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The economic impact of bean disease resistance research in Honduras

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Abstract

This paper presents evidence of recent adoption rates of disease resistant bean varieties (RVs), the farm-level benefits of RV adoption, and the ex post rate of return to disease resistant bean research in Honduras. Results from a farm-level survey in 2001 in the two principal bean-producing regions of the country show that 41–46% of bean farmers (depending upon the season) have adopted an RV, and that adoption is neutral with respect to farm-size and market orientation. An expected utility framework was used to estimate the farm-level benefits of RV adoption, using a combination of experimental trial and farm-level survey data. Adopters gain the equivalent of 7–16% (depending on the variety) in bean income from the yield loss averted through RV use. The ex post rate of return to disease resistant bean research in Honduras from 1984 to 2010 is 41.2%.

Keywords: Beans; Varieties; Yield; Adoption impact; Honduras

1. Introduction

In the 1970s, Bean Golden Yellow Mosaic Virus (BGYMV) began to spread through Central America, threatening the production of beans, an important food crop in the region (Morales and Anderson, 2001). The virus arrived relatively late to Honduras, but severe virus incidence in 1989 resulted in yield losses ranging from 10 to 100% (Rodriguez et al., 1994). Since the mid-1980s, bean research in Honduras has focused on the development of improved bean varieties resistant to key diseases, principally BGYMV, which has led to the release of five resistant varieties since 1990. The principal objective of this paper is to estimate the ex post rate of return to disease resistant bean research in Honduras.

Breeding for disease resistance in beans is an example of productivity maintenance research. Unlike productivity enhancement research, which develops technology to increase yield given a specified level of inputs, productivity maintenance research counteracts yield losses that result from changes in the biological or physical environment (Smale et al., 1998). While productivity enhancement is measured in terms of positive yield gains associated with adoption of new technology, productivity maintenance must be estimated in terms of the yield losses that would have occurred in the absence of the new technology, i.e., the yield loss averted (Smale et al., 1998; Morris et al., 1994).

Various authors have used experimental trial data to estimate yield loss averted through the use of a disease resistant cultivar (Smale et al., 1998; Morris et al., 1994), combined with adoption rates from surveys to estimate aggregate benefits. In contrast, Johnson and Klass (1999) used experimental trial data to estimate

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yield loss averted, develop a climate-based GIS model to predict disease incidence, and use an expected utility framework to predict adoption rates.

A methodological contribution of this paper is the use of a combination of experimental trial and farm-level survey data within an expected utility framework to estimate the farm-level benefits of adoption of disease resistant bean varieties (RVs). We then use recent survey evidence of RV adoption rates as well as the costs of varietal development to estimate the ex post rate of return to disease resistant bean research in Honduras.

2. Disease RVs

BGYMV is the principal bean disease in Honduras, and is one of the main production constraints in Honduran valleys (Martel, 1995). The virus is transmitted by the whitefly species *Bemisia tabaci*, which is normally found below 1000 m elevation in all growing regions of Honduras, and more frequently in the drier *postrera* season (September/October to December/January). Whitefly-transmitted geminiviruses cause significant yield losses of important food and industrial crops in tropical and subtropical agro-ecosystems around the world (Morales and Anderson, 2001). The exponential increase in geminivirus-induced diseases in bean and other crops in the 1990s coincided with the expansion in Honduran valleys of tomato and other horticultural crops (reproductive hosts for the whitefly) during the same period (Morales and Anderson, 2001).

Genetic resistance, rather than pesticide use, is considered the most sustainable means for small farmers to avoid yield losses from BGYMV, as RVs are scale-neutral and reproducible on-farm (Martel et al., 2000). In contrast, pesticides can only partially control the whitefly in the short term. They have proven ineffective in the long term, as the whitefly often develop resistance to specific pesticides (Morales and Anderson, 2001). Moreover, they are expensive for small farmers, and are often associated with negative health effects on farm labourers. Thus, compared with pesticides, RVs offer small farmers a more financially and ecologically sustainable means to control the virus.

Honduras' two bean breeding programs, which are implemented by Zamorano (Programa de Investigaciones en Frijol, Escuela Agricola Panamericana) and Direccion de Ciencia y Tecnologia Agricola (DICTA), the Honduran National Bean Program, work in collaboration with three organisations: (1) the USAID-funded Bean/Cowpea Collaborative Research Support Project (CRSP); (2) the Programa Cooperativo Regional de Frijol para Centroamerica (PROFRIJOL), Mexico y El Caribe, funded by COSUDE, the Swiss Agency for Development and Cooperation; (3) International Center for Tropical Agriculture (CIAT). The main RVs developed by Zamorano in collaboration with DICTA are Dorado (released in 1990), Don Silvio (1993) and Tio Canela (1997).

As is the case throughout Latin America, Honduran consumers have strong preferences for various characteristics of dry beans—colour, size, shape, freshness, cooking time, consistency when cooked and texture of the sauce—all of which can influence the farm-level price of dry beans. Martel (1995) found that, on average, farmers received 16% less for Dorado (due to its dark red colour) compared to traditional varieties (TVs). Don Silvio (1993), the second RV released, is very similar to Dorado in colour, yet has a shorter crop cycle than that of Dorado. Tio Canela (1997), however, is lighter red in colour and thus was expected to receive a higher farm-level price than Dorado (Rosas and Varela, 1996).

3. Survey methodology

In January–February 2001, the CRSP and PROFRIJOL implemented a random sample survey of Honduran bean farmers ($N = 210$) in collaboration with Zamorano and DICTA. This survey was designed to generate data required to carry out an ex post economic impact assessment of bean research in Honduras. Another objective of the survey was to provide Zamorano and DICTA with information about the characteristics of adopters and disadopters of improved bean varieties, and farmers' experience and opinions regarding various agronomic, market and consumption aspects of the improved and TVs that they planted. More specifically, the survey was designed to estimate the adoption rates of RVs, as well as their yield and price performance relative to TVs. The survey targeted the Mideast (El Paraiso and Francisco Morazan Departments) and Northeast

Table 1
Characteristics of sample farmers, Mideast and Northeast Honduras, 2001[a]

Characteristic	Farmer average (2000)	
	Primera	Postrera
Bean area (ha)	1.52	2.13
Average yield (kg/ha)	652	424
Applied compound fertiliser and/or urea (% farmers)	74	68
Applied insecticide (% farmers)	73	65
Sold beans harvested from this season (% farmers)	75	63
Of those who sold beans, % of production sold	65	80
Sample size (N)	170	202

[a] Source: CRSP/PROFRIJOL Bean Farmer Survey, January–February 2001.

Table 2
Bean varieties used by farmers in Mideast and Northeast Honduras, 2000[a]

Variety	Primera (% respondents)	Postrera (% respondents)
Tio Canela[b]	10.6	11.4
Dorado[b]	30.0	25.7
Don Silvio[b]	4.1	4.0
Total resistant	46.2[c]	41.1[c]
Total traditional	62.4[c]	76.2[c]
Sample size (N)	170	202

[a] Source: CRSP/PROFRIJOL Bean Farmer Survey, 2001 (N = 210).
[b] BGYMV-resistant variety.
[c] As some farmers planted more than one variety, the total is greater than 100%.

(Olancho) regions, which together account for about one-half of the annual bean production in Honduras.

The characteristics of respondents (Table 1) in our survey are quite similar to those identified in a survey conducted in the same two regions in 1993 (Martel, 1995). This suggests that our sample is representative of bean farmers in these two regions. Bean producers in Honduras are predominantly small farmers, the majority of whom use fertiliser and insecticide, market at least some of their bean production, and depend upon beans for a major portion of their household income (Martel, 1995).

4. Adoption of disease resistant varieties

Honduran farmers typically plant two crops during the year. In the *primera* (May/June to July/August), the rainy season, maize is the principal crop, and beans are either intercropped with maize or monocropped.[1] The postrera (September/October to December/January) is a drier season, during which beans are almost exclusively monocropped. The primera accounts for approximately 33% of annual national bean production, while the postrera accounts for 67% (1995–1999 average; SAG, 1999). Because the whitefly population is often highest under drier conditions, BGYMV is most frequent and severe in the postrera.

In primera 2000, 46% of the respondents planted an RV, 62% planted a TV (Table 2) and 13% of the farmers grew both an RV and a TV. Typically, farmers who grow both types plant a small area to the TV, which is intended for home consumption (due to preferred consumption and culinary characteristics), and a larger area to the RV, intended for the market.

In postrera 2000, 41% of the respondents planted an RV, 76% of farmers planted a TV and 22% planted both (Table 2). While BGYMV pressure is typically greater in the postrera, the lower RV adoption rate in this season is likely related to the increase in sample size, the lower rate of adoption in the Northeast region (in which beans are principally grown in the postrera alone), and the fact that Dorado's crop cycle is longer than preferred by farmers, especially in the drought-prone postrera (Martel, 1995).

Adoption of RVs in 2000 was neutral with respect to farm-size (where small farmers are defined as those having <3.5 ha of total farm area). It was also neutral with respect to market orientation for both primera and postrera 2000 (where market orientation is defined by whether or not each respondent sold beans in a given season). In addition, the value of on-farm reproducibility of RVs is demonstrated by the informal nature of the bean seed system: of the RV seed planted by our respondents in 2000, 59% was farmer-saved, 27% was obtained from a neighbour, and only 14% was sourced from government extension, a non-governmental organisation (NGO), a trader or an input supplier.

Disease RVs are not adopted neutrally with respect to production environment, however. Using altitude, as well as historical knowledge of BGYMV-prone areas

[1] In the following analysis, intercropped area is converted to "effective monocrop bean area" given information from each respondent on his/her intercropping system.

as a proxy for BGYMV pressure (Rosas, 2001), there is a statistical difference ($\alpha = 0.04$) between RV adoption in "BGYMV-prone" areas (typically <1000 m elevation) and "non-BGYMV-prone" areas in both primera and postrera 2000. However, as farmers in the "non-BGYMV" areas (mountains) often live in quite remote communities, it is unlikely that they have the same level of access to information about RVs and to the seed itself, as do farmers in the valleys. Zamorano/DICTA have targeted higher altitude farmers with Catrachita, a non-resistant, high-yielding variety released in 1987. Analysis of the adoption and impact of Catrachita is presented elsewhere (Mather et al., 2003).

5. Estimation of the farm-level impact of improved bean varieties

5.1. Limitations of experimental trial and survey data

Conventional ex post impact assessment methods have typically focused on productivity enhancement technologies, the benefits of which are estimated as the yield difference between traditional and improved technologies as observed in either experimental trials or from a cross-section of surveyed farmers. However, both of these data sources have limitations in constructing the counterfactual situation used to assess the farm-level benefits of productivity maintenance technologies. First, experimental trials often do not well-approximate farmer conditions. For example, disease frequency and intensity are fixed in experimental trials, yet under farmer conditions they may vary spatially according to weather patterns, altitude and crop management practices. Second, the presence of selection bias in farmer survey yield data will tend to underestimate the real benefits of disease resistant technologies (Johnson and Klass, 1999). Because farmers in areas of low disease incidence are likely to grow TVs, and farmers in areas of high disease incidence are likely to grow RVs, then observed survey yields of TVs will be higher than what would have been observed in the absence of RVs. Thus, Johnson and Klass (1999) argue that the appropriate comparison is between the yields of TVs and RVs under disease pressure in experimental trials, which control for sample selection bias.

Unlike previous research, we use a combination of experimental trial and farm-level survey data within an expected utility framework to estimate the farm-level benefits of RV adoption. Given that RVs historically have received price discounts in the market (Martel, 1995), gains in profitability due to yield loss averted are tempered by losses in profitability due to the poorer market characteristics of RVs. In an expected utility framework, we use survey data on varietal price discounts and disease frequency, combined with a range of estimates of yield loss averted from experimental trials, to compute the equivalent income that RV adopters gain due to avoiding the risk of yield losses to TVs under disease pressure.

5.2. Farm-level price discounts

Given the dispersion of farm-level bean sale prices over time and space, regression analysis was used to control for time of sale, region and remote areas by season. The results of various specifications show that the Dorado and Don Silvio price discount (relative to all TVs) for the primera 2000 ($N = 147$) is 15–20%, while for postrera 2000 ($N = 147$) it is 10–15%. The Tio Canela price differential with respect to TVs is not significant in any of the model specifications, perhaps due to its small sample size ($N = 23$). We thus compare the sample means of Tio Canela and TVs and find a 4% discount for Tio Canela in primera 2000 and a 9% discount in postrera 2000. Given these results, we take the average between the primera and postrera for each variety and thus assume a 16% price discount for Dorado and Don Silvio and a 7% discount for Tio Canela.

5.3. Experimental and survey yields

Yield performance trials were conducted on farmers' fields ($N = 53$) across Honduras. Farmer trials comprised a local check, typically a TV, and the farmers' choice of fertiliser application rate and management practice (the same for both varieties). Tio Canela yielded an average of 1200 kg/ha, 41% higher that the local check, which yielded an average of 850 kg/ha (Rosas and Varela, 1996). In experimental trials under severe BGYMV pressure, RVs have yielded an average of 50% more than TVs (Rosas, 2001). In our study, Dorado yielded 20% more than the local check in farmers' trials, and 50% more than the TV under BGYMV pressure in experimental trials.

However, while the mean RV yield was typically higher than the TV yield, the coefficient of variation (CV) in yield for all varieties in all years was high (ranging from 63 to 112%). Therefore, we could not find evidence that RVs have statistically higher yields than TVs under farmer conditions. Multivariate regression analysis was used to test for yield differentials between RVs and TVs, controlling for numerous factors which influence yield besides variety (e.g., fertiliser use, cropping system, altitude, season, region). However, these yield regressions also did not support the hypothesis that RVs are higher yielding than TVs, most likely because endogeneity of varietal choice may lead to biased estimates of the variety dummy coefficient. Testing for and correcting selection bias econometrically is beyond the scope of this paper. Computing intra-farm yield differentials between RVs and TVs demonstrated some evidence of RV yield gains (7–8% for some seasons). However, the number of farmers growing both varieties was small in all seasons ($N < 30$), and this method is still subject to potential selection bias which could underestimate yield loss averted. While the observed performance of any technology under farmer conditions typically falls short of the experimental trial results, the fact that the RV survey yields and CV are quite similar to those of TVs—given that price discounts exist, most farmers market beans, and adoption rates are fairly high—suggests that selection bias is present.

5.4. Disease frequency

To obtain a farm-level estimate of disease frequency, we showed respondents in Francisco Morazan and Olancho pictures of the six principal bean diseases in Honduras (without corresponding names), and asked them to identify the two diseases that have caused the most damage to their bean crop in the past 5 years. Thirty-one percent of the respondents recorded the BGYMV picture as one of their two principal diseases.[2] Those who indicated problems with a disease were then asked in which season (primera, postrera or both) the disease was most frequent, and how many times it had occurred in their fields in the past 5 years. One-half of these respondents claimed that BGYMV was a problem in both seasons, and 27% said it was a problem only in the postrera. The average frequency reported by these respondents was 4 out of 5 years. For our base scenario, we conservatively assume that BGYMV only occurs in the postrera, although we include sensitivity analysis to test this assumption.

5.5. Expected utility framework

We assume that farmers maximise profit and have risk preferences as defined by Constant Relative Risk Aversion with a risk coefficient $R = 1$. This assumption is not very strong, given that relative risk coefficients over income for developing country farmers typically fall between 0.3 and 1.7 (Binswanger, 1980), and that this coefficient is often assumed to be unity (Newberry and Stigliz, 1981). Valuation of the benefits of risk reduction typically involves total household income, as the household may have a portfolio of agricultural and non-agricultural activities, some of which are uncorrelated with the returns to the risky income component in question (Walker, 1989). As we do not have data on total household income, we only include bean income in this equation, and thus use a rather low risk coefficient.

We use the mean value from experimental trials (RVs yield 50% more, on average, than TVs under severe BGYMV stress) as an upper bound for "yield loss avoided". We assume that TV yield loss to BGYMV is 0, 15, 25, 35 or 50%, each with a probability of 0.20. Thus, we assume that disease frequency is 4 out of 5 years, based upon the survey data, and that the average yield loss is 25%. We solve the following equation for F to estimate what adopters are willing to pay to avoid the yield risk of the TV

$$\begin{aligned}\ln[(1-F)Y_0] &= 0.2\ln[Y_0] + 0.2\ln[0.85Y_0] + 0.2\ln[0.75Y_0] \\ &\quad + 0.2\ln[0.65Y_0] + 0.2\ln[0.5Y_0]\end{aligned}$$

where Y_0 represents bean income and F represents the value to farmers of an RV in terms of a percentage of bean income.

[2] It should be noted RV growers are unlikely to see symptoms of BGYMV on their bean plants, even though the virus may be present (and it should be noted that its presence in an RV does not result in yield loss). As expected, of those respondents who claimed that the virus was one of their two principal disease problems, only 33% grew RVs. However, this suggests that even in areas with lower disease pressure (where TVs are still grown), the virus is present in 4 out of 5 years.

The left-hand side of the equation represents the expected value of an RV, while the right-hand side represents the expected value of a TV, given our assumptions of yield losses and frequencies. This equation assumes that the yield of an RV and a TV are equal in the absence of disease pressure, and that each receives the same price. Solving for F results in 0.27, which indicates that a risk-averse farmer would be willing to pay up to 27% of bean income to avoid the risk represented by the TV. Thus, given that Dorado receives a 16% price discount, this implies that Dorado adopters gain the equivalent of 11% in net bean income due to the yield loss averted. Because Tio Canela's price discount is only 7%, Tio Canela adopters gain the equivalent of 20% in net bean income due to the yield loss averted. Of the 27% benefit, 2% can be attributed to our assumed nature of risk (relative) and the coefficient of risk aversion.

5.6. *Incremental farm-level costs*

For the following benefit-cost analysis, we assume that RV adopters incur no incremental costs per hectare. The vast majority of adopters obtained their seed from other farmers (uncertified seed), and even if they pay their neighbour more than what they would pay for a TV, the cost of seed is not a large proportion of input costs (Tshering, 2002). Although it is possible that RV adopters may be able to save both labour and input costs from reduced pesticide applications, the farm-level health and financial benefits from reduced pesticide use associated with RV adoption are not considered here.

6. Economic surplus analysis

6.1. *Aggregate benefits*

A small open-economy economic surplus model is used (Alston et al., 1995), which estimates the downward shift of the supply curve. In this model, the supply curve is linear and its shift is parallel, which is a reasonable assumption given that RV adoption is scale-neutral. The yield gain associated with RVs comes from the farm-level benefit of yield loss and risk avoided, with the price discount already deducted. We assume that yield loss averted is constant over time, which implies that BGYMV pressure remains constant. No market price effects are assumed in this model, as incremental volumes of production are assumed to be exported (El Salvador regularly imports Honduran beans). The choice between an open- or closed-economy model of this type typically has a small effect on the total surplus generated.

Area adoption curves were constructed for each RV using a logistic function fit to data points from the Martel's survey in 1993 (Martel, 1995) and our 2001 surveys in the Mideast and Northeast regions. The annual RV bean area was weighted by the seasonal and regional shares of the annual total of the two regions from the year of varietal release until 2010 (Fig. 1). The area adoption curves are quite similar to "farmer" adoption curves, given the relative homogeneity of farm-size in the sample.

For Tio Canela, we have only 4 years of farmer adoption behaviour, as the variety was released in 1997. However, it is clear that it is rapidly being adopted—both by former growers of Dorado or Don Silvio and by TV users. Therefore, we assume that its potential ceiling is equal to the area planted to Dorado in 1998 (37% in the primera and 31% in the postrera for the Mideast, and 34% in the primera and 22% in the postrera for the Northeast).[3] Thus, we project that Tio Canela will replace Dorado and Don Silvio by 2007, given Tio Canela's relative price advantage. For Don Silvio, we assume that the 2000 adoption level of 4% (average of primera and postrera 2000) is its ceiling in each region, and that growers gradually disadopt (switching to Tio Canela) until the rate falls to 0% in 2010.

The discount rate is assumed to be 10% and the supply elasticity 0.7, given that the short-run and intermediate supply responses of a semi-subsistence crop are generally assumed to be inelastic. The model also uses historic data on bean production by season and region from 1987 to 1999 (SAG, 1999). We assume that future (2000–2010) production levels by season and region will be the same as the 1996–1999 average levels (excluding postrera 1998, which was affected by

[3] Given that the distribution of seed post-Hurricane Mitch could have influenced adoption rates in 1999–2000, we use 1998, which is more representative of the typical demand for RVs.

	Dorado	Tio Canela	Don Silvio
1987	0.00%	0.00%	0.00%
1988	1.14%	0.00%	0.00%
1989	2.42%	0.00%	0.00%
1990	5.06%	0.00%	0.00%
1991	9.44%	0.00%	0.00%
1992	14.29%	0.00%	0.26%
1993	18.87%	0.00%	0.58%
1994	23.28%	0.00%	1.10%
1995	26.90%	0.00%	1.68%
1996	29.05%	0.00%	2.19%
1997	30.05%	0.49%	2.55%
1998	30.46%	1.31%	2.75%
1999	29.44%	3.29%	2.84%
2000	27.34%	7.51%	2.88%

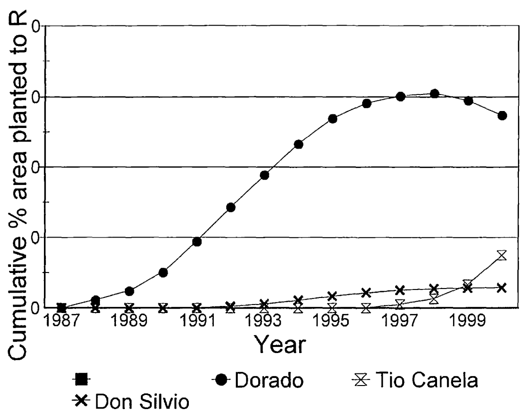

Fig. 1. Resistant Variety Adoption, Mideast and Northeast Honduras, 1987–2000.

Hurricane Mitch). The bean price series used for economic analysis is the Honduras "farmgate" price from 1987 to 1999. We assume that bean prices remain constant until 2010 at the 1999 level, which was among the lowest in the past decade. We use the farmgate price series rather than an import parity price, given that the Mideast and Northeast regions are close to the main export market of El Salvador, and Nicaragua, a shadow market (as per Martel, 1995). Thus, we assume that the farmgate price is the best approximation of export opportunities.

6.2. Research costs

Each of the improved varieties was developed, tested, released and extended by Zamorano and DICTA, supported by the Bean/Cowpea CRSP, PROFRIJOL and CIAT. CRSP and PROFRIJOL and have provided funding and training, while CIAT, with DICTA and Zamorano, has provided germplasm, training and collaboration in conducting regional field trials. Costs associated with the development of the RVs begin in 1984 (the initial developmental stages of Dorado) and continue to 1997 (when Tio Canela was released).

CIATs role in the development of Dorado (the cross, nursery and on-station trial stages from 1984 to 1986) is approximated by estimating the cost per released variety of CIATs bean program (during 1980–1985). CRSP supports the Zamorano bean program's research activities, as well as training. This analysis assumes that 60% of CRSP support to the Zamorano bean program budget and 60% of training investments during 1986–1997 can be attributed to the development and dissemination of RVs. Financial support from PROFRIJOL to Zamorano's bean program is included at the 100% level. Zamorano's variable cost contribution to the bean program—50% of the director's salary (research)—is included, while the fixed costs of buildings and the other 50% of the director's salary (teaching) are not included.

DICTAs national bean program began its work with Dorado in multi-locational trials in 1986 and 1987. We include 100% of DICTAs estimated bean research and extension costs for the Danli and Olancho experiment stations during the period 1986–1997. Financial support from PROFRIJOL to DICTA is also included at the 100% level.

Since structural adjustment in the late-1980s, improved bean varieties have primarily been extended through DICTAs artisan seed projects, Zamorano-based pilot projects, the sole private commercial seed supplier (Hondugenet, located in the capital Tegucigalpa), commercial sales by Zamorano, and governmental and non-governmental agricultural development projects (which typically obtain their seed from Zamorano). Various NGOs distribute improved seed to participants in their projects and support the development of local farmer seed banks across the country, although they are less active in the Mideast and Northeast than in other regions. The most prominent seed initiative has been the USAID-funded Honduras Post-Mitch Agricultural Recovery program, which multiplied and distributed improved bean seed via NGOs to farmers across the country following Hurricane Mitch. However, the NGOs distributing the seed focused their efforts on other regions of Honduras, which were hit harder (and are generally poorer) than Mideast and Northeast Honduras.

The extension efforts of NGOs and the Post-Mitch project are not included as costs in this analysis for two reasons. First, project records do not indicate how much seed was delivered to each region, although it is clear that the general location of the NGOs' operations prior to Mitch placed a minor emphasis on the two regions in this analysis. Second, only 9% of our sample received seed directly from an NGO following Mitch, and we do not know how many other farmers may have received seed indirectly.

6.3. Rate of return

For our base scenario, we assume that BGYMV causes yield losses to TVs only during the postrera season. Under this assumption, and those discussed above regarding the farm-level benefits of RV adoption and RV adoption rates, the ex post economic rate of return to breeding disease resistant beans in Honduras during 1984–2010 is 41.2%, and the net present value at a discount rate of 10% is US$ 29.6 million.

This analysis provides strong evidence that the return to disease resistant bean research in Honduras has been profitable on aggregate. We have assumed average yield losses to BGYMV that are one-half that of experimental trials, and that the current rate of RV adoption is the ceiling rate. In addition, we have assumed near-maximum variable costs of bean varietal development and dissemination. Furthermore, although data are not available to document the spillover impact in non-surveyed areas, key informants report that many farmers in other regions of Honduras, as well as in El Salvador and Nicaragua, have adopted both Tio Canela and Dorado. In addition, during the period of the analysis, Zamorano developed additional varieties (Catrachita in Honduras; Bribri in Costa Rica), for which benefits associated with their release are not considered here. Thus, this analysis charges Zamorano and DICTAs bean research expenditures against only the RVs that have been released in Honduras.

6.4. Sensitivity analysis

Sensitivity analysis demonstrates that the key parameters in the rate of return analysis relate to the disease pressure by season and the average expected yield loss to BGYMV (Table 3). For example, assuming that BGYMV causes yield losses to TVs during both the primera and postrera seasons, the economic rate of return increases to 48.1%, and the net present value at a discount rate of 10% increases to US$ 46.2 million. The actual situation is likely somewhere between these two scenarios, as BGYMV is known to be a problem in the primera, but with less frequency than that of the postrera. With respect to farm-level benefits, changes in the net farm-level value of yield loss averted would occur if we change our assumptions of either the average expected yield loss to BGYMV (itself a function of disease intensity and/or frequency) or the price discount by variety. Even at a considerably lower net farm-level value for Dorado and Tio Canela, the internal rate of return of 29% is still quite profitable.

We also add sensitivity analysis to the extension of benefits over time to examine the scenario in which the net value of yield loss averted by RVs decreases in the future due to either lower whitefly populations or diminished genetic resistance to the virus over time. And we test the implication of our assumption that Tio Canela (which has a higher net farm-level value) completely replaces Dorado by 2007. Analysis of both these sets of assumptions shows that the rate of return is not very sensitive to assumptions beyond the year 2000.

6.5. Distribution of benefits

The distribution of benefits appears to be widespread across producers, as even in the valleys of Honduras, beans are grown predominantly by farmers with less than 3 ha of land, and RV adoption is neutral with respect to farm-size and market orientation. However, the distribution by growing environment is not as equitable. It is clear from the widespread adoption of RVs and the declining use of Catrachita (a non-resistant improved variety targeted to mountain farmers) that farmers in lower altitudes have gained the most from bean research since the mid-1980s (Mather et al., 2003). However, Zamorano's current breeding priorities are focused on developing varieties

Table 3
Sensitivity of returns to bean breeding research to changes in key parameters[a]

Discounted benefits extended to (year)	IRR (%)	Net farm-level value of yield loss averted as % of total bean income	IRR (%)
2000	40	Dorado/Don Silvio 6%; Tio Canela 15%	29
2005	41	Dorado/Don Silvio 11%; Tio Canela 20%[b]	41
2010[b]	41	Dorado/Don Silvio 16%; Tio Canela 25%	50
BGYMV pressure by season	IRR (%)	Dorado area in 2000 replaced by Tio Canela by 2007?	IRR (%)
Postrera only[b]	41	Yes[b]	41
Primera and postrera	48	No, area of both remain at year 2000 level	41

[a] Source: calculated by the authors.
[b] Value used for the baseline scenario.

with improved drought tolerance (one of the principal production constraints of high-altitude bean farmers) as well as varieties with improved heat-tolerance (especially for the lowlands on the Atlantic Coast). In addition, Zamorano is continuing to improve the market acceptance traits of their disease resistant lines.

7. Conclusion

This paper provides evidence that investment in breeding disease resistant beans in Honduras has been profitable. Under the base scenario assumptions, the ex post economic rate of return to disease resistant bean research in Honduras during 1984–2010 is 41.2%. Moreover, RV adoption in Honduras has been widespread and neutral with respect to farm-size and market participation. This paper also demonstrates an approach that uses farm-level and experimental trial data within an expected utility framework to measure the farm-level benefits of RV adoption.

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