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Caught Between Scylla and Charybdis: Impact Estimation Issues from the Early Adoption of GM Maize in Honduras

José Falck-Zepeda
International Food Policy Research Institute (IFPRI), Washington, DC

Arie Sanders, Carlos Rogelio Trabanino, and Rolando Batallas-Huacon
Panamerican Agricultural School (Zamorano University), Honduras

Insect-resistant/herbicide-tolerant (Bt/RR) maize has been approved for commercialization in Honduras, and has been sold commercially since 2006. In 2007-2008, we conducted a survey of 113 farmers in the country, including 67 Bt/RR adopters and 46 conventional maize users. We also conducted agronomic, small- and large-plot experiments in situ and one crop-cycle planting with a Farmer Field School. Adopters were few and difficult to locate in a random sampling framework. We applied a battery of diagnostic and estimation methods to address these problems of outliers and endogeneity. Results based on robust and instrumental variables regression of survey data suggest that in the presence of target insects, producers may observe reduced pest damage and/or a decrease in pesticide applications. Results are quite sensitive to the presence of outliers. Nevertheless, results from the agronomic, in situ, and Farmer Field School tend to support the conclusions from our survey analysis.

Key words: Honduras, maize, endogeneity, insect resistance, herbicide tolerance, instrumental variables, robust regression.

Introduction

Maize is a very important crop for Honduras, as shown by maize area planted, the number and type of maize producers, and the role of maize in food security (Hintze, 2002). Maize area in 2010 was approximately 370,000 hectares, distributed in two crop cycles. About 25% of all arable land in the country is planted to maize. However, average yields are roughly 1.5 tons per hectare, which is one of the lowest yields in Latin America. Honduras also has a dual maize production system. Staple and subsistence crop producers with small land holdings coexist with relatively intensive, medium- and large-size land holdings with a commercial or semi-commercial objective.

Poor access to new technologies, productive inputs, and adverse biotic and abiotic constraints limit maize yields and productivity in Honduras. The Honduran government and private sector have launched several programs promoting access to inputs, information and knowledge, and technologies to increase yields in the country. In maize, one of the options has been the release of improved maize varieties, including open-pollinated varieties, hybrids, and genetically engineered (GE) maize varieties including insect resistant (Bt) and herbicide tolerant to glyphosate (RoundUp Ready^{TM} [RR]) maize.

There were approximately 3,000 hectares planted with GE maize in Honduras in 2007. Bt/RR maize planting is permitted in four states (“Departamentos”) in the country, including La Paz, Comayagua, Yoro, and Olancho. Yoro and Olancho produce approximately 90% of the total maize production in the country. This planting restriction was established in the biosafety permit authorized by the national biosafety committee of Honduras in order to protect against the potential out-crossing of the Bt/RR maize pollen with native, open-pollinated maize.

This analysis explores the performance of Bt/RR maize compared to conventional varieties in Honduras through a survey and other studies conducted in 2007-2008, with the aim of understanding its economic potential for corn producers in the country. Given the paucity of data in Honduras at the time of this research, we applied several methods simultaneously in order to glean as much information as possible. In the first research component, we conducted 1) an evaluation of primary and non-target insect pests in an experimental field, 2) a study of Bt/RR maize effectiveness *in situ* on larger plots of medium- and large-scale producers, and 3) a Farmer Field School (FFS) plot experiment with small producers. In the second component, given that no list of adopters was available, we implemented a survey of adopters using snowball sampling to collect data from known producers in the study site.

This multi-faceted approach, combined with a robust and instrumental variables (IV) regression model to manage sparse data, endogeneity, and outliers—coupled with a post-estimation analysis of stochastic dominance using SIMETAR© on the predicted values of yields—is the principal methodological contribution of this study. The next section outlines the major features of the maize economy in the Honduras context. This is followed by an explanation of the research design and methods, a description of the findings, and conclusions. The final section describes methodological lessons for ex-post economic impact evaluations.

The Maize Economy in the Honduras Context

Maize is a basic staple crop for a majority of the Honduran population, but it is also a product in great demand by the national agribusiness sector, especially for animal feeds. However, during the last decade, the relative importance of maize in agricultural gross domestic product (GDP) has declined significantly. In 1993, maize accounted for 12.5% of agricultural GDP, but by 2001 it accounted for only 9%. Aside from the overall growth in other sectors of the economy (such as tourism and light assembly industries) there are some structural reasons for the reduction in economic value of maize production in the country, including low, subsidized prices for major international producers in international markets and the fact that the domestic maize sector has become less competitive. Domestic production is insufficient to supply domestic demand. In recent years, the country has had to make major grain purchases in international markets to complement domestic production.

A majority of maize producers in Honduras have small land holdings and produce mostly for subsistence. Most of these farmers have little access to technology, knowledge, and credit. The bulk of the domestic maize crop is produced by medium- and large-scale farmers, who have greater access to new technologies (such as improved varieties) and, most importantly, financing by the banking sector.

The Government of Honduras and the private sector have initiated several programs to promote domestic maize production. To meet the growing demand for maize, the Honduran government sought alternatives that reduce insect damage and/or increase yield productivity per hectare. One strategy pursued was the promotion of improved maize varieties. One option was the commercial approval of the cultivation of GE insect-resistant maize in the country. The specific event approved in Honduras is a maize variety to which a gene from the bacterium *Bacillus thuringiensis* was inserted into the maize genetic composition. The Bt gene induces the maize plant to express a protein that is toxic to lepidopteran insects. The maize event in Honduras also incorporated a gene construct that confers tolerance to the herbicide glyphosate (Roundup Ready™ [RR]). We use the generic abbreviation, Bt/RR, for the stacked-gene maize variety approved and used in Honduras.

Bt/RR maize was introduced in Honduras in 2002, being the first—and, to date—the only Central American country to approve and adopt commercially this and other GE maize varieties. The cultivation of Bt/RR maize in Honduras is expected to grow in the near future, yet this expectation needs to be tempered by the fact that the rate of adoption of improved maize varieties in Honduras, after many years of public and private sector promoting the technology, is still less than 20% (Hintze, Renkow, & Sain, 2003).

The average size of maize land holdings in Honduras is roughly 1.2 hectares. Defining an average land holding precisely is complicated by the existence of two cropping seasons. The “first or rainy” season runs from early May to June, and the “second or dry” season runs from August to November. Furthermore, maize can be produced as a mono-crop or it can be inter-cropped, usually with red beans. The number of farmers and the area planted decreases significantly between the first and second seasons.

According to FAOSTAT, area harvested with maize in Honduras increased steadily from 250,000 hectares in 1961 to 425,000 hectares in 1991; however, area harvested has been decreasing steadily since 1991. By 2007, area harvested was roughly 300,000 hectares. Furthermore, yields in Honduras reported by FAOSTAT were roughly 1.0 ton/ha in 1961, having increased to roughly 1.54 ton/ha in 2007. This represents an average increase of 254 kg/ha over a period of 25 years (Figure 1). Yields per hectare have been increasing steadily but slowly over the past 35 years. The change in the later years has been significant and may be explained by an increase in the use of maize hybrids and cultivation increases in those areas with higher production potential, while discarding those areas with natural conditions unsuitable for planting the crop (Arias, 2003).

The low yields of farmers with small landholdings could be the result of a combination of behavior in the presence of risk, low education and knowledge, limited access to input and financial markets, adverse weather conditions, and pests and diseases, among other constraints. In Honduras, one of the most serious agronomic problems in relation to maize productivity is the damage caused by insects, mainly of the order Lepidoptera. Lepidopteron insects that can cause significant economic damage in Honduras include the “Fall armyworm”

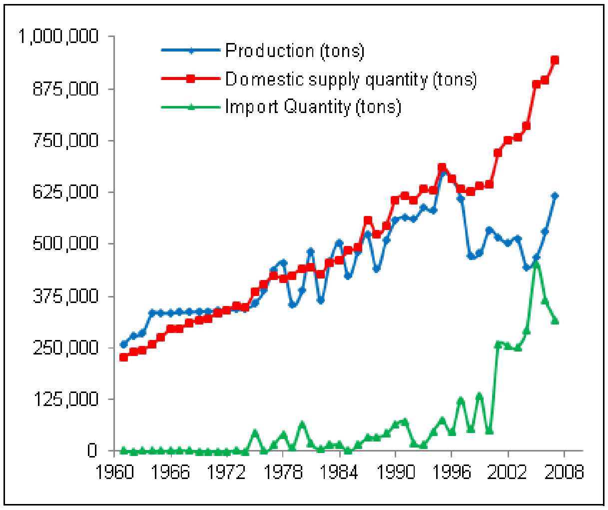

Figure 1. Maize production, domestic supply, and imports in Honduras (tons).
Source: FAOSTAT (2012)

(*Spodoptera frugiperda*), the "maize stalk borer" (*Diatraea spp.*), and the "maize earworm" (*Helicoverpa zea*). Damage by Fall armyworms (FAW) can reduce yields by 20-87% (Andrews, 1980).

Conventional methods to control lepidopteran insects include foliar applications of pesticides. In addition, farmers use granular insecticide sprays applied to each plant. However, farmers in Honduras have great difficulty in systematically identifying critical levels of damage, determining appropriate doses of pesticides, and timing pesticide applications. Pesticides are often applied at the wrong time or lower (or higher) than the recommended doses. These conditions promote the development of pest populations resistant to insecticides. Exploring new production alternatives and production-efficiency-improving policies is thus warranted, as it may open new opportunities for producers in the country.

Research Design

To examine the performance of Bt/RR maize in Honduras, we designed a multi-faceted research approach. We sought to combine experimental and field data to generate a more robust presentation of data and analysis in the Honduran context, an extremely poor country where adoption was in the early stages. We knew we would encounter few producers, that they would be widely dispersed, and that they would exhibit "first-adopter" biases. Thus, we separated our research activities into two distinct components.

Table 1. Insecticide application experimental treatments.

Treatment based on vegetative stage	Treatment description
From germination (VE) until plant reaches 8 leaves (V8)	Insecticide application when *S. frugiperda* population reaches a critical level of 15%
From 8 leaves (V8) until flowering (FL)	Insecticide application when *S. frugiperda* population reaches a critical level of 30%
From germination (VE) until flowering (FL)	Insecticide application when *S. frugiperda* population reaches a critical level of 15% or 30%
Control	No application of insecticide

In the first component, we conducted three activities focused on an agronomic and entomological evaluation of insect pests. We conducted 1) an evaluation of primary and non-target insect pests in an experimental field, 2) a study of Bt/RR maize effectiveness *in situ* on larger plots of medium- and large-scale producers, and 3), a FFS plot experiment with small producers.

In a completely randomized experimental field test, we examined the behavior (under commercial production conditions) of insect pests in maize with and without the GE events as compared to a conventional variety. We analyzed the effect of lepidopteran insect pest complex *Spodoptera frugiperda*, *Diatraea lineolata*, *Helicoverpa zea*, *Listronochus dietrichi*, and *Geraeus spp.* by stage of crop development and their natural enemies along the crop cycle.

Experimental treatments were the pest-control strategies based on vegetative state of the maize plant and the germplasm types. In the case of pest control, treatment was done according to the critical levels of the populations of *S. frugiperda*, which is the main target pest of the Bt/RR maize. The specific insect-control treatments are in Table 1 following the recommendation by Trabanino (1998): 15% in the range of germination to eight leaves (VE-V8), and 30% in the range of eight leaves until flowering (V8-FL). Additionally, a control treatment without the application of insecticides to control the target pests was included in the experiment. The pesticide used was Lambdacihalotrine with a dose of 1.4 liters per hectare, applied with a knapsack sprayer.

Three types of germplasm were used in the experiment. The first, hybrid DK234 RRYG, has insect-resistance and herbicide-tolerance. Hybrid DK2347, the second, is the isoline conventional hybrid. The third, Tuxpeño, is an improved open-pollinated variety that is widely grown in Honduras. These three varieties were cultivated following standardized and uniformly applied

Figure 2. Major maize producing areas in Honduras and field sites for producer survey.
Note: study sites in red and other major maize-producing areas in green.

agronomic procedures for fertilization, weed control, water, and other practices.

The statistical analysis was conducted with the program Statistical Analysis System® (SAS, 2003), using an experimental design of divided plots with a factorial arrangement of 3×4. Factor A was the maize genotypes, and Factor B was the vegetative time and control strategy combination. There were three repetitions, totaling 36 experimental units. Each of the experimental units averaged 450 m^2 per plot. We used the statistical approach of an analysis of variance (ANOVA) with a generalized linear model (GLM), with a separation of means and the test LSMENAS. We corrected the percent values using the function arc-sine. We used a minimal significance value of $P \leq 0.05$.

Evaluation *in situ* on the plots of medium- and larger-scale producers was carried out in two of the most productive areas of Honduras, the states of Comayagua and Olancho. We obtained seeds of the Monsanto hybrid DK234 (the isoline hybrid) to the hybrid DK234 RRYG (containing the Bt and Roundup Ready^{TM} gene). The seeds were given to farmers to plant two experimental plots in their own land holding, one with DK234 and the other with DK234 RRYG. Each of the plots had an area of 0.7 hectares. Farmers were allowed to manage the crop accordingly. We selected five sites in Olancho and three in Comayagua. The variables measured included the natural infestation of FAW, maize earworm, and maize stalk borer; overall yield for the hybrid and its isoline; and the population of non-target insects. For insect sampling techniques we used standardized methods with widely used protocols in the entomological, literature including visual observations, destructive sampling, and pitfall traps.

In Honduras, there is very little experience studying the use by smallholder farmers of new maize technologies, including either conventional or Bt/RR maize hybrids. To gain insights, we utilized a Farmer Field School organized by the project PROMIPAC (Integrated Pest Management Program for Central America), which builds smallholder capacity to use integrated pest-management techniques. Seeds for a Bt/RR hybrid, its isoline hybrid, and a conventional open-pollinated variety were distributed to farmers in the project and were managed by groups of participants in the FFS.

Seeds were planted and fertilized manually in experimental plots of an average area of 3,750 m^2 per plot in nine different villages in three states. Technical assistance was provided to evaluate production and to complete questionnaires. Variables measured include yields, natural infestation of FAW, net income, and producers' acceptance and perceptions about the production process and the outcome.

In the second component of the research design, we conducted a field survey to examine the potential socioeconomic impacts from the adoption of Bt/RR maize in Honduras. We designed a questionnaire to investigate the economic impact, management, knowledge, and perceptions about the crop during three stages of the production cycle. We focused our data collection in the three major maize-producing regions in Honduras, including Olancho, Comayagua, and El Paraiso/Oriente (Figure 2).

The first two were selected for being the largest producers of maize in the country. According to Hintze (2002), approximately 50% of commercial production of maize in Honduras is generated in the department of Olancho. The department of El Paraiso alone generates

Table 2. Percent damaged maize cobs by *H. zea* and *S. frugiperda*, *S. albula*, and total cob damage.

	Infestation (%)			
Genotype	***H. zea***	***S. frugiperda***	***S. albula***	**Total cob damage at harvest**
DK234 RRYG	1.16 ^{a}	2.33 ^{a}	0.33 ^{a}	3.83 ^{a}
DK234	10.17 ^{c}	11.67 ^{c}	6.00 ^{b}	27.83 ^{c}
Tuxpeño	4.00 ^{b}	8.00 ^{b}	4.00 ^{b}	16.00 ^{b}

^{a,b,c} *Values in the same column with different letter are statistically different at the probability level of (P<0.05)*

12% of commercial production of maize in Honduras; although Comayagua only contributes less than 1% of national production, it was selected for the study to include a different type of producer than the other two areas.

In Olancho and El Paraiso, maize producers cultivate relatively productive land, so they generally use chemical inputs and mechanization. The yields of these producers are among the highest in the country and production is mainly commercially oriented. In Comayagua, producers usually have smaller land and marginal quality holdings.

Most maize farmers in Olancho and El Paraiso plant season maize and beans first season. Some of these producers have highland coffee productions and may migrate away from their communities to perform work in other agricultural production during the harvest season. However, farming production systems that consistently generate income is maize production. On the other hand, for the typical producer of Comayagua, planting season occurs during both first and second seasons. In Comayagua, commonly planted crops include vegetables. Small producers may work for the larger producers of vegetables in the area. Off-farm work is the most important source of income for families of small farmers in this department.

We attempted to obtain a list of producers with the relevant Ministries and the technology developer but were unsuccessful in obtaining a current list of Bt/RR maize users that was complete. We opted for a combination snowball and referral sampling where the two enumerators hired to conduct the field work contacted seed retailers and marketers in the three departments surveyed to build a list of producers that used Bt/RR maize. The enumerators, to the best of their knowledge, captured all Bt/RR maize producers in the three departments up to a point where they could not find any more producers; however, there is no way of knowing whether this constitutes an exhaustive list of users. To collect data for conventional users, we chose at random from a pool of conventional producers with similar production characteristics in the same production area as the Bt/RR maize producers.

The final sample includes 67 Bt/RR growers and 47 conventional maize growers. The size was constrained by the time frame and the survey budget; it provided a cut-off point for the search done by the enumerators. We collected information that would enable us to estimate the economic impact, the management issues, and knowledge and perceptions about GE maize. We applied three survey instruments covering three production stages (planting, growing, and harvesting), including data on management, knowledge, and perceptions about Bt/RR maize.

Results

Agronomic Experiments

The three maize varieties used in the study reached eight leaves 26 days after planting and flowered at day 58. From the germination to eight leaves, *S. frugiperda* reached only the critical level of 15% infestation, once during the cycle at 23 days after planting and only in hybrid DK234 and Tuxpeño. Lambdacihalotrine was applied at the recommended dose. During the stage between eight leaves and flowering (V8-FL), the population of *S. frugiperda* did not reach the critical level of 30% in any of the three varieties.

The statistical analysis showed significant differences for the percent daily target pest infestation of *S. frugiperda* in the three maize varieties used in the study. The variety DK234 RRYG showed the lowest infestation levels in the two sampling periods (VE-V8 and V8-VF), followed by DK234 and then Tuxpeño. For the period VE-FL, which is the total daily infestation level, the same pattern of statistical significance is maintained at the significance level (P<0.05).

As expected, the lower infestation level of DK234 RRYG can be attributed to the Bt event and its actions on the larvae of *S. frugiperda*. Independently of the variety, there were significant differences in terms of the timing of pesticide applications in stage V8-FL. Those treatments where the insecticide Lambdacihalotrine

Table 3. Number of insects sampled and insecticide application thresholds.

	Fall armyworm (*Spodoptera frugiperda)*		Maize earworm (*Diatraea spp.*)		Maize stalk borer (*Helicoverpa zea)*	
Hybrids	**Comayagua**	**Olancho**	**Comayagua**	**Olancho**	**Comayagua**	**Olancho**
DK234 RRYG	11.6	5.0	32.1	15.9	11.1	7.3
DK234	31.7	13.0	48.8	19.5	16.0	16.7
Significance	0.08	0.01	0.22	0.14	0.47	0.02
Insecticide application threshold	15%		20%		20%	

Table 4. Number of insecticide applications and the productivity of grain for both hybrids.

	Olancho		Comayagua	
Hybrids	**Insecticide applications (#)**	**Yields (kg/ha)**	**Insecticide applications (#)**	**Yields (kg/ha)**
DK234 RRYG	0.0	6,513	0.3	3,750
DK 234	1.8	6,510	0.3	2,600

(VE-V8 and VE-FL) was applied had a lower percent of daily infestation compared to the no-insecticide-application and the V8-FL treatments. The daily infestation levels translated into cob damage as in Table 2.

Experimental results show that the Bt event is effective in controlling *S. frugiperda*. However, during the experiment, the *S. frugiperda* population remained under critical levels. In the case of the conventional hybrid and the conventional variety, the *S. frugiperda* population only reached its critical level once, triggering one application of insecticide during the stage from germination to the plant with eight leaves. Even though the Bt event is effective, it is not needed when pest populations are low. These results were not unexpected and point to the need to view the Bt event as insurance against potential pest attacks.

Large-plot Evaluation with Producers

For FAW, insect sampling counts indicated that only in Comayagua, with the isoline hybrid, would an insecticide application be necessary (31.5 exceeds the threshold of 15). In the case of maize earworm, the threshold for insecticide application was reached for both hybrids, implying high maize earworm population pressures. In the case of the maize stalk borer, none of the populations in either location reached the critical level.

Table 4 shows that yield for both hybrids were more or less the same in Olancho, even though the conventional hybrid (DK234) received approximately two applications, while the hybrid (DK234 RRYG) did not receive any application during the production cycle. In Comayagua the number of applications were the same, but yields were 1,150 kg/ha higher for the Bt/RR maize hybrid. These are not unexpected outcomes. In the absence of pest pressures, there is no reason why we would observe any yield difference.

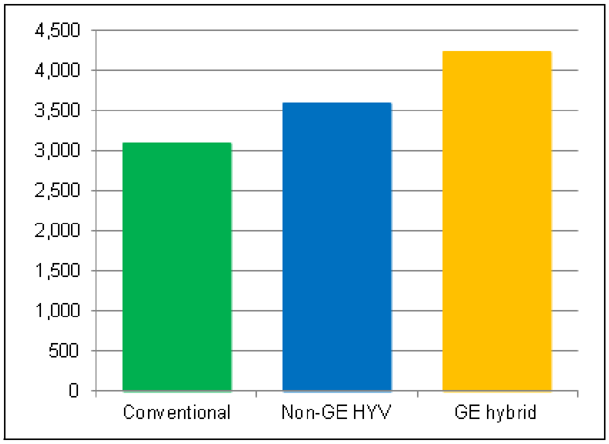

Figure 3. Yield by variety type with smallholder producers in Honduras (kg/ha).

Smallholder Experience

Figure 3 presents the average yields across all the experimental plots in the FFS. The Bt/RR hybrid produced 1,136 kg/ha more than the conventional variety. In turn, the Bt/RR hybrid produced 637 kg/ha more than the isoline hybrid. This represents a yield advantage of the Bt/RR hybrid of 36% and 17% over the conventional and isoline hybrid, respectively.

In terms of perceptions, nearly two-thirds of smallholder farmers (61%) indicated that they would adopt the Bt/RR technology, whereas slightly under one fifth (18%) indicated that they would adopt if they were not financially constrained. About one fifth of farmers (21%) indicated that they would not adopt the technology. Producers in the FFS identified desirable features of maize varieties, including high performance, ear quality, large and fully filled grains, resistance to pests, and adaptation to local soil and environmental conditions considering the water scarcity during the second season. All producers identified some of the advantages of Bt/RR maize. In spite of the fact that FFSs were conducted in different areas and ecosystems in the country, results obtained by farmers—and their perceptions—were similar. They found that, compared to landraces and improved varieties, Bt/RR maize had very low incidence of pests and diseases, better plant growth, saved labor for weed control, and had better performance.

The main reason producers chose not to grow the Bt/RR maize was the seed price, despite that the higher price could be offset by higher yields or reduced pesticide costs. Most producers indicated that if the seed could be obtained through credit, they would not hesitate to obtain in for each crop cycle. Access, in addition to cost, is an important consideration. For many smallholder farmers, the distance to input stores where improved seed is sold is great. In some cases, farmers rely on the good will of neighbors and friends who are conducting business to obtain seed, but then have little control over the type of seed that is brought back to the community.

Farmer Survey

From the standpoint of methods, the farmer survey was not a probabilistic sample. There is a distinct possibility that the farmers we interviewed are likely to be among the more advanced producers in the country, leading to overstatement of the advantages associated with the new technology. Related to this point is that it is not possible to generalize the results because the probability of selection is unknown. The results can be treated only as a pilot study.

In fact, there are two distinct observations we can make about the sample of producers in our dataset. First, we found a large variation in terms of area planted for a specific variety by producer. These range from small (1.25 hectares) to large (312 hectares). Smaller area planted in our sample may be a response to experimentation or familiarization processes within individual producers. Second, small land holding in the sample is not necessarily connected with the level of technology sophistication or binding productivity constraints, as producers may have been involved in other agricultural crops or production systems such as livestock.

Of the 113 producers surveyed, 74% are located in Olancho, 15% in Comayagua, and 11% in El Paraiso. For the purposes of the descriptive analysis, we disaggregated producers into three user group depending on their use of the GE maize. The three user groups are: 1) only plant Bt/RR maize varieties, 2) only plant conventional varieties, and 3) plant both GE and conventional varieties. Of the 113 producers surveyed, 37 produce only GE maize varieties, 48 cultivate conventional maize seed varieties, and 28 plant both types of maize. For the regression analysis we combined those who plant Bt/RR maize varieties only and those in a mixed production system.

Table 5. Characteristics of maize producers surveyed in Honduras.

Variable	Conventional producer	Mixed producer	Bt/RR producer
Land holding size (mean ha)	19.07** (51.61)	52.20** (69.62)	28.95 (64.18)
Area with Bt/RR maize (mean ha)	0.00	26.64** (36.93)	28.95 (64.18)
Area with conventional (mean ha)	19.07* (51.61)	25.56* (52.17)	-
Grain yield (kg/ha)	4,931** (19.1)	--	5,909** (23.28)
Own land (1=yes, 0=no)	0.96** (0.20)	0.88** (0.33)	0.95 (0.23)
Own machinery (1=yes, 0=no)	0.35** (0.48)	0.89** (0.32)	0.78 (0.48)
Irrigation (1=yes, 0=no)	0.06** (0.24)	0.26** (0.45)	0.26 (0.45)
Access to credit (1=yes, 0=no)	0.51** (0.51)	0.74 (0.45)	0.78** (0.42)
Farm insurance (1=yes, 0=no)	0.31 (0.47)	0.44 (0.51)	0.41 (0.50)
Mean number of herbicide applications at planting	0.90** (0.85)	0.67 (0.83)	0.37** (0.59)
Mean number of herbicide applications at growth	0.51** (0.82)	0.22 (0.51)	0.16** (0.37)
Mean number of fertilizer applications at planting	0.92** (0.28)	0.26** (0.45)	0.47 (0.51)
Mean number of fertilizer applications	1.00** (0.20)	0.78 (0.75)	0.50** (0.56)
Mean number of insecticide applications	1.08*** (0.79)	0.15*** (0.46)	0.24 (0.54)
N=	37	48	28

*Note: * = P < 0.10; ** = P < 0.05; *** = P< 0.01*

Farm Characteristics. Table 5 shows the differences between the types of producers using Bt maize, those using conventional varieties, and those using both varieties. The differences between the results shown in the table were validated with an ANOVA test, which showed significant differences between the types of producers in the farm size, farm machinery, irrigation, credit access, and use of chemicals.

Farmers with mixed production system are those that are more technologically advanced and who have larger farm sizes over the net producers of Bt maize, which in turn have farm sizes greater than conventional maize growers. According to the results shown in Table 5, Bt maize farmers attain 5,839 kg/ha^{-1}, whereas conventional producers reach only 4,931 kg/ha^{-1}. Crop management practices influence this result. As evidenced by use of machinery, more mixed-system producers have agricultural machinery compared with the other two groups. Regarding access to credit, producers in the mixed system and net producers of Bt maize have greater access to credit than conventional maize producers.

Regarding the use of chemicals, although the number of herbicide applications reduced seed stage of growth. Otherwise, the number of applications of fertilizer increases seed stage of growth, due to the demands of the crop. In general, conventional producers made more applications of herbicides, fertilizers, and insecticides as compared to mixed and net producers of Bt maize. The reduction in the number of insecticide applications by net producers of Bt maize (0.24) compared to the number of applications for conventional producers (1.08) should be noted, since genetic modification of the Bt maize variety aims to reduce insect damage.

A Robust Regression Approach. Robust regression methods focused on addressing the limitation that ordinary least squares (OLS) methods are not robust in the presence of outliers.

In our survey, a number of respondents reported unusually large or atypically small landholdings. Respondents reporting small areas of Bt/RR maize may be entrepreneurial agricultural producers who were experimenting with the new technology, but whose main production activity was livestock or other crops. Since we had a small number of respondents distributed in three regions, we also faced the potential for heterocedasticity.

Outliers may not be a problem if the observation is drawn from the tails of a well-defined distribution such as the normal. If outliers follow a non-normal distribution or are compromised by any other violation of the assumptions used by the OLS method, then OLS estimates can be inefficient, biased, or invalid. With larger samples, outliers may artificially inflate the variance of OLS estimates.

Robust regression models address these limitations, using either parametric or non-parametric approaches. Parametric approaches include M-estimators (see Huber, 1981), least trimmed squares (as described in Rousseeuw & Ryan, 1987), Theil-Sen, and S-estimators. The most frequently used estimators today are the MM-type estimators, who attempt to overcome the inefficiency of S-estimators while retaining the efficiency of the M-estimators.

With this background in mind, we pursued the general approach of testing for outliers using standardized residuals, estimating Cook's Distance index (D) statistic, and testing for heterocedasticity for a first-step conventional OLS regression. We found a total of 10 outlier observations in our sample based on the Cook's D statistic estimated using the formula $4/(N-K-1)$, which resulted in a value of the statistic of 0.045. Similar results were obtained through the graphical and tabular examination of standardized residuals.

We then applied the Robust Regression options in Stata through the RREG approach. RREG conducts a robust regression using iteratively reweighted least squares and is an M-type estimator. The procedure first calculates the Cook's D for each observation and then drops those with a value greater than 1. The next step assigns a weight to each observation, with higher weights given to the best-behaved observations. Weights are based on the absolute residuals. The iterative process ends when the weight for all observations is less than the tolerance level, from one iteration to the next.

Instrumental Variables. To test the impact of Bt maize adoption on outcomes, we implemented instrumental variables (IV). For the first-stage regression we first performed the test of excluded instruments where the null hypothesis is that the instruments are not relevant. The F (1, 98) statistic from *IVREG2* is 94.96. We thus reject the null hypothesis that the instruments are not relevant. Second, we performed the under-identification test using the Anderson canonical correlation likelihood ratio statistic. The Anderson canonical correlation test (LM) statistic has an estimated chi-square (1) value of 55.61 and critical P value of 0.00000. We thus reject the null hypothesis of the matrix being under identified. The same result is obtained through the Cragg-Donald (Wald) statistic, which has a chi-square value (1) of 109.49.

The third step is the Anderson-Rubin test of joint significance of endogenous regressors. The null hypothesis is that the over-identifying restrictions are valid. In this case, the Anderson-Rubin Wald (the F-test) statistic is 14.54 with a P value of 0.0002. We thus reject the null hypothesis with a 1% level of significance. These results are also similar to the Stock-Wright LM S statistic, which has a chi-square value of 14.60 and P value of 0.0001. The latter two tests provide credence to the rejection of the null hypothesis and the acceptance of the alternate hypothesis.

For the second-stage IV regression, we performed the Sargan test. In this test, the proposed null hypothesis is that the model is not over-identified. The Sargan statistic value is 0.000 and thus concludes that the equation is exactly identified. We repeated the IV regression procedures using corn and seed prices independently so that the equation was over identified as shown by the Sargan statistic. Results from this regression are quite similar to the ones presented here and are available upon request. We further conducted the test of heterocedasticity using the *IVHETTEST* option in Stata with a null hypothesis of the model being homoscedastic. The *IVHETTEST* approach calculated the Pagan-Hall general test statistic with a value of 1.206 and thus we fail to reject the null hypothesis of homoscedasticity, pointing out the need to run the two-stage least square regression for instrumental variables using the robust *VCE* matrix and/or the generalized method of moments (*GMM*), and the appropriate test would be Hanson-J.

Finally, we tested the endogeneity of whether a producer was an adopter of Bt/RR maize in Honduras. We used the Hausman-Wu test through the *IVENDOG* option in Stata. The null hypothesis is that the regressor is exogenous. The Hausman-Wu F-test statistic is 3.867 (df=1, 97) and a critical P value of 0.0529. The alternate Durbin-Wu-Hausman chi-square test statistic is 4.332. We thus reject the null hypothesis at the 5% level of significance for the chi-square test and at the 10% level for the Hausman-Wu test. Therefore, we conclude that there is moderate evidence that adoption of Bt/RR maize in Honduras is endogenous.

The hypothesis testing for the first- and second-stage regression using the instrumental variables approach shows that adoption of Bt is endogenous, and thus the use of a method to address endogeneity such as instrumental variables is warranted. The instruments chosen for the estimation are relevant and are exactly identified. The heterocedasticity test shows the need to run the IV regression with the robust and/or the *GMM* option.

Table 6. Outcome regressions from OLS, robust regression, and instrumental variables on yield as a dependent variable.

Variables	OLS	RREG	IVREG2
Whether a Bt/RR user (0=no, 1=yes)	1,127.05*** (332.21)	856.51*** (282.59)	1,781.24*** (472.56)
Located in the state of Olancho	569.05 (441.47)	414.45 (375.50)	776.83 (493.44)
Total area cultivated with corn	-0.52 (2.16)	-0.89 (1.84)	-0.81 (1.64)
Total land preparation	2.29 (2.62)	-0.37 (2.23)	1.42 (3.54)
Total planting costs	-3.47 (3.88)	-4.35 (3.29)	-5.11 (3.81)
Total cost labor	-14.34 (10.59)	-19.25** (9.01)	-15.59* (8.99)
Total costs fertilizer	-0.52 (3.11)	-0.44 (2.64)	-2.07 (3.20)
Total costs insecticide	8.01 (9.13)	11.10 (7.77)	13.41* (7.01)
Total costs herbicides	11.43 (11.48)	6.94 (9.76)	9.87 (9.27)
Insurance use (0=no, 1=yes)	-160.99 (308.08)	-226.99 (262.06)	-230.30 (335.77)
Irrigation system ownership (0=no, 1=yes)	914.49** (426.89)	516.22 (363.13)	920.87* (499.83)
Credit availability (0=no, 1=yes)	344.12 (305.61)	653.50** (259.97)	220.85 (303.56)
Years of experience	-15.29 (10.95)	-26.99*** (9.32)	-12.42 (10.42)
Availability of technical assistance (0=no, 1=yes)	181.40 (491.50)	161.76 (418.09)	173.87 (414.36)
Constant	4,223.324*** (933.88)	5,031.05*** (794.40)	4,111.32*** (965.44)

*Notes: 1) Standard errors in parentheses, 2) statistically significant at * =P<0.10; **=P<0.05; ***=P<0.01*

Table 6 introduces the results from the conventional OLS regression, robust regression, and IV procedures (*REGRESS*, *RREG*, and *IVREG2*) available in Stata.[1]

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[1] *We also conducted the MMREG procedure based on an MM method proposed by Verardi and Croux (2010) seeking to improve on RREG and other robust procedures in Stata by combining the robustness of S-estimators with the efficiency of M-estimators. We additionally estimated a quantile regression procedure in Stata (QREG evaluated at the 25, 50, and 75 quantiles) and the OLS procedure with robust estimation of standard errors (REGRESS with the robust option selected). In all cases, outcomes were rather poor and not substantially different than the OLS REGRESS options presented here.*

The outcome variable in the standard OLS and robust regression and the second-stage least squares in the IV regression is yield. In the case of the *2SLS*, the dependent (instrumented) variable was the adoption of Bt/RR maize variable, and the excluded instrument was the ratio of price of Bt/RR seed per kilogram to the price of corn grain per kilogram.[2]

The *REGRESS* procedure in Stata, which estimates an OLS regression, performed rather poorly. Only the dummy variable for Bt/RR use and the availability of an irrigation system were statistically significant at the significance level. The *RREG* approach in Stata improved the performance of the estimations. In the *RREG* procedure, whether a maize producer was GM adopter, total labor costs, credit, and experience were significant at the indicated levels of significance. Results from applying the *IVREG2* approach shows that GM adoption, labor, and insecticide costs are significant in explaining yields. From the standpoint of the objectives of this article, we are particularly interested in finding whether the use of Bt/RR had an advantage over conventional varieties. As the *RREG* and *IVREG2* approaches show, this difference can range from 856 to 1,781 kg/ha of a yield advantage of the Bt/RR maize over the conventional varieties.

The fact that both the robust regression and instrumental variables approach did not yield a more robust estimation point out the dual problem we have with the Honduras dataset. The level and complexity of outliers during the early adoption process has an impact on both types of estimation methods. Instrumental variables are now known to be sensitive to the presence of outliers and the need exists for robust IV approaches that are not sensitive to their presence. Alternatively, the need exists to significantly step up the methods that can be used to address outliers through robust regression approaches and endogeneity through instumental variables. This, along with an expanded dataset of producers planned for the future, is likely to improve the quality of results.

Decision Making Under Risk Approach

We used the program SIMETAR© to estimate stochastic dominance with respect to a function (SDRF) and the stochastic efficiency with respect to a function (SERF) as two measures for the analysis of the decision-making process under risk for the Bt/RR and non-Bt/RR producers (Richardson, Shumann, & Feldman, 2004). We performed the analysis for maize yield and for returns over variable costs (ROVC) using the predicted values from the robust and instrumental variables yield regression estimated in the previous section. This approach should ensure a comprehensive approach to addressing endogeneity of adoption and selection effects of observed characteristics on adopters. The accuracy of this approach can be improved with a larger number of observations. We contrast this result with those from the raw yield data.

Stochastic dominance is a nonparametric approach used to rank competing alternatives, strategies, or policies based on their risk characteristics. This approach ranks alternatives into dominating and dominated sets based on stochastic efficiency rules. Stochastic efficiency rules are pair-wise comparisons of the estimated cumulative density functions (CDFs) derived from observed and/or simulated data describing an outcome or action. In most cases, the CDFs tend to intersect, and thus additional (and more restrictive) assumptions are needed to allow the ranking. Stochastic dominance analysis assumes that the decision maker is an expected-value maximizer, risky alternative distributions are mutually exclusive, and that distributions are based on population representative probability distributions.

Hardaker, Richardson, Lien, and Schumann (2004) proposes SERF as a method of ordering risky alternative using certainty equivalents (CE) for suggested risk preference assumptions. The CE is defined as the amount of money or physical units by which the decision maker is indifferent between the risky alternative and a certain amount. In the SERF approach, alternative utility functions can be used to model risk attitude using risk-aversion coefficients. Risk aversion coefficients can be absolute, relative, or partial depending on the assumed behavior of the decision maker and the type of issue being examined.

We used a negative exponential utility function in our analysis leading to using an absolute risk-aversion coefficient (ARAC), defined as the negative ratio of second derivative of the utility function to the first derivative of the utility function(Pratt, 1964). The negative exponential utility function and the ARAC model is intended for a decision maker who prefers less risk given the same expected return. Furthermore, decision makers have a constant and absolute risk-aversion behavior that does not change with wealth.

When examining competing strategies, those with a higher CE are preferred to those with a lower CE. For most risk-averse decision makers, the CE is usually less than the expected value of the risky strategy. In most sit-

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[2] *Results from the first stage in the 2SLS procedure are available upon request.*

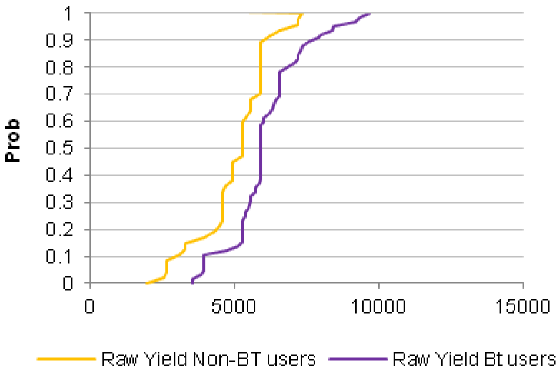

Figure 4a. Using "raw" yield data.

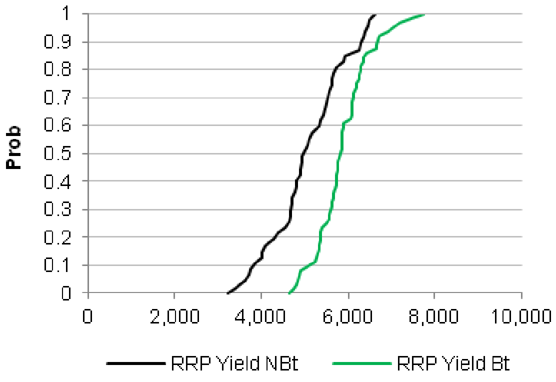

Figure 4b. Using predicted values from the robust regression having yield as dependent variable.

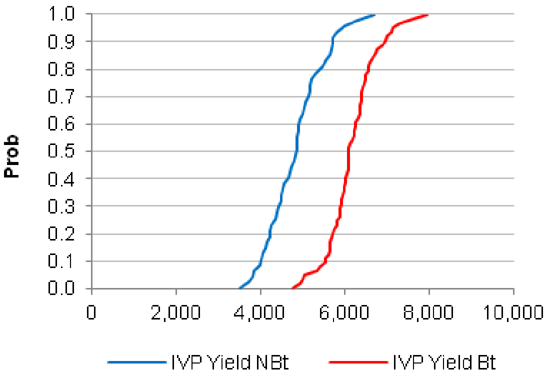

Figure 4c. Using predicted values from the instrumental variables regression with the GMM/Robust.

Figure 4. Stochastic dominance analysis using raw and predicted yields.

uations, Hardaker et al. (2004) shows that the SERF approach may be more efficient than stochastic dominance in selecting efficient strategies in a risky portfolio.

In our analysis, we used SIMETAR© to derive cumulative density functions (CDFs) for yields and returns over variable costs (ROVC) using the predicted values of yield from the instrumental variable regressions. The program calculates CE based on the selected negative exponential utility function and ranks the two strategies: Bt/RR and conventional maize use. Once the alternative strategies are ranked, the program calculates a utility-weighted risk premium, defined as the difference between the CE of the preferred strategy and the CE of the less preferred strategy. The utility-weighted risk premium is the amount of returns over variable costs or yield that the decision maker would have to be paid or gain to shift from the preferred to the less preferred strategy, given the specified risk-aversion coefficient. We used a risk-aversion coefficient ranging from zero (risk neutral) to very risk averse.

Yields

Figure 4a-4c introduces the cumulative density functions for the stochastic dominance analysis done using SIMETAR®. Note that both the CDFs for raw yields (Figure 4a) and for predicted values from the robust regression (Figure 4b) do not take into consideration endogeneity. In fact, if one compares the CDF using the predicted values from the robust regression (Figure 4b) with the CDF using the raw yield data (Figure 4a), one can see the effect of the robust regression as it considers outliers. In both Figure 4a and 4b, the CDF for the Bt/RR and non-Bt/RR maize do not cross. Therefore, the yield of Bt/RR dominates non-Bt yields in Honduras. Bt/RR maize thus exhibits first-degree stochastic dominance (FDSD) as decision makers prefer those distributions to the right. For those decision makers, the strategy that has a risk behavior ranging from risk neutral to very risk averse, the dominant strategy is the use of Bt/RR maize that has the yield distribution estimated from the survey data collected in Honduras. Figure 4c introduces the CDFs for the predicted values from the IV regression using the generalized methods of moments and with robust standard errors. As in the case of the raw and robust regressions, the yield of Bt/RR maize exhibits its FDSD over that of conventional varieties.

Returns over Variable Costs (ROVC)

Although yields are an important consideration for most producers, it is important to consider the net benefit from the use of a technology. One indicator of the potential benefits from the adoption of a technology is the ROVC. In our case, we may not have captured all the variable costs in the production of maize for the producers surveyed, thus we can qualify this indicator in our study as a quasi-ROVC indicator (q-ROVC).

For each of the 113 producers in the sample we calculated gross income by multiplying the reported grain yield by the maize price received when the grain was sold. We estimated variable costs as the sum of seed, labor, land preparation, planting, insurance, irrigation, insecticide, fertilizer, and—in the case of Bt/RR maize producers—the technology fee paid. To get q-ROVC we subtracted our estimate of variable costs from gross income for each producer and then entered all the data on SIMETAR$^{©}$.

Figures 5a-5c introduce a crude estimate of q-ROVC for both adopters and non-adopters of Bt/RR maize in Honduras. The estimate of q-ROVC is obtained by multiplying raw or predicted yield by the price received by each farmer and then subtracting the variable costs estimate per farmer. This is a crude and partial estimate of q-ROVC as we did not capture all potential variable costs in our estimation. Results are quite similar to the analysis done for yields. Results in Figures 5a-5c are similar to the stochastic dominance analysis for yields. The CDFs for the robust and IV regression for q-ROVC show that Bt/RR maize dominates with a first-degree stochastic dominance over non-Bt/RR maize. For most producers with risk-aversion coefficients ranging from risk neutral to very risk averse, Bt/RR is the dominant strategy.

Based on the previous analysis, the Bt/RR maize has been identified as a dominant strategy across all risk preferences, as it exhibits first-degree stochastic dominance. Thus, there is no explicit need to perform further analysis as in the case that no dominant strategy had been identified in the first place. When there is no dominant strategy, the need arises to perform second- or third-degree stochastic dominance. However, it is instructive performing a SERF- and utility-weighted risk premiums estimations to understand better the advantage of Bt/RR maize over conventional maize as estimated in our sample.

Figures 6a and 6b introduce the SERF and the utility-weighted risk premiums for the predicted yield using the instrumental-variables approach. As can be seen in

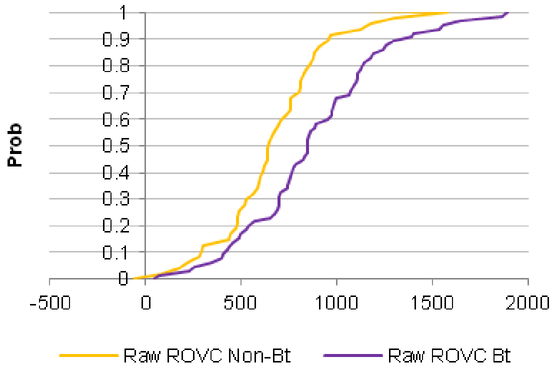

Figure 5a. Using "raw" ROVC data.

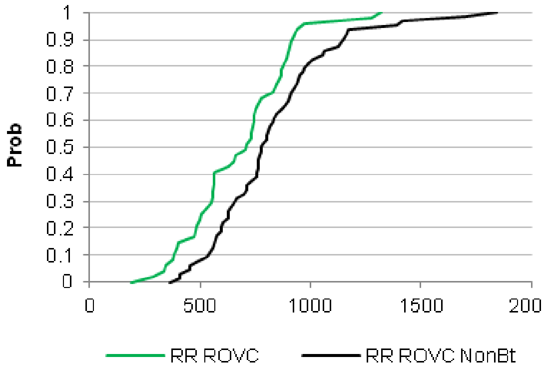

Figure 5b. Using predicted values from the predicted values of the robust regression.

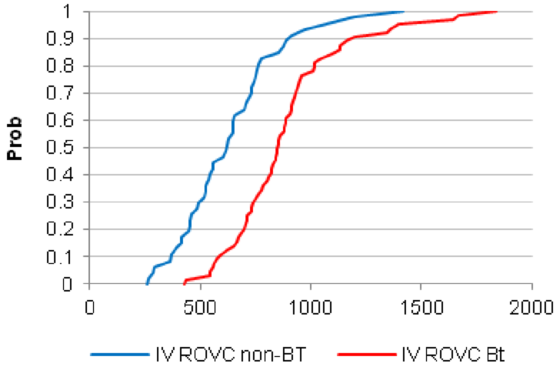

Figure 5c. Using predicted values from the instrumental variables regression.

Figure 5. Stochastic dominance analysis for q-ROVC using raw and predicted yields.

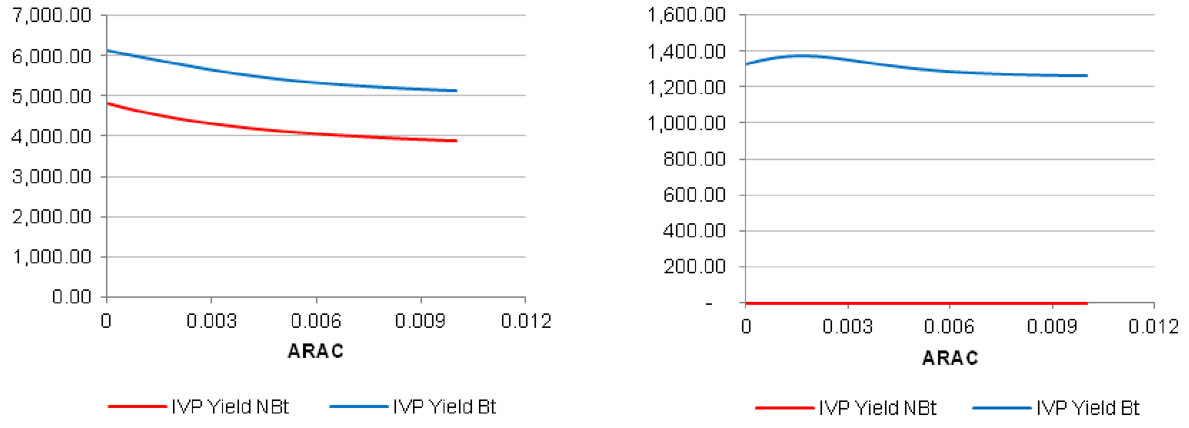

Figure 6a. Stochastic efficiency with respect to a function using negative exponential utility function.

Figure 6b. Negative exponential weighted utility risk premiums relative to predicted yield estimated from instrumental variables regression.

Figure 6. SERF and utility weighted risk premiums for yield.

Figure 6a, Bt/RR maize dominates conventional maize across all risk-aversion coefficients. This is a trivial result, as we have identified a first-degree stochastic dominant strategy. In turn, Figure 6b shows that a Bt/RR use will have to lose at least 1,400 kg ha^{-1} to abandon the technology. The alternative interpretation of this result is that a Bt/RR maize variety will need to provide at least 1,400 kg ha^{-1} in additional yield for a conventional maize producer to shift to a Bt/RR maize.

These results are obviously related to the quality of the predicted values and the underlying regression approaches and their limitation in the reality that this dataset includes outliers, endogeneity, and heterocedasticity. As impact assessors, we may need to balance the gains from addressing endogeneity, outliers, and/or heterocedasticity until the methods are developed that address multiple data limitations simultaneously. An example is the novel instrumental variables approaches being developed and validated that are not sensitive to outliers and which, by design, consider heterocedasticity through robust VCE matrices in their estimation (i.e., Cohen-Freue & Zamar, 2011).

Conclusions

The Bt/RR maize hybrid released in Honduras for potential adoption is working as designed. In the presence of target pest pressures, it protects the crop against damage, reducing the amount of pesticides and increasing the amount of grain harvested by reducing target pest damage for those producers of the characteristics described in this article. In the absence of the target pest or when it is not present at a level that can cause economic damage, there is no reason to observe any difference in damage reduction or pesticide applications. The agronomic and entomological experiments and the socioeconomic survey conducted in Honduras reported in this article support this notion.

The fact that adopting producers in Honduras may have intermediate and larger land holdings, better access to credit, insurance, information, and may be themselves commercially oriented and innovation first adopters, is indicative of the need to avoid the "technological triumph but institutional failure" syndrome described by Gouse, Kirsten, Shankar, and Thirtle (2005). Institutional issues such as access to credit and other financial services, productive and protective inputs, and information about how to properly use the technology may limit producer investment in this technology and may be endogenous. In fact our study showed that producers hardly changed their production system when using GE maize.

Change in production processes may be needed in order to maximize the potential benefits from using the technology, which may be restricted by the limited knowledge about the management of the crop under field conditions. If the Honduran government views this and other GE technologies as a potential alternative to enhance maize production in the country, it will need to further provide support to farmers in order to overcome the institutional limitations that can and do have an effect on the potential impacts from increased expansion of Bt/RR maize in Honduras.

Methodological Issues

When assessing the early adoption of a complex technology such as genetically engineered corn, the need exists to pay close attention to data collection and survey design in order to address the issues of statistical biases and outliers and endogeneity and outliers. As the literature has shown, the issues of simultaneity, selection bias including self-selection, placement bias, and other types of statistical sampling problems are more likely to occur in those early stages of technology adoption processes. Impact assessors may consider method triangulation, particularly ones that include other disciplines and qualitative/biophysical methods not only to help define the issues and the institutional setting/context but also to help explain issues identified or even unexplained during conventional quantitative data collection. Our article suggests that disregarding endogeneity can lead to substantially inaccurate measurements of impact and thus to incorrect policy recommendations. However, even when considering methods that supposedly address data problems—such as robust regressions or endogeneity—additional care needs to be focused on their implementation, weaknesses, and other limitations. We strongly recommend testing for endogeneity and outliers as a standard procedure in this type of study.

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