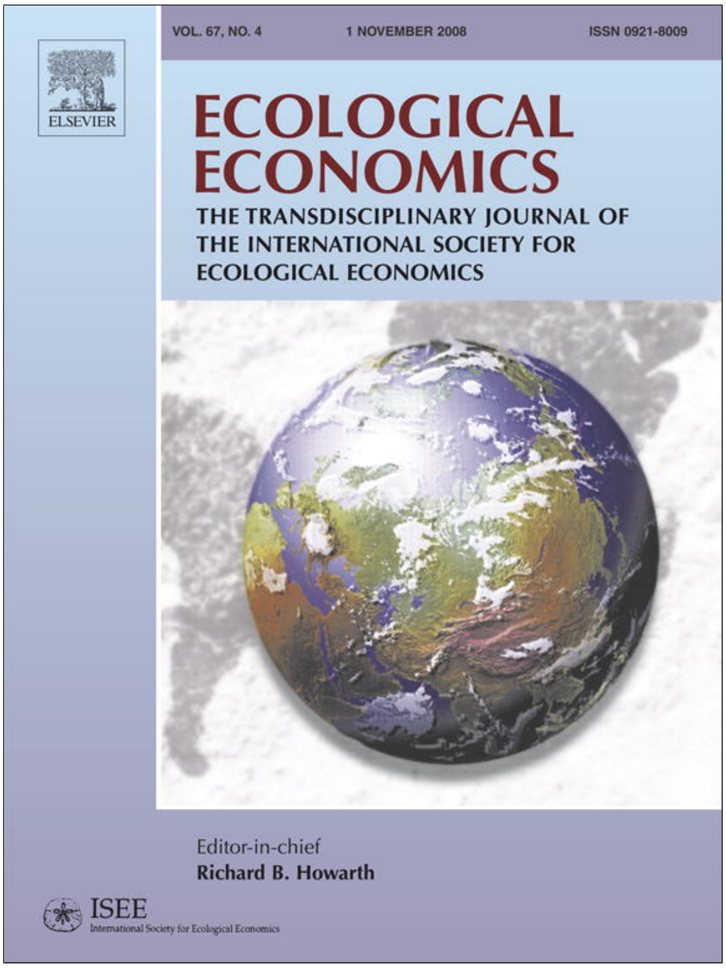
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ANALYSIS

Testing assumptions underlying economic research on transgenic food crops for Third World farmers: Evidence from Cuba, Guatemala and Mexico

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ABSTRACT

Transgenic crop varieties (TGVs) are being promoted as essential for improving small-scale Third World (SSTW) agriculture. Most economic research on this topic makes critical, untested assumptions, including that farmers will choose TGVs over other varieties because TGVs are economically optimal and because farmers are risk neutral profit maximizers. We tested these assumptions using data from a survey of 334 farmers in 6 communities in Cuba, Guatemala and Mexico in which farmers ranked 4 real and hypothetical maize varieties for eating and sowing. Our results did not support these assumptions. Most farmers preferred farmer varieties for sowing and especially for eating, avoiding TGVs, a preference associated with being risk averse and with non-monetary preferences. Farmers more integrated into modern agriculture were more likely to choose TGVs. These results suggest that farmers most in need of support and most important for conserving genetic diversity are least favorable toward TGVs, and that alternative ways of improving SSTW agriculture should receive more attention.

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1. Introduction

Small-scale Third World (SSTW) agriculture is necessary for feeding a significant proportion of the world population now, and will likely be necessary in the future, even with production increases in large-scale, industrial agriculture (Hazell et al., 2007). More than 2 billion people live on almost 500 million small-scale (less than 2 ha) farms in the Third World, including half of the world's undernourished people and the majority of people living in absolute poverty (Nagayets, 2005). Economic restructuring beginning in the 1980s removed government support for SSTW agriculture and led to migration from rural to urban areas, creating a crisis there (Hazell et al., 2007; Narayanan and Gulati, 2002; Wise, 2007). In addition to irreplaceable food production, SSTW agriculture has other benefits—it includes many of the world's centers of crop genetic diversity which farmers conserve *in situ*, along with rich cultural and linguistic traditions (FAO, 1996; Harlan, 1992). Thus, ways to support and improve SSTW agriculture are urgently needed.

Transgenic crop varieties (TGVs) are currently being promoted as one of the best ways to do this. TGVs are a rapidly growing agricultural technology, with area planted increasing 12% from 2006 to 2007 to 114.3 million ha (James, 2008),[2] or ~8% of cultivated land globally (calculated from FAO, 2007). TGVs grown today are primarily targeted to industrial agriculture and designed to enhance yield and net profit for farmers by directly reducing pest damage or facilitating herbicide use. Globally most of the area planted in TGVs is in large-scale industrial agriculture, but most of the farmers are in the Third World. Of the 23 countries growing TGVs in 2007, 12 were "developing" countries—estimated to account for 43% of the area planted and 90% or 11 million of the farmers growing TGVs, with 99% of these (10.9 million) in China and India, growing mostly *Bt* cotton (James, 2008). Currently, TGVs of food crops for Third World farmers are planned, being developed, in field trials, or approved and in production. A number of studies have evaluated their potential and actual impact, though small in number compared with studies on cotton TGVs.

Most major international development organizations and the governments of many major industrial nations, as well as the major biotechnology companies, strongly support TGVs as a key for the improvement of SSTW agriculture. There also appears to be a growing consensus about TGVs and SSTW agriculture within much of the development economics literature. Indeed, a number of economists working in development believe a consensus that TGVs are essential for the improvement of SSTW agriculture has already been achieved, e.g. "Development professionals have increasingly agreed to something like a standard narrative of biotechnology…an optimistic but cautious consensus" (Herring, 2007:7). Institutions adhering to this consensus frequently base their policies for SSTW agriculture on economic research about TGVs that is in turn based on assumptions which are controversial within the field of economics.

[2] This is the most widely cited source for data on TGVs in the Third World; James is the chair of the board of directors of the International Service for the Acquisition of Agri-Biotech Applications, an organization whose mission is to promote TGVs in the Third World and which publishes these annual reports.

In this article we test two key research assumptions using data from interviews with farmers in Cuba, Guatemala and Mexico, whose main crop is maize (*Zea mays mays*), one of the most important food crops in the Third World. This is the first published research on food TGVs that elicited preferences across a wide range of varieties for both eating and sowing among predominantly self-provisioning, SSTW farmers (hereafter simply "farmers") in areas which include the center of origin and centers of diversity for an important food crop. Our goal is to contribute to a more rigorously scientific discussion of the potential of TGVs for SSTW agriculture compared with possible alternatives, which is critical for a wider discussion about the goals for SSTW agriculture and the investment of limited resources to realize those.

2. Two key assumptions in economic research about TGVs that influence agricultural policy

Two of the most important assumptions in the economic research about TGVs and SSTW farmers are: 1) rational farmers will choose TGVs over other crop varieties because they are the product of the best science and the market place and will therefore maximize farmers' utility in monetary terms (i.e. profit), and 2) farmers are risk neutral and therefore seek to maximize their average profits, rather than minimize the variance in their profits, or avoid years with very low profits. To date, economic research on TGVs and SSTW farmers that we are aware of does not include farmers' experiences with or preferences toward alternatives to TGVs, or toward possible risks of adopting TGVs.

These assumptions are commonly used in development economics research on TGVs because they are simplifying and make complicated research questions tractable (e.g., Huang et al., 2004:44), even though many economists accept the increasing evidence that they are not valid (Gowdy and Erickson, 2005:209). Still, to the extent these assumptions are unjustified, they need to be tested in order to strengthen scientific knowledge as the basis for policy. Will TGVs result in the claimed benefits? If they can provide these benefits, are they the most effective means to achieve them? Will they be effective only under certain conditions? Testing these assumptions is important because if a large portion of the limited public sector resources available for increasing the sustainability of SSTW agriculture are committed to TGVs, it means that they are not available for alternative strategies, and if TGVs do not perform as proponents expect, problems in Third World agriculture are likely to become worse.

The assumptions central to so much of the economic research on TGVs that is cited as the basis for policy are empirically-based assumptions about the way the world works. These assumptions can be tested using data, providing information useful for confirming or adjusting research and policy frameworks. These are often embedded within larger value-based assumptions, what have been called "pre-analytic visions" (Costanza, 2001), the "more subjective, or normative, envisioning component" of scientific analysis essential for anchoring our ideas of how we believe the world works and how we wish it to be. A pre-analytic vision about the goals of agriculture may be, for example, that small-scale, low input agriculture should be replaced by large-scale, high-input agriculture (Lyson, 2002).

Testing of empirically-based assumptions is critical not only to assess their empirical validity, but because the results can also influence value-based assumptions. While it is probably human nature to use "rational" thinking to justify value-based preferences, it is also via interaction with others that conclusions based on these can be modified by more objective, scientific information (Haidt, 2007). To the extent that value-based assumptions also "draw on factual presumptions, often made in an implicit way", value assumptions remain "subject to revision in the light of more knowledge" (Sen, 2000: 942). Therefore, while value-based assumptions cannot be tested with data about the objective world, making them explicit and including them in discussion could improve science and policy development (Costanza, 2001).

In the following sub-sections we discuss the two key empirically-based assumptions in the economic research influencing development policy, and that we tested in this study.

2.1. *Research assumptions*

It is often assumed that rational farmers will choose TGVs over other crop varieties because this will increase their utility, usually defined monetarily,[3] since science and the market have resulted in development of TGVs as the best possible crop varieties for SSTW agriculture. For example, Huang et al. state that in using equivalent variation as a measure of welfare changes due to adoption of TGVs, that it is based on "utility derived from consumption" and "does not take into account other important aspects of human well-being…does not account for intrinsic, positive or negative, utility that might be attached to the introduction of new crop varieties" (Huang et al., 2004:44). This also means that if farmers do not choose TGVs it is due to market failure resulting from inadequate or inaccurate knowledge, legal restrictions, price distortions, or unfounded, non-scientific perceptions perpetrated by opponents of TGVs.

This assumption can bias research on ways to improve SSTW agriculture toward concluding that TGVs are the most, or one of the most, important approaches and, in adequately functioning markets, SSTW farmers will adopt them. From this perspective farmers do not need to be asked directly about TGVs; if a problem is documented to which TGVs can theoretically provide the solution, then it is assumed farmers would choose the TGVs. *Ex ante* research in Kenya[4] asked farmers about pest problems in their maize, and concluded that because farmers perceived problems with insect pests (e.g., stem borers), they would welcome pesticidal (*Bt*) maize TGVs (de Groote et al., 2005; Smale and de Groote, 2003),[5] even though farmers were never asked specifically about TGVs or alternatives to them. "It has become very clear that *Bt* maize responds to a problem perceived by farmers to be very serious and farmers are likely to adopt it" (de Groote et al., 2004). The Kenyan findings have had an influence on agricultural research agendas and national policy: they are part of the justification for continuing a major *Bt* maize project in that country that is a partnership between national and international agricultural research institutions and a major multinational biotechnology firm (CIMMYT, 2007), with project scientists actively supporting ratification of pro-biotechnology legislation in the Kenyan parliament (KARI and CIMMYT, 2007). While stem borer damage is a major cause of reduced maize yields in East Africa, it is not clear whether farmers and scientists have been able to consider other possible control strategies. Similarly, *ex ante* research on transgenic banana in Uganda concluded that "Perceived yield losses…reduce variety demand significantly, evidence that farmer demand for planting material is responsive to improving resistance through effective gene insertion for targeted traits" (Edmeades and Smale, 2006:357).

Under this assumption transgenesis is presumed to be acceptable to farmers, and TGVs are typically compared only with existing varieties and production conditions, e.g. reduction in pesticide spraying resulting from adoption of pesticidal (*Bt*) TGVs (e.g. Huang et al., 2005), or increased yields with *Bt* maize compared with isolines or conventional hybrids (Gouse et al., 2006). Not considered in such comparisons are alternatives such as more appropriate modern varieties (MVs), farmers' varieties (FVs), and improved FVs; only occasionally are transgenic FVs considered, for example in an *ex ante* evaluation of host variety traits—including of FVs—that would be most desirable in transgenic bananas for Uganda (Edmeades and Smale, 2006). Thus, while TGVs may be a valuable tool for addressing problems in SSTW agriculture, whether they are the optimal strategy cannot be accurately assessed until they are compared with other possible strategies, including ones that may require major investment in supportive infrastructure just as transgenic biotechnology does (KARI and CIMMYT, 2007).

Another key research assumption underlying the previous one is that farmers are risk neutral, and therefore, to maximize personal utility (profit), farmers will invest production resources based on expected returns. That is, to facilitate research, farmers are assumed to not be risk averse and therefore it follows that minimizing variance in yields or avoiding yield failure is not their goal (Hardaker et al., 1997). For example, Zilberman et al. (2007) assume that "the farmer is risk neutral, and the farmer's objective is to maximize expected profits". This leads to focusing on expected positive, average effects of crop varieties such as TGVs (e.g. higher

[3] We use "utility" here to refer to all possible benefits or the "happiness" an individual or unit such as a household may derive from a process or product (e.g., income, prestige, security, resources, power, reduced drudgery, etc.); included among these is profit which, when speaking of semi-subsistence agriculture, may be used synonymously—as we do here—with yield, that is increasing production/unit of land or labor, reducing production losses or costs/unit of land or labor or other investments (Ellis, 1993:25, 66, 90). As noted in the text, utility in the context of economic research on TGVs is typically defined monetarily.

[4] Carried out under joint sponsorship of the Kenya Agricultural Research Institute (KARI), International Maize and Wheat Improvement Center (CIMMYT), and The Syngenta Foundation for Sustainable Agriculture (created and funded by Syngenta AG, a major international TGV seed company) (KARI and CIMMYT, 2007).

[5] We use the example of the KARI–CIMMYT–Syngenta project in Kenya because that project, unlike many others, has been well documented and that information made publicly available. We appreciate that important effort by project scientists and administrators.

average yield, lower average pesticide use), and means that potential risks, including ones researchers may not be aware of, are not thought to influence farmer behavior.

2.2. Development organization assumptions

Advocates of TGVs for Third World farmers include the largest and most influential development organizations, including the CGIAR (2006), the Rockefeller Foundation (2007), the World Bank (2007), and major UN agencies (FAO, 2004; UNDP, 2001; WHO, 2005). Many industrial country governments are also TGV advocates, foremost that of the US (e.g. USAID, 2004), which is also the world's leader in the development and planting of TGVs. These organizations hold that TGVs are an essential technology for increasing production and income, reducing hunger and malnutrition and decreasing environmental degradation in SSTW agriculture, and should have the highest priority for support through investments in enabling infrastructure (research, centralized seed production, input manufacturing, transportation, credit institutions), and government policy.

The FAO report states that "The question therefore is not whether biotechnology is capable of benefiting small resource-poor farmers, but rather how this scientific potential can be brought to bear…Biotechnology holds great promise as a new tool…The challenge at present is to design an innovation system…" (2004:57), and the World Bank "The potential benefits of these technologies for the poor will be missed unless the international development community sharply increases its support to interested countries" (World Bank, 2007:163). A major part of this innovation system involves collaboration with the private sector since, unlike the Green Revolution, the biotechnology revolution is controlled by the private sector. "The CGIAR has a major strategic opportunity to involve the private sector in the pursuit of the System's global goals through the application of private sector biotechnologies in germplasm enhancement" (CGIAR, 2006:10). This means that major investments are required by the public sector to facilitate private sector involvement and investment in TGVs; "Capacity building for agricultural research and regulatory issues related to biotechnology should be a priority for the international community" (FAO, 2004:5). These organizations also assume that the development economics research provides a valid indication of the potential for TGVs. While aware of the preliminary nature of this research and the need for a case-by-case analysis of TGVs in comparison with alternative technologies (e.g. FAO, 2004:43, 178), organizations tend to accept the research conclusions at face value, and do not question the economic assumptions on which it is based (e.g. FAO, 2004:56–57; World Bank, 2007:177).

3. Materials and methods

We interviewed 334 farmers in six communities—one relatively traditional and one relatively modern agricultural community each in Cuba, Guatemala and Mexico (Table S1 in the Supplementary data). Although these countries contrast in many ways, our collaborative research was not designed as a comparative study, but to assess farmers' perspectives and the validity of key assumptions in each of our respective countries. Methods for selecting the maize farming communities and households, interviewing farmers in each household, and previous analyses were described in detail elsewhere (Soleri et al., 2005). Our definitions of "traditional" v. "relatively modern" agricultural community were originally based on assessments by those of the coauthors who are national maize scientists with many years of experience and personal familiarity with the descriptive data from their respective regions. These distinctions were confirmed in our study samples by the higher yields and higher proportion of households who sell maize in the market in modern communities compared with traditional communities (see Table S2). This distinction is not absolute, however, especially in Mexico where maize is the basis of rural diets and self-provisioning for maize is common across many types of farming households. Conversely, it is rare to encounter purely subsistence households in any of these locations because, at the least, small quantities of maize are sold to provide cash for school fees, medicine and other necessities. Other factors contributing to the distinction were greater access in modern communities to agricultural technologies and to information from the formal research and education systems.

Interviews were adapted to the characteristics of each country and community. Farmers ranked their preferences for four maize varieties for sowing and eating. We also analyzed the relationship between farmers' rankings and independent variables describing farmers, their farms and communities (Table S2).

3.1. Ranking exercise

In a varietal ranking exercise farmers ranked four types of maize: farmers' own variety (FV), a conventional modern variety (MV) they were familiar with, and those same varieties as backgrounds for a transgene—a transgenic farmers' variety (TGFV) and a transgenic modern variety (TGMV) (Fig. 1A). We asked farmers to rank these first as maize seed for sowing in their own fields, and then again as maize grain for their family to eat. The FV and MV represented two seed systems (informal v. formal, respectively) and different agronomic, storage and culinary characteristics with which farmers were already familiar. Farmers had no previous experience with TGVs, and only a small proportion (9.6%) said they had heard of them, although many of these were mistaken, having heard of something that was not a TGV (Soleri et al., 2005). Providing these four choices allowed us to distinguish farmers' preferences for varieties (FV v. MV) from their preference for a genetic technology (TGV v. non-TGV), an important distinction which is either overlooked or confounded in most research with farmers. TGVs were described neutrally to farmers and they were given a positive example of TGVs with the potential to decrease pest damage (see Section 3.3).

We analyzed data from the ranking exercise in two ways. First, object (maize variety) based analysis of the rank of individual varieties relative to each other using the basic Bradley–Terry (B–T) model of all possible pair-wise comparisons and the χ^2 test of goodness of fit (Soleri et al., 2005). Second, subject (farmer) based analysis of the relationship between farmers' ranking of crop varieties and independent variables characterizing farmers (including their households,

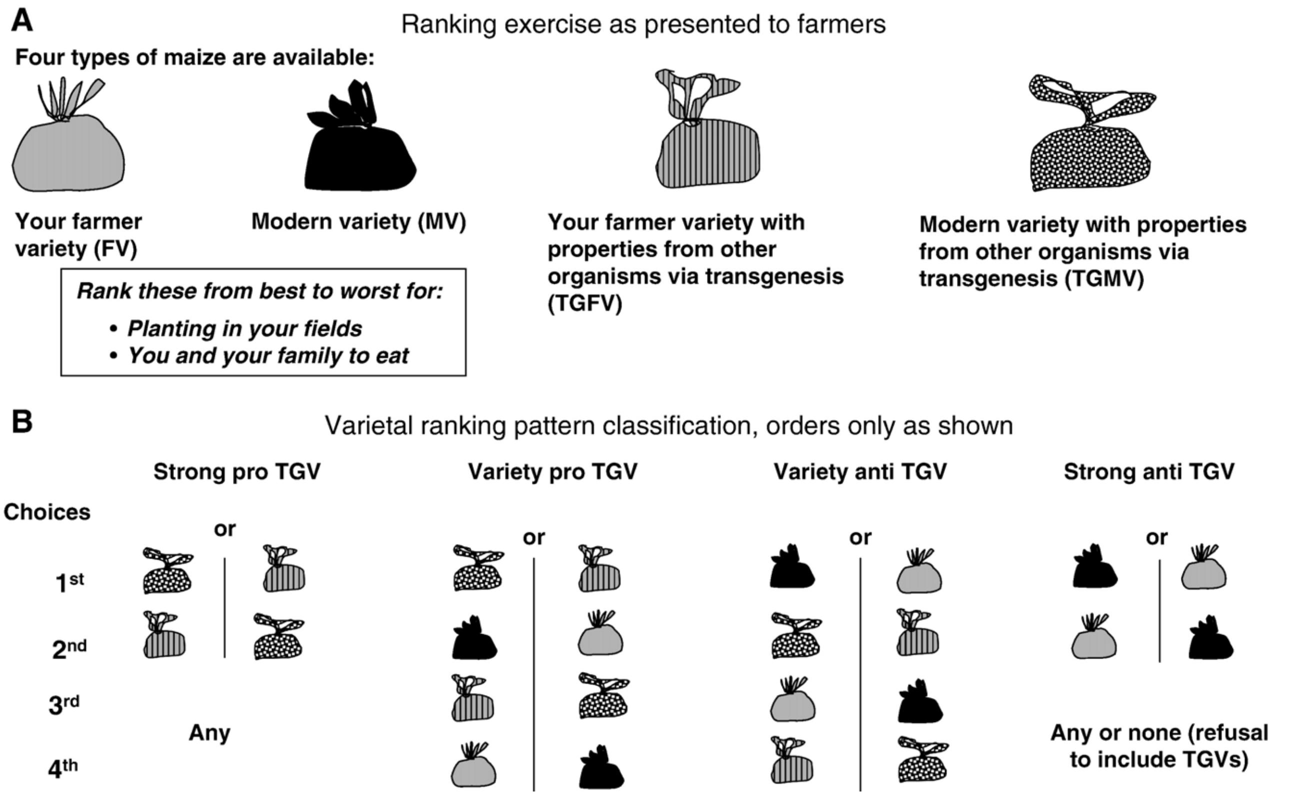

Fig. 1 – Maize variety ranking exercise. (A) Maize variety ranking exercise presented to farmers. (B) Ranking pattern classification system (based on choices in the maize varietal ranking exercise).

farms, communities and countries) (Soleri et al., 2005). One subject based analysis of individual varieties used the extended B–T model which is described fully in Dittrich et al. (1998), and a complete discussion of its application in our research is given in Soleri et al. (2005). Using the extended B–T model we analyzed the effect on farmers' ranking of each maize variety of country, type of agricultural community (traditional v. modern), hectares of maize sown, having heard of TGVs (yes/no), perceptions of transgenesis *per se* (bad v. not bad), and attitudes toward risk.

In addition, for both sowing and eating, we created an ordinal classification of farmers based on a ranking pattern using the order of each farmer's choices in the ranking exercise (Table 1, Fig. 1B). This classification was then used as a dependent variable in a second subject based analysis. The number and type of choices available allowed analysis of the characteristics of greatest importance to farmers, revealing the larger objective of their ranking choices. Their choices indicated the relative weight assigned by farmers to variety (FV v. MV) and genetic technology (TGV v. non-TGV).

Table 1 – Ranking pattern classification system based on farmers' ranking of four maize varieties, n = 334

		Ranking pattern classification system								
		4 = strong pro-TGV		3 = variety pro-TGV		2 = variety anti-TGV		1 = strong anti-TGV		All other patterns
Variety rank	1st	TGMV	TGFV	TGMV	TGFV	MV	FV	MV	FV	
	2nd	TGFV	TGMV	MV	FV	TGMV	TGFV	FV	MV	
	3rd	FV or MV	FV or MV	TGFV	TGMV	FV	MV	TGFV or TGMV	TGFV or TGMV	
	4th	FV or MV	FV or MV	FV	MV	TGFV	TGMV	TGFV or TGMV	TGFV or TGMV	
Percentage of all households interviewed (n)										
Sowing		18.0 (60)		3.3 (11)		10.5 (35)		53.0 (177)		15.3 (51)
Eating		1.5 (5)		0.3 (1)		16.2 (54)		70.4 (235)		11.7 (39)

FV = farmer variety, MV = modern variety, TGFV = transgenic farmer variety, TGMV = transgenic modern variety. Farmers who refused to include TGVs in their rankings were coded as strong anti-TGV.

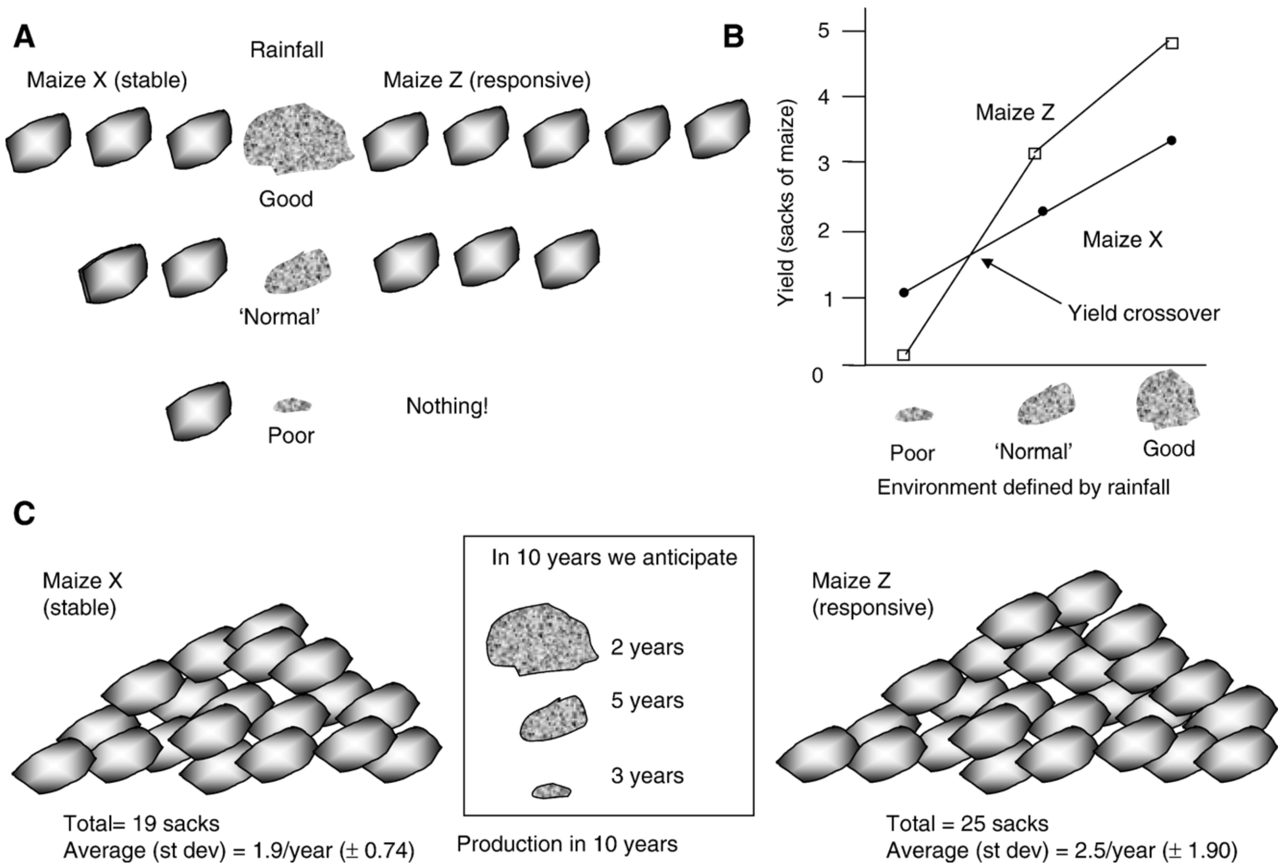

Fig. 2 – Risk scenario presented to maize farmers. Yield v. yield stability in response to environmental variation. Rocks of different sizes represent different annual rainfall, sacks of maize grain represent yield response of a variety to that rainfall. (A) Rainfall and yield for two varieties. (B) Cross-over of yields for two varieties. (C) Total and average yields for two varieties.

The ranking pattern classification system was coded so that higher numbers indicate a more favorable attitude toward TGVs, and then used as the dependent variable in an ordered logit regression. Elimination of households that did not fit that classification system (sowing=51, eating=39) or those missing data for one or more independent variables resulted in a final sample size of 269 for the ordered logit analysis of the ranking data for sowing. Analysis of ranking patterns for eating was not possible because there was insufficient variation in responses (see Section 4.3).

Unlike linear regression, ordered logistic regression makes no assumptions about distances between categories, but instead calculates the probability that an observation will fall into each category of the dependent variable. A negative coefficient on an independent variable indicates that higher values of that variable reduce a farmer's preference for TGVs, while a positive coefficient indicates that higher values of that variable increase a farmer's preference for TGVs.

For the ordered logit the independent variables were coded as follows: attitudes toward transgenic technology *per se* as

Table 2 – Risk scenario: yield and yield stability as a proxy for farmers' attitudes toward risk

Location (*n*)	Risk averse (prefer stable variety) percent (*n*)	χ^2 P values
Cuba	61.4 (70/110)*	0.004
La Palma, Pinar del Río (T)	58.9 (33/56)	0.181
Mayorquín, Holguín (M)	63.8 (37/58)*	0.036
Guatemala	51.9 (56/109)	0.773
El Rejón, Sacatepequez (T)	87.0 (47/54)*	0.000
La Máquina, Suchitepequez (M)	16.7 (9/55)+	0.000
México	76.4 (84/110)*	0.000
Sta Inez Yatzeche, Oaxaca (T)	76.4 (42/55)*	0.000
Comitancillo, Oaxaca (M)	76.4 (42/55)*	0.000
Total	63.3 (210/333)*	0.000

Data from authors' survey, some previously published in (Soleri et al., 2005). T = more traditional agricultural community; M = more modern agricultural community. The symbols * and + denote significantly more prefer stable variety or responsive variety respectively, χ^2 goodness of fit test.

described to farmers were coded 1 for those who thought transgenesis was bad *per se*, and 0 otherwise; the risk variable was coded 1 for those who preferred a stable maize variety in the risk scenario (risk averse), and 0 for those favoring a highly responsive maize variety (risk neutral) (see Section 3.2). The other binary (yes/no) independent variables (family member is a migrant, sells maize at market, acquires maize seed annually from formal system, observed diminished effect of pesticides) were all coded 1 if affirmative, 0 if negative. We also included indicator variables for each community in the study (using Mayorquín, Cuba as the baseline) to account for any differences in ranking patterns across communities not captured by the variables we examined.

Forecasted probabilities and their standard errors were obtained by taking 1000 random draws from the covariance matrix of the coefficients, and calculating forecasted probabilities for each category of the dependent variable for each observation using the coefficient draw and the values of the independent variables.

3.2. *Risk scenario*

Attitude toward risk was assessed on the basis of farmers' responses to a hypothetical scenario concerning yield and yield stability. Farmers were presented with a choice between two maize varieties whose yields vary in response to variability in growing environments (defined in terms of rainfall, the key limiting variable for maize production in the six communities) between years: *X* with more stable, but lower mean yield, and *Z* with less stable yield (i.e. highly responsive to changing environments) but higher mean yield (Fig. 2A).[6] These two varieties exhibit qualitative genotype-×-environment interaction, commonly referred to as a cross-over (Fig. 2B), so that farmers' choice is between higher average yield or higher yield stability (Fig. 2C). We classified those choosing *X* as risk averse, and those choosing *Z* as risk neutral. This scenario functioned as a cross-system comparison—an "anchoring vignette" (King et al., 2004)—for attitudes toward risk between farmers from different communities and countries. It is also a depiction of risk that is familiar to plant breeders and other scientists working on crop improvement (e.g. Ceccarelli et al., 1994; Evans, 1993; Simmonds and Smartt, 1999).

3.3. *Transgenesis per se*

According to the economic assumptions we tested, the two TGVs in the ranking scenario represented two variations of an economically rational, positive choice for farmers because we described the process of transgenesis in a neutral way, omitting mention of viral and bacterial material that is inserted into most commercial TGVs, and gave a positive example of a TGV that could provide a net economic gain for farmers, omitting mention of documented or potential negative effects. We described transgenesis as a process conducted by scientists that is a way of moving properties into maize from other organisms including other plants or animals, and gave the examples of a) a transgene used in maize that confers resistance to being eaten by caterpillars, and b) the idea of using material from a cold water fish to make strawberries resistant to cold temperatures.[7] We stated that TGVs were used in some countries, and thus far caused no problems. After this description, farmers were asked if they thought transgenesis *per se* (transferring properties from one type of organism into another) was good or bad.

Table 3 – Logit test of the association of the dependent variable risk aversion and other independent variables in this study

Independent variable	Coefficient	*P* value
Thinks transgenesis bad *per se*	0.334	0.291
Age of farmer, years	0.017	0.139
Formal education of farmer, years	0.056	0.242
Family member is a migrant	−0.284	0.377
Hectares of maize sown	0.064	0.344
Sell maize at market	−0.450	0.316
Acquire seeds annually from formal system	−0.689	0.268
Number of different maize fields	−0.051	0.728
Total number of maize varieties grown	−0.340	0.248
Number of farmer varieties grown	−0.175	0.340
Observed diminished effect of pesticides	−0.341	0.413
Traditional Mexican community	1.246	0.141
Modern Mexican community	−0.136	0.829
Traditional Guatemalan community	1.786	0.020
Modern Guatemalan community	−1.644	0.041
Traditional Cuban community	−0.732	0.269
Constant	0.628	0.562
LR χ^2 (15)	88.62	0.000

Data from authors' survey. Dependent variable is attitude toward risk as measured by preferences in the risk scenario (1 = prefer stable variety, risk averse; 0 = prefer responsive variety, risk neutral). Number of observations = 314.

4. Results

4.1. *Farmer choice of crop variety*

The ranking exercise was designed to assess farmers' a) past experiences with and attitudes toward maize varieties, including those that are the products of informal (FVs) v. formal (MVs) seed systems, and the entities farmers associate with them, and b) attitudes toward genetic technologies—non-transgenic and transgenic—based on the definition we provided. As in much *ex ante* economic research for development, this was not a direct evaluation of TGVs, but unlike that research we obtained data on farmers' attitudes toward two familiar crop varieties (FVs and

[6] We use the term "yield stability" to refer to yield with low variability across environments, sometimes referred to as "type 1 stability" in contrast to "type 2 stability" which is defined as having a response to environments close to the mean of varieties in a trial (Cleveland, 2001; Evans, 1993).

[7] Although the cold resistant strawberry TGV is an "urban legend" constructed around research that has not resulted in cold tolerant varieties (Kenward et al., 1999), it has been used by both proponents and opponents of TGVs to represent the wondrous or ominous potential of crop biotechnology (Cornell Cooperative Extension, 2003).

MVs) as well as one new, unfamiliar technology (transgenesis and TGVs made using this) through the ranking exercise.

We first tested the key assumption of economic research that farmers would prefer TGVs if given the choice. Object based analysis of the ranking data using the basic B–T model showed farmers preferred FVs above the other three choices for sowing and eating, with the same rank order from highest (most preferred) to lowest: FV, MV, TGFV, TGMV. As previously reported (Soleri et al., 2005), overall preference values for sowing (0.47, 0.24, 0.19, 0.10) and especially for eating (0.87, 0.09, 0.03, 0.01) favored FVs and were a clear departure from the values expected if farmers preferred the two TGVs (0, 0, 0.50, 0.50).

We therefore hypothesized that ranking patterns would reflect the same overall varietal preference for FVs over MVs—specifically that FV and TGFV in any order would be the most frequent first two choices. This hypothesis was rejected—avoiding transgenic maize ("strong anti-TGV", FV and MV in their first two choices) was the primary objective in a majority of farmers' ranking choices for sowing (χ^2=1.198, P=0.274) and eating (χ^2=55.377, P=0.000). Thus, farmers' desire to avoid an unfamiliar technology was a stronger motivation than their preference for a familiar genotype.

We also tested the hypothesis implicit in much economic research that farmers do not perceive transgenic technology as negative *per se*, based on farmer responses upon hearing our simple, neutral definition and positive examples. This assumption was upheld—a majority (66.2%) of farmers did not perceive transgenesis *per se* as negative (χ^2=71.694, P=0.000) (see Section 5.1).

4.2. *Farmer attitudes toward risk*

To understand the basis for farmers' rejection of TGVs, we tested the related assumptions that a) farmers are risk neutral, and that b) this supports a preference for TGVs. We used farmers' responses to the risk scenario to assess their attitude toward risk. We found a majority overall were risk averse (chose the more stable variety in the scenario) (χ^2=22.730, P=0.000). This was also true in five of the individual communities, although the opposite was true in La Máquina, Guatemala, the community most completely integrated with the market system (Soleri et al., 2005). That is, except in La Máquina, farmers are risk averse, not risk neutral, preferring lower rather than higher average yield, yield variance and risk (Table 2).

Risk aversion was not associated with level of education or age (Cochran's T test: t=0.590, P>|t|=0.555; t=−0.430, P>|t|=0.671, respectively), but was significantly more common among traditional v. modern agricultural communities (χ^2=35.503, P=0.000). Similarly, a simple logit including all independent variables and with attitude toward risk as the dependent variable found an association only between risk aversion and the traditional Guatemalan community (Table 3).

The corollary of the assumption that farmers are risk neutral is that they will therefore prefer TGVs, and so choose them in the ranking exercise. This hypothesis was upheld by our data; for both sowing (χ^2=18.030, P=0.000) and eating (χ^2=52.755, P=0.000) more risk averse farmers were strongly opposed to TGVs in the ranking exercise; more of the risk neutral farmers favored TGVs in that exercise. We look at this further in the ordered logit analysis below.

Subject based analyses using the extended B–T model showed that risk aversion and negative attitudes toward transgenesis *per se* were significantly associated with preference for FVs and MVs in the sowing rankings (Fig. 3, Table 4). Again, the unknown potential consequences associated with the new technology appeared to contribute to choosing a known variety, that is a less preferred (MV) over a transgenic version of the preferred variety (TGFV).

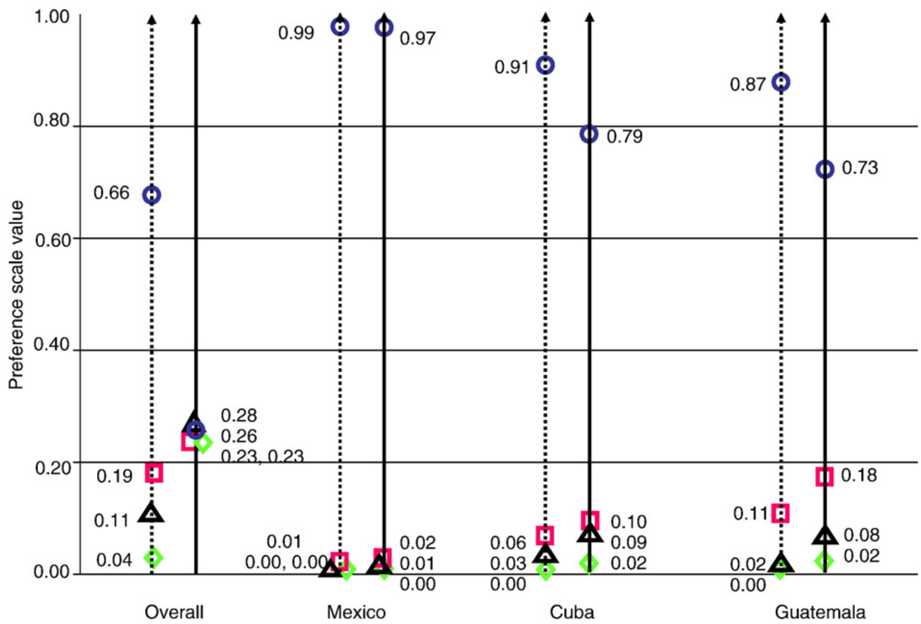

Fig. 3 – Farmer ranking preference scales for maize seed for sowing, by country and attitude toward risk. Risk averse (········) or risk tolerant (——) farmers; FV = farmer variety (○), MV = modern variety (□), TGFV = transgenic farmer variety (△), TGMV = transgenic modern variety (◇). Preference values calculated from the extended B–T model, Table 4 following Dittrich et al. (1998).

Table 4 – Farmers' varietal rankings for sowing and eating, extended B–T model, all countries

	Sow				Eat			
	Estimate	Standard error	P (>|z|)		Estimate	Standard error	P (>|z|)	
FV	4.79	0.27	<2e−16	***	3.70	0.32	<2e−16	***
MV	2.59	0.21	<2e−16	***	1.96	0.22	<2e−16	***
TGFV	1.68	0.19	<2e−16	***	1.31	0.20	0.00	***
TGMV								
FV:CTRY2	−1.93	0.21	<2e−16	***	−1.93	0.35	0.00	***
MV:CTRY2	−1.10	0.17	0.00	***	−1.16	0.25	0.00	***
TGFV:CTRY2	−0.60	0.15	0.00	***	−0.68	0.23	0.00	**
TGMV:CTRY2								
FV:CTRY3	−1.98	0.20	<2e−16	***	−0.73	0.34	0.03	*
MV:CTRY3	−0.82	0.16	0.00	***	−0.27	0.24	0.26	
TGFV:CTRY3	−0.69	0.15	0.00	***	−0.17	0.22	0.44	
TGMV:CTRY3								
FV:COMM	−0.76	0.13	0.00	***	0.62	0.26	0.02	*
MV:COMM	−0.22	0.12	0.06		0.55	0.19	0.00	**
TGFV:COMM	−0.60	0.11	0.00	***	0.06	0.18	0.72	
TGMV:COMM								
FV:FARM2	−0.20	0.17	0.22		−0.53	0.42	0.20	
FV:FARM3	−0.90	0.21	0.00	***	−2.05	0.32	0.00	***
MV:FARM2	−0.15	0.13	0.26		−0.49	0.29	0.09	.
MV:FARM3	−0.34	0.16	0.04	*	−1.40	0.26	0.00	***
TGFV:FARM2					−0.18	0.27	0.49	
TGFV:FARM3					−0.53	0.25	0.04	*
TGMV:FARM2								
TGMV:FARM3								
FV:HEAR	−0.41	0.18	0.02	*				
MV:HEAR	−0.33	0.15	0.03	*				
TGFV:HEAR								
TGMV:HEAR								
FV:THNK	−1.78	0.19	<2e−16	***				
MV:THNK	−1.16	0.16	0.00	***				
TGFV:THNK	−0.45	0.15	0.00	**				
TGMV:THNK								
FV:RISK	−0.9265	0.125	1.23e−13	***				
MV:RISK	−0.594	0.1125	1.29e−07	***				
TGFV:RISK	−0.2309	0.1105	0.036719	*				
TGMV:RISK								

Data from authors' survey. Null deviance: 3612.88 on 779 *df*, residual deviance: 480.59 on 366 *df*, AIC: 2705.9. Empty cells indicate non-significant covariate and model reverts from extended back to the basic B–T analysis. FV = farmer variety, MV = modern variety, TGFV = transgenic farmer variety, TGMV = transgenic modern variety. Subject specific covariates and states in extended models: CTRY = country, CTRY2 = Cuba, CTRY3 = Guatemala; COMM = modern community; FARM = farm size (ha maize sown), FARM2 = 2.5 < ha < 5.0, FARM3 = ha > 5.0; HEAR = have heard of transgenic maize; THNK = think transgenesis *per se* is acceptable; RISK = risk neutral (chose responsive variety in risk scenario). Covariate states for basic model: CTRY = Mexico; COMM = traditional; FARM = ha < 2.5; HEAR = have not heard of transgenic maize; THNK = think transgenesis *per se* is unacceptable; RISK = are risk averse. The symbols *, ** and *** denote significance at P = 0.05, 0.01 and 0.001, respectively.

4.3. *Household, community and country characteristics associated with varietal choice and risk attitudes*

To jointly analyze the effect of farm household characteristics on the ranking pattern classification for the sowing data,[8] we estimated an ordered logit regression (Table 5). Greater integration into the formal system, as represented by market sale of maize and annual MV seed acquisition from the formal system, was positively associated with favorable ranking of TGVs, as was older farmer age. Low ranking of TGVs was associated with risk aversion, negative perception of transgenesis *per se*, and greater number of maize fields. Several communities were significantly more likely to rank TGVs highly than the baseline community in the model (the modern Cuban community Mayorquín). This is likely due to perceived negative health consequences in Mayorquín, including increases in incidence of cancer and congenital diseases, attributed by farmers and some researchers to agrochemical intensive production there, making people in Mayorquín especially wary of new agricultural technologies (J. Anderes and O. Chaveco, personal communication, August 2005, La Habana, Cuba).

Our data do not allow a clear interpretation of the association of greater number of maize fields and younger farmer age with rejection of TGVs. Across all countries a higher number of maize fields were found in traditional v. modern communities (Table S2). The reasons for this likely vary between communities and may include a strategy to

[8] An equivalent ordered logit regression for the eating rankings could not be estimated as too few farmers gave TGVs favorable rankings—only 6 farmers were strong or variety pro TGV.

manage risk through use of environmental diversity (Goland, 1993), an artifact of land reform policies, inheritance patterns resulting in increasing land fragmentation (e.g. in Mexico, de Janvry et al., 1997), investment of remittances or other resources in new parcels. Younger farmers may have a more negative attitude toward TGVs because they are often leaders in movements to reclaim indigenous values and rights (e.g. in Oaxaca, González, 2005).

The community parameter is insignificant in the ordered logit analysis but significant in the extended B–T analysis. In part this is due to having different dependent variables derived from the same data. The B–T model has as its dependent variable the overall rankings of each individual maize variety used in the ranking exercise, while the ordered logit refers to the ranking pattern classification system. In addition, the extended B–T model is more restrictive in that it uses the complete set of ranking information and thus cell counts are necessarily smaller and fewer covariates included. If an identical covariate set is used in the ordered logit analysis, and the modern Guatemalan community (La Máquina) is set as the baseline community, the community effect is significant (Table 6). Thus the community parameter in the extended B–T model can be viewed as a proxy for the more detailed set of covariates in the ordered logit.

For eating, avoidance of TGVs (strong anti-TGV pattern) occurred significantly more frequently than any other pattern at the community (except for La Palma, Cuba) and country levels, as well as for the overall sample (Table 7). Ranking patterns for sowing were more varied, but the strong anti-TGV pattern was still the most frequent pattern in each country and overall. The exception is La Máquina, Guatemala where strong pro-TGV was the most frequent pattern, consistent with their integration with the formal seed and market systems and the predominance of MV seed use there (92.7% of farmers) as compared with all other communities in this study, either modern (49.6%), or traditional (12.7%). In La Palma, patterns of strong pro-TGV and variety pro-TGV for sowing and variety anti-TGV for eating were also common, and higher than in other locations, though not significant. Both of these variety classifications were dominated by FVs (TGFVs were the most frequent first choice among farmers following those two patterns). Attitudes of farmers in La Palma may have been influenced by recent positive experiences with a participatory plant breeding project (Zito, 2007) that introduced new maize diversity in the form of non-local FVs and MVs, giving farmers new enthusiasm for the diverse qualities of FVs as well as for the capacity of formal plant breeding technology to address their needs, including new MVs.

Table 5 – Ordered logit regression results for farmers' varietal ranking for sowing

Independent variable	Coefficient	P value
Risk averse (prefers stable variety)	−0.735	0.033
Thinks transgenesis bad *per se*	−1.339	0.000
Age of farmer in years	0.030	0.026
Formal education of farmer in years	0.040	0.441
Family member is a migrant	0.089	0.811
Observed diminished effect of pesticides	0.541	0.218
Hectares of maize sown	0.096	0.386
Sell maize at market	0.938	0.034
Acquire seeds annually from formal system	1.606	0.028
Number of different maize fields	−0.428	0.016
Total number of maize varieties grown	0.127	0.651
Number of farmer varieties grown	0.163	0.446
Traditional Mexican community	2.090	0.019
Modern Mexican community	0.308	0.682
Traditional Guatemalan community	1.090	0.187
Modern Guatemalan community	2.013	0.028
Traditional Cuban community	2.851	0.000
Cutpoint 1	3.471	–
Cutpoint 2	4.506	–
Cutpoint 3	4.978	–
LR χ^2 (15)	159.89	0.000

Data from authors' survey, n=269. Dependent variable is ranking pattern classification (4 = strong pro-TGV, 3 = variety pro-TGV, 2 = variety anti-TGV, 1 = strong anti-TGV).

Table 6 – Ordered logit test of the association of the dependent variable ranking pattern classification with the same independent variables as used in the extended Bradley–Terry test (Table 4) in this study

Independent variable	Coefficient	P value
Traditional Mexican community	−2.990	0.000
Modern Mexican community	−3.826	0.000
Traditional Guatemalan community	−3.538	0.000
Modern Cuban community	−3.242	0.000
Traditional Cuban community	−1.568	0.005
Farm size	0.307	0.312
Has heard of TGVs	0.263	0.631
Thinks transgenesis bad *per se*	−1.392	0.000
Risk averse	−0.474	0.139
Cutpoint 1	−2.483	
Cutpoint 2	−1.488	
Cutpoint 3	−1.042	
LR χ^2 (9)	147.75	0.000

Data from authors' survey, n=276. Dependent variable is ranking pattern classification system (4 = strong pro-TGV, 3 = variety pro-TGV, 2 = variety anti-TGV, 1 = strong anti-TGV). Farm size = ha maize sown, three classes 1=0<ha<2.5, 2=2.5<ha<5.0, 3=ha>5.0. TGV = transgenic crop variety.

5. Discussion

In Section 2 we documented two important, common assumptions about TGVs and SSTW farmers both in economic research with farmers and in the policies of development organizations working to improve Third World agriculture. In this section we briefly discuss how our results question these assumptions.

5.1. *Assumptions not supported by this research*

Our results do not support the assumptions that SSTW farmers prefer TGVs, or that farmers are risk neutral profit maximizers. The majority of farmers in this study preferred FVs specifically, or non-transgenic varieties in general (FVs and MVs) over TGVs. Most farmers we interviewed were risk averse, choosing more stable, lower yielding varieties, and

Table 7 – Distribution of ranking patterns from farmers' preference ranking of maize varieties for sowing and eating

Location (*n*)	Sowing					Eating				
	Variety pro-TGV	Variety anti-TGV	Strong Pro-TGV	Strong Anti-TGV	All other patterns	Variety pro-TGV	Variety anti-TGV	Strong Pro-TGV	Strong Anti-TGV	All other patterns
Cuba (114)	8.8 (10)	5.3 (6)	16.7 (19)	49.1 (56)	20.2 (23)	0.9 (1)	13.2 (15)	2.6 (3)	62.3 (71)*	21.1 (24)
La Palma, Pinar del Río (T) (56)	16.1 (9)	8.9 (5)	23.2 (13)	32.1 (18)	20.7 (12)	1.8 (1)	21.8 (12)	3.6 (2)	49.1 (27)*	25.0 (14)
Mayorquín, Holguín (M) (58)	1.72 (1)	1.72 (1)	10.3 (6)	65.5 (38)*	20.7 (12)	0	5.2 (3)	1.7 (1)	75.9 (44)*	17.2 (10)
Guatemala (110)	0.9 (1)	6.4 (7)	35.5 (39)	43.6 (48)	13.6 (15)	0	15.5 (17)	1.8 (2)	75.5 (83)*	7.3 (8)
El Rejón, Sacatepequez (T) (55)	1.8 (1)	10.9 (6)	3.6 (2)	76.4 (42)*	7.3 (4)	0	14.6 (8)	0	78.3 (43)*	7.3 (4)
La Máquina, Suchitepequez (M) (55)	0	1.8 (1)	67.3 (37)*	20.0 (11)	9.0 (5)	0	16.4 (9)	3.6 (2)	72.7 (40)*	7.3 (4)
México (110)	0	20.0 (22)	1.8 (2)	66.4 (73)*	11.8 (13)	0	20.0 (22)	0	73.6 (81)*	6.4 (7)
Sta Inez Yatzeche, Oaxaca (T) (55)	0	25.5 (14)	0	61.8 (34)*	12.7 (7)	0	25.5 (14)	0	70.9 (39)*	3.6 (2)
Comitancillo, Oaxaca (M) (55)	0	14.6 (8)	3.6 (2)	70.9 (39)*	10.9 (6)	0	14.5 (8)	0	76.4 (42)*	9.1 (5)
Total (334)	3.3 (11)	10.5 (35)	18.0 (60)	53.0 (177)*	15.3 (51)	0.3 (1)	16.2 (54)	1.5 (5)	70.4 (235)*	11.7 (39)

Percent (number). Data from authors' survey, some previously published in (Soleri et al., 2005). T = traditional agricultural community, M = modern agricultural community, FV = farmer variety, MV = modern variety, TGFV = transgenic farmer variety, TGMV = transgenic modern variety, TGV = transgenic crop variety. The symbol * denotes greater frequency than other patterns at that location when distribution of frequencies not random, χ^2 test of goodness of fit, $P<0.05$.

strongly avoiding TGVs. However, this is not because farmers are opposed to new technology, since the majority did not object to transgenesis *per se*, though farmers with a negative attitude toward transgenesis were more likely to reject TGVs. Farmers' stronger opposition to TGVs for eating than for sowing suggests they value characteristics other than just yield or profit, and seek to maximize their utility in terms of multiple characteristics, including post-harvest traits such as food quality. The assumption that risk neutrality is associated with being more favorable toward TGVs was supported by our data for a minority of respondents, almost all from more modern agricultural communities.

Many SSTW farmers' growing environments are characterized by high variability, with inputs required to reduce this variability, such as irrigation, physically or economically unavailable, and most crops have relatively low yields (Hardaker et al., 1997). Therefore, these farmers are often risk averse in response to short- and long-term variance in yield, and often prefer varieties with lower average yields but less yield variance (Soleri et al., 2002). Some of the potential risks of TGVs for SSTW farmers (inappropriate genetic background, dependence on the formal seed system, managing evolution of pest resistance) either do not exist for industrial, large-scale farmers, or are far more risky for SSTW farmers because they have almost no savings or surplus food stores to carry them through a bad year, and there is seldom any crop insurance or other government support.

It is important to put the finding that 66.2% of farmers did not see transgenesis *per se* to be negative into context with other results from our research (Soleri et al., 2005). First, for some rejecting transgenesis *per se* might have a profound cultural and spiritual basis, especially given the very long history of human reliance on maize in places like Mexico and Guatemala, and therefore their beliefs will need careful consideration in policy development.

Second, the technology *per se* must be distinguished from the products made using it, as well as the institutions associated with those products. In addition to the questions described here, we presented a simple scenario to farmers in Mexico and Guatemala, asking them to indicate their preference between variety A with relatively low average but stable yield, and inexpensive, locally available seed, and variety B with relatively high average yield, but with high initial yield declining over time, necessitating purchase of more expensive seed from the formal system (commercial seed stores in towns or cities). Variety B depicted hypothetical effects of a *Bt* maize TGV with declining yield due to evolution of pest resistance, eventually requiring purchase of a new TGV with a new, effective *Bt* transgene. In order to distinguish farmers' attitude toward transgenesis *per se* from some potential consequences of adopting TGVs, neither variety was identified as a FV, MV or TGV, and this question preceded all discussion of TGVs in our interviews. The results showed that farmers differentiated transgenic process and product—66.2% of farmers did not reject transgenesis *per se* (70.3% if considering Mexico and Guatemala only), yet only 13.7% preferred variety B representing some hypothetical consequences of growing TGVs (increased reliance on formal seed sources, initially higher yields declining over time). Seed price was not the primary issue; when farmers were asked their

Table 8 – Characteristics of risk averse and risk neutral farmers

Characteristic	Risk averse farmers (n=210)	Risk neutral farmers (n=123)	Test statistic [a]	P value
Average number of FVs growing (SD)	1.38 (0.76)	0.99 (0.90)	3.880	0.000
Average yield [b], kg (SD)	1818.4 (1286.8)	2177.4 (1151.6)	−2.370	0.019
Sell maize at market	52.22 (106/203)	70.94 (83/117)	10.761	0.001
Purchase MV seed annually	5.71 (12)	37.40 (46)	54.137	0.000
Strong pro-TGV rankings for maize for sowing	6.67 (14)	37.40 (46)	49.594	0.000
Strong pro-TGV rankings for maize for eating	2.38 (5)	0.81 (1)	0.374	0.541

Percent (number), unless otherwise noted. Data from authors' survey, total n=333. FV = farmer variety, MV = modern variety, TGV = transgenic crop variety.

[a] For means Cochran's T test; for comparison of frequencies χ^2 goodness of fit test.

[b] Calculated from farmer-reported maximum, minimum and modal yields (as described in Hardaker et al., 1997).

preference if seed of variety B cost the same as seed of A, those choosing B increased only slightly (to 18.1%). Many farmers may be receptive to new technology, however, acceptance of the products created using that technology (e.g. in this case TGVs) depends on many criteria; we have only touched on a few of these in this research.

Risk averse and risk neutral farmers differ for a number of characteristics relevant to their role in conserving maize genetic diversity (Table 8). Risk averse farmers maintain significantly greater maize diversity (FVs) *in situ* than risk neutral farmers, and report lower average maize yields. As already shown in previous analyses, risk averse farmers were also less integrated into the formal market and especially seed systems, and they tended to rank TGVs lower in comparison with risk neutral farmers. Farmers most integrated into the formal seed and market systems were most favorable toward TGVs and least likely to be maintaining maize genetic resources (FVs) *in situ*: 17.4% of all farmers obtained MV seed annually from the formal system, of these only 3.4% (2/58) also sow FVs. Forecasted probabilities estimated from the ordered logit model for sowing with ranking pattern classification as the dependent variable revealed that, across all communities, farmers are roughly three times as likely to rank TGVs at the bottom (strongly anti-TGV, P=0.596, S.E.=0.022) as opposed to the top (strongly pro-TGV, P=0.234, S.E.=0.019) of that classification system. Thus, overall, the predominant rejection of TGVs among farmers in this study was associated with many of the characteristics typical of farmers most in need of support from agricultural research and development investments, as well as those most likely to be conserving globally important genetic resources *in situ* and associated cultural and linguistic diversity.

Rejection by a majority of farmers of the maize with higher average yield (risk scenario) and of maize TGVs (ranking exercise) might be interpreted as irrational or based on lack of knowledge, as was often concluded in many agricultural innovation adoption studies since their development in the early 20th century (for a summary of these see Stone, 2007). However, there is increasing recognition that rejection of innovations may be based on farmers' rational evaluations of variables, some of which may not even be understood by researchers.

Many farmers we interviewed appear to have had experiences that alerted them to potential risks from new technologies, including maize MVs, and contributed to their responses regarding TGVs, as suggested by their comments, for example[9]: "How do we know it [TGV maize] will work well? Seeds and other things do not work here the way they do in other places"; "This maize might not be good because it might need lots of water and technology to grow"; "How do we *really* know this will be safe? People come here to test medicines on indigenous people in villages, I've seen that those [medicines] can be poisonous"; "Commercial seed sources are unreliable, too risky for farmers. What if they don't produce any seed? Each farmer needs to have their own seed, and seed that is right for the location"; "What we want is clean seed that won't harm our health", "With time this could harm us"; "Who knows if this could poison us?"; "I remember engineers (agronomists) coming here and giving us recommendations (about growing maize). That is fine, but they really do not know this place"; "I have seen bad effects of chemicals on soils, I want to stay away from these kinds of things like TGVs"; "For us maize is not a business, it is our sustenance".

5.2. *Are TGVs optimal for risk neutral farmers?*

As discussed above, TGVs are assumed to be an optimal choice for risk neutral, profit maximizing farmers, and based on the criteria used in this research, that hypothesis was upheld, though for a minority of farmers. Thus, one response to our research could be that SSTW agriculture has to be transformed via investments and infrastructure so that farmers can move toward risk neutrality. This is based on the assumption that the resources to do this are available, and that TGVs are less risky than other varieties or because transgenesis, in contrast to conventional breeding, "merely involves the introduction of one new resistance mechanism" (Qaim, 1999:400), and "genes are inserted into a host variety without affecting the levels of other traits and attributes" (Edmeades and Smale, 2006:360), is "low risk" for evolution of resistance to glyphosate (Qaim and Traxler, 2005), *Bt* proteins reduce "the risk associated with cotton production failures caused by insect infestations" (Traxler and Godoy-Avila, 2004:61), and TGVs are less risky than "non-adoption or non-availability of the new technology" (Chong, 2005:629). From this perspective potential effects of transgenic crop technology that could increase risk (yield instability, increased market dependency, negative ecological

[9] These comments were recorded by Soleri during interviews with farmers.

interactions) are rarely considered. However, TGVs can also carry higher risk than non-transgenic crop varieties because they include novel genetic constructs and there is unknown potential for negative genomic and ecological effects (Ellstrand, 2003; Gepts, 2002; Heinemann, 2007; Lu and Snow, 2005; Snow et al., 2005).

The results for cotton TGVs in the Third World in financial and yield terms are mixed, and depend on local conditions and the infrastructure needed to support them (Smale et al., 2006). Adoption of TGVs may be the result of social fads rather than rational, economic decision making (Stone, 2007), or the result of alternative choices being limited (Witt et al., 2006). In addition, most studies have been carried out for only one or a few years, and short term successes may not endure. For example, after three years of successful pest control, widespread use of *Bt* cotton by small-scale farmers in China led to outbreaks of a secondary pest with the result that farmers growing transgenic cotton sprayed the same amount of pesticide and had lower net returns compared to farmers growing non-transgenic cotton (Wang et al., 2006). Currently, *Bt* cotton in South Asia is reported to be experiencing a similar problem, leading to crop failures and large increases in pesticide applications (Padma, 2006; Singh Ashk, 2007).

6. Conclusion

Given the local and global importance of SSTW agriculture it is urgent that we evaluate the options and new technologies for improving it, including TGVs. Evaluation needs to be based on the unique characteristics of SSTW agriculture, many of which are vital to its past success and persistence (e.g., Soleri et al., 2006). Our results highlight the contrast between SSTW agriculture and industrial agriculture, where most of the TGVs and the methods for evaluating and regulating them have been developed (Cleveland and Soleri, 2005; Soleri et al., 2006). SSTW farmers who are most risk averse, experiencing the lowest yields, least integrated into modern agricultural systems, stewarding more crop genetic diversity *in situ*, and most in need of support and technical improvements, may be those least likely to accept TGVs, for some of the same reasons they find MVs unacceptable.

To evaluate the accuracy of key assumptions in economic research that influences policy we investigated farmers' preferences in scenarios and questions that presented those assumptions and some alternatives. Our findings did not support the key assumptions that TGVs are optimal and farmers will prefer them or that farmers are risk neutral. Instead, the majority of respondents preferred to avoid TGVs for sowing and especially eating, opinions associated with being risk averse.

Economic research on TGVs that includes these and similar assumptions may contrast with economic theory, but for simplicity's sake, or due to lack of other data and the challenges of applied research, such assumptions persist, and influence policy. Similarly, two economists have alluded to the disjunct that can exist between economic theory in general terms and its application "in the field": "Neoclassical theorists have by and large abandoned economic man and perfect competition; however, the policy recommendations of economists are still based on these outdated representations of human behavior and commodity production. Neoclassical welfare economics continues to offer bad advice in dealing with some of the most pressing environmental and social issues faced in the twenty-first century, including growing income disparity, global climate change and biodiversity loss" (Gowdy and Erickson, 2005).

As was the case when many SSTW farmers rejected green revolution MVs, the mainstream response to factors discouraging farmers from adopting TGVs is that those are obstacles to be removed, and that investments need to be made in creating "an enabling environment…including socioeconomic and political factors" and education of farmers and consumers (de Groote et al., 2004) to support TGVs. However, such responses do not consider the feasibility or desirability of those changes, or farmers' knowledge and the reasons for their preferences. Neither does such a response consider the benefits which might be accrued from investing in infrastructure to support alternative approaches.

TGVs have garnered much attention and funding, but lower cost alternatives that might fit better with the reality of SSTW agriculture, and support its positive attributes while increasing productivity and environmental sustainability, may deserve more serious consideration (see e.g. Lyson, 2002; Pretty et al., 2006; Uphoff, 2007; Zhu et al., 2003, 2000). Reflecting on lessons learned from green revolution MVs, the late, world renowned plant breeder Norman Simmonds argued that plant breeding in the future should take special care to ensure that "other possibilities which might accord better with social needs" are not neglected (Simmonds and Smartt, 1999).

We believe locally adapted research is needed that rigorously tests the potential for genetic, environmental, health and other forms of costs and benefits from *any* technology, including TGVs, proposed to improve SSTW agriculture. The results of such research need to be incorporated into discussion, research and decision making. While it is certainly true that "Risk assessment must (also) consider the consequences and risks of *not* using transgenics" (World Bank, 2007:179, emphasis in original), so too the risk of not exploring other alternatives should be considered. However, this is rarely done, in part because it is difficult, in part because many major development agencies have already decided which technologies they are prepared to support: "Countries and societies ultimately must assess the benefits and risks for themselves and make their own decisions. The international development community should stand ready to respond to countries calling for access to modern [transgenic] technologies" (World Bank, 2007:179).

In addition to local research, it is essential to include farmers directly in this process (NRC, 1996, 2002); here we have only investigated a small proportion of the potentially important variables affecting their preferences for crop varieties. In addition, there are other critical costs and benefits to be considered, e.g. to long-term biodiversity or ecosystem functioning, that will not directly affect farmers' well-being, knowledge or attitudes in the short term, but can be important in the long term for farmers and others. Large scale socioeconomic variables may also affect agricultural uncertainty and farmers' risk perception. One example is the large fluctuation in maize grain prices in Mexico over the past decade: market price of grain dropped during the 1990s due to the North American Free Trade Act then climbed suddenly in 2006, likely due to increased demand for maize-based ethanol. Because most SSTW farmers are both partially self-provisioning and participate in the market, the consequences of staple grain price variations may be diverse and unpredictable (Nadal, 2000), and may undermine farm viability, e.g., via out migration of farm labor or farm abandonment (Fitting, 2006; Wise, 2007).

Until such research is conducted, policies are needed to ensure that SSTW agriculture and the biodiversity it supports are not compromised. As an example, Wise (2007) outlines the policy options currently available to Mexico under the Cartegena Protocol, Convention on Biological Diversity and the International Treaty on Plant Genetic Resources for Agriculture that could protect Mexican maize diversity and strengthen support to small-scale maize farmers and the production and conservation services they provide. In addition, deep cuts in government funding for agriculture in many countries have made it difficult to establish public research programs in those areas private industry is unwilling to invest in, leaving little support for investigating alternatives to TGVs and conventional industrial production systems. Indeed, because the resources for developing TGVs are largely controlled by the private sector, many see public–private collaboration as essential for improving SSTW agriculture based on TGVs (e.g. CGIAR, 2006), as in the Kenya project cited above. This raises the critical issue of the influence on research agendas of sponsors' interests v. farmers' needs.

To make the best use of limited financial and natural resources for improving agriculture and reducing hunger and malnutrition in the Third World, we not only need discussion of the goals for environmental and social sustainability, but also sound science, as free as possible from unfounded or unexamined assumptions, on which to base agricultural development policy.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ecolecon.2008.01.031.

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