Journal of
Agrarian Change

Journal of Agrarian Change, Vol. 10 No. 4, October 2010, pp. 482–509.

Is *Bt* Cotton a Pro-Poor Technology? A Review and Critique of the Empirical Record

DOMINIC GLOVER

Policy makers, journalists and other commentators have hailed genetically modified (GM) crops as a 'pro-poor' success in the developing world. Their confidence appears to be justified by the encouraging conclusions reached by academic studies on the performance and impacts of GM crops, which seem to provide convincing evidence of substantial benefits for smallholders in developing countries. However, a detailed, critical examination of studies on transgenic, insect-resistant cotton in China, India and South Africa demonstrates that the technology's impacts have been evaluated and represented in selective and misleading ways. The performance and impacts of GM crops have in fact been highly variable, socio-economically differentiated and contingent on a range of agronomic, socio-economic and institutional factors. The shortcomings of the GM crop-impacts literature have done a disservice to public and policy debates about GM crops in international development and impeded the development of sound, evidence-based policy.

Keywords: China, India, South Africa, *Bt* cotton, GM crops

INTRODUCTION

Genetically modified (GM, transgenic) crops have been hailed as a 'pro-poor' success in the developing world (e.g. Brookes and Barfoot 2006; Gómez-Barbero and Rodríguez-Cerezo 2006; James 2008). Evidently, such claims have persuaded many commentators, policy makers and politicians that there is a good news story to be told about the impacts of transgenic crops in developing countries, which may help to convince reluctant consumers and anti-GM campaigners to embrace the technology. For instance, British politician and GM-enthusiast Dick Taverne has complained that '[t]he public in Britain and Europe seems unaware of the astonishing success of GM crops in the rest of the world' (Taverne 2007, 24). During 2008 and 2009, numerous signals have indicated that GM crop advocates, policy makers and politicians in the UK are attempting to reignite the public debate about agricultural

Dominic Glover, Technology and Agrarian Development Group, Wageningen University, PO Box 8130, 6700 EW Wageningen, The Netherlands. E-mail: dominic.glover@wur.nl

The work on which this paper was based was funded by the CERES–Wageningen Research School and was supported by the ESRC STEPS Centre, Brighton, UK. I am grateful to Aarti Gupta, Christina Holmes, Kees Jansen, Melissa Leach, Les Levidow, Erik Millstone, Peter Newell, Ian Scoones, two anonymous reviewers and the journal editors.

biotechnology in the developed world, in the clear expectation that evidence of the benefits of GM agriculture in developing countries will lead to a warmer public appreciation of transgenic crop technology than in the past (*The Guardian* 2007, 2008; *The Telegraph* 2008).

Scholars who have examined the empirical record, however, are more circumspect about the benefits of GM crops in smallholder farming contexts in developing countries. The performance and impacts of transgenic crops have varied widely in developing-country contexts, across farms and farmers, crop varieties, regions and seasons. Some farmers have clearly benefited, but others have not. The performance and impacts of GM crops depend crucially on a diverse range of factors, especially the performance and local adaptation of the background variety into which the new genetic traits have been introduced, together with a range of agronomic, socio-economic, political and institutional factors (Raney 2006; Smale et al. 2006a, 2006b; Smale et al. 2009; Tripp 2009a). Accordingly, some scholars have warned that biotechnology is likely to make only a limited contribution to agricultural development in the absence of fundamental policy and institutional change (IAASTD 2008; Scoones 2009; Tripp 2009a).

In the light of these findings, some say, 'the initial enthusiasm for the technology has been superseded by a more cautious weighing of economic advantages and disadvantages by crop and trait' (Smale et al. 2006b, 62–3). Nevertheless, many commentators and protagonists in the debate appear reluctant to let go of the powerful illusion of GM crops as a silver bullet against hunger and poverty. For instance, in April 2008, British newspaper columnist Dominic Lawson berated the authors of the IAASTD report for 'pandering to superstition' and indulging in 'anti-scientific hysteria' because they failed to endorse a technology from which 'Africa could benefit most' (Lawson 2008a).

It is hardly surprising that policy makers, politicians and journalists think they are on solid ground when they make such pronouncements, because serious academics have continued to strongly endorse GM technology as a necessary feature – not merely a useful, helpful or alternative one – of an equally necessary transformation of agriculture that will sweep aside the livelihoods of millions of peasants and supposedly release them to do something else for a living (e.g. Collier 2008). Cornell University academic Ron Herring has asserted that the 'narrative' of GM crops as a 'pro-poor' technology has attained the status of 'an optimistic but cautious consensus' among development professionals (Herring 2007, 7).

Against the background of assertions like these from respected scholars, it is hardly surprising that many policy makers, journalists and others engaged in the public debate believe that there is now a body of convincing empirical evidence to show that GM technology is good for the poor. Columnists like Dominic Lawson, for instance, have pointed to reports issued by responsible bodies like the European Commission, which have stated that 'analyses show that adoption of dominant GM crops and on-farm economic gains have benefited both small and large farmers . . . Moreover, detailed analyses show that increases in gross margin are comparatively larger for small and lower-income farmers than for larger and higher income farmers' (Gómez-Barbero and Rodríguez-Cerezo 2006, 35; see Lawson 2008b). In this article, I will show that such confident assertions are unwarranted and misleading, not because the claims themselves are strictly inaccurate, but because they represent a selective, incomplete and premature picture of the impacts of GM crop technology in real situations.

This paper presents a detailed, critical re-examination of the evidence base underlying the claim that GM crops have produced a range of benefits for poor farmers in the developing world. It focuses on the peer-reviewed academic studies that have sought to evaluate the productivity and socio-economic impacts of transgenic, insect-resistant cotton among smallholder farmers in China, India and South Africa. Based on a thorough search of the literature, the sample included all of the significant empirical studies and analyses I was able to find that were based on field-level data collected from farmers growing *Bt* cotton under ordinary conditions (i.e. not field trials) and published in peer-reviewed international journals. Studies that did not meet those criteria were excluded. In particular, the selection criteria required the exclusion of various critical reports and studies that have been published by national and international non-governmental organizations (NGOs) (e.g. FOEI 2007; Mayer 2002; Pschorn-Strauss 2005; Qayum and Sakkhari 2005). Such documents have provided valuable alternative perspectives, additional evidence and thoughtful arguments that shed useful new light on the track-record of *Bt* cotton in the developing world, but unfortunately they do not command universal respect because they are regarded as partisan and have not been formally peer-reviewed. This paper concentrates on those studies that are likely to be accepted without question as serious and credible by most professional researchers. The study therefore encompasses 46 studies across the three focus countries. The sample compares with those reviewed by other researchers (Smale et al. 2006a, 2006b; Tripp 2009a). Additional peer-reviewed literature, such as other scholars' reviews of the empirical record and other academic commentaries and analyses, are also cited in this paper wherever they appear to shed useful light or aid interpretation of *Bt* cotton's track record in India, China and South Africa.

I will argue that both methodological weaknesses and presentational flaws in the *Bt* cotton impact studies have produced a misleading picture of both the performance and the impacts of GM crops in smallholder farming contexts, and that this has seriously distorted public debate and impeded the development of sound, evidence-based policy. This article thus addresses the mutual responsibilities of parties on both sides of the research–policy interface. Academic scholars have a responsibility to explain clearly the implications of their research, acknowledging its limitations and avoiding any exaggeration of the conclusions and inferences that may be drawn from it. Journalists, policy makers and politicians, for their part, have an obligation to evaluate claims that are derived from research with considerable care and to pay due attention to the quality and weight of the evidence on which it is based.

The only GM crop that has been commercialized widely in the developing world is transgenic, insect-resistant cotton, known as '*Bt* cotton', which contains a gene taken from the soil bacterium *Bacillus thuringiensis*. Cotton plants modified with the '*Bt* gene' express an insecticidal protein that confers a degree of protection against a group of insect pests, primarily Lepidoptera, which are conventionally known as bollworms or 'the bollworm complex' (see FAO 2004, 44; University of Tennessee n.d.).

It is important to observe at the outset that *Bt* cotton has had some beneficial impacts in the developing world, as reflected for instance in productivity improvements on the macro scale. However, this study focuses on developmental impacts among poor smallholder farmers. As I will show in the sections that follow, the benefits for such groups are neither as simple, as uniform, as context-independent nor as sizeable as they have frequently been depicted to be.

Bt COTTON IN CHINA

Bt cotton was commercialized in China in 1997. The area under *Bt* cotton expanded rapidly, reaching about 3.7 million hectares in 2004. In 2005 the area fell back a little, before rising again to about 3.8 million hectares in 2007, equivalent to 69 per cent of the total cotton area in China that year (Tripp 2009b). In the northern, Yellow River cotton zone, *Bt* varieties are reported to account for nearly 100 per cent of the cotton area. The crop is said to be grown by about 7.1 million small-scale farmers in China (James 2007; Keeley 2006).

Yields and Profitability

According to an early study, *Bt* cotton farmers in China were spending between 20 and 33 per cent less on cotton cultivation than non-adopters (Pray and Huang 2003; Pray et al. 2001). They also received a very slightly higher price for their cottonseed, so that they made a small profit per kilogram of seed sold. Non-adopters suffered losses. On a cursory reading, the conclusion was obvious: farmers benefited from adopting *Bt* cotton; indeed, it appeared that *Bt* cotton rescued cotton cultivation from being a financially loss-making enterprise.

On closer examination, the case appears not to be so simple. The data presented by Pray et al. (2001) and Pray and Huang (2003) showed that, in a season with low pest pressure, yields had actually been broadly similar for *Bt* and non-*Bt* varieties, especially when controlling for farmer skill and location. In fact, the best-yielding variety was a newly released non-*Bt* variety that was regarded by government scientists as susceptible to bollworms. Clearly, the 1999 season was not one in which the benefits of insect-resistance would have been expected to make themselves felt. On top of that, *Bt* cottonseed was significantly more expensive than most non-*Bt* varieties, except for bollworm-resistant conventional varieties which, for some reason, cost 75 to 167 per cent more than the *Bt* varieties. And yet Pray, Huang and colleagues appeared to have identified a substantial financial benefit to cultivating *Bt* cotton. If the *Bt* varieties did not offer a yield advantage over bollworm-susceptible ones when pest pressure was low, where did the economic advantage come from?

According to the Pray–Huang group's calculations, the cost advantage of bollworm-susceptible, non-*Bt* seed was more than wiped out by the additional costs for pesticides and the labour required for spraying them. They found that *Bt* farmers spent between 9,100 and 10,700 yuan per hectare (RMB/ha), depending on the variety grown, whereas non-*Bt* farmers spent at least 11,270 and up to 14,200 RMB/ha. According to these figures, it could be anywhere from 570 to 5,100 RMB/ha at the extremes, or about 2,000–3,500 RMB/ha, more expensive to cultivate non-*Bt* varieties than *Bt* varieties, despite the cheaper price of non-*Bt* (bollworm-susceptible) seed (Pray and Huang 2003; Pray et al. 2001).

At first glance, these calculations seem reasonable and the results in line with the expectation that the high price of *Bt* cottonseed would be offset by savings in expenditure on pesticide applications. However, Pray and colleagues' results need to be interpreted with care. In particular, it is important not to lose sight of the distinction between economic and financial measurements. Not all of the costs incurred by farmers took the form of financial outlays. Unfortunately, that distinction was not always clear in the way that the Pray–Huang group interpreted and presented their findings. This can be seen in their treatment of labour inputs. For instance, when enumerating the various inputs cotton farmers had to provide and their respective costs, Pray et al. (2001) listed the cost of labour amid various other purchased inputs, including seeds, irrigation, fertilizers, plant growth regulators, plastic and agricultural taxes. Summarizing their labour cost estimates, they wrote that '[t]he *cost of labor increased* [for non-adopters] between 1,500 and 2,400 RMB/ha' (Pray et al. 2001, 818; emphasis added). They then calculated the farmers' net income by subtracting the costs of production, including labour, from the price received per kilogram of cottonseed, concluding that 'the *Bt* varieties clearly are more profitable than the non-*Bt* variety. The net income from growing non-*Bt* varieties were negative, while the net income from all of the *Bt* varieties were positive' (Pray et al. 2001, 819). Those particular ways of describing the income advantages of transgenic cotton implied that the *Bt*-adopters were in fact *financially* better off than non-adopters – indeed, that they had turned a profit while non-adopters had made losses. A closer reading indicates that that may not have been the case, as I will explain below.

It is important to state clearly that, if indeed there is a labour saving associated with *Bt*-cotton technology, it would represent an important benefit for smallholder farming households. Although it would manifest itself primarily as a saving of time and energy, it is nevertheless important to estimate its economic value, which is an opportunity cost. Thus, Pray and colleagues took the farmers' labour inputs into account by monetizing them, using the local farm labour wage as an index. Alongside their income calculations, they also calculated the returns to labour – which showed, indeed, that the *Bt* varieties had an advantage over non-*Bt* varieties on that measure.

There are, however, two key difficulties with Pray and colleagues' approach, both of which point to the problems involved in focusing on broad averages at the expense of paying insufficient attention to wide variations in factor endowments and outcomes for different kinds of farmers. The first issue is that most of the labour used in the region is not paid labour but family labour (Pray and Huang 2003; Pray et al. 2001). Consequently, a labour saving cannot necessarily be equated directly with a monetary gain. The farming families concerned are unlikely to have had the financial resources to substitute their own labour with paid labour. Nor can one assume that, had they benefited from labour savings through cultivating *Bt* cotton, they would necessarily have been in a position to sell their own labour to others for financial gain.

Second, and relatedly, applying a standardized labour wage for all farmers risks suppressing the variation that exists in farm household characteristics and outcomes.[1] Farm households differ in their relative labour endowments and their

[1] I am grateful to an anonymous reviewer for encouraging me to develop this point.

capacity to engage in different kinds of income-generation. Thus, the opportunity costs associated with labour use are not the same for all households. Therefore, the Pray–Huang team's approach made it difficult to understand how much, and why, *Bt* cotton's impacts differed from one farming family to the next.

Of course, it would be difficult to take every nuance into account in every survey. Nevertheless, that caveat should merely reinforce the need to interpret with great care Pray and colleagues' overall finding of a substantial economic advantage to cultivating *Bt* cotton. In financial terms, the outcomes of cotton cultivation were rather similar for *Bt*-adopters and non-adopters in a season with low pest pressure. Non-*Bt* farmers actually realized, on average, a small financial profit per kilogram of seed cotton, despite the net loss of income highlighted in the authors' analysis of their findings (see Pray and Huang 2003, table 12.5). Thus, it would be reasonable to conclude that not adopting *Bt* technology might be a fully rational choice for those farm families that were poorly endowed with financial capital but had adequate labour to invest. That could well be the case if, for example, the price premium attached to *Bt* seed made the technology unaffordable, especially if it is correctly understood as a form of insurance against risk. (I will return to the issue of risk below.) Unfortunately, we know very little about the reasons why some Chinese farmers adopted *Bt* cotton and others did not in those early years following commercialization. It may well be, however, that the two categories represent two different types or classes of farmers making rational decisions in contrasting circumstances. I will develop this point further in the discussion on *Bt* cotton's impacts in India.

In the analysis by Pray and colleagues (Pray and Huang 2003; Pray et al. 2001), the imputed monetary figure, representing the additional labour expended by non-*Bt* farmers or saved by *Bt* farmers, created the impression that *Bt* cotton had significantly out-performed non-*Bt* cotton during the season in question. That being the case, one is left with the nagging question why, in a season when low pest pressure prevented *Bt* cotton from demonstrating its possible technical advantage, so many cotton farmers were still spending significant sums of money and a good deal of time on pesticide spraying. The next section turns to that question.

Reducing Pesticide Use and Poisonings

Pray et al. (2001) claimed to show that the adoption of *Bt* cotton by Chinese smallholders had led to a reduction in pesticide use and a consequent reduction in incidents of pesticide poisoning among farmers. Other papers by the same group of authors have affirmed the same finding (Hossain et al. 2004; Huang et al. 2002, 2003; Pray and Huang 2003; Pray et al. 2002). The confident conclusion that '*Bt* cotton . . . reduces chemical use' (Pray et al. 2001, 822) has been widely cited ever since.

Although Pray, Huang and colleagues have indeed shown a substantial reduction in pesticide use by Chinese *Bt*-cotton farmers, they have not established a convincing causal relationship between the adoption of *Bt* cotton and the fall in pesticide consumption. The most they have shown is a correlation between the two phenomena. Yet the precise mechanism of causation should be of great interest to agronomists and policy makers. Excessive use of pesticides by both cotton and rice farmers in China is widely recognized as a serious environmental, human health and economic problem (Huang et al. 2003; Widawsky et al. 1998). Farmers' use of pesticides is very often not guided by careful evaluation of pest pressure or detailed cost–benefit analysis (Huang et al. 2002). These observations ought to raise questions about whether the adoption of a new pest-control technology, even if it is effective in technical terms, will necessarily lead to a fall in pesticide consumption in line with the observable reduction in the risk to crops.

Unfortunately, Huang et al. made precisely that assumption in their model, because they relied on an *ex post* assessment by the farmers in their sample about 'the per cent of the crop that the farmer believed would have been lost if he had not sprayed' (Huang et al. 2002, 378). Yet, it is at least strongly plausible that the more judicious and safer use of pesticides may be attributable in large part to the manner in which the new *Bt* seeds were promoted to farmers, rather than to the performance of the technology itself. That implies that similar benefits might be attained independently of *Bt*-cotton adoption. For example, if *Bt*-cotton varieties were introduced to farmers as new varieties that 'do not require spraying' or are 'immune to pests', it would not be surprising if farmers adopting the technology reduced the amount of spraying they undertook. Similarly, the promotion of *Bt* cotton may involve sensitizing farmers to the dangers of excessive and unsafe pesticide use. Farmers exposed to such messages might change their behaviour in response to the message itself, rather than because they had observed the superior insect resistance of the new varieties. Disentangling the different potential causes of changes in farmers' behaviour should therefore be a central concern.

Work by other researchers has shown that these are not simply mischievous speculations. Fundamental questions have been raised about the Pray–Huang group's conclusions, with regard to both the finding of reduced pesticide use and the attribution of such an effect to the adoption of *Bt*-cotton technology *per se*. For instance, Pemsl et al. (2005) have shown that many Chinese smallholders have continued to spray very high levels of pesticides, including some very hazardous chemicals, despite having adopted *Bt* cotton. Two studies by Yang and colleagues (Yang et al. 2005a, 2005b) showed that Chinese *Bt*-cotton farmers significantly overestimated the damage caused by cotton bollworms and sprayed too much pesticide as a result. Yang et al. (2005b) found that training in integrated pest management (IPM) methods was associated with a much bigger reduction in pesticide use than the adoption of *Bt* technology by itself. Indeed, they found that IPM training had a bigger impact than *Bt* cotton on the population dynamics of pests and their natural enemies. Very similar conclusions were reached in a similar study by Lifeng et al. (2007).

Huang et al.'s (2002) own research indicates that both *Bt*-adopters and non-adopters applied pesticides far above the optimal level, even though *Bt* farmers applied much less than non-*Bt* farmers. When evaluating pesticides as a damage-abatement technology rather than a production-enhancing one, they concluded that 'one assessment of the results is that farmers are using so much pesticide that even when they adopt *Bt* cotton their marginal effect is near zero' (Huang et al. 2002, 382). In their concluding remarks, Huang and colleagues acknowledged that levels of pesticide use might be socially, culturally and institutionally shaped:

> Although a discussion of why farmers overuse pesticides is beyond the scope of the present paper, it is clear that such behaviour is systematic and even

> exists when farmers use *Bt*-cotton varieties. One thought is that farmers might be acting on poor information given to them by the pest control station personnel. In fact, such a hypothesis would be consistent with the findings of work on China's reform-era extension system in general. (Huang et al. 2002, 384–5; citation deleted)

The role played by information, its reliability and its effects on perception and behaviour would indeed seem to be a vital area for further investigation. In a context where pesticide use is known to be economically and environmentally non-optimal, it would not make sense to assume that the technical effectiveness of *Bt*-cotton technology would have a direct, linear impact on farmer's pesticide decision-making. Another paper by Huang et al. (2003) showed that farmers' decisions to spray were not influenced by pesticide prices, which further undermines any suggestion that farmers were making careful cost–benefit calculations when deciding whether to apply pesticides. However, that finding conflicts with a key assumption made by Huang et al. (2002) in their earlier paper, where they posited that pesticide use would depend on the profitability of its use. In short, Huang, Pray and colleagues' confident assertions that *Bt* cotton 'caused' or even 'enabled' a reduction in pesticide use are not supported by the available evidence. It should be elementary that a mere correlation does not provide firm evidence of causation.

This criticism is important because, though the observed reduction in pesticide use may be real, and even though it may be indirectly associated with the adoption of a particular kind of technology, if it is not driven directly by that adoption itself – that is, by the farmer's observation of the new technology's superior performance – then there is no reason to suppose that further adoption or energetic promotion of the technology will necessarily, or sustainably, replicate that outcome. In short, though Huang, Pray and colleagues have identified changes in pesticide consumption, they cannot account for them. The precise mechanisms driving the changes remain obscure.

In any case, Wang et al. (2008), reinforcing earlier findings by Wu et al. (2002), found that initial reductions in pesticide use had been reversed after a few seasons of *Bt*-cotton cultivation because of a resurgence in the populations of formerly secondary pests (specifically, various non-lepidopteran sucking pests, notably mirids, which are not targeted by the *Bt* toxin). In other words, according to a body of evidence, the adoption of *Bt* cotton may be neither necessary nor sufficient to produce substantial reductions in pesticide use, especially over the medium and long term.

Bt COTTON IN INDIA

Bt cotton was officially commercialized in India in March 2002, although unapproved *Bt* varieties are known to have been grown in the state of Gujarat and parts of Maharashtra, Madhya Pradesh, Andhra Pradesh and Karnataka for an uncertain period of several years prior to that date (Scoones 2005). After a difficult start (Glover 2007; Scoones 2005), *Bt* cotton spread to about 6.2–6.4 million hectares by 2007, equivalent to 73 per cent of the total cotton area that year, when the crop was reported to be grown by about 3.8 million small-scale farmers (James 2007; Tripp 2009b).

Productivity, Profitability, Variability

Early studies of the performance of *Bt* cotton in India reported very large benefits for farmers (Qaim 2003; Qaim and Zilberman 2003), but the value of these studies was compromised by the fact that they were based on field-trial data (Arunachalam and Bala Ravi 2003; Sahai 2003). One study in particular, published in the prestigious international journal *Science* (Qaim and Zilberman 2003), provoked a storm of criticism in India, where questions were raised about the validity of the results, the rigour of *Science*'s peer-review process and the ethics of the article's publication (Sahai 2003; Scoones 2005; Shantharam et al. 2008).

The largest group of publications on the impact of commercial *Bt*-cotton cultivation in India has been produced by a group of academics from Reading University in the UK. The group's first set of papers presented the findings of research on the 2002 and 2003 growing seasons in Maharashtra (Bennett et al. 2004a, 2006b; Kambhampati et al. 2006; Morse et al. 2005b). In their first paper, Bennett et al. (2004a) found that the costs of cultivating both *Bt* and non-*Bt* cotton during 2002 were very similar, but that *Bt* cotton produced a significant yield advantage and an overall boost to farm productivity. The higher costs of *Bt* seed were offset by savings in pesticide use and an improved yield.

One has to read the paper carefully to notice the observation, which is mentioned almost in passing, that the area chosen for the study had the benefit of irrigation and 'good growing conditions', which enabled higher-than-average production for all types of cotton (Bennett et al. 2004a, 99). However, as the authors noted, 'Most of the cotton in India is grown in rainfed conditions, and about a third is grown under irrigation' (Bennett et al. 2004a, 96). The dataset therefore apparently had a significant placement bias. Hence, despite Bennett and colleagues' conclusion that '*Bt* cotton has had a significant positive impact on yields and on the economic performance of cotton growers in Maharashtra' (Bennett et al. 2004a, 99–100), the results clearly could not be generalized to farmers who lacked the benefits of irrigation and favourable growing conditions.

The finding of a productivity advantage should also have been qualified by the observation that any yield advantage of *Bt* cotton should be expected only in seasons where bollworm pest pressure is significant, since *Bt* is not an intrinsically yield-enhancing technology. Similarly, Bennett et al.'s (2004a) conclusion that *Bt*-cotton adoption led to reductions in pesticide use also needs to be treated with caution, for the reasons discussed in the previous section: observed reductions in pesticide use by *Bt*-cotton adopters in India cannot be convincingly attributed to the performance of *Bt* technology without knowing something about farmers' decision-making processes, as well as the levels of pest pressure in particular seasons. Unfortunately, Bennett et al. (2004a) did not present any such data.

However, they implicitly acknowledged the cognitive and social factors that shaped farmers' decision making on pesticides. Data showed that farmers had initially sprayed slightly less pesticide against sucking pests on *Bt* cotton than non-*Bt* cotton, but in the second season slightly more. Bennett and colleagues commented: 'It may be that in the first season some farmers did not fully understand the nature of the new technology and reduced sucking pest spray input, believing that the *Bt* variety needed less of such sprays. Bad experiences in 2002 may have led to an upsurge in spraying against these pests by *Bt* adopters in 2003' (Bennett et al. 2004a, 97). That explanation is indeed plausible. The possibility that cotton farmers' spraying behaviour may have been based not on careful observation of pest pressure but shaped by *a priori* assumptions about the expected pest-resistant attributes of *Bt* cotton, which may have been based on misinformation or confusion, points to the error involved in assuming that changes in farmers' use of pesticides can be attributed directly to the performance of a particular kind of new seed.

The Reading group's Maharashtra 2002–03 dataset was also presented in three other articles (Bennett et al. 2006a; Kambhampati et al. 2006; Morse et al. 2005b). In these papers, it becomes apparent that there was in fact a very large degree of variation in the experiences of farmers in the sample. In their 2004 paper, the authors had claimed that 'As sample sizes were large, the standard errors were small and would not be seen as bars on [our] graphs' (Bennett et al. 2004a, 97). In later papers based on the same dataset, however, Morse et al. (2005b) and Bennett et al. (2006a)[2] reported standard deviations of considerable size in key statistics. For instance, revenue from *Bt* cotton in 2002 was recorded as 42,948 Indian rupees (Rs.) per hectare, with a standard deviation of Rs. 20,853; the corresponding values for non-*Bt* cotton were Rs. 31,081 and Rs. 49,903, respectively. Cotton farmers' profits ranged from Rs. 25,730 per hectare (non-*Bt* cotton, 2002) to Rs. 50,903 per hectare (*Bt* cotton, 2003), but the standard deviations of these statistics were Rs. 49,708 and Rs. 22,744, respectively (Morse et al. 2005b, table 1). Clearly, these statistics indicate very high levels of variability in the experiences of cotton farmers with both types of cotton. It should be noted, in addition, that the lesser degree of variation seen in the output of *Bt* cotton does not necessarily mean that they were intrinsically more dependable varieties in themselves, since the category 'non-*Bt*' encompassed a wide range of different 'conventional' varieties, which would be expected to exhibit a wide range of performance characteristics. The high degree of variation in *Bt*-cotton productivity in Maharashtra during 2002–03 and 2003–04 was confirmed by Ramasundaram et al. (2007), who identified it as a source of substantial financial risk for resource-poor farmers.

Remarkable degrees of variation could also be seen in farmers' pesticide use. For example, Bennett et al. (2006a) and Kambhampati et al. (2006) presented a breakdown of their data across three different regions of Maharashtra for the year 2002. The figures revealed a complex, confusing picture of farmers' spraying behaviour and a startling degree of variability in their cotton output. Why was *Bt*-cotton output so widely variable in the Vidarbha region, with a standard deviation more than 2.6 times as high as the average? Why was there so much variability in the spraying behaviour of farmers in Marathwada against sucking pests, but much less in Khandesh and Vidarbha? On the other hand, why did farmers in Khandesh and Vidarbha spray such widely varying amounts against bollworms, while the corresponding levels in Marathwada varied comparatively little around the average? The huge variation in these numbers was passed over without comment by the authors, yet it should have raised fundamentally important questions about how *Bt* cotton

[2] Bennett et al. (2006a) presented additional data to earlier papers, as well as a more detailed breakdown of their results by sub-region of Maharashtra.

had fitted into farming systems in Maharashtra and the factors that may have caused widely different outcomes to be observed.

The wide variability in cotton farmers' experiences can also be seen in two papers presenting data on the 2003 growing season in Gujarat (Bennett et al. 2005; Morse et al. 2005a). Although the authors concluded that officially approved Monsanto *Bt*-cotton hybrids had out-performed unauthorized *Bt*-cotton as well as non-*Bt* cotton varieties, the very large standard deviations reported in both papers made it clear that there had been a very large degree of variability in the yield, revenue and gross margin for all cotton types. The variability of cotton output in Gujarat during the 2002–03 season was also found by Roy et al. (2007) in their interviews with farmers.

In other words, the average values that Morse, Bennett and colleagues highlighted in their discussion of their data should be heavily qualified. They mask the much more important fact that cotton farmers' experiences had varied very widely. Indeed, it appears that cotton cultivation of all types may have been a deeply uncertain and hence risky proposition for many, perhaps most, cotton farmers. However, that possibility is difficult to assess, because the authors did not indicate the median or mode values that might have helped the reader to judge whether the averages were in fact representative of any real farmers. Making that judgment is important because, as the next section discusses, the characteristics of different farmers and the contexts in which they farm play vital roles in shaping their capacity to use *Bt*-cotton technology to advantage.

A Different Kind of Farmer?

The Reading group returned to their analysis of the 2002 and 2003 cotton seasons in Maharashtra with a set of papers published in 2007, based on data from the district of Jalgaon (Crost et al. 2007; Morse et al. 2007a, 2007b). Morse et al. (2007a) set out to examine whether *Bt* cotton might exacerbate inequality. Although their paper purported to address the claim that *Bt* cotton could increase inequality between richer farmers able to take advantage of the new technology and poorer ones who could not, the analysis actually concentrated on measurements of equality *among* groups of adopters and non-adopters rather than *between* the groups. Finding that, on some measures, including income from cotton, there was less inequality among the adopting households, the authors asked, 'So what has *resulted in* this greater equality of cotton income among the adopter group of [households] relative to the non-adopters?' (Morse et al. 2007a, 47; emphasis added).

Morse and colleagues were thus making an assumption that patterns of cotton income among *Bt*-adopters had become more equal following – presumptively, because of – their adoption of the new technology. Unfortunately, there is no longitudinal data that could have enabled them to compare measures of inequality among the same group of farmers before and after adopting *Bt* cotton. Instead, Morse et al. (2007a) inferred a causal relationship indirectly. In particular, they searched for possible correlations between measurements of equality in different factors of production, especially between land ownership on one hand and income from cotton on the other. They concluded that the smaller degree of income inequality observed among *Bt*-adopters must be attributable to the greater degree of uniformity they found in gross margins per unit of land for *Bt*-cotton plots. However, the two types of measurements they used cannot be compared directly. One was a measurement of the distribution of income across a sample of farm households of different sizes, while the other was a measure of the input–output performance of cotton on plots of land of the same size. One particular problem with such a comparison is that there may be efficiency effects associated with different sizes of farms or plots. Accordingly, the correlation found by Morse et al. (2007a) should be interpreted with great caution.

More importantly, Morse et al. (2007a) neglected to consider the possibility that the more uniform harvests apparently achieved by the *Bt*-cotton farmers may have been associated at least partly with those farmers' greater access to irrigation, which is evident in their statistics on the farmers' production costs. This apparent difference in access to irrigation is surprising in view of Morse et al.'s assertion that 'Only a few differences in terms of general background features of the farmer and household were discernible between adopters and non-adopters of *Bt* cotton' (2007a, 46). Part of the issue here is the important distinction between 'statistical significance' and everyday significance (Ziliak and McCloskey 2008). Morse and colleagues did not address the statistical significance of the apparent difference in average levels of irrigation used by *Bt*-adopters and non-adopters, but in relation to labour they did find 'some suggestion ($P < 0.1$) that adopters had more full-time and male labor available for agriculture than did the non-adopters' (2007a, 46). In fact, the margin between the average investment of labour by *Bt*-adopters and non-adopters was of considerable magnitude and showed up consistently in relation to both the adopters' *Bt* and non-*Bt* plots and in both seasons studied. The same can be said for the statistics on irrigation (Morse et al. 2007a). One begins to suspect that there actually may have been some rather significant differences – in the everyday sense – between adopters and non-adopters of *Bt* cotton. It seems distinctly possible that, had longitudinal data been available, they might well have shown that there was already greater equality in productivity among farmers having the benefit of greater access to labour and irrigation before *Bt* cotton was commercialized.

A second article by the same set of authors, which was based on the same dataset and published in the same year (Morse et al. 2007b), revealed that the *Bt*-adopters and non-adopters had been rather different from one another, after all. On top of their advantages in terms of labour and irrigation, *Bt*-adopters had much more credit and land than non-adopters, devoted a bigger proportion of their land to cotton, were significantly more likely to be involved in livestock production and earned twice as much income on average from livestock as non-adopters. A higher proportion of non-adopters' household incomes came from farming. Interestingly, however, the non-adopters typically earned more than adopters from similar areas of non-cotton cultivation and overall the average household income of non-adopters was actually higher than that for adopters, albeit within a wider range of variation. It was also clear (as in the previous paper) that *Bt*-adopters showed a preference for a particular hybrid, Bunny, for their non-*Bt* plots. As the authors noted: 'This suggests that the categories of adopter and non-adopter may reflect two quite different types of farmer. Adopters concentrate more on cotton, and have more land and higher incomes from livestock. Non-adopters are generalists in terms of the crops that they grow, and have less land and less of an emphasis on cotton' (Morse et al. 2007b, 494).

Further evidence of important differences between *Bt*-adopters and non-adopters during the 2002–03 and 2003–04 growing seasons in Maharashtra has been supplied by Ramasundaram et al. (2007). They found that the average land-holdings for adopters during those first two seasons of official *Bt*-cotton cultivation were 6.26 hectares and 3.28 hectares, respectively, compared with an average land-holding per capita in rainfed areas of the region of less than one hectare. They also found that *Bt*-adopters were more literate than non-adopters (on Gujarat, cf. Shah 2008).

Having found clear evidence that adopters and non-adopters 'are indeed quite different', Morse et al. concluded that 'while there is a "farmer" effect, the data point conclusively towards there also being a clear economic advantage to growing *Bt* cotton' (2007b, 499). They estimated that the 'farmer effect' accounted for about half of the apparent advantage of growing *Bt* cotton. That general conclusion was confirmed by Crost et al. (2007) in a paper based on the same Jalgaon dataset. However, Crost et al.'s analysis also highlighted the wide variation in pesticide use among farmers, noting that 'at least a portion of the farmers use pesticides in a very inefficient way . . . generally, the efficiency with which farmers use inputs seems to vary widely and is not explained well by their observable characteristics' (Crost et al. 2007, 33).

The discovery of clear differences between farmers adopting *Bt* cotton and those not doing so is a fascinating and important observation. Morse et al.'s (2007b) data suggest rather strongly that the kind of farmers who first adopted *Bt* cotton in Maharashtra were not only wealthier but perhaps also more commercially oriented farmers, for whom farming represented a smaller proportion of their economic activity, who allocated more of their land to cotton and livestock and who were actually less productive in their cultivation of non-cotton crops. Not only did the non-adopters lack the resource advantages of their richer counterparts, it seems distinctly likely that they may have been pursuing a different kind of livelihood strategy, one that was more dependent on agriculture as a whole but less dependent on cotton in particular. That could also help to explain why *Bt*-adopters showed a preference for Bunny on their non-*Bt* plots, whereas non-adopters planted some Bunny but also chose a range of other varieties. It may be that these non-*Bt* types, though they may have been less productive than Bunny or the *Bt* hybrids, nevertheless had other characteristics that the non-adopters valued. They may have been preferred, as Ramasundaram et al. (2007) found, because they performed better in rainfed conditions and so produced a more dependable, albeit less spectacular, yield from season to season. If so, Morse et al.'s (2007b) data could be a timely and important reminder that not everyone wants a thoroughbred racehorse; sometimes a sturdy, reliable mule is what you really need (see Soleri et al. 2008).

A key point to notice is the Reading group's assumption that the *Bt*-adopters were 'better' farmers (Morse et al. 2007a, 44), a factor that supposedly drove their preference for 'improved' varieties and also helped to explain the higher levels of productivity they achieved with all kinds of cotton. The implicit corollary of the 'better farmers' assumption is that the *Bt*-adopters' example is one that could and should be emulated by non-adopters; and also that it should be a goal for agricultural policy makers to encourage all farmers to be more like the *Bt*-adopters – not merely in their choice of crop varieties, but in their commercial orientation.

However, it is hard to sustain the assumption that *Bt*-adopters were more competent farmers in the face of the contrary evidence that some non-adopters clearly achieved better results on their non-cotton plots, even though they had fewer resources at their disposal (Morse et al. 2007b). Furthermore, the fact that non-adopters in Morse et al.'s (2007b) sample actually had a higher average household income than *Bt*-adopters, which they apparently generated from smaller areas of land and in spite of a lower income from cotton cultivation, ought to raise questions about whether encouraging them to emulate the adopters' livelihood strategies and style of farming would necessarily make those households better off.

Bt COTTON IN SOUTH AFRICA

Bt cotton was commercialized in South Africa in 1998. About 1.8 million hectares of GM crops were grown in South Africa in 2007, including varieties of *Bt* cotton and maize and herbicide-tolerant varieties of soybeans and cotton (James 2007). *Bt* cotton accounted for a little more than 10,000 hectares in 2007, nearly 90 per cent of the total cotton area (Tripp 2009b). Small-scale cultivation of *Bt* cotton is concentrated in the Makhathini Flats region of KwaZulu–Natal province, where about 3,000 black smallholders grew the crop on about the same number of hectares in 2000–01 (Thirtle et al. 2003). Smallholder cotton production in the region has since fallen back, however, as will be discussed below (Fok et al. 2007; Gouse et al. 2005).

Yields, Profits and Institutional Factors

As in China and India, a number of impact studies have been published since *Bt* cotton was commercialized in South Africa. Some of these studies were carried out by the Reading group of researchers, but other studies have been contributed by researchers from King's College, London, South Africa itself, Germany, France and the USA.

Early studies by the Reading group, based on a survey of 100 farmers and covering the first two seasons of commercial cultivation (1998 and 1999), concluded that '*Bt* cotton adopters experience significant benefits from the new technology' (Ismael et al. 2002c, 348), including better yields and reduced expenditure on pesticides, leading to a higher gross margin (Ismael et al. 2002a, 2002b, 2002c). A smaller study by Bennett et al. (2003), which involved in-depth interviews with 32 farmers, endorsed these conclusions and added the observation that reported incidents of pesticide poisoning at the local hospital had declined alongside the spread of *Bt* cotton. These results were broadly confirmed by Thirtle et al. (2003), who supplemented the data from the same original questionnaire survey of 100 farmers with data from the detailed farm records held by the local cotton company, Vunisa. They found that *Bt*-adopters had actually been financially slightly worse off than non-adopters during the first season, when growing conditions were favourable for cotton, but that they were more efficient than non-adopters in their use of inputs during both seasons. Gouse et al. (2003) broadly confirmed these findings, although they found indications that the early adopters were generally more efficient farmers in the first place. Shankar and Thirtle (2005) presented data from a survey of 100 farmers conducted during the 1999–2000 season. Again, their data revealed a yield advantage for *Bt* cotton in a year with significant pest pressure, but also indicated that *Bt*-adopters were more prosperous farmers to begin with.

Later studies, involving larger samples across three seasons (1998–99, 1999–2000 and 2000–01), appeared to confirm the success story of *Bt* cotton in South Africa (Bennett et al. 2004b, 2006b; Morse et al. 2004, 2006). The following summary is fairly typical:

> The results show significant, substantial and consistent benefits of adopting *Bt* cotton for resource-poor smallholders in the Makhathini area of South Africa over the first three significant years of adoption. Benefits were largely in the form of increased yields, reduced pesticides and labor for spraying that, despite higher seed and harvesting labor costs, resulted in substantial improvements in gross margin. Results also suggest that those benefiting most from the technology were the smaller and more intensive cotton growers. (Morse et al. 2004, 380)

Further, Bennett et al. (2004b) found that inequality had increased between adopters and non-adopters, but declined among adopters as time passed. They also calculated that reduced pesticide spraying by *Bt*-adopters had resulted in a reduced toxic load to the environment, a claim that was confirmed, using a slightly different method, by Morse et al. (2006). Using the same dataset, Bennett et al. (2006b) further argued that *Bt* cotton reduced risk for adopters, on the grounds that the technology helped to prevent crop losses in years with unfavourable weather.

Together, these studies appeared to provide convincing evidence that *Bt* technology in the Makhathini Flats was a success story. However, it was also evident that there was a wide degree of variability in the results experienced by different Makhathini smallholders and between seasons. Also, as in the Chinese and Indian cases, none of the studies established a convincing causal mechanism linking the adoption of *Bt* cotton to observed reductions in pesticide use. In fact, Bennett et al. (2004b) showed that the reduction in toxic load attributable to *Bt*-cotton plots was partly due to the fact that *Bt*-adopters had reduced their use of non-bollworm pesticides, even though the *Bt* trait provided no protection against pests other than bollworms. They also showed that that the overall toxic load to the environment from all types of cotton agriculture had actually increased over the first three seasons since *Bt* cotton had been commercialized, although this was largely because non-adopters were using more pesticides against non-bollworm pests. These observations placed question marks over the mechanisms driving pesticide use, farmers' comprehension of the pest-control technologies they were using and the sustainability of the environmental benefits that Bennett and colleagues had identified. On the basis of a separate survey, Hofs et al. (2006) confirmed that the adoption of *Bt* cotton had not led to the adoption of a substantially less hazardous or more environmentally friendly pest management regime in the Makhathini Flats.

These equivocal effects are perhaps not surprising because Makhathini smallholders typically spray pesticides prophylactically rather than in response to observed pest pressure (Shankar and Thirtle 2005). Nevertheless, owing to constraints of time, labour and money, Makhathini cotton farmers still applied somewhat less pesticide than the economic optimum, which suggests that *Bt* cotton might enable only modest reductions in pesticide use in that particular setting, even if the technology has the expected effects on farmer practice. In such a context, the built-in insect resistance provided by transgenic *Bt* technology could offer a particular advantage to poorer farmers in the area, which would manifest itself in the form of an improved yield rather than reductions in pesticide use. Shankar and Thirtle (2005) also concluded that *Bt* cotton was not overall a labour-reducing technology in the Makhathini Flats, which could be construed as an advantage for rural wage labourers.

In principle, those benefits could indeed represent significant advantages for Makhathini smallholders, especially poorer members of the community, provided that the technology is affordable and the productivity and economic benefits sustainable. Indeed, the Makhathini case appears to provide some support for the argument that the key advantage of transgenic insect-resistance is that the technology, being incorporated 'in the seed', can help developing country farmers to overcome the institutional constraints they face. Instead of having to struggle for money, time and labour to apply pesticides, transgenic *Bt* technology can help them to recover potential yield that they were previously losing to pests (see Shankar and Thirtle 2005).

Unfortunately, however, that argument founders on contrary evidence that institutional arrangements have played a central role in the recent history of cotton production in the Makhathini Flats, positively and negatively, to a degree that eclipses the role played by *Bt* technology itself. The initial success of *Bt* cotton in the Makhathini Flats depended heavily on the joint support of the local cotton company, Vunisa, and the local credit agency, the Land Bank. Between them, these two agencies provided the farmers with a ready supply of inputs, information and credit, backed by loan guarantees, as well as a market for their cotton output. Following the breakdown of this supportive institutional framework in 2002, cotton production in the Makhathini area collapsed in the 2002–03 growing season and continued to fluctuate dramatically, upwards and downwards, in the following seasons. Since then, cotton production has been a much more precarious venture for smallholders, especially for those who lack irrigation (Fok et al. 2007, 2008; Gouse et al. 2005; Shankar and Thirtle 2005; Witt et al. 2006).

These institutional factors were evident from the earliest seasons and even recognized as 'a critical component of the farming system in Makhathini' (Ismael et al. 2002b, 108) and it is unfortunate that they did not receive greater attention. A more rigorous analysis of their implications might have restrained some of the more exaggerated inferences that were drawn about the likely impacts of GM crops in other smallholder farming contexts elsewhere in the developing world:

> Makhathini Flats was a special case . . . as it was a large smallholder development scheme that was something of a show-piece for the international community. As a result, the Makhathini Flats Scheme has an experimental farm and an extension service that is far better than in other areas and this must be taken into account when considering the wider applicability of the results. (Thirtle et al. 2003, 719; citation deleted)

Bt COTTON AND RISK

Some analysts have asserted that that transgenic insect-resistant cotton reduces risk for smallholders, on the grounds that *Bt* technology smoothes out the variability of cotton output from one season to the next, thus making farming more predictable (e.g. Bennett et al. 2006b; Zilberman et al. 2007). More precisely, however, *Bt* technology functions primarily as a form of crop insurance, which spreads risk rather than reducing it. Thus, it only confers a substantial economic advantage in seasons where there is a serious outbreak of the target pest. In other seasons, adopters of insect-resistant crops have to carry the additional costs of transgenic seed but gain no particular yield advantage over non-adopters who may have paid much less for their seed. Furthermore, the *Bt* trait protects the crop against only one kind of threat. Having staked more money on a good harvest, *Bt*-adopters remain critically vulnerable to shocks such as adverse rainfall or outbreaks of so-called secondary pests. Hence economic modelling shows that, depending on the circumstances, spraying pesticides may remain a more prudent, flexible strategy of risk management than adopting *Bt* cotton (Pemsl et al. 2004).

Risk management is of course an important consideration for smallholder farmers, but a viable risk-management strategy needs to take into account the fact that they face an array of different risks. Thus, the cost of insurance needs to be affordable and proportional. In the early seasons following *Bt*-cotton commercialization in China, India and South Africa – which is when most of the data were collected for the studies discussed in this article – Monsanto's proprietary *Bt*-cotton varieties were comparatively expensive. For instance, in India, the first officially approved *Bt*-cotton hybrids were marketed at Rs. 1,500 rupees for a 450 g packet of seed, compared to about Rs. 300–400 for conventional hybrids (Damodaran 2002).[3] In China, *Bt*-cotton varieties developed by the Chinese Academy of Agricultural Science were also available alongside Monsanto's varieties, some of them at a more moderate price (Pray et al. 2001). In both India and China, however, a wide variety of unofficial, counterfeit and farmer-saved *Bt*-cotton seeds are also widespread. While these are typically cheaper than the officially approved *Bt*-cotton varieties – sometimes significantly so – they are also of varying and uncertain quality (Pemsl et al. 2005; Roy et al. 2007; Tripp 2009c, 2009d). Under such circumstances, farmers have to make the best choice they can from among a range of sources of seed offering different performance at different prices, which may or may not perform as advertised (see Roy et al. 2007; Stone 2007).

Over time, the price of *Bt* cottonseed has come down considerably in both China and India, driven partly by reductions in the technology fees charged by Monsanto and partly by competition among the increased range of official and unofficial varieties now on the market (Herring 2009; Pemsl et al. 2005; Tripp et al. 2007). One important recent development in India was the release in June 2009 of two new publicly developed *Bt*-cotton varieties, undercutting the price of those available from the private sector (*The Hindu Business Line* 2009). Reductions in the

[3] The total package price was Rs. 1,600, which included 120 g of conventional hybrid cottonseed, worth a nominal Rs. 100, that was to be planted by farmers as a 'pest-refuge' in accordance with the officially mandated pest resistance-management strategy for *Bt* cotton in India.

price of high-quality *Bt* seed will serve in principle to make the technology more accessible to poorer farmers, reducing the temptation to choose unofficial seeds that are cheaper but less dependable. Meanwhile, however, farmers still face formidable problems in deciding how to manage the risks they face in cotton cultivation. Alongside the confusing range of seeds on the market, Chinese and Indian farmers, in particular, are also faced with a bewildering array of pesticides of uncertain provenance and quality (Pemsl et al. 2005; Tripp 2009c). Farmers therefore face a very difficult and uncertain set of trade-offs when determining their risk-management strategy.

Unsurprisingly, generalized claims that *Bt* cotton reduces risk for poor farmers have been challenged. A key problem with the study by Zilberman et al. (2007) is that the authors did not seriously consider the magnitude of the downside risk from the farmers' point of view. As Shankar et al. (2007) and Ramasundaram et al. (2007) have noted, smallholder farmers are well known to be risk-averse, having good reason to be so. Poorer farmers are particularly vulnerable to various kinds of shock; they can ill afford the loss of important household assets, so it is rational for them to adopt a strategy that prioritizes the preservation of those key resources rather than taking greater risks in the hope of reaping higher returns (Carter and Barrett 2006; Zimmerman and Carter 2003). Thus, Hofs et al. (2006) and Fok et al. (2007) were in no doubt that the high technology fee attached to *Bt*-cotton seed increased financial risk for cotton farmers in the Makhathini Flats, particularly in the light of persistently low yields and wide variability in outputs and revenues from one season to the next. Similar conclusions were reached by Ramasundaram and colleagues (2007) in their study on *Bt* cotton in Maharashtra.

However, while Shankar et al. (2007) stated unequivocally that *Bt* cotton increased production risks for Makhathini smallholders, they nevertheless argued that the superior average performance of *Bt* cotton (the same feature which led Zilberman and colleagues to label the technology 'risk-reducing') made it preferable, even for risk-averse smallholders. Whereas that conclusion might make sense for farmers who can cope with a bad harvest, the logic is less compelling in the case of farmers who may have good reason to prefer a smaller financial risk and to choose cotton varieties that offer a lower but more stable yield from one season to the next. It is also important to observe that *Bt* cotton's impacts on risk also depend critically on the local context; for instance, Crost and Shankar (2008) found that the technology reduced risks for cotton farmers in India, but found no clear effect in South Africa.

THE IMPACTS OF *Bt* COTTON IN DEVELOPING COUNTRIES: A REAPPRAISAL

A number of specific methodological limitations and weaknesses can be identified in the *Bt*-cotton impacts literature. For instance, samples in some of the early studies contained forms of selection bias, stemming from the fact that *Bt* technology was initially promoted to, and primarily taken up by, larger and better resourced farmers – a factor that was not always sufficiently controlled for in the analytical methods or acknowledged in interpretation of the results. Some studies relied solely on farmers' *ex post* recollections about seeding rates and expenditure on pesticides in previous seasons. Overall, a rather narrow range of econometric methods has been applied. Most of the papers published to date have been produced by only a small number of research groups and based on just a few datasets, covering a small number of farmers over a few growing seasons (Smale et al. 2006a, 2006b). A wider range of approaches is needed in order to understand *Bt* cotton's impacts on different kinds of households and groups such as labourers and women, and its implications in terms of risk (Shankar and Thirtle 2005).

A fundamental problem stems from the underlying assumptions on which many of the *Bt*-cotton studies have been built. In particular, researchers have assumed that farmers are inclined to maximize average profits rather than reduce risks, and hence prioritize productivity over food security or cultural values; those preferences and priorities may not reflect the attitudes of real farmers (Soleri et al. 2008). The assumption that farmers are profit-maximizers underlies the mistaken belief that transgenic *Bt* and chemical pesticides should be treated as 'substitutable' inputs for pest control – in other words, that an increase in the use of one technology would necessarily be counterbalanced by a corresponding, presumably proportional, decrease in the other (e.g. Huang et al. 2002; Shankar and Thirtle 2005). In general, however, the assumption that novel technology will substitute for, and thus displace, existing technology is an unreliable one (Edgerton 2007; Geels and Smit 2000; Sellen and Harper 2003). In the case of *Bt* cotton, as discussed above, some Chinese cotton farmers have been observed to continue using large quantities of pesticides alongside *Bt* cotton, which may be a rational, risk-averse response to institutional and market failures and uncertainty (Pemsl et al. 2005). A recent study found that some *Bt*-adopters in Colombia spent considerably more on insecticide than non-adopters, alongside increases in other inputs. The explanation seems to be a combination of having the financial capacity to increase their expenditure and choosing to spend more in order to protect their greater investment in the more expensive transgenic cottonseed (Zambrano et al. 2009).

Above all, evaluation of the merits of *Bt* cotton to date has rarely addressed the question of how transgenic crop technology compares with other technical interventions or alternative approaches to the improvement of smallholder agriculture, despite the strong indications that, for example, irrigation may have a much more significant impact on cotton yields than *Bt* technology, or that effective farmer training can lead to major beneficial changes in yields and productivity independently of *Bt*-cotton adoption.

Nevertheless, we now have a body of evidence that can tell us something about the performance and impacts of *Bt* cotton in smallholder agriculture in the developing world. The picture is complex and differentiated, since impacts depend not only on the technical performance of the technology and its local adaptedness, but also on the nature of the pre-existing circumstances and problems in the farming systems of different countries and regions of the world (Lipton 2007; Tripp 2009a).

On the positive side, there can now be little doubt that *Bt*-cotton technology works – in the limited, technical sense that cotton plants transformed with the *Bt* gene express the *Bt* toxin and that the toxin provides some protection for the plant against bollworm pests. In seasons where bollworms cause a serious problem, the technology can help to prevent major crop losses and there is some evidence that, consequently, the technology helps to smooth out the seasonal fluctuations in cotton yields. Those features are potentially useful tools in a crop-pest management system and not to be underestimated.

Beyond that, however, the messages emerging from the *Bt*-cotton impact studies are much more equivocal and constrained. The performance of *Bt*-cotton varieties depends critically on the local suitability of the background germplasm and is also heavily dependent on favourable rainfall or reliable irrigation. *Bt* cotton is just as vulnerable as non-*Bt* cotton to drought or outbreaks of non-bollworm pests. Where *Bt* seed is more expensive than non-GM seed, the magnitude of the potential downside risk is increased. On the other hand, for farmers who are able to afford the additional cost of the seeds without taking on excessive levels of debt, the insurance function provided by the *Bt* trait and its smoothing effects on yields can provide a substantial advantage.

The relationship between *Bt* cotton and pesticide consumption is complicated, as this paper has discussed. In China, India and South Africa, changes in pesticide consumption have been observed that coincided with the adoption of *Bt* cotton. However, those changes happened against a background of economically non-optimal and often excessive pesticide use. It is not clear that observed reductions in pesticide use are attributable to farmers' adoption of *Bt*-cotton varieties or to other factors. Some *Bt*-cotton farmers continue to apply excessive quantities of pesticides and there is some evidence that initial reductions in pesticide use have been reversed because of a resurgence in non-bollworm pests. In some studies, when compared with farmer training and the adoption of IPM methods, *Bt* cotton has been found to have a relatively minor impact on both pesticide use and pest populations.

Finally, the evidence suggests that different kinds of farmers, or different kinds of livelihood strategies, create different kinds of preferences in relation to *Bt*-cotton technology. It may be that those differences are obscured as *Bt* adoption becomes more widespread and the *Bt* trait becomes available in a wider range of the cotton varieties farmers like to plant. But that possibility should not deflect our attention from exploring the likelihood that *Bt* technology and other similar kinds of plant improvement may, perhaps unwittingly, be prioritizing the interests of particular kinds of farmers and livelihood strategies at the expense of neglecting others (see Soleri et al. 2008). The realization of GM crop technology's potential contribution to poverty alleviation will depend on whether a delicate balance can be achieved between the technology's various potential technical, economic and social effects for different groups of people (Lipton 2007; Subramanian and Qaim 2009). That observation suggests that there is a need to consider whether technology development strategies, in both public and private sectors, could be retuned to address the preferences and priorities of diverse types of farmers and livelihoods. Despite the numerous studies discussed in this article, we still know very little about the differential impacts of *Bt* cotton on different kinds of farm households or groups such as women and landless labourers.

The argument is sometimes made that, regardless of the criticisms and caveats recorded here, *Bt* cotton should be judged a success because farmers themselves appear to like it. The technology has been adopted widely and spread quickly. Although some farmers have apparently preferred not to adopt the technology and some instances of disadoption have been recorded (e.g. Malkarnekar et al. 2005), surely the weight of evidence that farmers have embraced the technology in large numbers should count for something (Herring 2008)? No doubt Chinese, Indian and South African smallholders have both the sense and the incentive to make their own careful judgements about the technology they find valuable, and so their revealed preferences should be taken into account. But there is much more to the *Bt*-cotton story than a successful product launch. A company might judge a technology to be successful just because it sells, but development practitioners and policy makers should be interested in wider questions: Why and how is it spreading? What are its developmental effects? What are its impacts in terms of equity and equality? The 'market success' argument is persuasive as long as one accepts that the technology has been shown to be scale-neutral or even pro-poor. However, as this paper has discussed, the empirical record suggests that the technology – like other technologies – is more accessible to more prosperous farmers and depends heavily on an array of other technical inputs and supportive institutional arrangements in order to deliver its potential benefits (Tripp 2009a).

Those technical and institutional factors are of the first importance. Another argument sometimes heard is that the '*Bt* gene' itself cannot be blamed for the fact that some farmers have had negative experiences with transgenic cotton. Instead, such instances should be attributed to various other problems, including poorly adapted background germplasm, drought, poor soils or institutional failures in input markets and regulatory systems. The wide variability that has been observed in cotton productivity surely does have a lot to do with the prevalence of poorly adapted background varieties, poor-quality *Bt* seeds such as second-generation hybrids and counterfeit seeds that purport to be *Bt* but are not. But the dysfunctions of seed markets serve primarily to underline the degree to which the performance of the *Bt* trait and its beneficial impacts depend on being available in well-adapted background varieties and at an affordable price. Unless those technical and institutional factors are in place, the insertion of a novel gene construct into a crop plant can only have a marginal impact on a farmer's final outcomes. Thus, different institutional arrangements help to explain why both the patterns of adoption and the impacts of *Bt*-cotton technology have been different in different countries (Tripp 2009a). For instance, the spread and apparent success of *Bt* cotton in China and South Africa can be seen to have had as much to do with supportive institutional frameworks as with the technical performance of the technology itself (Fok et al. 2005; Gouse et al. 2005; Keeley 2003). That should not come as a surprise. Technology has to function in particular socio-technical and institutional settings. *Bt*-cotton technology is, therefore, not just 'in the seed'; it is actually a rather knowledge-intensive technology. Taking advantage of it therefore depends on measures to promote seed quality and the provision of accurate, transparent and accessible information, as well as farmers' knowledge and training (Hillocks 2005; Showalter et al. 2009; Tripp 2009c).

CONCLUSION

The 'pro-poor success' of *Bt* cotton in China, India and South Africa has been exaggerated, based on a selective and optimistic reading of the available evidence. In a number of subtle but identifiable ways, partial, ambiguous and equivocal data have been interpreted and represented so as to emphasize encouraging findings and downplay negative ones. For instance, analysts have focused on the positive story told by average values while glossing over the very wide variability that has been observed in the impacts of *Bt* cotton between different farms, households and seasons. Clear indications of differences between *Bt*-adopters and non-adopters have been found, but not thoroughly explored. Economic analysis has been used to argue that *Bt* cotton is a rational choice, without sufficiently considering whether the real resource constraints faced by poorer smallholders might prevent them from affording the up-front costs or bearing the downside risks of an expensive technology.

Similarly, observed reductions in pesticide use have been attributed to the adoption of *Bt* cotton, without thoroughly examining the issue of causation and despite the abundant evidence showing that farmers' pesticide decision making often does not conform to simplistic notions of economic rationality, being shaped by obscure and complex institutional, economic, technical and cognitive factors in a context of limited information, risk and uncertainty. *Bt* cotton has been selectively portrayed by some analysts as a technology that reduces risk because it smoothes out the variability in cotton production from one season to the next, rather than one that might amplify risk for poorer farmers because the higher cost of the seeds increases the potential for financial losses if the crop is destroyed. In other words, the full scope and depth of the risks faced by poor smallholder cotton farmers has not been adequately taken into account. In particular, production risk has been emphasized, whereas financial and asset risks should also be considered.

Because some academics, and behind them commentators, policy analysts and politicians, have been too eager to draw general conclusions from insufficient evidence, a misleading impression has been created in public and policy discourse that *Bt* cotton has already proved its value as part of a sustainable, productive agricultural livelihood for poor farmers in China, India and South Africa. That conclusion is not well supported by the available evidence. *Bt* cotton is evidently a functional technology that can be advantageous for some farmers in certain circumstances, but it is still not conspicuously 'pro-poor'.

The manner in which the impacts of *Bt* cotton have been evaluated, interpreted and represented has therefore done a disservice to the public and policy debates that surround the benefits, risks, social purposes, human values and trade-offs involved in pursuing the GM route towards crop improvement and attacking hunger and poverty. There is a risk that bad policy decisions will be made, on the basis of insufficient evidence and inappropriate interpretation of such data as is available.

The argument of this paper is certainly not that the scholars responsible for the *Bt*-cotton impact studies have deliberately misled policy makers and others, but that the analytical methods used have not been sufficient to support the optimistic conclusions that have been drawn from the results. The studies' authors could and should have been more reflexive about the ways in which their conclusions would be understood, interpreted and represented in the media and policy debates.

To be clear, it is apparent that agricultural economists have resorted to some increasingly refined and sophisticated methods in their effort to isolate the effect of the transgenic trait alone (Smale et al. 2006b). The complexity of the analytical tools required tells its own story of the difficulty of parsing the many different factors that contribute to the profitability or productivity of agriculture and rural livelihoods.

The efforts of analysts have been largely confounded, though, not only by the sheer complexity of the factors involved but because the external variables they have struggled to control and exclude are actually essential to understanding the impacts of the new crop varieties on farms. In other words, the strenuous effort to rule out the effects of 'externalities' is not merely a methodological challenge to be overcome, but can be seen as a reflection of a basic failure to appreciate the fundamental importance of those contextual factors in a complex socio-technical system like a small farm in a developing country.

A proper assessment of the implications of currently available GM crop technology for developing-country smallholder farmers will require a broader range of research questions and methods than have been brought to bear in the economic studies published so far. As well as weighing both their potential benefits and disadvantages, a full appreciation of transgenic crop technology's likely future impacts should also acknowledge the limitations of what can be achieved by enhancing just a few crop traits in a complex agronomic system. From a public policy perspective, it is particularly important that the opportunity costs and benefits of investing in transgenic crop-improvement are assessed dispassionately alongside a full range of alternative technical, policy and institutional interventions and strategies for agricultural development.

REFERENCES

Arunachalam, V. and S. Bala Ravi, 2003. 'Conceived Conclusions in Favour of GM Cotton? A Riposte to a Paper in *Science*'. *Current Science*, 85 (8): 1117–9.

Bennett, R., T.J. Buthelezi, Y. Ismael and S. Morse, 2003. 'Bt Cotton, Pesticides, Labour and Health: A Case Study of Smallholder Farmers in Makhatini Flats, Republic of South Africa'. *Outlook on Agriculture*, 32 (2): 123–8.

Bennett, R., Y. Ismael, U. Kambhampati and S. Morse, 2004a. 'Economic Impact of Genetically Modified Cotton in India'. *AgBioForum*, 7 (3): 96–100.

Bennett, R., Y. Ismael, S. Morse and B. Shankar, 2004b. 'Reductions in Insecticide Use from Adoption of Bt Cotton in South Africa: Impacts on Economic Performance and Toxic Load to the Environment'. *Journal of Agricultural Science*, 142 (6): 665–74.

Bennett, R., Y. Ismael and S. Morse, 2005. 'Explaining Contradictory Evidence Regarding Impacts of Genetically Modified Crops in Developing Countries. Varietal Performance of Transgenic Cotton in India'. *Journal of Agricultural Science*, 143 (1): 35–41.

Bennett, R., U. Kambhampati, S. Morse and Y. Ismael, 2006a. 'Farm-level Economic Performance of Genetically Modified Cotton in Maharashtra, India'. *Review of Agricultural Economics*, 28 (1): 59–71.

Bennett, R., S. Morse and Y. Ismael, 2006b. 'The Economic Impact of Genetically Modified Cotton on South African Smallholders: Yield, Profit and Health Effects'. *Journal of Development Studies*, 42 (4): 662–77.

Brookes, G. and P. Barfoot, 2006. 'Global Impact of Biotech Crops: Socio-Economic and Environmental Effects in the First Ten Years of Commercial Use'. *AgBioForum*, 9 (3): 139–51.

Carter, M.R. and C.B. Barrett, 2006. 'The Economics of Poverty Traps and Persistent Poverty: An Asset-based Approach'. *Journal of Development Studies*, 42 (2): 178–99.

Collier, P., 2008. 'The Politics of Hunger: How Illusion and Greed Fan the Food Crisis'. *Foreign Affairs*, 87 (6) (http://www.foreignaffairs.org/20081001faessay87605/paul-collier/the-politics-of-hunger.html?mode=print) Accessed 13 November 2008.

Crost, B. and B. Shankar, 2008. 'Bt-cotton and Production Risk: Panel Data Estimates'. *International Journal of Biotechnology*, 10 (2/3): 122–31.

Crost, B., B. Shankar, R. Bennett and S. Morse, 2007. 'Bias from Farmer Self-selection in Genetically Modified Crop Productivity Estimates: Evidence from Indian Data'. *Journal of Agricultural Economics*, 58 (1): 24–36.

Damodaran, H., 2002. 'Monsanto Cotton Seeds a Sell-out with Farmers'. *The Hindu Business Line*, 17 August (http://www.blonnet.com/2002/07/17/stories/2002071700560900.htm) Accessed 6 August 2009.

Edgerton, D., 2007. 'Creole Technologies and Global Histories: Rethinking How Things Travel in Space and Time'. *History of Science and Technology*, 1: 75–112.

FAO, 2004. *Agricultural Biotechnology: Meeting the Needs of the Poor? State of Food and Agriculture 2004*. Rome: Food and Agriculture Organisation.

FOEI, 2007. *Who Benefits from GM Crops? An Analysis of the Global Performance of GM Crops (1996–2006)*. Amsterdam: Friends of the Earth International.

Fok, M., W. Liang and Y. Wu, 2005. 'Diffusion du coton génétiquement modifié en Chine: leçons sur les facteurs et limites d'un succès [The Diffusion of Genetically Modified Cotton in China: Lessons about the Factors and Limits of a Success]'. *Economie Rurale*, 285 (January–February): 5–32.

Fok, M., J.-L. Hofs, M. Gouse and J. Kirsten, 2007. 'Contextual Appraisal of GM Cotton Diffusion in South Africa'. *Life Science International Journal*, 1 (4): 468–82.

Fok, M., M. Gouse, J.-L. Hofs and J. Kirsten, 2008. 'Smallholders' Use of Bt Cotton Under Unfavourable Context: Lessons from South Africa'. Paper presented at the Cotton Beltwide Conference, 8–11 January 2008, Nashville, Tennessee, USA.

Geels, F.W. and W.A. Smit, 2000. 'Lessons from Failed Technology Futures: Potholes in the Road to the Future'. In *Contested Futures: A Sociology of Prospective Techno-science*, eds N. Brown, B. Rappert and A. Webster, 129–56. Aldershot: Ashgate.

Glover, D., 2007. 'The Role of the Private Sector in Modern Biotechnology and Rural Development: The Case of the Monsanto Smallholder Programme'. Unpublished DPhil thesis. Brighton: University of Sussex.

Gómez-Barbero, M. and E. Rodríguez-Cerezo, 2006. *Economic Impact of Dominant GM Crops Worldwide: A Review*. Technical Report Series EUR22547 EN. Seville: European Commission, Directorate General Joint Research Centre, Institute for Prospective Technological Studies, Sustainability in Agriculture, Food and Health Unit.

Gouse, M., J. Kirsten and L. Jenkins, 2003. 'Bt Cotton in South Africa: Adoption and the Impact on Farm Incomes Amongst Small-scale and Large Scale Farmers'. *Agrekon*, 42 (1): 15–28.

Gouse, M., J. Kirsten, B. Shankar and C. Thirtle, 2005. 'Bt Cotton in KwaZulu Natal: Technological Triumph but Institutional Failure'. *AgBiotechNet*, 7 (134): 1–7.

Herring, R., 2007. 'The Genomics Revolution and Development Studies: Science, Poverty and Politics'. *Journal of Development Studies*, 43 (1): 1–30.

Herring, R., 2008. 'Whose Numbers Count? Probing Discrepant Evidence on Transgenic Cotton in the Warangal District of India'. *International Journal of Multiple Research Approaches*, 2 (2): 145–59.

Herring, R., 2009. 'Persistent Narratives: Why is the "Failure of Bt Cotton in India" Story Still with Us?' *AgBioForum*, 12 (1): 14–22.

Hillocks, R.J., 2005. 'Is There a Role for Bt Cotton in IPM for Smallholders in Africa?' *International Journal of Pest Management*, 51 (2): 131–41.

Hofs, J.-L., M. Fok and M. Vassaiyre, 2006. 'Impact of Bt Cotton Adoption on Pesticide Use by Smallholders: A 2-year Survey in Makhatini Flats, South Africa'. *Crop Protection*, 25 (9): 984–8.

Hossain, F., C.E. Pray, Y. Lu, J. Huang, C. Fan and R. Hu, 2004. 'Genetically Modified Cotton and Farmers' Health in China'. *International Journal of Environmental Health*, 10: 296–303.

Huang, J., R. Hu, S. Rozelle, F. Qiao and C. Pray, 2002. 'Transgenic Varieties and Productivity of Smallholder Cotton Farmers in China'. *Australian Journal of Agricultural & Resource Economics*, 46 (3): 367–87.

Huang, J., R. Hu, C. Pray, F. Qiao and S. Rozelle, 2003. 'Biotechnology as an Alternative to Chemical Pesticides: A Case Study of Bt Cotton in China'. *Agricultural Economics*, 29 (1): 55–67.

IAASTD, 2008. 'International Assessment of Agricultural Knowledge, Science and Technology for Development – Executive Summary of the Synthesis Report'. (http://www.iaastd.org) Accessed 12 September 2008.

Ismael, Y., R. Bennett and S. Morse, 2002a. 'Benefits from Bt Cotton Use by Smallholder Farmers in South Africa'. *AgBioForum*, 5 (1): 1–6.

Ismael, Y., R. Bennett and S. Morse, 2002b. 'Farm-level Economic Impact of Biotechnology: Smallholder Bt Cotton Farmers in South Africa'. *Outlook on Agriculture*, 31 (2): 107–11.

Ismael, Y., L. Beyers, C. Thirtle and J. Piesse, 2002c. 'Efficiency Effects of Bt Cotton Adoption by Smallholders in Makhathini Flats, KwaZulu-Natal, South Africa'. In *Economic and Social Issues in Agricultural Biotechnology*, eds R.E. Evenson, V. Santaniello and D. Zilberman, 325–50. Wallingford: CABI Publishing.

James, C., 2007. *Global Status of Commercialized Biotech/GM Crops: 2007*. ISAAA Brief 37. Ithaca, NY: International Service for the Acquisition of Agri-Biotech Applications.

James, C., 2008. *Global Status of Commercialized Biotech/GM Crops: 2008*. ISAAA Brief 39–2008. Ithaca, NY: International Service for the Acquisition of Agri-Biotech Applications.

Kambhampati, U., S. Morse, R. Bennett and Y. Ismael, 2006. 'Farm-level Performance of Genetically Modified Cotton: A Frontier Analysis of Cotton Production in Maharashtra'. *Outlook on Agriculture*, 35 (4): 291–7.

Keeley, J., 2003. 'The Biotech Developmental State? Investigating the Chinese Gene Revolution'. *IDS Working Paper* 207. Brighton: Institute of Development Studies.

Keeley, J., 2006. 'Balancing Technological Innovation and Environmental Regulation: An Analysis of Chinese Agricultural Biotechnology Governance'. *Environmental Politics*, 15 (2): 293–309.

Lawson, D., 2008a. 'Feed the World? Tear Down Trade Barriers and Let GM Crops Flourish Across the Globe'. *The Independent*, 18 April (http://www.independent.co.uk/opinion/commentators/dominic-lawson/dominic-lawson-feed-the-world-tear-down-trade-barriers-and-let-gm-crops-flourish-across-the-globe-811176.html) Accessed 5 November 2008.

Lawson, D., 2008b. 'The Prince is Entitled to His View – But Not His Ignorance'. *The Independent*, 15 August (http://www.independent.co.uk/opinion/commentators/dominic-lawson/dominic-lawson-the-prince-is-entitled-to-his-views-ndash-but-not-his-ignorance-897493.html) Accessed 12 November 2008.

Lifeng, W., D. Pemsl and H. Waibel, 2007. 'The Role of Farmer Training in the Diffusion of Biotechnology in Cotton in China: A Multi-period Analysis'. Paper presented at the Conference on International Agricultural Research for Development, 9–11 October 2007, University of Kassel-Witzenhausen and University of Göttingen.

Lipton, M., 2007. 'Plant Breeding and Poverty: Can Transgenic Seeds Replicate the "Green Revolution" as a Source of Gains for the Poor?' *Journal of Development Studies*, 43 (1): 31–62.

Malkarnekar, A., H. Waibel and D. Pemsl, 2005. 'Why Some Indian Cotton Farmers Do Not Adopt Bt Cotton'. Poster presented at Tropentag 2005 conference, 11–13 October 2005, University of Hohenheim, Stuttgart (http://www.tropentag.de/2005/abstracts/posters/298.pdf) Accessed 14 August 2009.

Mayer, S., 2002. *Genetically Modified Cotton: Implications for Small-scale Farmers*. Pesticides Poverty and Livelihoods Series. London: Pesticides Action Network UK.

Morse, S., R. Bennett and Y. Ismael, 2004. 'Why Bt Cotton Pays for Small-scale Producers in South Africa'. *Nature Biotechnology*, 22 (4): 379–80.

Morse, S., R. Bennett and Y. Ismael, 2005a. 'Comparing the Performance of Official and Unofficial Genetically Modified Cotton in India'. *AgBioForum*, 8 (1): 1–6.

Morse, S., R. Bennett and Y. Ismael, 2005b. 'Genetically Modified Insect Resistance in Cotton: Some Farm Level Economic Impacts in India'. *Crop Protection*, 24 (5): 433–40.

Morse, S., R. Bennett and Y. Ismael, 2006. 'Environmental Impact of Genetically Modified Cotton in South Africa'. *Agriculture, Ecosystems and Environment*, 117 (4): 277–89.

Morse, S., R. Bennett and Y. Ismael, 2007a. 'Inequality and GM Crops: A Case-Study of Bt Cotton in India'. *AgBioForum*, 10 (1): 44–50.

Morse, S., R. Bennett and Y. Ismael, 2007b. 'Isolating the "Farmer" Effect as a Component of the Advantage of Growing Genetically Modified Varieties in Developing Countries: A Bt Cotton Case Study from Jalgaon, India'. *Journal of Agricultural Science*, 145 (5): 491–500.

Pemsl, D., H. Waibel and J. Orphal, 2004. 'A Methodology to Assess the Profitability of Bt Cotton: Case-study Results from the State of Karnataka, India'. *Crop Protection*, 23 (12): 1249–57.

Pemsl, D., H. Waibel and A.P. Gutierrez, 2005. 'Why Do Some Bt-Cotton Farmers in China Continue to Use High Levels of Pesticides?' *International Journal of Agricultural Sustainability*, 3 (1): 44–56.

Pray, C. and J. Huang, 2003. 'The Impact of Bt Cotton in China'. In *The Economic and Environmental Impacts of Agbiotech: A Global Perspective*, ed. N. Kalaitzandonakes, 223–42. New York: Kluwer Academic/ Plenum Publishers.

Pray, C., D. Ma, J. Huang and F. Qiao, 2001. 'Impact of Bt Cotton in China'. *World Development*, 29 (5): 813–25.

Pray, C., J. Huang, R. Hu and S. Rozelle, 2002. 'Five Years of Bt Cotton in China – The Benefits Continue'. *The Plant Journal*, 31 (4): 423–30.

Pschorn-Strauss, E., 2005. 'Bt Cotton in South Africa: The Case of the Makhatini Farmers'. *Seedling*, April (http://www.grain.org/seedling/?id=330) Accessed 14 August 2009.

Qaim, M., 2003. 'Bt Cotton in India: Field Trial Results and Economic Projections'. *World Development*, 31 (12): 2115–27.

Qaim, M. and D. Zilberman, 2003. 'Yield Effects of Genetically Modified Crops in Developing Countries'. *Science*, 299 (5608): 900–2.

Qayum, A. and K. Sakkhari, 2005. *Bt Cotton in Andhra Pradesh: A Three-year Assessment*. Hyderabad: Deccan Development Society.

Ramasundaram, P., S. Vennila and R.K. Ingle, 2007. 'Bt Cotton Performance and Constraints in Central India'. *Outlook on Agriculture*, 36 (3): 175–80.

Raney, T., 2006. 'Economic Impact of Transgenic Crops in Developing Countries'. *Current Opinion in Biotechnology*, 17: 174–8.

Roy, D., R. Herring and C. Geisler, 2007. 'Naturalising Transgenics: Official Seeds, Loose Seeds and Risk in the Decision Matrix of Gujarati Cotton Farmers'. *Journal of Development Studies*, 43 (1): 158–67.

Sahai, S., 2003. 'The Bt Cotton Story: The Ethics of Science and its Reportage [Letter]'. *Current Science*, 84 (8): 1–2.

Scoones, I., 2005. *Science, Agriculture and the Politics of Policy. The Case of Biotechnology in India*. Hyderabad: Orient Longman.

Scoones, I., 2009. 'The Politics of Global Assessments: The Case of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD)'. *Journal of Peasant Studies*, 36 (3): 547–71.
Sellen, A.J. and R.H.R. Harper, 2003. *The Myth of the Paperless Office*. Boston, MA: MIT Press.
Shah, E., 2008. 'What Makes Crop Biotechnology Find its Roots? The Technological Culture of Bt Cotton in Gujarat, India'. *The European Journal of Development Research*, 20 (3): 432–47.
Shankar, B. and C. Thirtle, 2005. 'Pesticide Productivity and Transgenic Cotton Technology: The South African Smallholder Case'. *Journal of Agricultural Economics*, 56 (1): 97–116.
Shankar, B., R. Bennett and S. Morse, 2007. 'Output Risk Aspects of Genetically Modified Crop Technology in South Africa'. *Economics of Innovation and New Technology*, 16 (4): 277–91.
Shantharam, S., S.B. Sullia and G.S. Swamy, 2008. 'Peer Review Contestations in the Era of Transgenic Crops'. *Current Science*, 95 (2): 167–8.
Showalter, A.M., S. Heuberger, B.E. Tabashnik and Y. Carrière, 2009. 'Development, Agronomic Performance and Sustainability of Transgenic Cotton for Insect Control'. In *Biotechnology and Agricultural Development: Transgenic Cotton, Rural Institutions and Resource-poor Farmers*, ed. R. Tripp, 49–71. London: Routledge.
Smale, M., P. Zambrano and M. Cartel, 2006a. 'Bales and Balance: A Review of the Methods Used to Assess the Economic Impact of Bt Cotton on Farmers in Developing Countries'. *AgBioForum*, 9 (3): 195–212.
Smale, M., P. Zambrano, J. Falck-Zepeda and G. Gruère, 2006b. 'Parables: Applied Economics Literature About the Impact of Genetically Engineered Crop Varieties in Developing Economies'. EPT Discussion Paper 158. Washington, DC: IFPRI, Environment and Production Technology Division.
Smale, M., P. Zambrano, G. Gruère, J. Falck-Zepeda, I. Matuschke, D. Horna, L. Nagarajan, I. Yerramareddy and H. Jones, 2009. *Measuring the Economic Impacts of Transgenic Crops in Developing Agriculture During the First Decade: Approaches, Findings, and Future Directions*. IFPRI Food Policy Review 10. Washington DC: International Food Policy Research Institute.
Soleri, D., D.A. Cleveland, G. Glasgow, S.H. Sweeney, F.A. Cuevas, M.R. Fuentes and L.H. Rios, 2008. 'Testing Assumptions Underlying Economic Research on Transgenic Food Crops for Third World Farmers: Evidence from Cuba, Guatemala and Mexico'. *Ecological Economics*, 67 (4): 667–82.
Stone, G.D., 2007. 'Agricultural Deskilling and the Spread of Genetically Modified Cotton in India'. *Current Anthropology*, 48 (1): 67–103.
Subramanian, A. and M. Qaim, 2009. 'Village-wide Effects of Agricultural Biotechnology: The Case of Bt Cotton in India'. *World Development*, 37 (1): 256–67.
Taverne, D., 2007. 'The Real GM Food Scandal'. *Prospect*, 140: 24–7.
The Guardian, 2007. 'Brown Must Embrace GM Crops to Head Off Food Crisis – Chief Scientist'. *The Guardian*, 28 November (http://www.guardian.co.uk/science/2007/nov/28/foodtech.gmcrops) Accessed 7 November 2008.
The Guardian, 2008. 'Science Minister Attempts to Reopen the Debate on GM Crops'. *The Guardian*, 22 September (http://www.guardian.co.uk/environment/2008/sep/22/gmcrops.food) Accessed 7 November 2008.
The Hindu Business Line, 2009. 'Desi *Bt* cotton set to blossom in farms this year'. *The Hindu Business Line*, 6 June (http://www.thehindubusinessline.com/2009/06/06/stories/2009060651151800.htm) Accessed 3 August 2009.
The Telegraph, 2008. 'Genetically Modified Crops "May Be Answer to Global Food Crisis" '. *The Telegraph*, 19 June (http://www.telegraph.co.uk/news/uknews/2154307/

Geneticaly-modified-crops-'may-be-answer-to-global-food-crisis'.html) Accessed 7 November 2008.

Thirtle, C., L. Beyers, Y. Ismael and J. Piesse, 2003. 'Can GM-technologies Help the Poor? The Impact of Bt Cotton in Makhathini Flats, KwaZulu-Natal'. *World Development*, 31 (4): 717–32.

Tripp, R., ed., 2009a. *Biotechnology and Agricultural Development: Transgenic Cotton, Rural Institutions and Resource-poor Farmers*. London: Routledge.

Tripp, R., 2009b. 'Cotton Production and Technology'. In *Biotechnology and Agricultural Development: Transgenic Cotton, Rural Institutions and Resource-poor Farmers*, ed. R. Tripp, 23–48. London: Routledge.

Tripp, R., 2009c. 'Transgenic Cotton and Institutional Performance'. In *Biotechnology and Agricultural Development: Transgenic Cotton, Rural Institutions and Resource-poor Farmers*, ed. R. Tripp, 88–104. London: Routledge.

Tripp, R., 2009d. 'Transgenic Cotton: Assessing Economic Performance in the Field'. In *Biotechnology and Agricultural Development: Transgenic Cotton, Rural Institutions and Resource-poor Farmers*, ed. R. Tripp, 72–87. London: Routledge.

Tripp, R., N.P. Louwaars and D. Eaton, 2007. 'Plant Variety Protection in Developing Countries: A Report from the Field'. *Food Policy*, 32 (3): 354–71.

University of Tennessee, Extension Service, n.d. 'Bt cotton' (http://www.utextension.utk.edu/fieldcrops/cotton/cotton_insects/*Bt*cotton.htm) Accessed 18 January 2009.

Wang, S., D.R. Just and P. Pinstrup-Andersen, 2008. 'Bt Cotton and Secondary Pests'. *International Journal of Biotechnology*, 10 (2–3): 113–21.

Widawsky, D., S. Rozelle, S. Jin and J. Huang, 1998. 'Pesticide Productivity, Host Plant Resistance and Productivity in China'. *Agricultural Economics*, 19 (1/2): 203–17.

Witt, H., R. Patel and M. Schnurr, 2006. 'Can the Poor Help GM Crops? Technology, Representation & Cotton in the Makhatini Flats, South Africa'. *Review of African Political Economy*, 33 (109): 497–513.

Wu, K., W. Li, H. Feng and Y. Guo, 2002. 'Seasonal Abundance of the Mirids, *Lygus lucorum* and *Adelphocoris* spp. (Hemiptera: Miridae) on Bt Cotton in Northern China'. *Crop Protection*, 21 (10): 997–1002.

Yang, P., M. Iles, S. Yan and F. Jolliffe, 2005a. 'Farmers' Knowledge, Perceptions and Practices in Transgenic Bt Cotton in Small Producer Systems in Northern China'. *Crop Protection*, 24 (3): 229–39.

Yang, P., K. Li, S. Shi, J. Xia, R. Guo, S. Li and L. Wang, 2005b. 'Impacts of Transgenic Bt Cotton and Integrated Pest Management Education on Smallholder Cotton Farmers'. *International Journal of Pest Management*, 51 (4): 231–44.

Zambrano, P., L.A. Fonseca, I. Cardona and E. Magalhaes, 2009. 'The Socio-economic Impact of Transgenic Cotton in Colombia'. In *Biotechnology and Agricultural Development: Transgenic Cotton, Rural Institutions and Resource-poor Farmers*, ed. R. Tripp, 168–99. London: Routledge.

Zilberman, D., H. Ameden and M. Qaim, 2007. 'The Impact of Agricultural Biotechnology on Yields, Risks, and Biodiversity in Low-income Countries'. *Journal of Development Studies*, 43 (1): 63–78.

Ziliak, S.T. and D.N. McCloskey, 2008. *The Cult of Statistical Significance: How the Standard Error Costs Us Jobs, Justice, and Lives*. Ann Arbor, MI: University of Michigan Press.

Zimmerman, F.J. and M.R. Carter, 2003. 'Asset Smoothing, Consumption Smoothing and the Reproduction of Inequality under Risk and Subsistence Constraints'. *Journal of Development Economics*, 71 (2): 233–60.