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Bt- cotton Productivity Considerations from India and China

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Abstract

By 2002 the global area planted to Bt cotton has reached 2.2 Mill ha and transgenic varieties became increasingly popular in developing countries. The main cotton producing countries China and India gave commercial approval for Bt cotton in 1997 and 2002, respectively. Today Bt varieties have reached over 50% of the total cotton area in China. The Bt technology is a mean to control lepidopteran cotton pests, hence offering the possibility to reduce the application of chemical pesticides and lowering production costs.

Previous studies, which assess the Bt technology, claim a sharp reduction in pesticide use accompanied by significant human health and environmental benefits. In these studies the conclusions on benefits were derived from a comparison between Bt and non-Bt varieties rather than from an analysis of the pest control effects of Bt crops. Furthermore, costs of possible long-term ecological effects of Bt crops were not included and, none of the studies has taken into account the uncertainty that underlies the main parameters. Thus, there is a danger that if results from case studies are generalized, wrong conclusions are drawn about prospects, opportunities and constraints of Bt crops on a global scale.

The approach presented here complements previous studies by using a stochastic partial budgeting model that captures the key pest control properties of Bt cotton taking into account uncertainty.

Keywords: *Bt cotton, productivity, technology assessment, uncertainty*

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Introduction

Transgenic Bt cotton varieties are a pest control technology that has raised great expectations for the successful control of one of the major cotton pests, the cotton bollworm. In 2002 some 16% of the global cotton area were planted with Bt cotton varieties. Two major cotton producing countries are outstanding when it comes to the area planted to Bt cotton: the United States and China with a share of 48 and 57%, respectively, while in India, the country with the largest cotton area in the world, the area planted to Bt cotton is still negligible (James 2002). In China, diffusion of Bt cotton has been extremely rapid, suggesting that the benefits of Bt varieties to farmers must be considerable. In fact, economic studies claim that on average the profits of Chinese cotton farmers were more than tripled (Table 1). Benefits are due to two factors: yield increase and pesticide cost savings. Available results e.g. from India have led economists to conclude that benefits of Bt crops will be huge (Qaim and Zilbermann 2003) and there is a general believe that the Bt technology will be a major factor in boosting productivity of agriculture especially in developing countries. Additional positive effects on human health and the environment due to reduced pesticide use levels are also attributed to the Bt technology.

Table 1: Performance differences [% change] between Bt and conventional cotton varieties

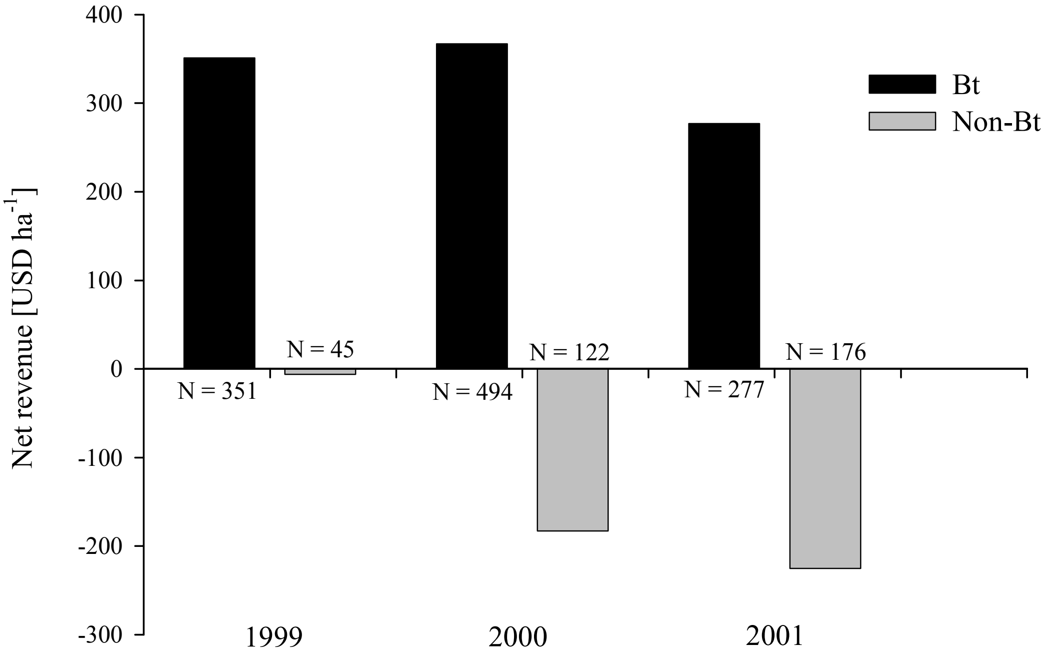
	Argentina	China	India	Mexico	South Africa
Bt cotton[1] [% of cotton area]	5	40	2	71	10
Lint yield [% change]	33	19	80	11	65
Chemical sprays [No.]	-2.4	-13.2*	-3.0	-2.20	na
Pest control costs [% change]	-47	-67	-39	-77	-58
Seed costs [% change]	530	95	82	165	89
Profit [% change]	31	340	83	12	299

Source: Argentina: Qaim and deJanvry, 2003. China: Pray et al., 2002; India: Qaim and Zilbermann, 2003; Mexico: Traxler et al., 2003.; South Africa: Bennett et al., 2003. Data are averages over all surveyed years. *1999 data.
[1] James 2002, FAOSTAT 2002

In all studies summarized in Table 1 the analysis was based on a comparison of adopters and non-adopters of Bt cotton. Data sources included farm surveys and data from on-farm experimental plots (India). The duration of the studies ranged from only one to a maximum of three seasons.

When analyzing the studies in detail one can find a number of factors in the study design that could have pre-determined the unanimously positive results. One common problem is the counterfactual scenario used to measure the impact of the Bt system. For example, in China, where Bt cotton has spread quickly in the provinces where it got approval, the impact studies

(Pray et al 2002) followed the "adoption trail" by interviewing adopters and non-adopters in new provinces but subsequently loosing their non-adopters in the provinces with earlier adoption. In addition, the sample size for adopters exceeded those of non-adopters by a factor of four on average. Remarkably, non-adopters had negative net returns from cotton production in all the three years of the study (see Figure 1).



Source: Own presentation, data from Huang et al 2003

Figure 1: Net revenues of Bt and non-Bt cotton production in China [US$ ha^{-1}]

Generally, in impact studies of Bt cotton the assumption has been made that the alternative to planting Bt crops is routine pesticide application, thus leaving aside other possibilities of a need-based, judicious use of chemicals like practiced in Integrated Pest Management (IPM). Therefore, the reduction in pesticide use due to Bt adoption could be overestimated.

Furthermore, measurement of farmer pesticide use in developing countries is prone to numerous sources of error. The abundance of pesticide brands and the common practice of mixing several pesticides make it difficult for farmers to provide valid and accurate information in response to recall questions at the end of the cropping season (Pemsl et al 2003). Next, Bt cotton impact studies were always based on a comparison between Bt and non-Bt varieties. This opens the possibility that variety effects other than pest control properties of Bt are the cause for observed differences in productivity. For example, farmers planting Bt crops were given new seeds while the use of own seeds is common farmer practice. Finally, the short-term nature of the economic studies renders the possibility of tremendous uncertainty in the data pertaining to possible climatic and agro-ecosystems variability. For example, the study of Qaim and Zilberman (2003) and Qaim (2003) on Bt cotton in India did not differentiate between irrigated and non-irrigated cotton production, while over two thirds of cotton production in India is non-irrigated. Results of other studies (Orphal 2003, Qayum and Sakkhari 2003) suggest that Bt cotton performs poorly under non-irrigated conditions.

A stochastic partial budgeting approach to assess the farm level performance of Bt cotton

Using a Bt cotton variety is nothing but a new option in cotton bollworm control. It can at least partially substitute pesticide treatments against the same pest. Comparing the two control measures (Bt varieties and chemical pesticides) and their combination (see Table 2) requires an identification of the distinct properties of each measure. One important distinction is that Bt crops are a prophylactic pest control treatment where costs occur at the beginning of the season when farmers do not yet know the severity of bollworm attack. On the other hand, while in most cases farmers may tend to apply pesticides prophylactically they can be applied judiciously and in response to actual pest pressure and potential yield level. Pesticides effective against the cotton bollworm may also be effective against other cotton pests while Bt varieties are specific against only one group of pests. Furthermore, as observed in India seed cotton quality of Bt varieties is lower than that of conventional varieties[3]. Combining both strategies, planting Bt varieties and applying chemical pesticides will increase costs of control but may increase effectiveness of damage abatement.

An economic assessment of pest control can be performed in the context of a partial budget analysis by calculating the marginal net revenues of the various control methods (Herdt et al 1984). In the case of cotton bollworm control the factors that determine the average marginal net revenue are the potential yield, bollworm pest pressure, the effectiveness of bollworm control, the price of cotton as well as the control costs (see Equation 1).

$$MNR_j = [Y_0 * (1- L_0 * k_j) - Y_0 * (1 - L_0)] * p_Y - C_j \quad (1)$$

MNR_j is the marginal net revenue of bollworm control, j the respective control strategy (Bt, pesticides, combination), Y_0 the potential seed cotton yield, i.e. the yield without any effect of bollworm, L_0 the potential bollworm damage, k_j the effectiveness of bollworm control, p_Y the

[3] This is because at the current state only medium staple Bt cotton varieties have the approval for commercial production in South India. Long staple varieties that catch higher prices might be released in the future.

seed cotton (output) price and C_j the costs of bollworm control, comprising of material, labor and health costs. Under farmers' conditions[4] all parameters of Equation 1 are stochastic. To capture the uncertainty inherent in the data a simulation approach can be used. Monte Carlo techniques (see Figure 1) are an appropriate tool to integrate relevant observations especially in a sparse data situation (Anderson et al 1977).

Table 2: Comparison of Bt varieties and Pesticides as cotton bollworm control measure

	Bt variety	Pesticides	Bt variety & Pesticides
Direct Benefit	➢ CBW control	➢ CWB control ➢ Effect on other pests	➢ CWB control ➢ Effect on other pests
Direct Costs	➢ Increased seed costs ➢ Lower lint quality & output price	➢ Cost of pesticides ➢ Labor for application ➢ Human health costs	➢ Increased seed costs ➢ Lower lint quality & price ➢ Cost of pesticides ➢ Labor for application ➢ Human health costs
Other Effects	➢ Prophylactic treatment ➢ Refuge area ➢ Ecosystems effects ➢ Hybrid seed	➢ Need based (threshold) ➢ Ecosystems effects ➢ Hybrid seed ➢ own/saved seed	➢ Prophylactic treatment ➢ Partly need based ➢ Refuge area ➢ Ecosystems effects ➢ Hybrid seed

Source: Own compilation

Each observation can be treated as an event in a random process used to generate a cumulative distribution of outcomes F(x), i.e. the marginal net revenue of alternative bollworm control methods, Bt variety (Bt), chemical pesticides (P) and a combination of the two (BtP). The cumulative distribution functions (CDF) can then be compared by applying the criteria of first- and second-degree stochastic dominance (see Equations 2 and 3).

The criterion for first-degree stochastic dominance (Equation 2) is that all values of x (marginal net revenue) of control method one, (e.g. Bt) dominate those of method two (e.g. Pesticides). In second-degree stochastic dominance (Equation 3) the Bt strategy will be preferable to strategy P if the area under F_{Bt} is less than the area under F_P and F_{BtP} respectively, assuming risk averse behavior of the decision-maker (Hardaker et al 1997).

$$F_{Bt}(x) < F_P(x) \quad (2)$$

$$F_{Bt} = \int f_{Bt}(x)\,dx \leq F_P = \int f_P(x)\,dx \leq F_{BtP} = \int f_{BtP}(x)\,dx \quad (3)$$

[4] Contrary to researcher managed trials

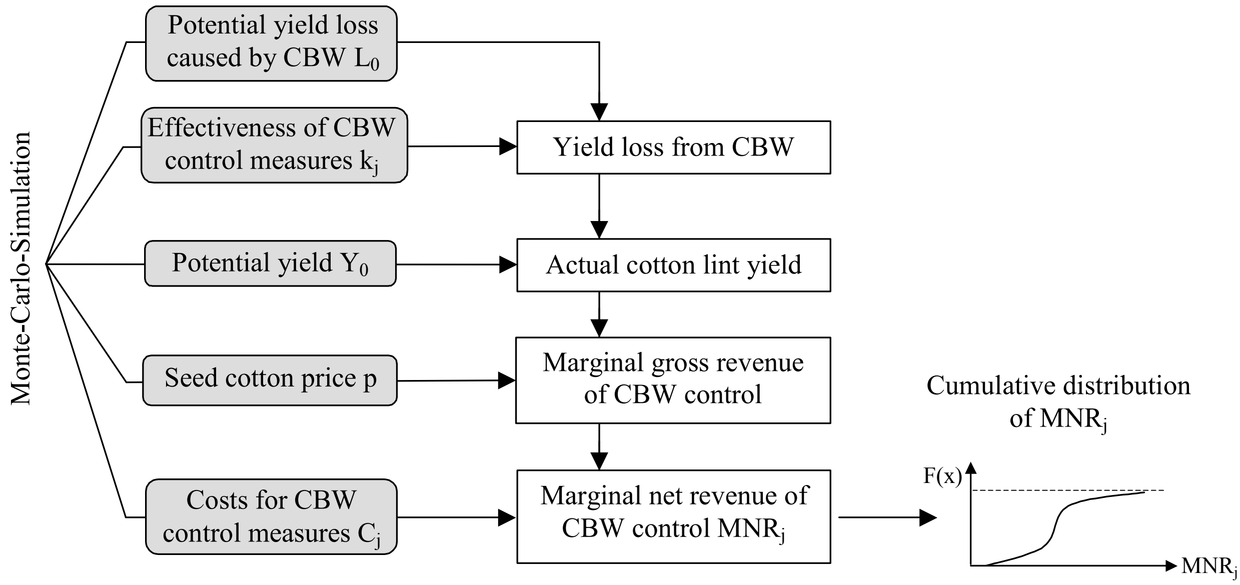


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Figure 2: Structure of the simulation model

Data and Results

The data used in our simulation model are a reflection of the situation of cotton production in South India and are largely drawn from a cross-sectional survey of 100 cotton farmers in the state of Karnataka (Orphal 2003). In addition, information from the literature (e.g. Qaim and Zilberman 2002), the agricultural statistics of India and expert judgments has been used to compile a set of plausible assumptions. In Table 3 the parameters entering the model, their core values and the types of distribution are presented. Reflecting the agro-ecological situation in India a distinction is made between irrigated and non-irrigated cotton production. Also, the observed price difference of seed cotton from Bt and conventional cotton varieties has been taken into account. The assumed maximum yield loss from cotton bollworm (60%) is based on the results of Qaim and Zilberman (2002) since in India in 2001 the bollworm population was especially high. On the other hand it is reported that there are years with very low cotton bollworm pressure (Qayum and Sakkhari 2003). The costs of pesticides are doubled to account for on-farm human health costs associated with pesticide spraying following the findings of Rola and Pingali (1993).
While the model results must be interpreted in the context of the situation in South India they nevertheless can serve as a general assessment model of Bt cotton provided the biological, technical and the price relationships can be linked to a specific agro-ecological and agro-economic situation.

Table 3: Assumptions for stochastic parameters in the model

Parameter	Unit	Probability distribution			
		Type*	Min	Mode	Max
Potential yield Y_0					
irrigated system	[kg ha^{-1}]	▲	1000	2500	3500
non-irrigated system	[kg ha^{-1}]	▲	350	1200	2000
Potential CBW caused yield loss L_0	[%]	▲	10	30	60
CBW control effectiveness of					
Bt varieties	[%]	▬	60	–	90
Chemical pesticides	[%]	▬	40	–	90
Price for seed cotton output					
Bt varieties (lower quality)	[US$ kg^{-1}]	▲	0.38	0.43	0.47
Non-Bt varieties	[US$ kg^{-1}]	▲	0.38	0.49	0.61
Seed premium for Bt varieties	[US$ ha^{-1}]			25	
Pesticide costs (per application)					
Price pesticide	[US$ ha^{-1}]	▲	5	10	15
Labor costs	[US$ ha^{-1}]	▲	2	3	4
Human health costs	[US$ ha^{-1}]	= Pesticide costs (1:1)			

* Triangles and rectangles indicate an underlying triangular or rectangular distribution, respectively.
Source: Own assumptions based on 2002 field study results

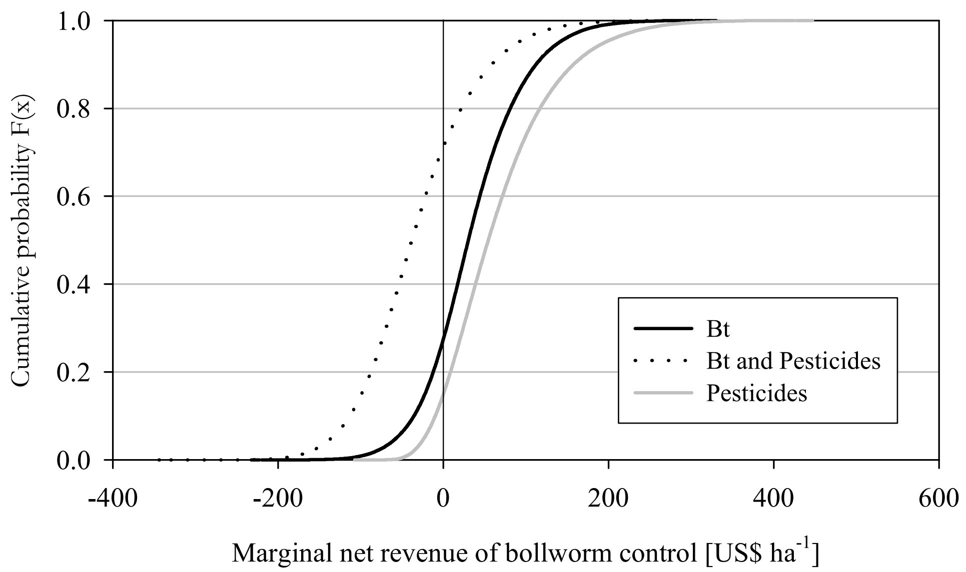
In the following, results of three scenarios are presented. These include the conditions for cotton production under non-irrigated and irrigated conditions under the assumption of different and equal price levels for seed cotton of Bt and non-Bt varieties.

Figure 3 shows the CDFs for the three different bollworm control options, Bt, pesticides and their combination under non-irrigated production conditions. Applying the criteria of first-degree stochastic dominance the prophylactic use of pesticides to control cotton bollworm clearly dominates the use of Bt varieties as well as the use of a combination of both control tools. Furthermore, in the non-irrigated system there is a 30% probability that the marginal net revenue of Bt control becomes negative while there is a chance of about 15% that marginal net revenue of the pesticide strategy is negative. A factor that contributes to these results is the low and highly variable potential yield under non-irrigated conditions. This increases the chance of an economic loss below the break-even point, i.e. the economic threshold for control is not reached in many cases. Considering that costs of prophylactic control measures are fixed like it is the case for the use of Bt varieties and for prophylactic pesticide applications, negative net revenues occur. This indicates that the net revenues of control could be increased by a need-based application of pesticides. Since the additional costs of Bt seeds under farmer conditions in India exceed those of pesticides and in addition seed cotton prices of Bt varieties are lower (due to lower quality of lint) than prices for conventional seed cotton, the use of Bt varieties is economically unattractive. Hence, under non-irrigated conditions there would be no economic reason for farmers to adopt Bt cotton under the given assumptions. These results confirm initial observations from field studies in India (Orphal 2003).

In an irrigated production system (Figure 4) the relative attractiveness of control methods show the same pattern of results. However, the mode of the marginal net revenues of all three control options is clearly positive, ranging between US$ 54 and US$ 132 per ha at the probability level F(x) = 0.50. The probability that control costs exceed their revenues, i.e. bollworm populations are below the economic thresholds exists for Bt, F(x) = 0.08, and the combined control option, F(x) = 0.22, while the pesticide option is always economical. The main factor that generates this result is the lower seed cotton price for output from Bt varieties.

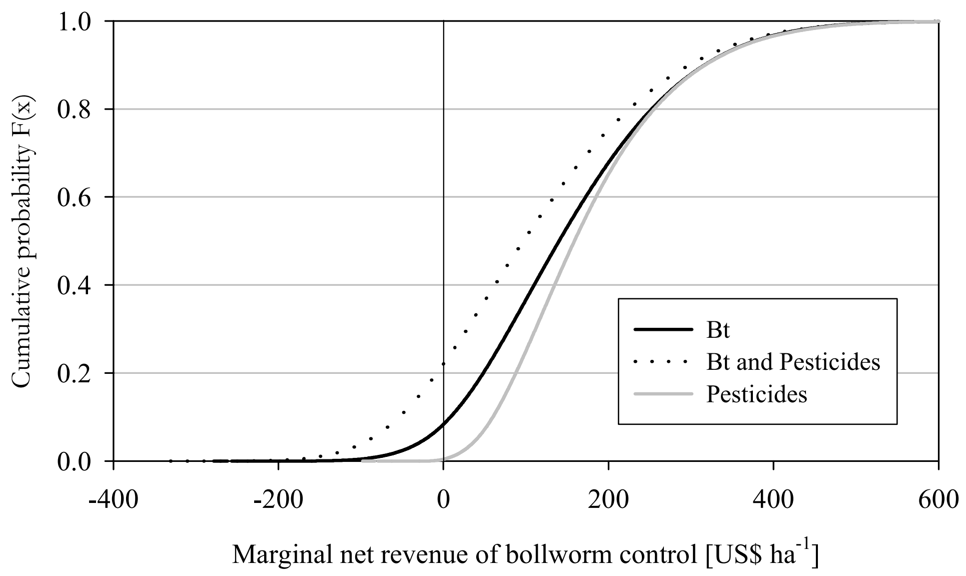
Recalculating the results under the assumption of identical output prices for Bt and non-Bt varieties (Figure 5) leads to stochastic dominance of the Bt strategy over pesticides. On the other hand all strategies show a clearly positive modal value of the marginal net revenues with a difference between the Bt and the pesticide strategy of around 44%.

Currently, no long-staple Bt varieties have commercial approval in South India but it seems likely that this will happen within the next few years, hence rendering the price difference nil.



Source: Own modeling results

Figure 3: CDFs of MNR for three bollworm control methods under non-irrigated production (with price difference and pesticide health costs)



Source: Own modeling results

Figure 4: CDFs of MNR for three bollworm control methods under non-irrigated production (with price difference and pesticide health costs)

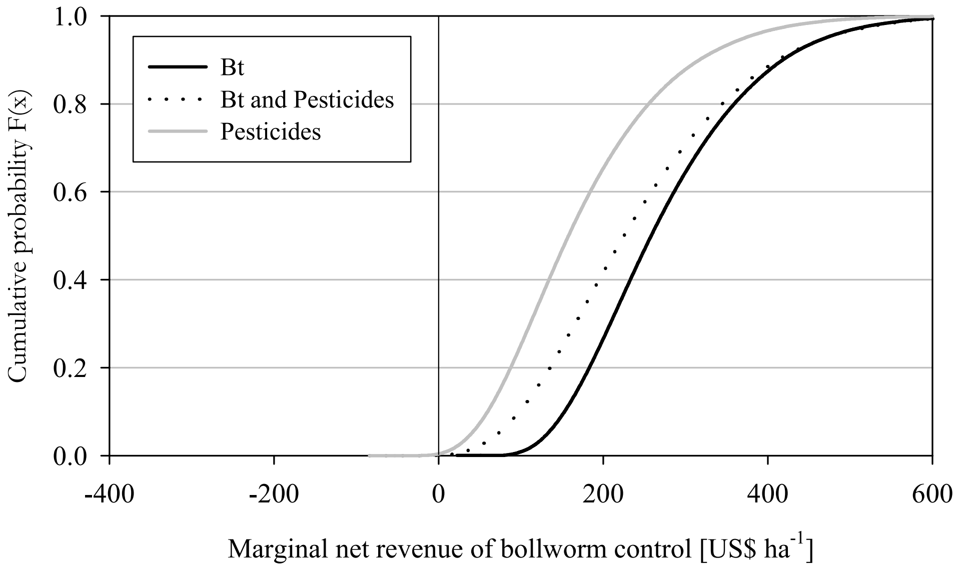
Concluding from the situation in China regulatory control of the Bt cotton seed market may then no longer be effective possibly leading to a decline in seed quality. This will have repercussion for the control effectiveness of Bt cotton (Pemsl et al 2003).

Conclusions

When reviewing the available economic studies on Bt cotton it becomes clear that care needs to be taken when interpreting results from initial studies based on data from only one or few years. Bt cotton is not a new green revolution variety but just another option of bollworm control. Its economics is determined by the severity of pressure of lepidopteran insects. The latter depends on the environmental conditions and the prior human interferences in the cropping system. For example, indiscriminant use of pesticides over a long time period reduces the potential for natural control through beneficial insects.

Hence, in addition to the simple comparison of Bt and non-Bt varieties on the basis of crop budgets or farm income, a partial budgeting approach that incorporates the main parameters can provide further insights for the economics of Bt control. Such an approach has been used widely in the economics of pest control and it can be applied to the case of Bt cotton as well.

The strength of such a methodology is that it easily allows incorporating uncertainty in the main parameters by applying stochastic simulation. Such methodology provides a universal framework for assessing Bt crops by specifying the conditions of the respective agro-ecosystem.



Source: Own modeling results

Figure 5: CDFs of MNR for three bollworm control methods under irrigated production, (no difference in seed cotton price and pesticide health costs.

In the case presented here, we refer to the situation pertaining in South India. The results generated by the model on the basis of data from farmer surveys in one state, data from the literature and expert assessments suggest that the high expectations that were raised with Bt cotton, perhaps cannot be met.

The first reason for a less optimistic judgment of the prospects of Bt cotton under the Indian conditions is that of a low and highly variable cotton yield under the prevailing non-irrigated conditions. This makes prophylactic pest control by external inputs only justifiable if bollworm infestation exceeds the economic threshold level. This is often not the case, so farmers who invest a substantial amount of cash in buying expensive seeds and betting on high bollworm infestation risk loosing that money in case the situation turns out to be otherwise. In addition this decision can cause further costs. If non-bollworm pests (e.g. aphids, white fly) for which Bt does not provide any protection, occur later in the season, small scale farmers may then lack the funds to buy pesticides which they might need for well targeted interventions.

The second reason for a possible lower than expected performance of Bt cotton is the observation that the currently available Bt variety in South India are of poorer quality as compared to the traditional varieties resulting in a lower seed cotton price. As shown by the simulation results the output price greatly affects the economics of bollworm control by lowering the economic threshold.

Following on from the previous argument it can be expected that as the Bt technology becomes more popular domestic breeding efforts will be augmented possibly turning out Bt varieties that are of better quality. However, the consequences of a rapid build-up of a domestic seed industry can be observed from China. Here, meanwhile the seed market has become atomistic but the result is that seed quality has suffered and quality control has become a problem. It is not unlikely that similar developments will take place in India. If there is no quality assurance for Bt crops the situation will most likely correspond to pesticide markets in many developing countries, i.e. non-compliance with standards and product adulteration.

Looking at the results of our model calculations and looking at the properties of the Bt technology, it is quite surprising why there is so much excitement about Bt crops as regards their prospects to solve the food insecurity problem in developing countries. While Bt can certainly be an effective tool for the control of bollworm pests its true impact is limited to just that. Furthermore, the question should be asked why there is not more discussion on how to effectively incorporate Bt crops into the concept of Integrated Pest Management (IPM). Looking at it from a pest management point of view Bt varieties as a single technology take us back to the time of expensive prophylactic treatments, no longer by broad-spectrum pesticides like twenty years ago, but by putting a specific pesticide “inside the plant”. To conclude that Bt crops are an “easy technology” because all they demand is that farmers “do not forget to plant the seeds” could be a big mistake. It is naive to assume that a good technology alone means a good solution of the problem when in fact the real problem is to find institutions that channel technology in the right direction.

In addition, Bt is a damage abatement input and therefore the principles of allocation efficiency need to be applied like with any other input. By the same token, the agro-ecological and the agro-economic conditions in which Bt crops are likely to produce economic benefits need to be identified before making any conclusions on aggregated benefits (Qaim 2003, Huang et al 2003)

Furthermore, pest susceptibility to Bt toxins is a natural resource, which requires taking into account user costs and externalities. User costs or resource rent refer to the intertemporal opportunity costs of resource depletion. The resource “Bt” could be depleted because of resistance (Wu et al 2003). Externalities can occur due to negative side effects on beneficial insects. Such effects need to be costed in future studies in order to realistically conclude about the true net benefits of Bt cotton.

The model presented in this paper could be extended to better capture the biological realities i.e. through bio-economic simulation.

Lastly, the model could be used in a participatory manner, e.g. through an internet-based electronic conference the underlying assumptions could be specified from cotton experts from around the world. The model could be run and feedback provided to the cotton experts and results could be discussed perhaps leading to a more realistic assessment of benefits prior to release of Bt varieties. At the same time the model could be extended by incorporating suggestions of experts during the course of this process.

In conclusion, our example has shown that there is scope for economic and ecological expertise to work together more intensely and more effectively. This will lead to better advice especially for developing countries in adopting biotechnology solutions and could take some of the steam out of the sometimes-overheated debate on the prospects of GM crops in agriculture.

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