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ENVIRONMENT AND PRODUCTION TECHNOLOGY DIVISION OCTOBER 2006

EPT Discussion Paper 158

Parables: Applied Economics Literature About the Impact of Genetically Engineered Crop Varieties in Developing Economies

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Acknowledgments

This review was undertaken with the support of IDRC and in collaboration with Oxfam-America. Some of the work on Bt cotton, in particular, was funded by the Africa Region Environment and Social Development Unit of the World Bank. In particular, the authors thank the following researchers and organizations for their insights: John Baffes, Lamissa Diakité, Svetlana Edmeades, Latha Nagarajan, Kimberly Pfeifer, Tony La Vina, Rob Tripp, and the secretariat of the International Cotton Advisory Committee (ICAC). Mélodie Cartel searched the French language literature. A first draft of this paper was prepared for a Project Inception Meeting held at Oxfam-America, Washington D.C., May 10-11. The authors thank meeting participants for their comments and suggestions. The authors alone are responsible for any errors of finding or interpretation.

Abstract

A vast literature has accumulated since crop varieties with transgenic resistance to insects and herbicide tolerance were released to farmers in 1996 and 1997. A comparatively minor segment of this literature consists of studies conducted by agricultural economists to measure the farm-level impact of transgenic crop varieties, the size and distribution of the economic benefits from adopting them, consumer attitudes toward GE products, and implications for international trade. This paper focuses only on the applied economics literature about the impact of transgenic crop varieties in non-industrialized agricultural systems, with an emphasis on methods. A number of studies have surveyed the findings for both industrialized and non-industrialized agriculture, at various points in time, but surveys of methods are less frequent and have typically examined only one overall question or approach. Clearly, the methods used in research influence the findings that are presented and what they mean. Understanding the methods therefore enhances understanding of the findings. Four categories of impact analysis are considered: farmers, consumers, industry and trade. In part due to methodological limitations and the relatively brief time frame of most analyses, results are promising, but the balance sheet is mixed. Thus, findings of current case studies should not be generalized to other locations, crops, and traits. The aim of this review is to progress toward the defining a "best practices" methodology for national researchers who seek to produce relevant information about emerging crop biotechnologies for national policymakers.

Keywords: genetically engineered crops, economic impacts, technology adoption, developing economies, economics methods

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OBJECTIVE AND SCOPE

A vast literature has accumulated since crop varieties with transgenic resistance to insects and herbicide tolerance were released to farmers in 1996 and 1997. Several years after their release in the U.S, the first genetically engineered crop varieties were released to farmers in countries with developing economies and non-industrialized agricultural systems. Essays, editorials, newsletters, web conferences, articles and books have debated the pros and cons of genetic engineering (GE). A comparatively minor segment of this literature consists of studies conducted by agricultural economists to measure the farm-level impact of transgenic crop varieties, the size and distribution of the economic benefits from adopting them, consumer attitudes toward GE products, and implications for international trade.[5] An even smaller subset treats the impacts of transgenic crops in developing economies. This paper reviews the applied economics literature about the impact of transgenic crop varieties in non-industrialized agricultural systems, with an emphasis on methods.

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[5] Frohlich (2005) and Fransen (2006) provide useful insights into the broader literature.

There are several reasons why the decision was made to focus on methods rather than findings. First, a number of studies have surveyed the findings for both industrialized and non-industrialized agriculture, at various points in time, but surveys of methods are less frequent and have typically examined only one overall question or approach. Second, the methods used in research influence the findings that are presented and what they mean. Understanding the methods, their strengths and weaknesses, enhances the understanding of the scope of research findings.

A brief digression on methods illustrates this point. In general, this review shares the perspective of Ramaswami (2005), who describes the applied economics literature on genetically engineered crops as “reduced form.” In applied economics, a “reduced form” equation presents relationships only in terms of major explanatory factors and outcomes that depend on those factors, without explicit treatment of structural details. At the same time, a theoretical framework and set of mathematical and behavioral assumptions are implicit in a reduced form. The reduced form is often the equation that is estimated statistically with survey data. Thus, outcomes or stylized facts are interpretable only within the theoretical framework and statistical model applied by the researcher. In farm-level, sector, or trade analyses, sensitivity analysis or simulation is often used to illustrate the extent to which outcomes might change given changes in levels of some explanatory variables, parameters, or a policy decision (e.g., a GE import ban, a regulatory delay). Studies of consumer preferences typically employ hypothetical situations, or stated rather than observed preferences.

A third reason for focusing on methods in this review is to progress toward a “best practices” methodology for researchers who seek to produce relevant information about emerging crop biotechnologies for national policymakers in developing economies. This paper is a background assessment for a multi-country project undertaken this year with IDRC in collaboration with Oxfam-America. Designing "best practices" are a project goal.

The review has been organized according to four major research questions addressed by the literature, which correspond to four components of the agricultural economy: 1) what are the (potential, actual) advantages of genetically engineered (GE) crops to *farmers*? 2) what are *consumers* willing to pay for non-GE products, and how will this affect the market? 3) what is the size and distribution of the economic benefits from adoption of GE crops in an *industry*? 4), what is the international distribution of economic benefits from adoption and *trade* of GE crops?

Summary information from the search is presented next. Then, the methods applied by authors, research findings, and limitations are grouped by research question.

SEARCH SUMMARY

To facilitate direct comparisons of methods, the boundaries of the literature reviewed were rather narrowly delineated. A statement of method and presentation of data were two criteria for including a study in our review, so that theoretical studies and critical essays have been omitted. Only literature reviewed by peers has been included (reports, discussion papers, presented papers and journal articles), although the review is sometimes minimal (discussion papers). Research conducted in the U.S. and Europe has been consulted for purposes of identifying specific methodologies, but not as comprehensively as research implemented in countries with less fully commercialized agriculture. The review concentrates on observed or estimated impacts on farms, industries, or trade, whether these are estimated ex ante or ex post. Thus, the studies that assess the effects of property rights regimes on agricultural research and development have been set aside. French and English language literature has been searched exhaustively, and well as a web-based review of Spanish language literature.

The search approach used for this compilation included four principal sources: CAB Direct, ISI Web of Knowledge, other published bibliographies, and references from published articles. CAB Direct and ISI are both searchable databases, which have millions of references in various fields. As of January 12, 2006, CAB Direct had 3,477 references under agricultural economics and biotechnology. The vast majority of these references did not meet our criteria, and our first cut of this literature included less than one-tenth of them.

To provide contextual information, Table 1 lists articles that consist of reviews of findings or methods. Nine are global in coverage, only four focus on industrialized agriculture, and 12 address impacts in non-industrialized agriculture. These numbers suggest a relatively high level of professional interest in the potential and actual impacts of genetically engineered crops in developing economies.

Table 1--Reviews of the impacts of genetically engineered crops in industrialized and non-industrialized agriculture

First Author	Year	Publication	Crops	Period	Focus	Review type
a. Global						
Brookes, G.	2005	AgBioForum	multiple	1996-2005		findings
Fernandez-Cornejo, J.	2006	ERS Electronic report	multiple	1996-2006	USA	findings
Marra, M.	2002	AgBioForum	multiple	1996-2002	USA	findings
Purcell, J.	2004	AgBioforum	cotton	1996-2003		findings
Wu, F, Butz,W	2004	Rand	multiple	1996-2003		findings
FAO	2004	State of Food and Agriculture	multiple	1996-2003		findings
Babu, S. C.	2003	Asian Biotech. & Dev. R.	multiple	-		methods
Scatasta, S.	2006	Mansholt Diss. Paper				methods
Shoemaker, R.	2001	ERS	multiple	1996-1999	USA	
b. Industrialized countries						
Demont, M.	1999	KU Leuven	multiple	-	EU	methods
Carpenter, J.	2001	Nat. Center for Food and Ag. Policy	maize, cotton, potatoes, soybeans	1996-2000	USA	findings
Caswell.M.F.	1994	ERS Ag Econ. Report		up to 1994	USA	findings
Price, G.	2003	USDA/ERS	soybean, cotton	1997	USA	methods findings
c. Non- industrialized countries						
Falck-Zepeda	2003	OECD	multiple			findings
Huesing,J.	2004	AgBioforum	multiple	1996-2003		findings
Qaim, M.	2005	Quarterly J. of International Ag.	multiple	1996-2005		findings
Raney, T.	2006	Current Opinion in Biotechnology	cotton, maize, soybeans	1996-2005		findings
Schaper, M.	2001	Grupo Zapallar	multiple	1996-2001	LAC	findings
da Silveira, J-M	2005	Bellagio	soybean	1996-2004	Brazil	findings
Toenniessen, G.	2003	Current Opinion in Plant Biology	multiple	1996-2001		findings
Nuffield Council on Bioethics	2004	Nuffield	multiple			findings
Trigo	2002	IDB	multiple	-	LAC	findings
ISNAR	2002	ISNAR		-		methods
OECD	2000	OECD		-		methods
Qaim, M.	1998	ZEF	multiple	-		methods

The count of articles by research question that applied a stated economics method to an empirical dataset is shown in Table 2. After reviewing the contents of each of over 300 of these, 106 peer-reviewed articles published from 1996 through mid-2006 met our criteria. Of these, over half (58) address farm level impacts, 18 treat consumer impacts, 14 analyze industry impacts, and 18 assess impacts on international trade. Thus, as indicated by counts of peer-reviewed publications, evaluating technology impacts on farmers represents the foremost research concern during the first decade of growing genetically engineered crops.

Table 2—Count of peer-reviewed, English, Spanish and French language articles about the economic impact of genetically engineered crops in developing economies, by research question, 1996-2006

Question	Publications *No.*
Farmers	52
Farmers, industry	6
Consumers	17
Consumers, industry	1
Industry	12
Trade	18
Total	106

Note that some articles address both farm-level and industry impact, or both consumer and industry impact.

Within the third category of "industry" a few articles address questions such as the impact of GE varieties on seed supply and product channels, the costs and benefits of regulation, the potential health benefits of the next generation of GE crop varieties (product quality), and the effects of irreversibility. These issues could affect economic costs and benefits at any level of analysis (farm, consumer, industry, trade). For example, the costs of regulatory delay affect farm-level benefits, benefits generated to the productive sector, and possibly, benefits generated through trade.

Table 3 shows the count of articles by research question and crop (trait). By far the most researched crop-trait combination is insect-resistant cotton (56 articles). The next largest category includes general analyses, addressing consumer attitudes and willingness-to-pay. Articles analyzing impacts of genetically engineered maize, rice and soybeans follow. A residual category includes other crops: bananas, potatoes, sweet potatoes, cassava, wheat, oilseeds, eggplant, mustard, and coarse grains. Categories total to more than the total number of articles because some articles treat more than one crop-trait combination.

Table 3—Count of articles assessing the economic impact of genetically engineered crops in developing economies, by research question and crop (and trait)

	Farm	Farm/ Industry	Consumer	Consumer, Industry	Industry	Trade	Total
Cotton (IR)	44	3			5	4	56
Maize (IR)	4	1			3	6	14
Rice (HT, IR)	2		3	1	1	5	12
Soybeans (HT)	3	1	1		1	6	12
All other crops	1	1	1		4	2	9
GM –general			14		1	3	18
	54	6	19	1	15	26	121

IR: Insect resistant; HT: Herbicide tolerant; Other crops: bananas, potatoes, sweet potatoes, cassava, wheat, oilseeds, eggplant, mustard, coarse grains.

Table 4 reports the distribution of articles by research question and country. Again, categories total to more than the total number of articles because some articles treat more than one country. The fact that Bt cotton dominates publications means that the overall distribution is very much affected by the distribution among articles treating Bt cotton. China, India, and South Africa figure heavily among peer-reviewed publications based on studies in developing economies.

Table 4—Count of articles assessing the economic impact of genetically engineered crops in developing economies, by research question and country

	Farm	Farm/ Industry	Consumer	Consumer, Industry	Industry	Trade	Total
China	13	1	13		1	4	32
India	16				2		18
South Africa	16						16
Argentina	5	1	1		1	1	9
Philippines	1	1	1	1		1	5
Mexico		2			1		3
Colombia			1		2		3
Kenya		1			2		3
Brazil	1					1	2
West Africa					1	1	2
Other countries	1		3		1	2	7
Global					1	11	12
Total	53	6	19	1	12	21	112

The predominance of farm-level studies, and studies of the impacts of Bt cotton on farmers, lead us to devote more space to this research question and crop-trait combination. Additional tables summarizing authors, year of publication, and other study parameters are provided in the sections about consumers, industry, and trade. Given the sheer number of articles, a detailed summary table for farm-level studies is not provided.

IMPACT ON FARMERS

Findings and methods

Two main approaches are used in this literature: 1) farm accounting, or partial budgets, and 2) econometric analysis to test hypotheses about factors affecting variation in output per hectare (partial productivity), input use per hectare (cost savings), and output per unit of input (efficiency). A third set of articles attempt to estimate the farm-level impact of transgenic crop varieties ex ante. The first main approach involves calculation of marginal returns based on comparisons of per unit changes in variable costs and benefits. The second involves the application of a statistical model to continuous data based on a theoretical economics model. Both are based on the farm survey data (often the same sample of farmers or plots), or in some instances, trial data. Combined with the first type of analysis, some survey analyses present information about pesticide use, farmer perceptions of effects on health, and biocide or inequality indices.

Ex post, farm survey analyses in developing countries (HT soybean, IR cotton, IR maize) tend to find positive economic returns to adopting farmers, but these are highly variable over years, country, and regions within countries. Returns depend on initial practices, pest infestations, seed costs, and other attributes of farmers, farm production, and markets. Economic returns also depend on the crop and trait. Periodic reviews of the impacts on U.S. farmers, using larger data sets over a longer time period, with analytical methods that are well suited to the agricultural economy, indicate the same (Klotz-Ingram et al. 1999; Shoemaker et al. 2001; Fernandez-Cornejo and Caswell 2006).

Findings and methods are presented in more detail next, by crop and trait. The most extensive body of ex post evidence has been compiled for China, South Africa, India and Argentina, with some findings reported for Mexico, Brazil and the Philippines (Cabanilla 2004, Yorobe and Quicoy 2004).

IR cotton

South Africa

Thirtle et al. (2003: 731) describe Makhathini Flats as “a low potential area for cotton production,” and “atypical in that the biotech companies are locally present and support services are unusually good, which affects the wider applicability of this study.” Over 31,500 ha were planted to cotton in South Africa in 2001/2, with 22,000 in the drylands, of which Makhathini Flats represented only 31% (6,800 ha) (Gouse et al. 2003). At least in 2002-4, insecticide prices were substantially higher in Makhathini Flats in than in other parts of the province (Hofs et al. 2006). Thus, research in Mahkhathini Flats is purposive in placement, and findings can be generalized to other locations only to the extent that these locations bear the same characteristics. Otherwise stated, there may be statistical bias with study placement, as in any case study.

Of the 14 articles published on Bt cotton in South Africa, 7 are based on the same sample of only 100 farmers. Authors have been careful to cite some concerns with sampling methodology. For example, “there was some potential for bias in the selection process, as Vunisa agents purposely targeted farmers with larger areas of cotton during the first year of Bt cotton release, and to a lesser extent also in the second year” (Ismael et al. 2002a: 3). Though the survey spanned two seasons (1998/9 and 1999/2000), neither year was normal; there was drought in the first season and late heavy rains in the second (Kirsten and Gouse 2003).

Partial budgets tend to indicate some advantages from growing Bt cotton in terms of either yield or pesticide costs. Ismael et al. (2002b, 2002c) found that farmers who grew Bt cotton had both higher yields and lower pesticide costs than those who did not, outweighing the higher seed costs. They estimated the difference in gross margins at 11% in 1998/99 and 77% in 1999/2000, however. Based on data from Vunisa (the cotton gin in Makhathini Flats), Gouse et al. (2005) found no clear yield advantage to the Bt variety in either year, though pesticide costs were lower.

Whether or not growing Bt cotton is associated with reduced pesticide use has since been questioned by researchers. Reduced pesticide use can lead not only to lower production costs and labor savings, but lower exposure of farmers and the environment to hazardous chemicals. Hofs et al. (2006) compared near-isogenic lines and monitoring agrononomic practices daily, using a different sample of 20 farmers in Makhathini Flats. They observed a decrease in pyrethroid use during the 2002-3 and 2003-4 seasons, though farmers did not abandon it altogether. At the same time, farmers applied substantial amounts of organophosphates to control pests not affected by the Bt toxin. The extent of the labor savings was not as great as expected. Surprisingly, "more money was invested in insect management for Bt cotton than for non-Bt cotton crops, probably because farmers… upgraded their seed-cotton yield objectives and adjusted their investment' (Hofs et al. 2006: 5). Note also that while concern with identifying the correct counterfactual was the reason why the authors used isogenic lines, rigor with respect to analyzing agronomic practices in this study was not matched by the rigor in sampling farmers. Only 20 farmers were studied in close proximity, raising potential for placement bias.

Similarly to Hofs et al. (2006), Bennett et al. (2005b) concluded that while financial returns were good during the time period studied (higher yields, lower insecticide spray costs, and higher gross margins), overall levels of Biocide indices rose in Makhathini Flats with the introduction of Bt cotton. These authors based their analysis on large samples of farm records drawn from Vunisa Cotton data, over three seasons (1998/9 to 2000/1). In contrast to Hofs et al. (2006), they found that although Bt growers applied lower amounts of pesticides and had lower Biocide indices than growers of non-Bt cotton, some of this advantage was due to a reduction in non-bollworm insecticide, due to an apparent misunderstanding.

Analyses that compare economic returns per ha between smallholder and larger-scale producers in South Africa conclude that smallholders are major beneficiaries of the Bt cotton (Ismael et al 2002b; Gouse et al. 2003). Despite the differential in technology fee between large- and small-scale farmers, Gouse et al. (2004) present data indicating that the large-scale farmers in irrigated areas earn the greatest amount of yield benefits per hectare, as well as the greatest reduction in pesticides, and the greatest income advantage. The greatest percentage benefit for small-scale farmers is due to yield advantages rather than decreased pesticide use, and large-scale farmers in the drylands gain the least at the margin. Gouse et al. (2003, 2004) report that larger-scale farmers save in terms of lower diesel and tractor costs, and "managerial freedom." While there is some evidence that Bt cotton reduced inequality in Makhathini flats, Ismael et al. (2002b) concluded that "the per capita distribution of income from cotton in this area is about as unequal as the distribution of per capita incomes in the Western European countries" (p. 346).

In their latest publication, Bennett et al. (2006b) carefully assemble all available farm record and survey data, reviewing gross margin advantages by year and farm size. They conclude that while adoption is linked to slightly larger farm sizes in years 1 and 3, adoption is linked to smaller farm sizes in year 2. In all three seasons, adopters had gross margin advantages over non-adopters, but this was particularly the case in the wetter year, when the smallest producers growing less than one hectare of cotton fared the worst. They report data suggesting that the number of accidental pesticide poisoning cases has declined. While acknowledging that no data or method is above criticism, they argue that the evidence is broadly consistent with the conclusion that the Bt cotton varieties have benefited the farmers of Makhathini Flats.

Although labor costs were not recorded in the data, authors hypothesized that cost saving in labor was a major reason why farmers chose to grow Bt cotton. The duress of backspraying, and collecting water for spraying (often accomplished by women and children), cannot be understated. This area is also hard-hit by HIV/AIDS. Kirsten and Gouse (2003) note that labor saved because of fewer pesticide applications could have been canceled out by the need for more harvesting labor with higher yields. In their most recent published work, Shankar and Thirtle (2005) conclude that Bt is not labor-saving in the case of smallholder farmers in South Africa.

Though the 7 articles based on the same sample of 100 farmers represent a single case study, researchers have tested more subtle hypotheses over time with increasingly sophisticated econometric approaches. The initial approaches included deterministic frontier models (Ismael et al. 2002c), stochastic frontier models (Thirtle et al. 2003; Ismael et al. 2002b), and data envelope analysis (Gouse et al. 2003). Gouse et al. (2003) and Thirtle et al. (2003) found that Bt cotton growers, whether smallholders or large-scale farmers, were more technically efficient than growers of non-Bt cotton. Gouse et al. (2005) subsequently estimated a damage control model, which explicitly treats the fact that pesticides are not output-enhancing inputs but damage-abating, adding nothing to output if there are not pests.

In the most thorough analysis based on this same sample, Shankar and Thirtle (2005) estimated a damage control production function, and explored the efficiency of pesticide use with the estimated value of the marginal product, also testing for sample selection bias and for the endogeneity of pesticide use[6]. They conclude that farmers do not apply pesticides in response to pests but in a pre-determined, prophylactic way.

An important conclusion drawn by Shankar and Thirtle (2005) is that adoption in Makhathini Flats is driven by supply rather than by demand. Shankar and Thirtle (2005) begin to assemble other pieces of the jigsaw puzzle in Makhathini Flats in a systematic way. Contrary to evidence from China and Argentina, where pesticides are over-used and the principal benefit to farmers is reduced pesticide use, pesticides are not heavily used. Yields are 600 kg/ha, as compared to 3000 kg/ha in China. The damage control framework, unlike the approaches they previously applied (data envelope analysis, stochastic frontier), does reveal the productivity of pesticide use and that smallholders under-use pesticide with both Bt and non-Bt cotton relative to the economic optimum. Nonetheless, the yield effect is more important than damage abatement for smallholders

[6] A problem of endogeneity would mean that the same factors that influence yield also influence whether or not the farmer chooses to apply pesticides, leading to biased regression coefficients.

in Makhathini Flats. The authors report the limitations they notice in their own work, mentioning the need for a household economics framework and analysis of the insurance function of Bt cotton.

Given supply-driven adoption, whether a new variety fails or succeeds is particularly sensitive to the organization of the marketing channel, a point underscored by Gouse et al., 2005). Over 90% of cotton farmers in Makhathini Flats grew Bt cotton in 2001/2002. The Vunisa cotton company supplied growers with inputs and credit and bought the cotton they produced, also providing some extension advice. After a few seasons, farmers defaulted on loans from Vunisa by selling to a new gin, and in the following year, no seed or credit was supplied. Production declined in subsequent seasons. Gouse et al. (2003) proposed that, contrary to expectations, it may have been the vertical integration in the cotton industry, with the monopsony of the local ginnery that also supplied seed and credit, which enabled success to occur in Makhathini Flats.

Given farmer vulnerability to external market arrangements, combined with a harsh production environment, year-to-year swings in farmer benefits from Bt cotton can be wide. For this reason, Hofs et al. (2006) caution that, given current management practices, the level of expected income generated is not sufficient to generate tangible and sustainable improvement in farmer well-being, and may in fact increase financial risk of smallholder cotton farmers such as those of Makhathini Flats.

China

So far, the peer-reviewed, published literature suggests that China is the most successful case for Bt cotton in terms of sustained, positive effects on reduced pesticide use, crop income, health and environmental benefits, regional coverage, and sustainability since 1999 (Huang et al. 2002a, 2002b, 2002c, 2003, 2004; Pray et al. 2001, 2002). Still, other points of view add some complexity to the case regarding Bt effectiveness and regional variation in the benefits to farmers (Yang et al. 2005; Pemsl et al. 2006; Fok et al. 2005).

Huang and colleagues have implemented continuous, in-depth survey research. As in the case of Makhathini Flats, they have applied increasingly sophisticated statistical and econometric methods; unlike the Makhathini Flats case, they are able to base their analyses on larger samples. The first year of survey data in China (1999) included 282 farmers in Hebei and Shandong provinces, cultivating an average of 0.78 ha per household, of which 39 percent was planted to cotton. While Bt and non-Bt growers shared similar socio-demographic and farm characteristics, and yields did not differ significantly between the two groups, the difference in pesticide use was marked (five times higher in quantity and seven times the costs for non-Bt growers). The cost of production for Bt varieties was only 77-80% that of growing non-Bt varieties due to reduced pesticide and labor use. Returns to labor were over twice as high for Bt growers, and net income was positive, while it was negative for non-Bt growers. The authors also reported some initial evidence that farmers perceived positive health effects from reduced pesticide use. The survey data suggested that pesticide use declined by an average of 47 kg/ha, which would imply a reduction of 15,000 tons in the regions studied.

Multivariate analysis of the first-year survey data, published in 2003 (Huang et al.), confirmed that Bt use reduced the use of pesticides, and particularly organophosphates, contributing to labor savings and more efficient production. The main benefit came from savings in pesticide expenditures and labor, since the yields of major Bt and non-Bt varieties were statistically "indistinguishable" (2003: p. 61). Since some farmers saved seed, and seed use was lower per hectare for Bt seed, overall seed costs were not much lower for non-Bt seed. Furthermore, they found all Bt cotton varieties—including those introduced by foreign life science companies and those bred by China's research system—to be "equally effective."

Huang et al. (2002c) then estimated a damage control production function, also recognizing that farmers chose pesticide levels in response to pest pressures by implementing an instrumental variables model, specifying interactions between use of Bt and use of pesticides. Findings regarding effects of Bt cotton use on efficiency and reduced use of pesticides were substantiated in this article. Still, they were based on only one year of survey data. Next, they expanded the sample coverage. Huang et al. (2002b) develop their most complete analysis, with three years of survey data and expanded sample coverage, a damage control production function, and an attempt to correct for the potential bias from endogeneity of pesticide use and farmers' decision to grow Bt cotton varieties. Applying more advanced methods, they conclude that growing Bt cotton varieties 1) *does* have a positive effect on crop yield and not just damage abatement; 2) Bt cotton also reduces yield losses through abated damage; 3) pesticide use on non-Bt cotton varieties only abates damage; 4) benefits from Bt cotton vary across provinces, and are lowest in Henan and Jiangsu; 5) farmers overuse pesticides, even when they grow Bt cotton.

The first conclusion reflects the fact that when comparisons are made without the use of isogenic lines, observed yield advantages are the outcome of the effectiveness of the trait, the genotype, management, environment, and interactions among all of these factors. Trade-offs in yield potential and resistance levels among non-Bt cotton varieties, combined with the variety choices farmers make and their management practices, provide possible explanations for their results. The authors note that farmers generally grow non-Bt varieties that are resistant, but lower in yield. Higher yielding, more susceptible, non-Bt varieties are grown on minor areas. On the other hand, once Bt substitutes for other mechanisms of genetic resistance, it is likely that farmers choose to grow the highest-yielding Bt varieties. Breeders are also likely to have inserted the gene into higher-yielding, susceptible varieties. Finally, farmers who choose to grow Bt varieties may also be those who attain higher average yields.

Which factors have contributed to the success of Bt cotton in China? Some outsiders have argued that China's success reflects heavier government control of production, seed supply and marketing systems, but Huang and colleagues highlight two other major considerations. First, China is most likely the largest pesticide user in the world and cotton producers have used pesticides most intensively. Estimated damage control functions demonstrate that Chinese farmers tend to over-use pesticides, while observation reveals that they do not protect themselves (Huang et al. 2002c). Thus, the health benefits and reduced costs of Bt cotton are readily observable to farmers. Second, in China, the public research program had the capacity to develop and disseminate transgenic IR cotton varieties (Pray et al. 2002), so that technology fees were not imposed by Monsanto, dependence on external supplies was lessened, and seed prices were more competitive. The Beijing-based Biotechnology Research Institute of the Chinese Academy of Agricultural Sciences (CAAS) obtained patent, plant variety and trademark protection in China for its Bt cotton. The original transgenic lines were sub-licensed to provincial seed companies and transgenes were backcrossed into more than 22 locally-adapted varieties (Toenniessen et al. 2003).

Yang et al. (2005) concluded that in Liqing County, Shandong Province, farmers grew more than six varieties of Bt cotton but were still over-using pesticides, recommending farmer training in IPM and basic ecology to ensure sustainable production. In Shandong province, for the 2002 cropping season only, Pemsl et al. (2006) employed a damage control framework, estimated simultaneously with an insecticide use function. Bt concentration, measured by sampling leaves, was employed as a much more precise indicator than a zero-one variable for growing a Bt variety. Their results confirmed that Bt growers also overuse pesticides, but they also found that neither insecticide use nor Bt use reduced damage from bollworm. They caution that problems such as measurement errors in recording pesticide use and monitoring response, varying control effectiveness under farmers' conditions, and lack of farmer knowledge, imply that the benefits of Bt cotton in China and in other developing countries could be lower than argued elsewhere.

Fok et al. (2005) combine a detailed review of farm-level profitability in other studies with an in-depth treatment of the institutional and epidemiological context of Bt cotton production in China. They affirm the success of Bt cotton in the Yellow River region of China where resistance to insecticides had evolved and farmers applied 10-12 treatments, as compared to 2-4 in most countries; however, they cite evidence to the contrary in the Yangtze river valley (Jiangsu) and other provinces, where pest pressures are lower and the germplasm is not as well adapted. They highlight the importance of a number of institutional factors, such as 1) the decentralization of breeding efforts in China, leading to the “enviable wealth of cotton varieties,” 2) low seed costs for both the newly released cotton hybrids and varieties, 3) the competitive nature of the seed market, and 4) despite the elimination of support prices and subsidies, an effective price premium due to import controls in the domestic cotton industry.

India

Studies conducted in India illustrate several points of major importance for measuring farm-level impact. The first is that the more heterogeneous the growing environment, pest pressures, farmer practices, and social context, the more variable the benefits are likely to be. This “truism” holds for any new crop variety, now matter how widely-adapted. Cotton is grown in most of the India’s agro-ecological zones on approximately 9 million hectares distributed in just over nine states. Sixty percent of this area is rainfed. While the most damaging pests are bollworms, hundreds of other pests are widespread and the soil and climatic conditions are difficult.

A number of the published studies demonstrate this fact, using different approaches. For example, by introducing risk and uncertainty into the analysis of per hectare economic returns, Pemsl et al. (2004) concluded that a prophylactic chemical control strategy would be superior to the use of Bt hybrids in both irrigated and non-irrigated cotton in Karnataka. As in their China study, they argue that the high expectations placed on Bt cotton may not be met from an economic point of view: “Bt cotton is not a new green revolution variety but simply another option of bollworm control (p. 1256).” Hence, the economics of Bt cotton are determined by the severity of pressure by lepidopteran insects. Another study in the state of Karnataka found that for 100 farmers sampled, Bt cotton growers used lower numbers of pesticides applications than non-Bt cotton farmers, but the promise of higher yields was only realized for irrigated farms (Orphal 2005). Local varieties appear to perform better than Bt hybrids under rainfed conditions.

Narayamamoorthy and Kalamkar (2006) collected data for the 2003 rainy season in two districts in the Vidarbha region of Maharashtra, targeting their analysis to pairwise yield comparisons of two Bt and non-Bt varieties hybrids (MECH 162 and MECH 184 for Bt; Bunny 145 and Ankur 651 for non Bt). They found that yield advantages differed for the same hybrid by region and within regions, by hybrid.

Bennett et al. (2004) and Morse et al. (2005b) analyzed farm survey data for over 9,000 cotton plots. Gross margins/ha were higher on Bt plots, but the difference was much greater in 2003 than in 2002, varying spatially among subregions. Bennett et al. (2006b) estimated a production function that introduces use of Bt hybrids as a shift and interaction variable, with a large sample of pooled cross-sectional and time-series data recorded at the plot level, collected by company extension agents. Their analysis confirmed the spatial and temporal variation in partial productivity of Bt cotton. In some areas, they found that farmers did not benefit at all.

A second theme is unique to the India case relative to other cases. Given the context of agro-ecological and social heterogeneity, an active civil society that is vocal for and against GM seed has polarized perspectives. Polarization is evident even in the peer-reviewed literature. Perhaps more significantly, the debate in civil society is carried into government decision-making fora. Thus, methods limitations, which occur in any applied research, take on particular significance.

For example, data from on-farm trials of the first three approved Bt hybrids in Maharashtra, Madhya Pradesh and Tamil Nadu formed the basis for Qaim and Zilberman's initial, optimistic report of 80 to 87 percent yield advantages (Qaim 2003; Qaim and Zilberman 2003). Generally, trial data is not considered to be representative of farmers' conditions, though budgets based on trial data can be adjusted in order to provide greater insights. Qaim (2003) acknowledges these limitations. Arunachalam and Ravi (2003) and Sahai and Rehman (2003) were among the first critics of Qaim's results. Aranachalam and Ravi (2003) questioned the data, claiming that more reliable data from trials conducted by Punjab Agricultural University in 2002 showed yields were higher for non-Bt materials than for the three MMB hybrids.

Sahai and Rehman (2003) conducted a random sample survey for the first cotton season after the commercial release of the Bt hybrids in 2002, reporting that the only advantage they found for Bt cotton was a shorter growing period and that Bt cotton was more costly to produce. Losses were reported for some farms, and they state that 98 percent of farmers had no interest in growing Bt cotton. Sample sizes are small (25 farmers in Maharashtra and 75 in Andhra Pradesh), and sampling details are not elaborated. In 2004, the same authors implemented another survey in four districts of Andhra Pradesh, reporting economic losses for 60 percent of farmers growing Monsanto Bt cotton hybrids. To the discredit of the Qaim and Zilberman study, they argued that farmers sought unapproved Bt variants and good local hybrids because these outperformed the Monsanto hybrids.

In contrast, Barwale et al. (2004) reported the advantages of the MMB varieties over non-Bt varieties, including the higher yields, higher profits, and lower application of pesticide. The survey of 1,069 farmers was implemented by Mahyco extension workers in the six states where Bt cotton seed was sold in the 2002 season. Methods for selecting farmers are not elaborated in the article. Economic "profits" were based on imputed prices rather than actual survey data.

In a 3-year study in Andhra Pradesh, Qayum and Sakkhari (2005) found that Mahyco-Monsanto Bt cotton (Bollgard) was inferior to non-Bt cotton in terms of yields, pesticide use was negligible for both types of cotton, non-Bt farmers had higher profits, lower costs of cultivation, and suspected Bt cotton of a root rot that affected their soils for subsequent crops. The Deccan Development Society, which implemented the study, used a number of research approaches, but the sampling methods are not detailed, and the report was not published in a peer-reviewed journal. This study is mentioned in our discussion (but not in our search count) because it has been so widely publicized, generating controversy.

A third theme that recurs in the studies is the importance of host germplasm, given Bt effectiveness. The first three Bt cotton hybrid seeds (MECH-12 Bt, MECH-162 Bt and MECH-84 Bt) were developed by Mahyco-Monsanto Biotech Ltd. and were approved for commercial release in March 2002. There was some suggestion that the host germplasm was not broadly adapted to Indian growing conditions (e.g., Aruchalam and Ravi 2003; Sahai and Rehman 2004). Naik et al. (2005) and Qaim et al. (2006) estimated a production function for farmers in four states in India. They found a high degree of heterogeneity among farmers in terms of agroecological, social and economic conditions, also noting that the better adaptation of local non-Bt hybrids compared to Bt hybrids (germplasm effect) influence farm level benefits. They also report circumstantial evidence that black market sales of unapproved cultivars and sales of F2 seed at lower prices explain some crop losses.

The importance of the host germplasm is consistent with at least one of the arguments made by Qaim and Zilberman in their 2003 article: the yield effect of newly released Bt varieties can be greater in poorer countries because in richer countries they are used to replace or enhance chemical control only. For that reason, the local adaptation of the germplasm into which the gene construct is backcrossed is of crucial importance to the success of the new seed type. Concurring with this point, Bennett et al. (2005) show that official Bt varieties significantly outperform the unofficial varieties but unofficial, locally produced Bt hybrids can also perform better than non-Bt hybrids. They report that second generation F2 Bt seed appears to have no yield advantage compared to non-Bt hybrids but can save on insecticide use. The Bt gene still confers some advantage, and farmers regard it as GM.

Mexico

Mexico provides an example of "farming by formula," or a form of contract farming for Bt cotton. There, the strength of the institutional arrangements for delivering Bt technology and marketing cotton, combined with Bt effectiveness, solved a major production problem for farmers in the Comarca Lagunera region of Durango and Coahuila states. Bt is effective against the major pest threats, pink bollworm and tobacco budworm, a spectrum of the pest population that is not economically significant in other

Mexican states (Traxler and Godoy-Avila 2004; Traxler et al. 2003). Given this situation, a moderate – sized sample served as the representative basis of the authors' analysis of industry impact using an economic surplus model.

IPR were strictly enforced, as in the U.S. To protect their revenue, Monsanto established contracts with farmers and gins owners. Farmers who desired access to the Bt cotton technology were obligated to forfeit the right to save seed, and to have cotton ginned only where "authorized." In their contracts, farmers specify the total area to be planted and Monsanto spot checked cotton fields for compliance. Gins are given the opportunity to be authorized (and hence, become monopsonists) by agreeing to refrain from selling Bt seed obtained in the ginning process. Contracts with the innovators Monsanto/Deltapine where drawn to protect IP, but also with private sector credit agencies, banks and large cooperatives to gain access to credit. These contracts delineated the terms for technical assistance to be provided by the credit agencies themselves, production processes, as product marketing.

Argentina

The case of Argentina has limited applicability to other cases in developing economies, but reveals the significance of IPR in determining adoption rates and net returns to farmers. As compared to the smallholder farmers of South Africa, China, and India, Bt cotton adopters in Argentina farm an average of over 400 ha of cotton on farms of over 1000 ha—they are representative of the medium and large-scale farmers running family businesses that typically employ one or more permanent workers (Qaim and de Janvry 2003).

In Argentina, Monsanto strictly enforced intellectual property rights on Bt cotton contributing to low net returns and low rates of adoption in cotton (Trigo and Cap 2004; Qaim and de Janvry 2003). Technology fees were imposed, and seed was sold at $103/ha by a sole supplier. The authors point out that this price is equivalent to a technology premium of $78, approximately the same as what US farmers have to pay for Bt cotton. In addition, while Argentine seed law allows farmers to reproduce their cotton seed for one season before buying new, certified material, the seed supplier prohibited the use of farm-saved seed (ibid.)

Methods applied in the Argentina case are exemplary from the standpoint of disciplinary excellence. Qaim and de Janvry used a combined stated and revealed preference approach to estimate farmers' willingness to pay for Bt seed. By constructing farmer demand functions for seed and profit functions for the supplier, they showed that both farmers and monopoly supplier would have been better off at a lower seed price, contributing also to incentives to cheat through illegal seed sales.

In one of the most comprehensive approaches applied in the literature, the authors (Qaim et al. 2003; Qaim and de Janvry 2005) use a damage control framework to estimate the effectiveness of Bt use and predict the impact of the technology by farm size. They concluded that while large family businesses benefit primarily through reduced pesticide use (pesticide use is positively correlated with farm size), smallholders, who use few pesticides, would attain the highest gross benefits per hectare because of substantial yield advantages (of up to 42 percent). They included a physiological model of the Bt cotton-test system calibrated with entomological data from Argentina, drawing implications for the size of Bt refuge areas need to ensure the durability of farm level benefits.

Other crops and traits

A major explanatory factor attributed to the success of HT soybeans in Argentina is the fact that Monsanto failed to patent its soybean innovation. Therefore, Monsanto could not enforce IPRs which in turn enabled the emergence of an active black market for HT seeds. There are other critical factors that have contributed to the success of HT soybeans including the technology's ability to enable no-till/ reduced-till and ultra narrow row production systems (Trigo and Cap 2003, Penna and Lema 2003).

Qaim and Traxler (2005) found no bias against small-scale farmers in the adoption and impact of HR soybeans in Argentina, concluding that use of HT soybeans lead to a large increase in the amount of glyphosate used, a reduction in more hazardous chemicals, and conversion to no-till production. Other effects such as an increasing concentration of land among larger-scale farms, displacement of small farmers that resulted from rising land prices, and use of environmentally fragile areas are mentioned but not calculated (Muñoz 2004).

Qaim and de Janvry's (2005) analysis of HR soybeans in Argentina is one of the most complete single articles in terms of hypotheses tested and methods applied. The authors build a series of econometric models to estimate the farm level impacts of HT soybeans on pesticide use, yields, efficiency, and equity. They then develop a biological model to portray the durability of the benefits. Qaim and de Janvry conclude that Bt use is associated with lower rates of pesticide use, and that since Argentine farmers use lower levels relative to some countries, yield gains are relatively higher. For the same reason, smallholder farmers gain even more. Since other host plants for Bt target pests are grown locally, rapid resistance buildup is unlikely given minimum refuge areas are preserved.

For Brazil, da Silveira and Borges (2005) have reviewed local studies and in particular, a study conducted by EMBRAPA, based on technical coefficients elicited from experts and field interviews. They conclude that the likely economic gain from HT soybeans is minimal, and while the crop may be easier to manage for larger-scale farmers, increased use of glyphosate makes up for its lower toxicity.

Cabanilla (2004) has estimated the potential impact of Bt maize on farms in the Philippines using a mixed integer programming procedure, based on representative technologies and farms. Yorobe and Quicoy (2004) estimated the partial productivity impact of Bt maize in the Philippines with sample data from 470 farmers in four provinces of the country, for a single cropping season. They controlled for agroclimatic factors by selecting adjacent adopters and non-adopters, correcting for sample selection bias benefits through application of a two-stage, Heckman procedure. Yield and income were higher among Bt growers, and insecticide expenditure was lower. The converse was also true: income, as well as education, were factors that significantly influenced the adoption of Bt maize.

Gouse et al. (2004, 2006) present the first few years of evidence about Bt (white) maize adoption and impact among large- and small-scale farmers in South Africa, beginning in 1998. Using farm survey analysis alone, they find that yields are higher for both groups and pesticide applications are reduced particularly for large commercial farmers. In the later article, they recognize the consumption characteristics of white maize, noting that the highest valued yield benefits were among those farmers who grind maize for home consumption. South Africa is the first developing economy to release a genetically engineered food crop, and this point has implications for other countries. Furthermore, they remark that in the last season, the fourth consecutive dry season, Bt maize growers and growers of non-Bt hybrids produced similar yields. This last finding reinforces the point, also made in other studies, that the advantages of a Bt variety will depend on the extent of pest pressure.

Edmeades and Smale (forthcoming) predict the demand for disease and pest-resistant highland bananas in East Africa using a trait-based model and survey data on cultivar attributes, household farm and market characteristics. Unlike the other adoption studies conducted in the literature mentioned above, this model uses a household economics framework that considers the role of imperfect markets in production decisions.

Methodological limitations

For a number of reasons, the balance sheet at the farm level is mixed. First, the effects of seed technical change in farming communities are difficult to establish both because of the direction of causality and subsequent, indirect effects that occur with the passage of time, and expansion from favorable into more marginal growing environments.[7] A second is the small number of *different* authors publishing case studies in peer-reviewed, international journals. Narrowness is particularly evident in this topic

[7] For example, a first round of studies on the effects of the Green Revolution in Asia found increasing inequality of assets and income distributions (Griffin, 1974). Second-generation studies of the effects of the Green Revolution in Asia concluded that, at least in the more favorable production areas, absolute poverty declined when food price effects and indirect linkages to the rural non-farm economy were taken into account (Mellor and Johnston 1989; Hazell and Ramaswamy 1991; Lipton and Longhurst 1989; Pinstrup-Andersen 1979) . One stylized fact of the Green Revolution that it is most often the underlying social structure that predetermines much of the social impact of technology adoption.

area. A third is related to methodological problems, although it is important to recognize that no method is perfect, and typically, multiple methods will be needed to generate a fuller analysis of impact.

There are at least five limitations associated with these studies.

1. Use of partial budgets:
    a. Partial budgets are deceptively simple, when in fact, considerable care must be used to construct them (CIMMYT 1988; Ramaswami 2005). In many of the studies, only gross margins are reported. Gross margins include the costs of intermediate inputs but ignore the use of labor and land. Net margins include these costs. Note also that the cost and yield implications of HT and IR traits differ.
    b. Partial budgets are "partial" because they treat only one farm activity at a time. Even where farmers are fully commercialized, the net impact on whole-farm production, factors of production, income or well-being cannot be deduced. No studies have yet been published about the impacts of Bt cotton on wider dimensions of farmer income-generation and vulnerability.
2. Household farm decision-making: Even if the whole-farm is considered, when farmers are not fully commercialized, and operate in situations with market imperfections, the input and output prices that influence their decisions are endogenously determined and household-specific.
3. Institutional context. Findings clearly point to the hypothesis that marketing arrangements, the extent of vertical coordination, monopsony as compared to competition, affect the farm-level impact and adoption. Yet this aspect has received less systematic attention that is due.
4. Sampling methods.
    a. Identifying the counterfactual (which variety the farmer would have grown in the absence of the GM variety, and which practices the farmer would have used) is necessary in order to have an unbiased assessment of the net benefits of adoption—yet this information is generally missing. There are factors influencing whether a farmer grows a Bt cotton variety that may also affect marginal returns to that variety, and these have not, in general, been taken into account. Some are observed and some are unobserved, but there are ways to take account of them. Whether they are observable or not, such factors

create a bias due to program placement and program participation (often referred to as "selection bias").

b. When sample sizes are small, sampling errors are great.
c. When they are large, as in the case of farm records, non-sampling (measurement) errors are expected to be substantial.

5. Environmental and health externalities. These have been addressed in very simplified forms in the literature, with biocide indices or farmer perceptions. More advanced methods may warrant consideration.

Recognizing the temporal limitations of survey data, and the inherent uncertainty of yields and prices in agriculture at the time that farmers make seed choices, some researchers have used stochastic simulation to generate a statistical distribution of crop incomes (see Chapter V in this report). Concern for the limitations of partial budget analysis led a number of authors to apply more sophisticated econometric methods; yet, generally speaking, the econometric analyses are only as good as the survey data that underpins them.

To overcome the limitations of small sample sizes and selection bias, some authors have used farm records for different plots cultivated by the same farmers. This approach is not feasible where farmers adopt completely, and plot-wise analysis gives a very incomplete picture of whole-farm or farm family effects. Later articles tend to address the representativeness of findings, and the study by Shankar and Thirtle (2005) is the most thorough seen in its consideration of selection bias. Econometric analysis of this topic presents statistical challenges because of the possible endogeneity of both pesticide use and Bt choice.

Use of damage control production functions in later analyses is a major improvement, since these recognize that pesticides are a damage abatement rather than productivity-enhancing input. Perhaps the most daunting task is to improve our understanding of the interactions of pest populations and traits, especially as problems with secondary pest resistance emerge. Several authors have insisted on the importance of monitoring practices daily, in order to develop a more realistic picture of the full range of biotic pressures (several bollworms, sucking insects, other fungal diseases).

Most authors of these studies have now moved beyond the confines of technique in order to better examine the relationship of institutional arrangements and sustained impact, highlighting the role of national research capacity (China), agricultural dualism (South Africa), effective IPR (Argentina), regulatory management (Pray et al.2006; Contini et al. 2005), and supply channels (Kambhampati et al. 2005). Morse et al. (2005) recognized that their analysis "says nothing about the biological sustainability of the single-gene-based Bt resistance or even the impact of official/unofficial Bt cotton hybrids on the sustainability of people's livelihoods in such complex socioeconomic contexts as those of India" (p. 6). Complexity is a matter of fact in most contemporary societies, however.

IMPACT ON CONSUMERS

Findings and methods

There are two main bodies of literature that address this question: 1) surveys designed to elicit consumer attitudes toward GE products, and 2) applications of recent advances in stated preference methods for estimating consumer willingness to pay for non-GE products (Table 3). The first records whether or not consumers are concerned, and the nature of the concern. The second is intended to provide decision-makers with estimates of the price premium that would be necessary to market a genetically-engineered product successfully. Estimates of willingness to pay are needed to determine the welfare implications of labeling policies. The genetically-engineered product is a close substitute for the non-genetically-engineered product, resembling it in all attributes except that at least one ingredient is derived from genetically engineered raw materials.

Most of the methods applied in the second body of literature elicit hypothetical choices using carefully constructed menus of options, or choice sets presented to consumers. Researchers recognize that there is often a difference between what people state they will do and what they actually do. The most recent advances in these methods involve combining stated preference methods based on hypothetical situations and revealed preference methods that record actual situations.

Stated preference models also continue to evolve. Kontoleon (2003) found that the latent segmentation model is superior statistically to other methods, including 1) multinomial logit with interacted individual characteristics, 2) random parameter logit, 3) covariance heterogeneity models, and 4) latent class models. Using choice experiment data from a sample of consumers, the latent segmentation model enables the researcher to segment consumer demand and simultaneously explain choices for each segment of the population.

Lusk et al. (2004) conducted a meta-analysis of 25 studies on consumer demand for GE food. They concluded that a) consumer characteristics b) the method used by the researcher and c) the food studied explained 89 percent of the variation in the estimated willingness to pay for non-GE food. They propose their simpler model as a parsimonious means of generating rapid estimates for policy makers with reasonable accuracy.

A list of publications about consumers' attitudes and willingness-to-pay for (or accept) GE products is provided in Table 3. Including all articles identified in the search, only 14 were identified for non-industrialized agriculture. China is the most heavily represented. Mucci et al. (2004) report results for Argentina, and Pachico and Wolf (2004) present an analysis for Colombia.

Table 5—Study descriptors, consumer acceptance and willingness to pay for genetically engineered food

Region	Authors	Year published	Country – city or region	GE Food	Selected findings
A. Non Industrialized (14 papers)					
	Chern, W. S., K. Rickertsen, N. Tsuboi, and T. Fu	2002	Taiwan – Taipei	Vegetable oil	WTP 17~21% more for non-GE
	Curtis, K. R., and K. Moeltner	2006	China	Rice	Consumers WTP is 0.81
				Soybean oil	Consumers WTP is 0.74
	Govindasamy, R., B. Onyango, W. Hallman, H.-M. Jang, and V. Puduri	2004	Korea	General	face to face inteview with 903 adults, regarding WTA. Less educated and women are less likely to accept GE
	Ho, P., and E. B. Vermeer	2004	China - Beijing, Shiajiazhuang	General	40% willing to consume foods containing GE-based ingredients, 51% were neutral, and 9% were rather unwilling or very unwilling.
	Hu, W., and K. Chen	2004	China – Beijing	General	67 percent were concerned about biotechnology.
	Huang, J., H. Qiu, J. Bai, and C. Pray	2006	China – Eastern	General	Door to door urban survey, consumers, WTP GE for 15% less
	Li, Q., K. R. Curtis, J. J. McCluskey, and T. I. Wahl	2002	China – Beijing	Rice	In-person interview with grocery shoppers WTP 38% more for GE tangible consumer benefit
				Soybean oil	WTP -16.3%
	Lin, W., A. Somwaru, J. Huang, and J. Bai	2005	China - Eastern coast	Bt rice	Door to door urban survey, 68% of consumers willing to buy Bt rice at same price
				Soybean oil	60% of consumers willing to buy GE soybean oil at same price
	Mucci, A., G. Hough, and C. Zillani.	2004	Argentina	General	WTP low except for consumer enhanced GE
	Pachico and Wolf, 2004	2004	Colombia – Cali	General	66.5% might at least try genetically modified foods, although nearly 3/4 perceived GE in general as potentially risky.
	Wang, Z.	2003	China		Not consulted in this study
	Zhang, X.	2005	China – Tianjin		Not consulted in this study
	Zhong, F., M. A. Marchant, Y. Ding, and K. Lu	2002	China – Nanjing	General	40 percent would buy GE foods

Table 5—Study descriptors, consumer acceptance and willingness to pay for genetically engineered food (continued)

B. Industrialized (36 papers)

Baker, G. A., and T. A. Burnham	2001	USA	Corn flakes	Mail survey data, consumers WTP 39.84% for non-GE.
Boccaletti, S., and D. Moro	2000	Italy – Northern	General	Phone survey data, consumers WTP 1.06% for non-GE; consumers WTP 6.63% more for GE tangible consumer benefit
Bredahl, L.	1999	Denmark, Germany, UK, and Italy	Beer and yogurt	In all four countries applying genetic modification was associated with unnaturalness and low trustworthiness
Bugbee, M., and M. L. Loureiro	2004	USA - Western	Tomato	Mail survey WTP 12.37% more for GE tangible consumer benefit
			Beef	WTP 32.6% more for GE tangible consumer benefit
Buhr, B. L., D. J. Hayes, J. Shogren, and J. B. Kliebenstein	1993	USA - Ames, IA	Pork sandwich	In experimental auctions, students WTP 14.44% more for GE tangible consumer benefit (10-20% leaner)
Burton, M., D. Rigby, Y. Trevor, and S. James.	2001	UK –Manchester	General	In-person survey data, consumers WTP 168.83% for non-GE.
Burton, M.and D. Pearse	2002	Australia	Beer	Younger consumers WTP $A 0.72 less and older consumers $A 0.40 less for beer made with GE barley.
Chen, H., and W. S. Chern	2002	USA - Columbus, OH	Vegetable oil	Mail survey WTP 6.5% for non-GE
			Corn flakes	WTP 14.5%
			Salmon	WTP 21.5%
Chern, W. S., K. Rickertsen, N. Tsuboi, and T. Fu	2002	USA - Columbus, OH	Vegetable oil	In-person survey data, Students WTP WTP 50~62% more for non-GE
		Norway – As	Vegetable oil	WTP 55~69% more for non-GE
		Japan –Tsukba	Vegetable oil	WTP 33~40% more for non-GE
		USA	Salmon (fed)	WTP 41% more for non-GE
		USA	Salmon (meat)	WTP 53% more for non-GE

Table 5—Study descriptors, consumer acceptance and willingness to pay for genetically engineered food (continued)

		Norway	Salmon (fed)	WTP 54% more for non-GE
		Norway	Salmon (meat)	WTP 67% more for non-GE
Curtis, K. R., and K. Moeltner	2006	Romania	Potatoes	Consumers WTP is 0.19
			Sunflower oil	WTP is 0.19
Gallup	2001	USA	General	52 percent support the application of biotechnology
Grimsrud, K. M., J. J. McCluskey, M. L. Loureiro, and T. I. Wahl	2004	Norway – Liertoppen	Bread	In-person interview grocery shoppers WTP 49.87% for non-GE. Consumers required discounts of 37-63 percent to buy GE bread
Hallman, W., W. Hebden, C. Cuite, and J. Lang	2006	USA	General	47 percent approved or leaned toward approval of the use of GE to make plant-based foods, 41 percent disapproved or leaned toward disapproval, and 12 percent were unsure.
Heller, R. (ed.)	2003	UK	General	Identified three statistically robust “attitudinal clusters” towards GE: Cluster 1 Implacably Opposed to GE, 47% of sample; Cluster 2 Somewhat Opposed to GE, 32 % of sample, and Cluster 3 No Fixed Position on GE 12 % of sample
Hoban, T.	1998	US	General	More than two thirds of American respondents are positive about plant biotechnology
Huffman, W., J. F. Shoegren, M. Rousu, and A. Tegene	2003	USA - Des Moines, IA and St. Paul, MN	Vegetable oil	In experimental auctions, consumers willing to pay 15.38% more for non-GE
			Corn chips	WTP 16.125%
International Food Information Council (IFIC)	2005	USA	General	In 1997 77% of consumers answered ' Total likely' to buy IR crops. By 2005 this % was 64%. For consumer enhanced GE crops these % were 66 for 1997 and 50 for 2005
James and Burton, 2003	2003	Australia - Western Australia	General - plant	Mail survey data, consumers WTP 18.2% for non-GE.
			General - animal	WTP 21.05%

Table 5—Study descriptors, consumer acceptance and willingness to pay for genetically engineered food (continued)

Kaneko, N., and W. S. Chern	2003	USA	Vegetable oil	Phone survey data, consumers WTP 20.49% for non-GE.
			Corn flakes	WTP 14.8%
			Salmon (fed)	WTP 24.8%
			Salmon (meat)	WTP 29.7%
Loureiro and Hine, 2002	2002	USA – Colorado	Potatoes	In-person interview with grocery shoppers WTP 5.55% for non-GE
Lusk, J. L.	2004	USA – Mississippi	Golden rice	Mail survey consumers WTP around 23 cents more for GE “golden rice” with added vitamin C
Lusk, J. L., J. Roosen, and J. Fox	2003	USA - Starkville, Mississippi	Corn chips	In-person survey students WTP 11.33% for non-GE; WTP -0.339% for tangible consumer benefit
Lusk, J. L., M. Moore, L. House, and B. Morrow	2002	USA - Manhattan, Kansas	Corn chips	In experimental auctions, students WTP 13% more for non-GE
Lusk, J. L., M. S. Daniel, D. R. Mark, and C. L. Lusk	2003	USA	Beefsteak	Mail survey data, consumers WTP 38.94% for non-GE.
		UK		WTP 74.24%
		Germany		WTP 90.24%
		France		WTP 109.6%
Lusk, J. L., W. B. Traill,L. House, C. Valli, S. R. Jaeger, M. Moore, and B. Morrow	2006	USA - Lubbock, Texas	Chocolate chip cookie	In experimental auctions, women mean WTA is between $2.44 and $2.13
		USA - Long Beach, California		WTA between $5.23 and $ 4.03
		USA - Jacksonville, Florida		WTA between $ 0.03 and $ 0.194
		UK – Reading		WTA between $ 4.82 and $ 3.58
		France - Grenoble		WTA between $ 8.51and $ 6.95
McCluskey, J. J., H. Ouchi, K. M. Grimsrud, and T. I. Wahl	2003	Japan - Matsumoto City	Noodles	In-person interview grocery shoppers WTP 60.34% for non-GE
Moon, W., and S. K. Balasubramanian	2001	UK	Breakfast cereal	56% of online survey panel of consumers willing to pay a premium to avoid GE

Table 5—Study descriptors, consumer acceptance and willingness to pay for genetically engineered food (continued)

		USA		35% of online survey panel of consumers willing to pay a premium to avoid GE
Nelson, 2001	2001	USA	General	Consumers are largely ambivalent about GE foods
Noussair, C., S. Robin, and B. Ruffieux	2004	France - Grenoble	Corn flakes	In experimental auctions, consumers willing to pay 29.63% more for non-GE
			Cookie	Experimental data, Random sample consumers WTP 51.01% for non-GE.
Onyango, B., Jr. R. M. Nayga, and B. Schilling	2004	USA	Beef and chicken	68% were willing to consume if fed on GE corn or soybeans
				49% were willing to consume if GE targeted food poisoning but had higher hormones
Pew Initiative on Food and Biotechnology	2003 & 4	USA	General	27 percent favor introduction of GE foods
Rousu, M., W. Huffman, J. Shogren, and A. Tegene	2004	USA - Des Moines, IA and St. Paul, MN	Vegetable oil	In experimental auctions, consumers WTP 5.263% more for non-GE
			Corn chips	WTP 10.294%
			Potatoes	WTP 12%
Tegene, A., W. Huffman, M. Rousu, and J. Shogren	2006	USA	Vegetable oil	In experimental auctions, consumers willing to pay 14 percent more for non-GE food.
Tonsor, G., and T. Schroeder	2003	UK – London	Beefsteak	In-person interview grocery shoppers WTP 101.61% for non-GE
		Germany – Frankfurt		WTP 29.589%
		France – Paris		WTP 32.369%
VanWechel, T., C. J. Wachenheim, E. Schuck, and D. K. lambert	2003	USA - Fargo, ND	Potato chips	In experimental auctions, consumers willing to pay 8.6% more for non-GE
			Cookie	WTP 0.067%
			Muffin	WTP 11.009%
Verdurme, A., and J. Viaene	2003	Belgium - Flemish speakers	General	15 percent opposed to GE foods
West, G. E., B. Larue, and R. Lambert	2002	Canada	Tomato	Phone survey data, consumers WTP 67% more for GE tangible consumer benefit
			Potato chips	WTP 63% more for GE tangible consumer benefit
			Chicken	WTP 24% more for GE tangible consumer benefit

Source: Fernandez Cornejo, 2006; Lusk 2005; authors' compilation

Building on Wang (2003), Zhang (2002), Zhong et al. (2003) and Zhou and Tian (2003), Huang et al. (2006) sampled a subset of the nationwide Urban Household Income and Expenditure Survey respondents, conducted personal interviews with over 1000 households in 11 cities of Northern and Eastern China. Using a survey instrument that had previously been applied in the USA, EU, Canada, and Korea, and careful interview approaches, they attained a high response rate. The authors found that despite awareness of genetically engineered foods, consumer knowledge was limited; however, Chinese consumers demonstrated a greater acceptance of and willingness to pay for genetically engineered foods than is evident in other countries. Zhang (2002) documents that in Tianjin city, highly educated and variety-seeking consumers will be the most likely to buy genetically engineered food products. Curtis and Moeltner (2005) report that Chinese consumers perceive low levels of risk.

Methodological limitations

Lusk et al. (2004) are able to demonstrate the fundamental point that the literature has reported estimates of consumers' willingness to pay for the GE attribute, conditional on the method employed by the researcher. The approach they recommend merits attention if it can be employed at lower cost to generate the minimum information needed within acceptable confidence intervals. Other limitations that need to be addressed include the following:

1. The food types and traits considered in the studies are clearly limited in number, and they are also heterogeneous in the sense that the final product may contain different proportions of ingredients derived from genetically engineered crops.
2. In most cases, researchers admit that stated preference approaches tend to overstate willingness to pay, suggesting that the discounts that must be applied

to make genetically-engineered food marketable have also been overestimated.

3. Revealed preference approaches, on the other hand, are known to suffer from statistical shortcomings and can only be implemented where genetically-engineered food products have already been marketed.
4. The fact that almost all published studies have been implemented in industrialized economies does not in itself suggest that the methods are inappropriate for consumers in developing economies. However, large-scale mail, phone or internet surveys are cheap compared to the personal interview format that would most likely be needed to study consumer preferences in developing economies.
5. In at least one case with voluntary consumer participation, there was also evidence of the same type of selection bias discussed under Question 1.

IMPACT ON INDUSTRY

Findings and methods

Most ex post or ex ante analyses of the size and distribution of economic benefits from adopting transgenic crop varieties in a nation are conducted with adaptations or versions of the economic surplus approach detailed in Alston et al. (1999). This approach is also termed a partial equilibrium displacement model because it considers only the effects of the technology change in the market where the technical change occurs. Effects in other markets, such as the input market, are disregarded. In the standard model, the estimated magnitude and distribution of the economic benefits depends on many factors. These include: the price elasticities of supply and demand for the crop, whether the country is a large or small producer (price setter or price taker), whether the country trades the crop internationally, the nature of the innovative change induced by the technology, the crop itself, and for genetic enhancement of agronomic traits, weather and pest infestations. Data are typically drawn from some combination of sample surveys of farmers, (field and greenhouse) trial data, and/or secondary data. The analysis may be conducted at the regional, national, or global level.

Several modifications of the basic economic surplus have been proposed to deal with specific conditions encountered in either developed or developing countries. When households are consumers as well as producers, as is often the case for food crops in developing agriculture, Hayami and Herdt (1977) made an adjustment to the basic model for subsistence consumption in a country that does not trade the crop. The adjustment partitions the aggregate supply curve into partial supply curves in order to estimate differential effects in the income of farmers. This procedure allows for distinct rates of technical change and adoption for the different producer groups, particularly those with different production sizes.

In another example, Moschini and Lapan (1997) proposed a theoretical framework to account for temporary monopoly conferred through IPR. Applying the Alston et al. (1999) and Moschini and Lapan (1997) theoretical framework to the case of Bt cotton in the US from 1996-1999, Falck-Zepeda et al. (1999, 2000a, 2000b) laid out a model that has since provided the foundation for economic surplus applications in developing economies.[8] This model has also served in further analysis of the crop biotechnologies in U.S. agriculture (e.g., Price et al. 2003).[9]

In developing economies, two other types of models have been used in the literature here reviewed. Huang et al. (2004) applied the GTAP (Global Analysis Trade Project) model to the Chinese national economy. Cabanilla et al. (2004) developed a linear programming model to estimate the impact of Bt cotton in West Africa. t. A summary of study descriptors is provided in Table 6.

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[8] The findings of studies conducted in the US are of interest, though they are not reported in the text. Falck-Zepeda et al. found that, over the 3 years studied, the innovator (Monsanto) and seed supplier (Delta and Pineland) and farmers shared almost equally in the benefits even in a temporary monopoly situation. Traxler and Falck-Zepeda (1999) explain that the monopolist must provide farmers with an adoption incentive by setting a price that makes the new input more profitable than existing options—a principle that is well established. Consumers gained very little, which is expected to be the case for agronomic traits as compared to product quality attributes. Price et al. (2003) reported that US farmers captured a much larger share of benefits for Bt cotton than for HT soybeans and HT cotton. For HT cotton, US consumers and ROW received the bulk of the benefits.

[9] Particularly in industrialized economies where supplementary databases can be consulted, numerous additions to the basic model have been proposed. Examples include adding spatial data on pest and disease incidence (Alston et al. 2002, for rootworm resistant maize in the U.S.), and a bio-economic model with stochastic simulation (Demont et al. 2004). A remaining subset of this literature includes several articles that recommend and/or apply the real options approach to address the issue of irreversibility in costs and benefits of genetically engineered crop varieties (e.g.,Wesseler 2002; Morel et al. 2002).

Table 6—Study descriptors, industry (sector) impact of genetically engineered crops

Authors	Year published	Crops	Data type	Scale	Country	Methods
Avila, A.F.D., T R. Quirino, E.Contini, and E L Rech Filho	2002	GM			na	
Cabanilla, L. S., T. Abdoulaye, and J. H. Sanders	2004	cotton		country	Mali focus, also Burkina Faso, Bening, Cote d'Ivoire, Senegal	linear programming, sensitivity
De Groote, H, Mugo, S	2005	maize	on farm trial data	country	Kenya	farm survey analysis, consumer survey analysis, direct crop loss estimation, consumer surplus, closed economy, participatory rural appraisal, brief
De Groote, H, Overholt, W	2003	maize	on farm trial data	country	Kenya	direct crop loss estimation, economic surplus, closed economy
Falck-Zepeda, J., N. Barreto-Triana, I. Baquero-Haeberlin, E. Espitia--Malagon, H. Fierro -Guzman, and N. Lopez.	2006	potato	on farm data, focus groups	sub-country	Colombia	economic surplus
Hareau, G, Mills,B	2004	rice	trade	country	Uruguay	economic surplus, small country, open economy, stochastic simulation, endogenous adoption
Kambhampati, U., S. Morse, R. Bennet, and Y. Ismael	2005	cotton	key informant	sub-country	India	supply chain analysis
Pachico, D., Z.Escobar, L.Rivas, V.Gottret, S.Perez.	2002	cassava		country	Colombia	
Pray, C. E., B. Ramaswami, J. Huang, and R. Hu	2006	cotton	key informant, government data	sub-country	China	cost analysis
Pray, C. E., P. Bengali, and R. Bharat	2005	cotton, also hybrid mustarnd and Bt eggplant	key informant	country	India	regulatory costs, social benefits, simulation
Pray, C., D. Ma, J. Huang, and F. Qiao	2001	cotton	statistical survey, key informant	sub-country	China	farm survey analysis, economic surplus
Qaim, M.	2001	sweetpotato	pilot survey, key informant	country	Kenya	farm survey analysis, economic surplus, closed economy, cost-benefit analysis, sensitivity
Qaim, M.	1999	potato	pilot survey, key informant	country	Mexico	economic surplus, small country, closed economy, benefit-cost, sensitivity
Qaim,M, Traxler, G	2005	soybeans	pilot survey, key informant	sub-country	Argentina	farm survey analysis, economic surplus, large open economy, three regions, institutional analysis

Table 6— Study descriptors, industry (sector) impact of genetically engineered crops

Authors	Year published	Crops	Data type	Scale	Country	Methods
Traxler, G., and S. Godoy-Avila	2004	cotton	statistical survey, key informant	sub-country	Mexico	farm survey analysis, economic surplus, small open economy, brief
Traxler, G., S. Godoy-Avila, J. Falck-Zepeda, and J.J. Espinoza-Arellano	2003	cotton	statistical survey, key informant	sub-country	Mexico	farm survey analysis, economic surplus, brief
Trigo, E., D. Chudnovsky, E. J. Cap, and A. Lopez	2002	soybeans, maize, cotton	government data	country	Argentina	adoption model, simulation model
Yorobe, J.M, Quicoy	2004	maize	statistical survey	sub-country	Philippines	farm survey analysis, adoption model, production function, producer surplus
Zimmermann, R, Qaim, M	2004	rice	statistical survey, key informant, government data	country	Philippines	DALYs, cost-benefit, simulation

Ex ante studies in developing economies

Ex ante analyses for developing economies include those conducted by Hareau et al. (2004) for HT Rice in Uruguay, De Groote et al. (2003) for Bt maize in Kenya, Cabanilla et al. (2004) in Mali, and a number of studies by Qaim on IR potatoes in Mexico, sweet potato in Kenya, and Bt cotton in India.

Hareau et al. (2004) add stochastic simulations and endogenous adoption to the economic surplus framework described above, using farmer survey data and secondary information. Uruguay's rice economy is small but involves trade. They project that the potential benefits are minor because of the small production base. Given the fact that multinational firms are not likely to develop locally adapted transgenic rice varieties without strategic partnerships with local institutions, they concluded that the genetically engineered trait would not pay.

Qaim (ZEF-ISAAA, 1999; AE 2001) applied the Hayami and Herdt (1997) adjustment for virus- and insect-resistant sweet potatoes in Kenya and virus-resistant potatoes in Mexico (ISAAA 1998, RAE 1999) in order to better represent the semi-subsistence nature of producer households in these countries. Qaim's findings suggested that VR and IR sweet potatoes would particularly benefit poorer Kenyan populations. In Mexico, Qaim concluded that the productivity-increasing potential for the VR potato is greatest for smaller-scale farmers, yet he warns about farmer access to planting material. Qaim noted that large scale farmers bought certified seeds every year for 33 percent of their total potato area, which means that there is complete seed replacement with transgenic material after three years for the respective varieties. Medium and small-scale farmers buy seeds annually for only 20 percent and 15 percent of their potato area, respectively, although seed exchange of varieties occurs via informal markets. Qaim's explicit reference to seed systems is one of the few in this literature, though seed and information systems are known to pose major challenges for the adoption of any improved variety, and particularly genetically engineered crops (Tripp, 2001).

Massieu et al. (2000) criticized Qaim's assumption that conventional varieties would be completed replaced by a red potato variety ("Rosita") in the study area, arguing that production alternatives were available to farmers and that production of a single variety would not be promoted because of its impacts on agricultural biodiversity. They also point out that the assumption of a public delivery system of potato seed developing in Mexico was inappropriate since it did not then exist.

The analysis by De Groote et al. (2003) and Mugo et al. (2005) for insect resistant maize in Kenya, are straightforward applications of the economic surplus approach backed by detailed farm level data about production practices and on farm trial data measuring crop losses. The authors highlight a policy dilemma that the Kenyan government may choose to consider. About 80 percent of the estimated value crop losses to stem borers in Kenya accrue in the moist transitional and highlands zones, where adoption rates for maize hybrids are greatest and the nation's surpluses are produced. Only 12.5 percent of the national value of crop losses to stem borer occurs in the lower potential, dry and lowland tropics zones. The estimated marginal value per hectare from Bt insertion, however, is equal in the high and low potential zones (De Groote et al., 2003). Although maize yields are much higher in the high potential zone, losses to *Chilo partellus*, against which Cry proteins were found to be very efficient, are considerably less. The distribution of stem borer species indicates that the foremost species in the higher potential zone is *Busseola fusca*, for which an effective Bt protein has not yet been identified. Furthermore, the equity impact of developing materials for the low potential zones could be substantial, since these farmers have fewer alternative sources of income and are generally unable to meet their maize subsistence requirements from their own production.

Cabanilla et al. (2004) develop a linear-programming model to assess the potential cost to West Africa (in particular, Mali) of not adopting Bt cotton. Parameters are drawn from detailed farm-level studies already conducted in Mali, and published experiences in China, South Africa and Mexico. On their representative farm, they include groundnut and cereals cultivation to meet subsistence needs. Application of the model generates estimates of optimal land area allocations, output, farm profit, and whole farm income. They then aggregate their findings to the national level and conduct sensitivity analysis, introducing the effects of various technology fees. Their results indicate that even with a technology fee, there are large benefits that would be foregone without the adoption of Bt cotton, including more stable farm income. At the level of the fee charged in South Africa, however, groundnuts and non-Bt cotton are no longer produced. They point to important institutional factors, such as whether the technology will be imported, adapted, or generally adapted.

Ex post studies

The first ex post study reviewed was conducted by Pray et al. (2001) on Bt cotton in China. Based on the Falck-Zepeda et al. (2000) approach, for a single year of data, Pray et al. found substantial economic benefits for smallholder farmers and no consumer benefits because the government bought almost all of the cotton at a fixed price. Because of weak IPR, farmers obtained the major share of the benefits, with very little accruing to Monsanto or the public research institutions that developed local Bt varieties. The first paper by Pray et al. was later expanded with other papers detailing different impact assessment issues while documenting relatively the extensive experience of China with the adoption of Bt cotton (see Huang et al 2002 and other papers cited under Question 1).

Huang et al. (2004) applied the GTAP (Global Trade Analysis Project, see Question 3) with detailed factor-specific information and primary survey data to estimate the economy-wide impacts of Bt cotton and Bt rice given various policy scenarios regarding trade bans and labeling. In the most optimistic scenario, with both Bt cotton and Bt rice, the total welfare gains they estimated were 5 billion US. Their analysis illustrates how the effects of adopting genetically engineered crop varieties differ between a food crop that represents a large sector of the economy and a cash crop that occupies a more minor position. Because the food staple (rice) has low demand elasticity with respect to price, consumers can spend their increased income and money on other products. These income effects increase demand from other sectors of the economy. Indirect effects are not observed as much for cotton, though there are positive income effects for farmers, health effects, and forward linkage effects on the domestic textiles industry. The domestic textiles industry serves a large export market and generates foreign exchange earnings.

The remaining ex post studies have been conducted for cotton in Mexico and soybeans in Argentina by Traxler and colleagues. Based on survey data for a 1997-1998, Traxler et al. (2003 and 2004) find that Bt cotton reduced costs and raised revenues for farmers in the Comarca Lagunera in North-Central Mexico, such that “cotton has become a low pesticide crop, benefiting both farmers and residents of the region" (p. 61). They estimated that seed suppliers and innovators earned an average over the two years of the study of only 15 percent of the benefits from adoption, while farmers earned the remainder. The authors assert that the risk of crop failure has declined with the use of the Bt cotton technology.

In Argentina, Qaim and Traxler (2005) combined farm survey data from three regions (but a small sample), institutional information, and secondary data for 1996-2001 to examine the impacts of HT soybeans. The US and Argentina gained economic benefits while the non-HR producing countries of the world lost them. Farmers in Argentina gained more than US farmers as a share of the total benefits because of weaker IPR protection. An interesting detail is that some of the model parameters they employ are those estimated for the US, reinforcing the perception that soybean producers in Argentina are relatively large-scale, fully commercialized growers. They attribute the success of the technology in Argentina to: a) a suitable agro-ecology; b) a strong seed sector that sold a lot of seed even though IPR was weak and there were black market sales, c) adaptive research capability, and d) a functioning regulatory framework. These are key factors that govern how benefits derived from gene events produced in one country spillover to other potential adopting countries.

Methodological limitations

Scatasta et al. (2006) and Alston et al. (1995) have pointed out the advantages and limitations of the economic surplus approach. The major advantages are that the methods are parsimonious with respect to data and can be used to portray the distributional effects of various institutional and market structures. The principal disadvantages are:

1. The surplus calculated is Marshallian, accounting for price effects but not for changes in the income of farmers.
2. The approach ignores transactions costs, assuming that markets clear and function perfectly.
3. As with any partial equilibrium model, they fix prices and quantities of other commodities produced by farmers.
4. Effects on input markets are unclear, and in particular, they do not account explicitly for returns to land and labor, which are important factors for measuring the impact of new technologies.
5. Furthermore, farmers are considered to be risk-neutral, price-takers who either maximize profits or minimizing costs.
6. As in farm-level studies (Question 1), year-specific effects on productivity can be large but are not accounted for in single-year, ex post studies. Location-specific effects on the farm budget data that serve as the basis for some parameters can also be large. These aspects are salient for production systems in developing countries where crop management practices and conditions are so heterogeneous.

In other words, the assumptions best depict an industry with commercially-oriented farmers who buy and sell in well-organized markets and grow their crop under relatively homogeneous conditions.

The quality of the underlying data is crucial to the validity of the results. In general, reliable cross-sectional time-series data are not yet available for these technologies in developing economies because they are too costly. In contrast, in the US, extensive surveys have been conducted continually (e.g., the ARMS survey on which many of the detailed analyses are based), and cheaper methods are feasible (mail and phone interviews). “Pure” ex ante analyses (with no field observations) are even more limited, since all model parameters must be projected based on expert interviews and existing secondary data. Nonetheless, it should be remembered that adaptations are feasible to treat some of these challenges, and this type of estimation provides the type of information that most national policy makers require.

IMPACT ON TRADE

Findings and methods

Nielsen et al. (2003) reviewed empirical trade studies of the introduction of genetically engineered crops, but several new studies have been published since then. Aside from purely theoretical treatments, or more cursory forms of forecasting (Brookes and Barfoot 2003; Paarlberg 2006), there are two major categories of applied trade models. The first category use partial equilibrium models that model one or several sectors of the economy in a few countries, focusing on particular vertical or horizontal linkages. They have the advantage of being more flexible, which enables the representation of a more complex set of institutional and market policies. However, they do not take into account the linkages with multiple sectors and specific regulations affecting bilateral trade relationship with sensitive importing countries. The second type uses multi-country general equilibrium models. These models provide a consistent and comprehensive structural representation of the economy and of international trade linkages, but because they are highly aggregated and based on important assumptions about the market, they are less conducive to representing specific policies and institutional arrangements.

The partial equilibrium approach is applied in several articles by Moschini and Sobolevsky. Moschini et al. (2000) examined the welfare effects of HR soybeans and various IPR scenarios in a partial equilibrium, three-region model composed of the US, Brazil and Argentina, and the ROW (rest of the world). Their results suggest that the US gains most, with the innovator capturing the largest share of the gains. US farmers gain too, but not if the innovation enhances yields. Technology spillover to Latin America erodes the competitive position of US soybean producers. With weak IPR in Latin America, profits from sales of the new technology just offset the loss of US producer welfare. Consumers in every region gain from adoption of HR soybeans.

Based on secondary data and the findings from the application of this model, Moschini (2001) underscored the role of disparities in IPRs across countries in the distribution of benefits from adopting biotechnology innovations. IPRs are perceived to be necessary to address market failures in research and development of improved germplasm, leading to some efficiency losses. Yet, exercise of market power reduces benefits of adoption because the innovation is not used "as is socially desirable…. Consumers gain less, and farmers' welfare is reduced. Innovators gain more." (p. 113). He adds that consumer resistance, labeling and market segregation complicate the economic evaluation of these technologies.

Sobolevsky et al. (2005) use a partial equilibrium trade model but include product differentiation and the costs of identity preservation in segregating markets. This approach generates some unexpected findings and new hypotheses. The authors examine the trade and welfare effects of HT soybeans on the US, Argentina, Brazil and ROW (rest of the world). Consumers in the importing region view GE soybeans and products as weakly inferior substitutes. Sobolevsky et al. (2005) find that in a world where no segregation is feasible, the long run equilibrium is worldwide adoption. This leads to lower prices with the U.S. leading in exports and all regions and economic agents gaining except U.S. farmers. When segregation technology is available at a cost, the US emerges as the only region with partial adoption, and all other regions specialize in HT soybeans. Output subsidies cause a welfare reduction to the U.S. and only the ROW gains because it offsets the distorted prices caused by monopoly in the innovation. With import bans by the ROW and Brazil, Brazilian farmers would benefit and the ROW could benefit if segregation costs are not too low.

Berwald et al. (2006) use another partial equilibrium trade model to study the global and regional welfare effects of adoption or non-adoption of HT wheat in the United States and Canada. In addition to these two countries, Argentina and a region grouping major wheat producers in the developing world are included in the simulation. The model features heterogeneous consumers (differentiated by region, type and taste), segregation costs, and the effects of two types of labeling regulations for GE food in major trading countries. Labeling affects world prices and consumer shares purchasing GE or non-GE wheat. Berwald et al. (2006) find that Canada and the United States will face significant welfare losses if they do not adopt GE wheat while Argentina and other wheat producers do. Their results also show that most gains from GE wheat adoption would occur in the developing world, but all adopting countries gain despite the barriers to entry in sensitive importing countries. They conclude that the decision of North America to reject GE wheat "supports the misleading argument that market segregation is absolutely impossible and that sensitive markets should dictate choices over agricultural biotechnology".

Fourteen distinct published articles apply general equilibrium models. All fourteen articles use a modified version of a computable general equilibrium model based on the GTAP data base (Hertel 1997) that includes vertical and horizontal linkages in the economy. This modeling framework is used to examine the effects of GE technology adoption on multiple sectors and regions. They differ by their assumptions about the productivity effects of the technology, the rate of adoption, and according to the scenarios they depict concerning trade policies, consumer perceptions, and the structure of the non-GE/GE market chain. Overall, these papers can be divided into four groups according to their successive contribution to the improvement in the evolution of the modeling methodology.

Two papers led the way in evaluating the economy-wide international effects of GE crop introduction. Nielsen et al. (2001) studied the introduction of GE soybeans and maize in seven regions. They modeled the technology with a 10 percent Hicks-neutral productivity shift of primary factors, with costless segregation of GE and non-GE food and consumer price sensitivities differences by adjusting demand elasticities of substitution between GE and non-GE. They show the effect of changing consumer acceptance on the different market factors in developing countries. In parallel, Nielsen and Anderson (2001) provided a global study of the introduction of GE soybeans and maize in a larger number of countries and regions, using a 5 percent Hicks-neutral productivity shift on factors and intermediate consumption to model the effect of the technology. [10] They simulated scenarios that show the effects of a 25 percent decrease in consumer demand in sensitive countries or an EU ban of imports of GE food.

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[10] Nielsen and Anderson (2001), and authors of papers following them believe that 5% is a conservative estimate of the potential of the technology. Yet this opinion is not shared by all. For example, Felloni et al.

A second group of papers provided slight refinements to the methodology. Stone et al. (2002) focused on Australia within a multi region world, and modeled the introduction of GE maize and soybeans based on updated data, using more accurate productivity shifts (6 percent for oilseeds and 7.5 percent for others), more realistic national adoption rates, and consumer demand changes, as well as regulatory costs. Nielsen et al.(2003) used their former model to study the effects of consumer acceptance on the benefits of GE food by combining the two modeling options pursued before: they vary price sensitivity and add utility shifts (consumer acceptance) to show how consumer acceptance can affect results and improving the segregation of GE and non-GE. Anderson and Yao (2003) focused on China and applied the same method to cotton, maize and soybeans, with an additional a scenario that eliminates the Chinese voluntary export restraint on textile. Anderson and Jackson (2003) used the productivity shifts of Stone et al (2002), and consider various trade restrictions in the case of GE soybeans and maize introduction to focus on the political economic implications of the EU-US regulatory differences.

Third, van Meijl and van Tongeren (2004) provided a study of GE introduction in the EU and United States with a change of methodology. The change reflected a significant criticism of the Nielsen and Anderson (2001) approach. They replaced Hicks-neutral shifts by factor-biased productivity shifts for cereals and introduced technology spillover. The authors also included a more realistic representation of the European Union's Common Agricultural Policy (CAP) by including the isolation of EU countries from world prices. Despite its ongoing reform, several CAP programs contribute to the

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(2003) show that in order to assure grain self sufficiency, plant biotechnology would have to result in an annual 4% productivity shift, which they believe is very unrealistic.

disconnection between world prices and EU prices. Van Meijl and van Tongeren show that because they did not take this situation into account, Nielsen and Anderson (2001) largely overestimated the negative welfare effects of an EU import ban on EU consumers.

The fourth and latest group of published studies focused on specific regions and commodities. Authors employ more realistic assumptions with mixed, Hicks-neutral/factor-biased productivity shifts and additional layers of complexity. Huang et al. (2004) analyzed the effects of GE cotton and GE rice introduction in China, based on regional farm-level survey data, adding labeling costs, loss of demand in export markets, and dynamic adoption, but without adoption of these crops in any other country. Elbehri and MacDonald (2004) evaluated the potential effects of Bt cotton in West and Central Africa based on a careful analysis of productivity effects in the region (using farm and national budgets) and comparing various productivity shifts. Anderson et al. (2004) evaluated the effects of GE rice introduction (Bt and Golden Rice) in developing countries, with updated assumptions about factor-biased productivity and potential moratoria in Europe and South-East Asia. Anderson and Jackson (2005) used the same framework to focus on the introduction of rice, wheat, maize and soybeans in Australia and New Zealand under various trade scenarios. Hareau et al. (2005) evaluated the effects of three different GE rice events (Bt, herbicide tolerant and drought tolerant) with factor-biased productivity shifts, accounting for intra-national differences in land type, but without including any trade policies. Finally, Anderson, Valenzuela and Jackson (2006) evaluated the effect of Bt cotton introduction in Sub-Saharan Africa with or without WTO trade reform using an updated GTAP database and much more extensive economy representation. Study descriptors are shown in Table 7.

Table 7—Study descriptors, impact of genetically engineered crops on international trade

Authors	Year published	Crops	Data type	Scale	Country	Methods
Anderson, K, Jackson, L	2004	rice	trade	global, focus on Asia	na	applied general equilibrium model
Anderson, K, Jackson, L	2005	rice, coarse grains, oilseeds, wheat	trade	global, focus on SSA	na	applied general equilibrium model
Anderson, K., and S. Yao.	2003	rice, maize, cotton, soybeans	trade	global, focus on China	China	applied general equilibrium model
Anderson, K., C. P. Nielsen, R. Sherman, and K. Thierfelder	2001	GM	trade		na	applied general equilibrium model
Anderson, K., E. Valenzuela, and L. A. Jackson	2006	cotton	trade	global, emphasis on SSA	Global	applied general equilibrium model
Annou, M M., F.H. Fuller, E.J. Wailes	2005	rice	trade	global	na	Arkansas Global Rice Model
Berwald, D., Carter, C.A. and G. P. Gruere	2006	wheat	trade	global, focus on USA and Canada	USA, Canada, Argentina	partial equilibrium world trade model, segregation, voluntary and mandatory labeling
Diaz Osorio, J., R.Herrera, J.Valderrama, J.L.Llanos Ascencio	2004	maize	company data	country	Chile	partial equilibrium
Elbehri, A., and S. Macdonald	2004	cotton	trade	global, focus on WCA	Benin, Burkina Faso, Chad, Mali, Togo, Cote d'Ivoire, Cameroon, CAR	applied general equilibrium model
Felloni, F., J.Gilbert, T.I.Wahl, P.Wandschneider	2003	grain	trade	global, focus on China	China	applied general equilibrium model, recursive dynamic
Hareau, G, Mills,B	2005	rice	trade	global, focus on Asia	China, India, Indonesia, Bangladesh, Vietnam, Thailand, Philippines, Japan	applied general equilibrium model
Huang, J., R. Hu, H. van Meijl, and F. van Tongeren	2004	cotton	statistical survey, field trials, trade	global, focus on China	China	applied general equilibrium model, modified GTAP
Moschini, G	2001	multiple	trade	global	na	review, findings, world trade model, brief
Nielsen, C, Anderson, K	2000	maize, soybeans	trade	global, selected countries	na	applied general equilibrium model
Nielsen, C, Thierfelder, K	2003	maize, soybeans	trade	global	na	multi-region computable general equilibrium model

Table 7— Study descriptors, impact of genetically engineered crops on international trade

Authors	Year published	Crops	Data type	Scale	Country	Methods
Nielsen, C.P., K.Anderson.	2001	maize, soybeans	trade	global	na	applied general equilibrium model
Nielsen, C.P., Robinson S, K.Thierfelder	2001	maize, soybeans	trade	gobal	na	applied general equilibrium model
Paarlberg, R	2006	GM	trade	multi-country	na	review, calculations with secondary data
Sobolevsky, A, Moschini, G, and H. Lapan	2005	soybeans	trade	global, focus on US, Argentina, Brazil	Argentina, Brazil	partial equilibrium world trade model, segregation, import bans

Methodological limitations

Only a few published articles used partial equilibrium simulation models to evaluate GE crop introduction, and even less focus on developing countries. In addition to building customized models of existing regulations and segregated markets for GE and non-GE crops, the modelers have to obtain relevant data to make realistic assumptions about the parameters that determine the effect of the regulations at the international level and more specifically in developing nations. For instance, it is difficult to obtain data about the demand for GE or non-GE crops given the product-specific nature of labeling regulations in major OECD importers. Assumed segregation costs are based on studies mostly conducted in industrialized countries. Furthermore, simulations in partial equilibrium rely on relatively simplistic assumptions on the adoption and the productivity effects of the technology. Overall, this field of studies will be strengthened with better representation of the technology effects and improved calibration on the effects of trade related regulations. Future studies would benefit from using the improved models developed at the industry level to represent the productivity effects of the technology as a basis for studying the effects of international differences in trade related regulations.

The progressive improvement in applied general equilibrium modeling in the published literature has resulted in the deflation of the computed welfare effects associated with the introduction of the technology. Initially, the world gains with GE introduction amounted to $10 to $12 billion with soybeans and maize, but the more recent models estimate these gains to be about $4-7 billion with the same GE crop as well as cotton and rice. More realistic assumptions concerning productivity shifts, adoption rates, the updated GTAP database with more realistic economy linkages on the one hand,

and segregation, demand and trade-related regulations on the other, have improved the accuracy of the results. Yet, several key methodological issues remain:

1. None of the published studies make an effort to adjust for the aggregated sectors of the GTAP database: to model the introduction of maize, they induced technology shifts on the cereal sector of GTAP, which excludes wheat and rice, but also includes many other significant crops, such as barley, sorghum, and millets, among others. Similarly, the oilseed sector of GTAP is used for introduction of GE soybean, thus neglecting rapeseed, mustard and others; the GTAP plant-based fiber sector represents only cotton, despite the fact that jute and linen can represent a significant share of production in this sector.
2. Stone et al (2002) is the only study to have introduced a temporary cost of segregation for non-GE, and none of the papers model the real situation with pure non-GE as opposed to GE and non-GE mixed commodity trade.
3. Trade regulations on GE food are represented by moratoria in the EU, Japan or South Korea, when in fact these countries do import very large volumes of undifferentiated soybeans and/or maize from GE producing countries for animal feed and non-food uses.
4. Illegal seed markets that result from the introduction of new GE crops are not represented, although certain countries are known to have loose controls at borders.
5. Despite the great improvement in productivity modeling, there is still a lot to do to improve the models according to regional differences, labor effects, land types, and seed prices.
6. Consumer acceptance and labeling effects may need some refinements.
7. There is no effort to model market imperfection in the input sector.
8. Adoption rates are exogenous and somewhat arbitrary. Modeling adoption in as endogenously determined in a dynamic framework would improve the utility of these models.

These limitations call for as many improvements in the methodology. While applied general equilibrium evaluations can be improved through use of more realistic field and regulatory data, some of the issues of policy interest may be difficult if not impossible to model within already complex macroeconomic models of international trade. Overall, if all these issues were successfully tackled, a relative slight decline in the estimated welfare effects associated with the introduction of GE crops would be expected, thus reflecting a lower productivity shift counterbalanced by less stringent trade regulations than what has been used so far in published articles.

CONCLUSIONS

An exhaustive review of peer-reviewed, applied economic literature about the impacts of genetically-engineered crops in non-industrialized agriculture leads us to several general conclusions. As expressed in publication counts, agricultural economists have focused relatively more attention on assessing impacts at the farm level. Among crops, case studies of IR cotton in China, South Africa, and India have dominated the literature. Other than IR cotton, only IR maize and HT soybeans have been analyzed ex post, since these are the technologies that have been widely diffused so far. Studies of consumer acceptance have been conducted primarily in industrialized agricultural economies, or in China. Since the most intensive field research has been conducted in only a handful of locations, crops, and traits, most with very small sample sizes and a narrow range of authorship, findings cannot be generalized.

We have mentioned a number of methodological limitations that are apparent in the literature, many of which are recognized by authors, and most of which are common to any impact analysis. Clearly, economists have applied increasingly sophisticated analytical methods, and, in general, the initial enthusiasm for the technology has been superseded by a more cautious weighing of economic advantages and disadvantages by crop and trait.

On the one hand, the balance sheet of this “reduced form” literature is fairly consistent with the broader literature about the impacts of new crop varieties in agriculture. First, any particularly variety, even if widely adapted, will perform with considerable variation across location and time. Second, the net economic impact of new crop varieties on society is not easily measured. No single method is in and of itself sufficient to analyze the impacts of seed technical change. Third, the length of the time period of observation of adoption and use matters for assessment of impact, since discontinuities in adoption are common where markets function poorly, production environments are variable, or economic policies shift dramatically from one year to the next..

Fourth, the institutional and social context of technology introduction is often of greater significance for determining the direction and magnitude of impacts than the effectiveness of any particular trait. In fact, the necessary conditions for smallholder farmers to benefit from genetically engineered crops exist in few countries (FAO 2004, Chapter 4). Given this fact, there are marked gaps in this first phase of literature with respect to analysis of institutions and market function.

Finally, the next wave of economics studies will need to look more critically at impacts on labor, health, environment, equity, and poverty—which have not yet received rigorous treatment in the peer-reviewed, applied economics methods.

On the other hand, some aspects of impact analysis for genetically-engineered crops are unique, though much of what is unique is unrelated to the technology itself. For example, the technology is knowledge-intensive in the development phase, in mounting the regulatory framework needed to release it to farmers, and in terms of farmer understanding of the technology. For agronomic traits such as pest and disease resistance, the chances of sustained, high returns improve with the adoption of the resistant variety as farmers' management practices are fine-tuned to account for secondary pests and resistance evolution. Yet, integrated pest management is also knowledge-intensive, whether or not it is associated with a genetically-engineered crop variety. Furthermore, some argue that embodying the pesticide or insecticide in the seed removes much of the uncertainty or risk in timing and intensity of chemical applications, particularly for less literate or poorly informed farmers.

Health and environmental hazards, ethical considerations, and the involvement of civil society in an active debate distinguish genetically-engineered crop varieties from other modern varieties. Thus, risk assessment and analysis of regulatory frameworks and their potential impact play a much larger role than would otherwise be the case. We do not consider these here. The significance of consumer attitudes against GM technology in general (as compared to more common questions of product quality, tastes and preferences) leads to the need for more advanced consumer analysis as part of the technology assessment. The structure of the industry entails the need to develop models that account for transfer fees and rents from non-competitive market structures. Trade models must take segregated markets and other policies into account for genetically-engineered crops that are sold on world markets. Thus, at present, the overall complexity of the impact analysis is much greater with GE varieties as compared to other modern varieties.

The gradual evolution of the methods, and a changing picture as findings accumulate, provide some insights into "best practices" in terms of disciplinary excellence. Some elements of best practices from the perspective of disciplinary excellence are proposed in Annex 1. In terms of economic surplus approaches, there is need for more robust sensitivity analyses and the incorporation of lessons learned from biophysical models, such as input/output abatement for insect resistant crops, especially within an ex-ante economic surplus industry level framework. In addition, issues specific to GM biotechnology innovations such as intellectual property considerations, imperfect markets and the merging of two distinct bodies of knowledge (plant breeding and molecular biology) embedded in the seed, needs to be taken into account. In the farm-level analysis, treatment models should be explored. Methods of environmental valuation are needed to investigate externalities. Most recent advances in choice modeling are needed for analysis of consumer attitudes, and some of these can be adapted to research in developing economies. More nuanced trade models are feasible, and international studies should better incorporate trade related regulations affecting developing countries in partial and general equilibrium modeling frameworks. In order to attain disciplinary excellence, researchers need to recognize the advantages and disadvantages of each approach and ensure that the assumptions invoked are transparent.

There is little doubt that multiple, applied economics approaches as well as pluri-disciplinary approaches will also be part of a "best practices" portfolio for national researchers seeking to inform decision-makers in developing economies. Furthermore, criteria other than disciplinary excellence should be taken into consideration. For example, budgetary constraints and the timeliness of research results will be decisive.

Further research on this project will seek to propose and apply a framework with takes these factors into consideration.

ANNEX 1

Some elements of a proposed approach, based on the criterion of disciplinary excellence only

Approach	Data requirements
Impact on farmers	
1. Stochastic budgets (partial and whole farm) to calculate returns to labor, enterprise, and farm while taking risk and uncertainty into account; household farm modeling	Structured survey instruments that include monitoring of labor use, agronomic practices, and use of all chemical inputs
2. Gender and collective action analysis	Range of structured to less structured instruments
3. Treatment or selection model that accounts for both sample selection bias and program placement, testing impacts on poverty and vulnerability .	Requires either areas where adoption has and has not occurred or on-farm trials; dictates the sample design and statistical model used to measure impacts
4. Production function with input/output damage abatement, economic threshold or economic injury models. Include biophysical modeling of pest resistance evolution, to quantify the separate and combined impacts on productivity and pesticide use	Data in point 1.
5. Analysis of farmer attitudes toward GE crops and willingness to pay (accept compensation for) GE and other variety attributes	Stated preferences or combined stated and revealed preference methods (e.g., Birol and Rayn, 2006)
6. Measurement of environmental externalities	Improvements in measurement n
7. Measurement of health effects	Improvements in measurement
Impact on market	
1. Participatory value chain analysis	Market channel maps, structure and performance analysis
2. Institutional analysis in inputs markets and regulations	Institutional economics, political economy (existing literature, update assessments)
3. Analysis of consumer attitudes and willingness to accept compensation for GM products, with latent class model	Choice experiment

Impact on industry	
1. Application of stochastic economic surplus models	Use prototype economic surplus created in Phase I with better field data obtained from farm and market data shown above.
2. Equilibrium displacement (surplus) models	Incorporate modeling techniques, approaches, and (imperfect) market structures based on farm and market analysis; explicitly into equilibrium displacement (surplus) models
Impact on trade	
1. Partial equilibrium models with disaggregated effects of trade related regulations of GM products, accounting for segregated markets and imperfect competition	Demand parameters, cost of specific regulations, international market parameters.
2. Augmented computable general equilibrium; consider dynamic adoption, seed premia, imperfect competition, and non-GM segregation; check fair trade and organic production issues; consider trade reform	Data on productivity changes in each region of each country of study; data on non-GM production and consumption worldwide

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