Define* $(P_{it}/K-P_{it})=y$	
Independent variable	Random effects panel regression on 9 states from 2002-08 for Model 1.	Random effects panel regression on 9 states from 2002-08 for Model 2.	Random effects panel regression on 9 states from 2002-08 for Model 3.
Constant	-5.036674	-4.516211	-4.768946
$P_{s_{it}}.t$	-.0003853*	-.0005521	-.0003811 **
$p_{c_{it}}.t$	.0004145 ***	.0004354***	.0003933 ***
$T_{it}.t$	.0034174 *	.0033621*	.0036701 **
D_{2003}	0.165856		
D_{2004}	0.2774892	0.3329655	0.2557017
D_{2005}	0.4741183 **	0.1610635	0.0059502
D_{2006}	0.1771958 *	0.3742744	0.164289*
D_{2007}	0.1200054*	0.1129435 *	0.1089667 *
$\mathbf{T_{05}}$		0.0382094 *	.0395252 *
$\mathbf{T_{06}}$		-0.0082176	
R Squared	within = 0.8800 between = 0.0534 overall = 0.8160	within = 0.8854 between= 0.0557 overall = 0.8265	within = 0.8842 between = 0.0566 overall = 0.8267
Wald Chi(2)	Waldchi2(8) =275.04***	Waldchi2(9) = 287.59***	Wald chi2(8) = 292.02***
Numberof observations	54	54	54

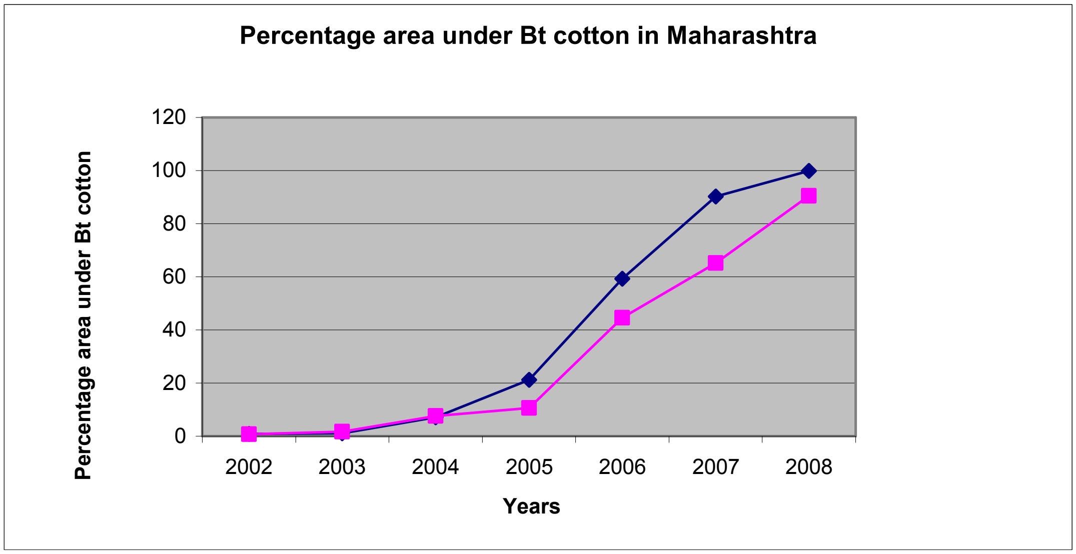
Note: *, **, * denote significance at 1 percent, 5 percent, 10 percent respectively.**

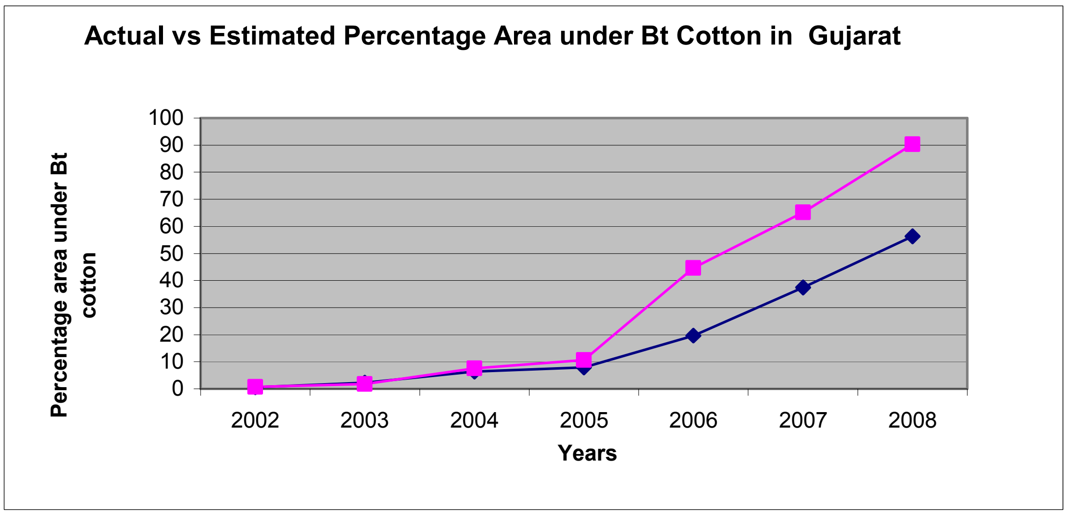
Fig1. Adoption of Bt cotton in India, 2002 to 2009 (Million hectares)

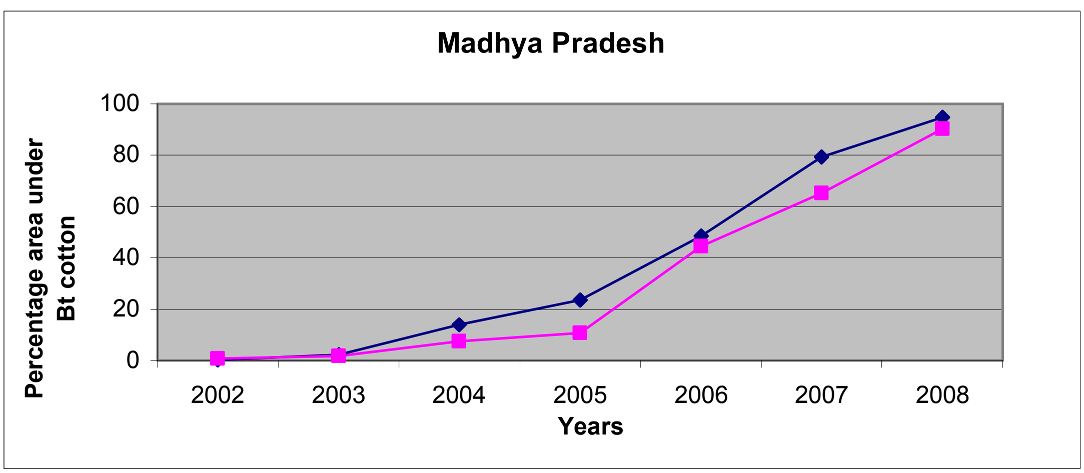


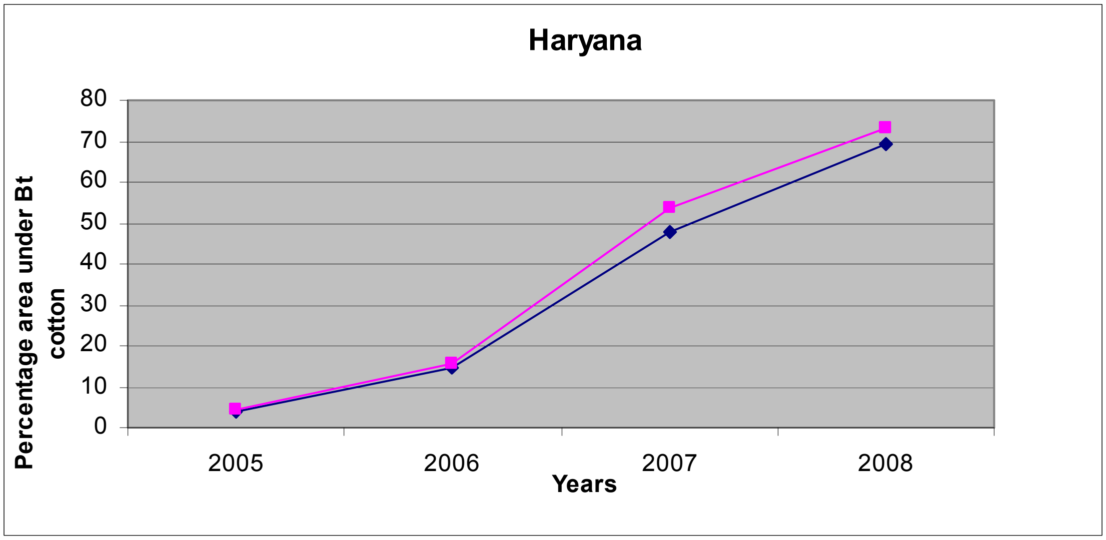
Source: James C (2009), Preview: Global status of commercial Biotech Crops: 2009, ISAAA Brief No.41, Ithaca, NY.

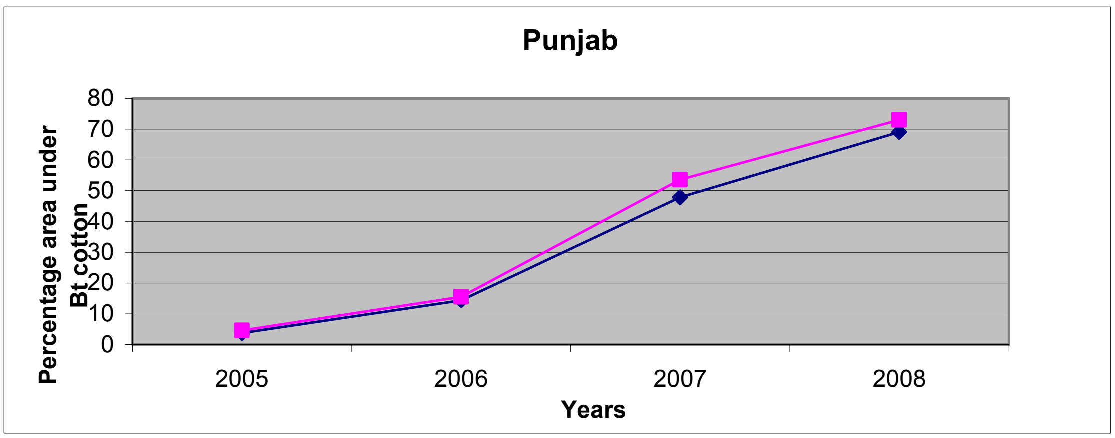
Fig 2 Actual vs estimated area under Bt cotton for 9 major states








Haryana
Percentage area under Bt cotton
80
70
60
50
40
30
20
10
0
2005
2006
2007
2008
Years


Punjab
Percentage area under Bt cotton
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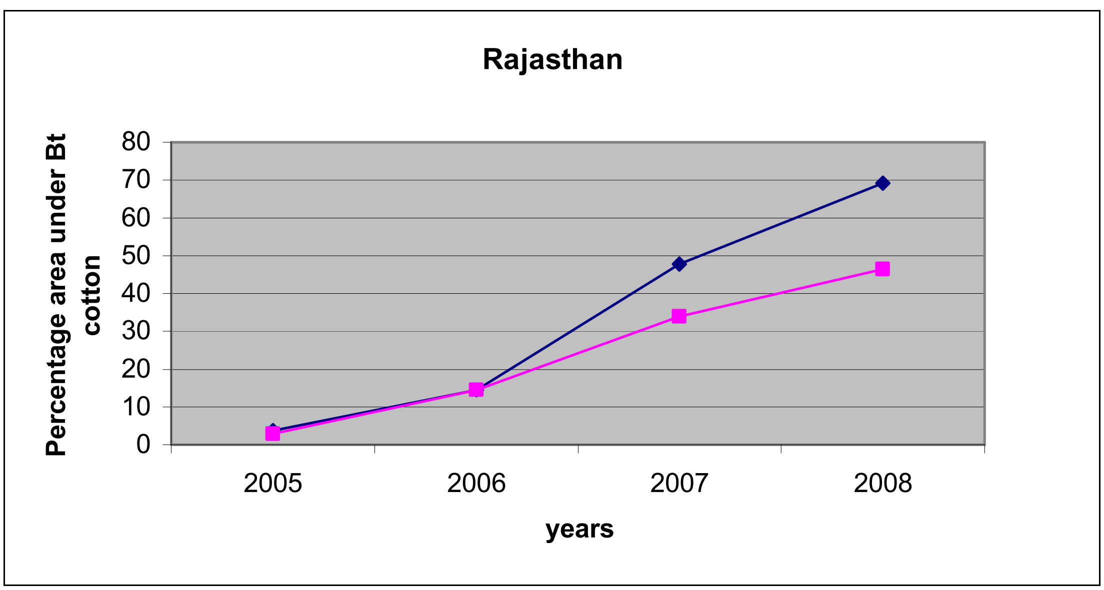
Rajasthan
Percentage area under Bt cotton
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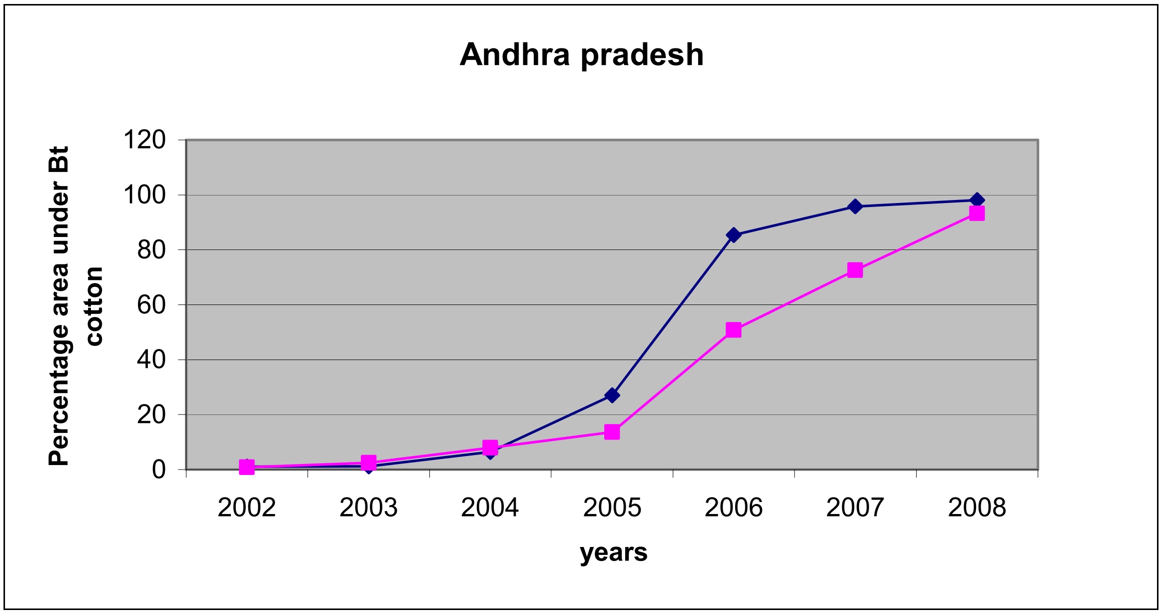
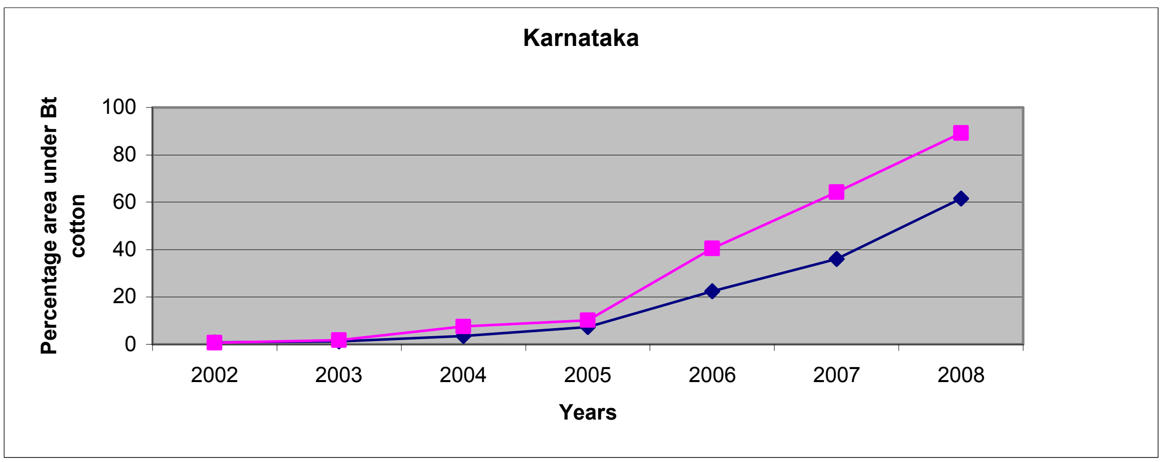
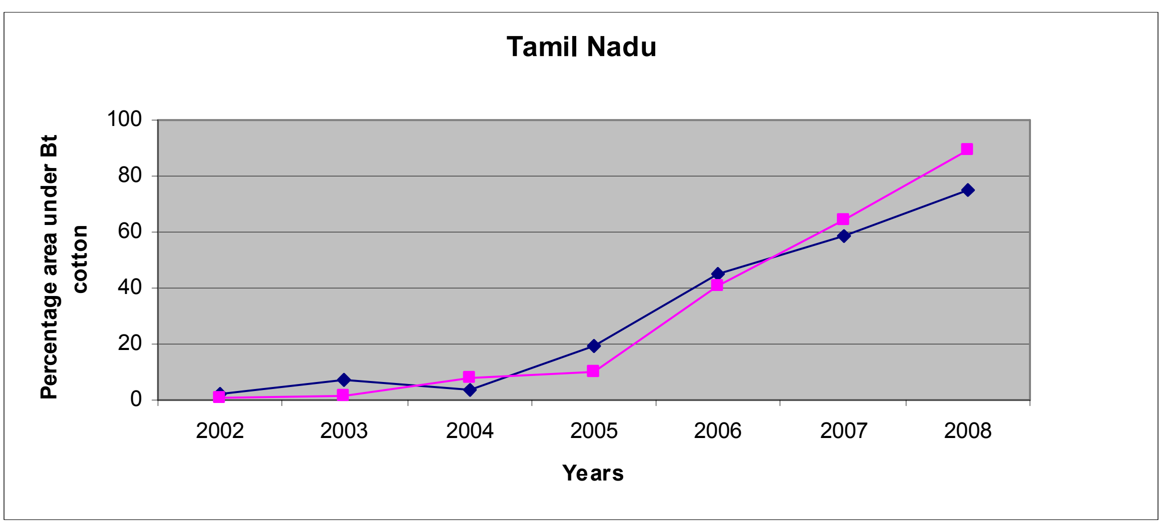
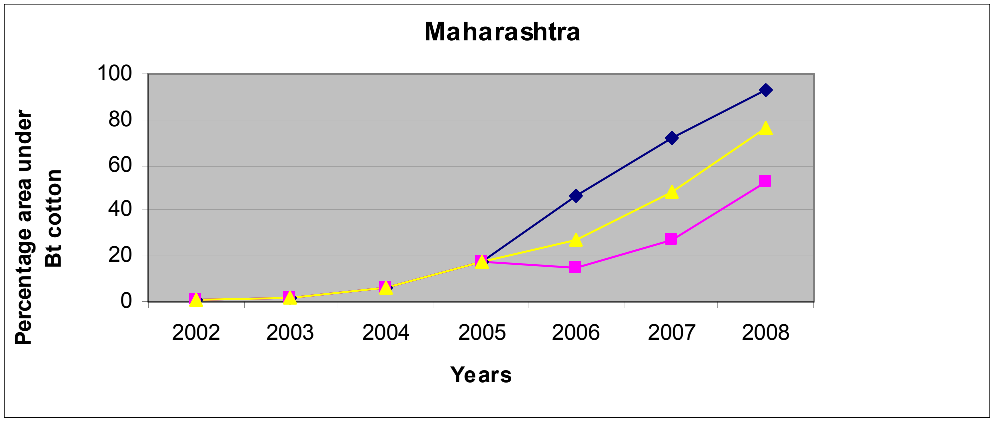


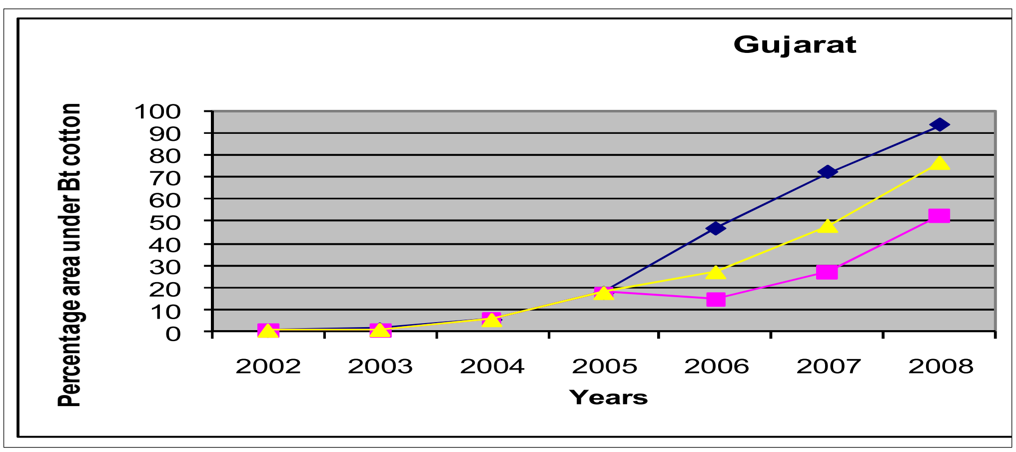


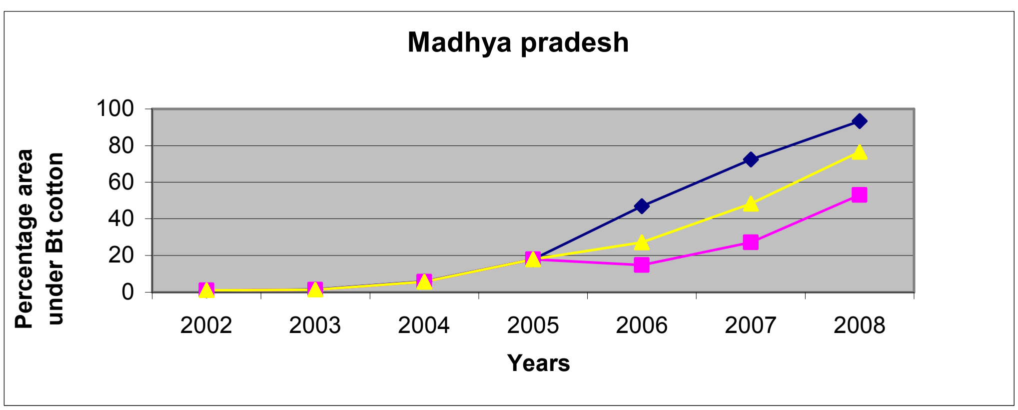


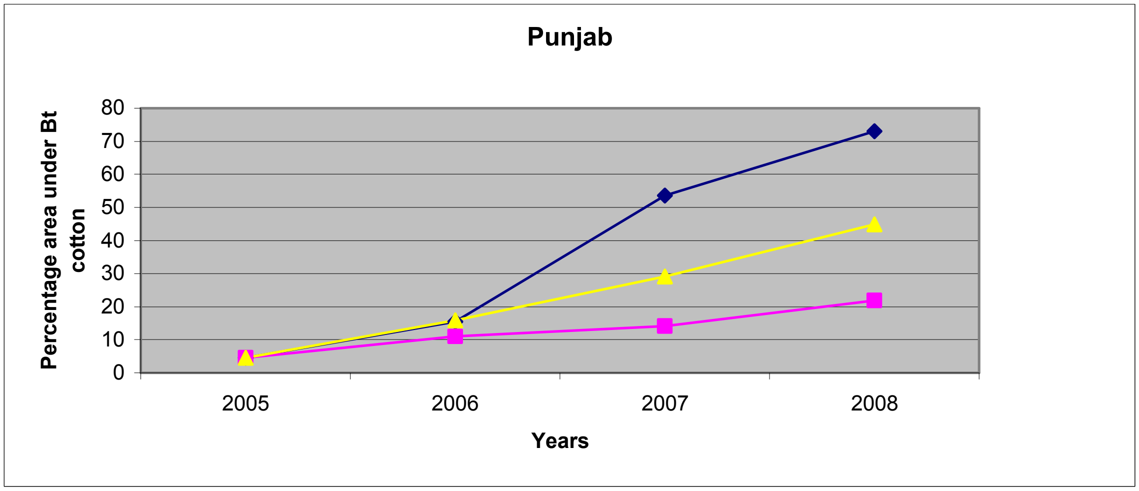
The blue line denotes the actual percentage area under Bt cotton.
The pink line denotes the estimated percentage area under Bt cotton.

Fig 3 Actual percentage area under Bt cotton (with interventions) vs estimated area under Bt cotton (without interventions i.e. seed price at Rs1600) vs estimated area when seed prices are kept at Rs1200 since 2006.








Punjab
Percentage area under Bt cotton
80
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40
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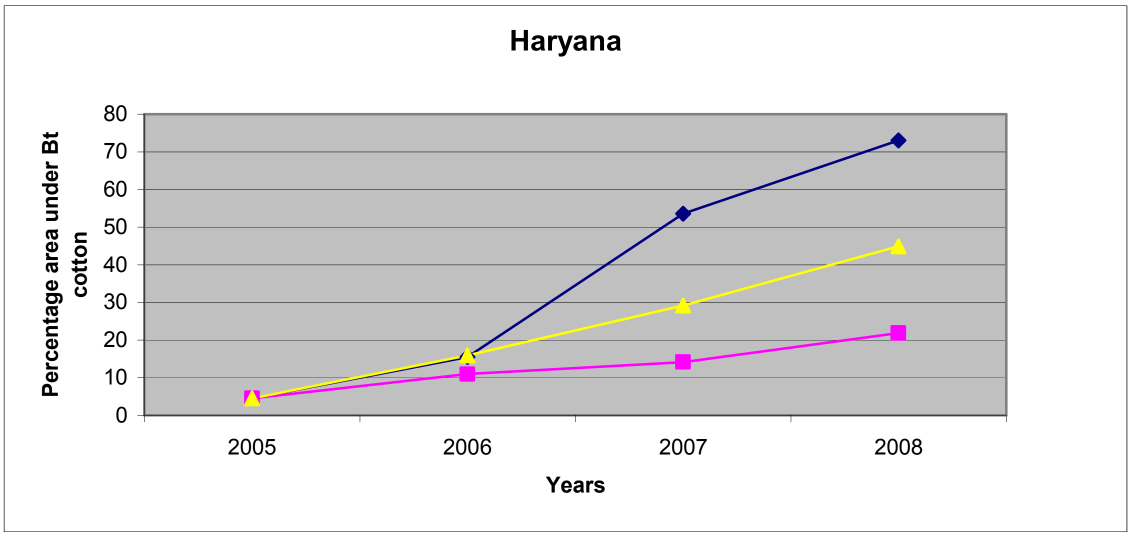
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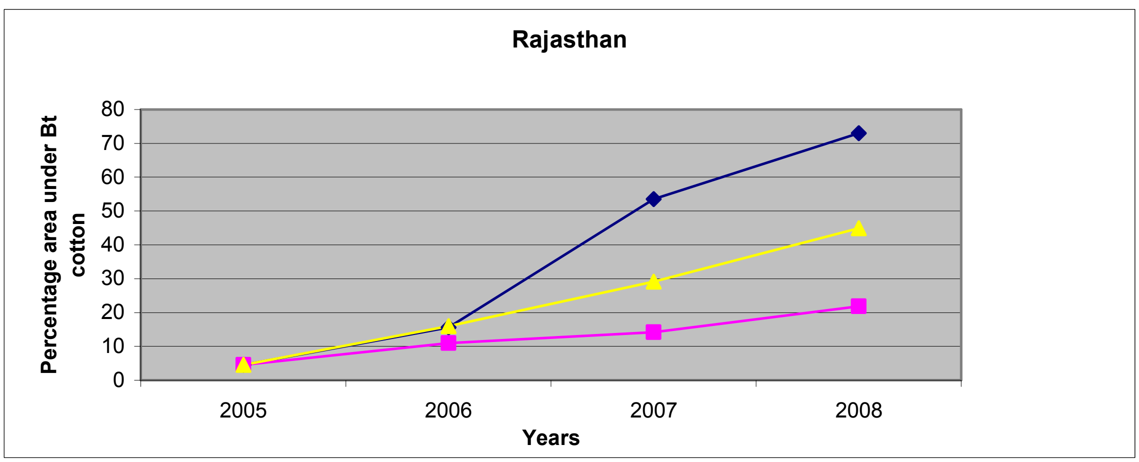
Rajasthan
Percentage area under Bt cotton
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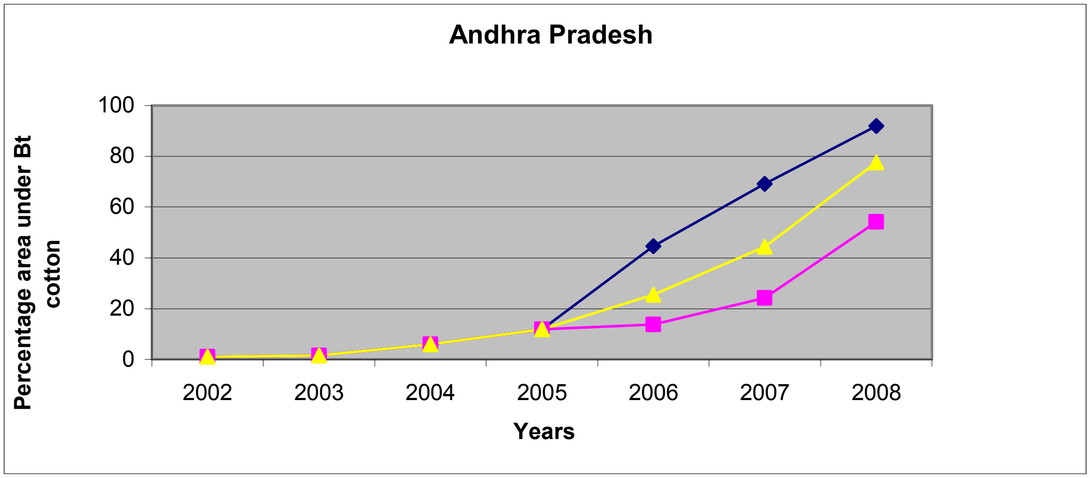

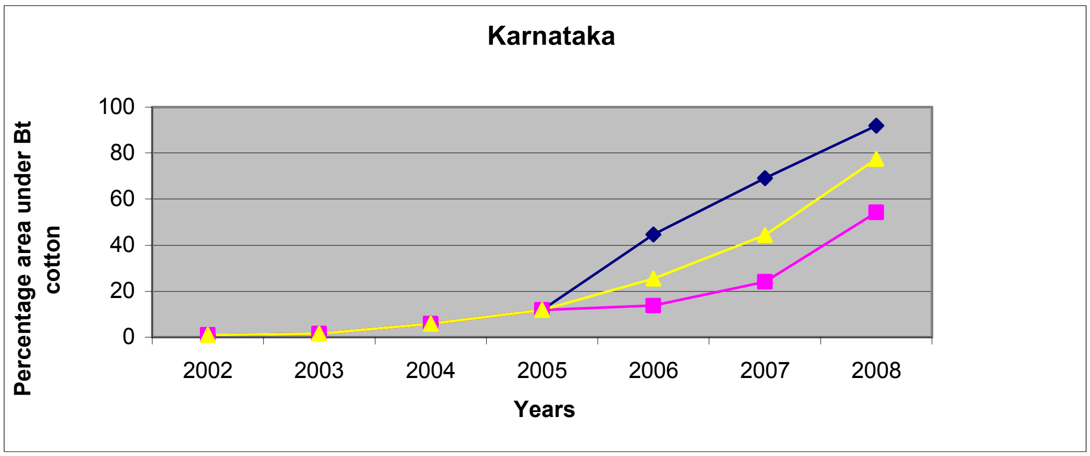

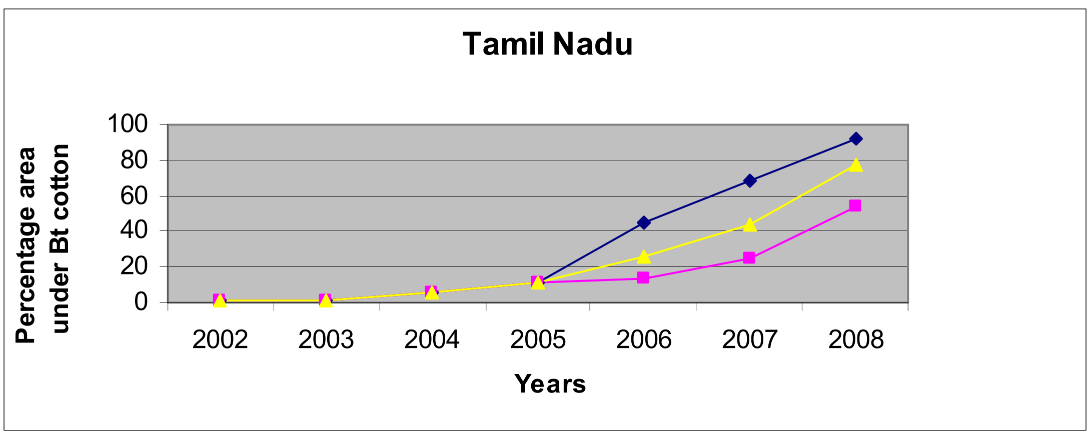

The blue line shows the estimated area under Bt cotton with government intervention.

The pink line shows the estimated area under Bt cotton without government intervention.

The yellow line depicts the estimated area when seed prices are kept at Rs 1200.

Table 3: Price of Bollgard-1 across all three zones of India from 2002-08.

Year	Central Zone	Northern zone	Southern zone
2002	1600		1600
2003	1600		1600
2004	1600		1600
2005	1675	1675	1675
2006	750	1390	750
2007	750	750	750
2008	650	750	750

Source: Mahyco Monsanto Biotech estimates

Table 4. Hausman Test (Random effect or fixed effect model)

Hausman fixed	Ho: difference in coefficients not systematic. chi2(4) = 1.54 Prob>chi2 = 0.851

Table 5:Results of F test

F test after dropping T06 T06=0 chi2(1) = 0.21 Prob > chi2 = 0.6495	F test after dropping d2006 d2006=0 chi2(1) = 0.63 Prob > chi2 = 0.4292

Table 6. Number of Hybrids approved of Bollgard-1 event across all 3 zones since 2002-08.

Year	Central Zone	Northern Zone	Southern Zone
2002	3		3
2003	3		3
2004	4		4
2005	15	6	12
2006	31	12	26
2007	62	25	55
2008	82	28	84

Source: Indian GMO Research Information System

Table 7 Average Annual Price of kapas (raw cotton) for major varieties – Bengal Desi, LRA, J-34, H-4, S-6 and DCH-32.

Year	Price of cotton (in Rs per quintal)
2002	1840.6
2003	2278
2004	2556.6
2005	2041.5
2006	2381.6
2007	2297.2
2008	2559.45
2009	2887.5

Source: Handbook of statistics, Cotton Corporation of India (CCI)