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Richard H. Bernsten
Major professor

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Dissertation Advisor

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ESSAYS ON THE ECONOMIC IMPACT OF DISEASE-RESISTANT BEAN RESEARCH IN HONDURAS

By

David Len Mather

A DISSERTATION

Submitted

in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

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ABSTRACT

ESSAYS ON THE ECONOMIC IMPACT OF DISEASE-RESISTANT BEAN RESEARCH IN HONDURAS

By

David Len Mather

The three essays in this dissertation address different aspects of the impact of disease-resistant bean research in Honduras and are each based upon a random sample survey of Honduran bean farmers (N=210) in 2001. The first essay 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 bean research in Honduras from 1982-2010. The results demonstrate that the 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 the period 1982-2010 is 41.2 %. In addition, adoption of RVs is widespread and scale-neutral; 42% of sample bean farmers used an RV in the postrera season of 2000.

The second essay addresses the methodological challenges involved in the evaluation of a technology which maintains rather than augments yield, and demonstrates an econometric method (borrowed from the wage differential literature) to construct appropriate counterfactuals in the estimation of the impact of maintenance research technologies. The method is applied to test for selection bias and estimate differentials between RV and traditional variety (TV) bean yields in survey data from Honduras by constructing the counterfactual to RV yields as what yields RV users would have

obtained had they continued to grow TVs (*i.e.,* the TV yield of RV users). The corrected yield model predicts that RV growers enjoy net income gains of 13 to 19% in the postrera season, compared to what they would have earned growing TVs; while the uncorrected OLS model predicts that RV growers see either no income gain or even losses by growing RVs (relative to TVs). This application demonstrates that the implications of this method are significant for the assessment of maintenance research impacts.

The third essay uses the farm survey data in probit analysis to investigate the significance and magnitude of "varietal/ breeding" factors vs. "access" factors in the adoption of early and recent generation RVs in Honduras. The results indicate that adoption of early RVs, Dorado and Don Silvio, are more constrained by poor market characteristics (breeding factors) than lack of access. The poor market characteristics of these early generation RVs, reflected in average price discounts of 15% relative to TVs, has constrained adoption primarily to disease-intense areas, and has reduced the net income gains for adopters. By contrast, the results of analysis of a recent generation RV, Tio Canela (released in 1997), indicate that the market acceptance (breeding) aspects of the variety appear to be much improved over those of Dorado, as Tio Canela has been adopted in areas of both historically high and low disease pressure. However, the principal constraint to further Tio Canela adoption is information and seed access (a policy aspect). With increased access, current Dorado users (in disease-intense areas) would be expected to switch to Tio Canela and enjoy larger net incomes due to Tio Canela's smaller price discounts. The adoption of Tio Canela outside of traditionally high-disease pressure areas implies that the variety offers positive net benefits for growers in low-disease pressure areas as well.

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INTRODUCTION

International agricultural research systems are currently faced with the dilemma that while funding levels for agriculture and agricultural R&D have declined in recent years, demands on agricultural research systems to develop agricultural technologies which are more sustainable, equitable, and better-targeted to marginal areas have increased. Available evidence suggests that after several decades of strong support, international funding for agriculture and agricultural R&D began to decline in both absolute and relative terms around the mid-1980s as support for economic infrastructure as well as health, education, and other social services began to grow (Pardey and Bientema, 2001).

There is an abundance of literature concerning the positive and negative impacts on poverty, equity, and the environment in developing countries of Green Revolution modern rice and wheat varieties (MVs) – the technologies that embody the early decades of agricultural R&D. A recent review of 292 impact studies demonstrates that rates of return to agricultural research remain quite high and have not fallen over time (Alston *et al.*, 2000). Yet, favorable rates of return alone have not alleviated continued (and increasing) under-investment in agricultural R&D.

International agricultural research systems have switched from the "high payoff input" approach (Hayami and Ruttan, 1985; Schultz, 1964), based on MVs and the use of external inputs, to a broader concern for sustainable agriculture and technologies for marginal areas, including maintenance research and reduced reliance on external inputs

(Byerlee, 1996). In fact, since the early Green Revolution MVs, a significant share of crop improvement research (both biotech and traditional) in grains, vegetables, fruits, *etc*., has shifted in focus from that of increasing yield to improving resistance to disease, drought, and pests both to maintain yield and to enable reductions in pesticide application. Yet, there is a much smaller body of literature concerning the development of such technologies.

These developments present a challenge for impact assessment, given the increasing number of impact indicators demanded, and the fact that – as some argue – the "low-hanging" fruit of agricultural research have already been picked. That is, the high-payoff input model technologies have already been developed and extended, and the returns to research are not likely to be as high for technologies geared towards directly reducing poverty, inequality, and improving environmental outcomes. In addition, generating evidence to document links between these technologies and desired outcomes more challenging than implementing traditional impact studies.

Bean research in Central America provides an interesting example of agricultural R&D within the context of the developments discussed above. Funding for bean research in Central America has followed the same pattern as that of agriculture in general: the Centro Internacional de Agricultura Tropica (CIAT), bilateral donor-funded research networks such as USAID Bean/ Cowpea Collaborative Research Support Program (CRSP) and the Swiss-funded Programa Cooperativo Regional de Frijol para Centroamerica, Mexico, y El Caribe (PROFRIJOL), and NARS in Central America have all been experienced substantial budget cuts. Yet, in Central America, beans are predominantly produced by small, resource-poor farmers, and represent an important source of cheap protein for rural and urban poor. Both the CRSP and the CIAT Bean Improvement Program have set breeding for disease and drought resistance as a top priority – both to better address the constraints of resource-poor farmers and to reduce their dependence on pesticides and fungicides.

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 in 1989, severe virus incidence resulted in yield losses ranging from 10 to 100 percent (Rodriguez *et al.*, 1994). Since the mid-1980s, bean research in Honduras has focused on developing improved bean varieties resistant to key diseases, principally BGYMV, which has led to the release of five resistant varieties since 1990.

The three papers in this dissertation address different aspects of the impact of disease-resistant bean research in Honduras and are each based upon a random sample survey of Honduran bean farmers (N=210) implemented by the CRSP and PROFRIJOL in February, 2001. The first 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. The second paper addresses the methodological challenges involved in the evaluation of a technology which maintains rather than augments yield, and demonstrates an econometric method (borrowed from the wage differential literature) to construct appropriate counterfactuals in the estimation of the impact of technologies which mitigate adverse outcomes. The third paper investigates the characteristics of farmers who have adopted disease-resistant bean varieties, and the relative role of access (extension) and agronomic/economic (breeding) factors in their varietal decision.

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THE ECONOMIC IMPACT OF DISEASE-RESISTANT BEANS IN HONDURAS

ESSAY ONE

1. Introduction [1]

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 in 1989, severe virus incidence resulted in yield losses ranging from 10 to 100 percent (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 – the yield loss averted (*ibid*, 1998; Morris *et al.*, 1994).

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[1] This paper is based on: Mather, D., Bernsten, R., Rosas, J.C., Viana, A.R., Escoto, D. 2003, *forthcoming*. The Economic Impact of Disease-Resistant Bean Research in Honduras. Agricultural Economics. It includes sections from an earlier version of the paper which was presented at the Conference on Impacts of Agricultural Research and Development, San Jose, Costa Rica, February 4-8, 2002.

Various authors have used experimental trial data to estimate yield loss averted through 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) use experimental trial data to estimate yield loss averted, develop a climate-based GIS model to predict disease incidence, and then 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 RV adoption. We then use recent survey evidence on 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-resistant bean varieties

BGYMV is the principal bean disease in Honduras, and 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 1,000 m 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 agroecosystems 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) valleys during the same period (*ibid*, 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, are expensive for small farmers, and are often associated with negative health effects on farm laborers. In addition, pesticides have proven ineffective in the long term, as the whitefly often develop resistance to specific pesticides (Morales and Anderson, 2001). Thus, compared with pesticides, RVs offer small farmers a more financially and ecologically sustainable means to control the virus.

Honduras has two bean research programs, which are implemented by Zamorano (Programa de Investigaciones en Frijol, Escuela Agricola Panamericana) and DICTA (Direccion de Ciencia y Tecnologia Agricola), work in collaboration with three organizations: the USAID-funded Bean/Cowpea Collaborative Research Support Project (CRSP); the Programa Cooperativo Regional de Frijol para Centroamerica, Mexico, y El Caribe (PROFRIJOL), funded by COSUDE, the Swiss Agency for Development and Cooperation; and CIAT (Centro Internacional de Agricultura Tropical). In the late 1980s, the Honduran Ministry of Natural Resources significantly decreased funding for agricultural research and extension as a result of structural adjustment. In the wake of these budget cuts, Zamorano became the bean breeding program in Honduras[2], while DICTA retained its regulatory mandate, as well as some screening activities. The main RVs developed by Zamorano in collaboration with DICTA are Dorado (released in 1990), Don Silvio (1993), and Tio Canela (1997) (Table 1).

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[2] Zamorano also coordinates bean trials for Central America.

Table 1. Improved Bean Varieties Released in Honduras Since 1987.

Variety	Color	Reaction to Diseases					Year Released
		BGYMV	BCMV	Rust	WB	CBB	
Tio Canela	small red	R	R	S	I	I	1997
DICTA 122	small red	R	R	S	S	I	1996
DICTA 113	small red	R	R	S	S	I	1996
Don Silvio	dark red	R	R	I	S	I	1993
Dorado	dark red	T	R	I	I	I	1990
Oriente	shiny red	S	R	I	I	S	1990
Catrachita	shiny red	I	R	I	S	S	1987

BGYMV=Bean Golden Yellow Mosaic Virus, BCMV=Bean Common Mosaic Virus, WB=Web Blight, CBB=Common Blight Bacteria.
R=Resistance, T=Tolerance, S= Susceptible, I= Intermediate
Source: Martel, 1995; Rosas and Varela, 1996.

As is the case throughout Latin America, Honduran consumers have strong preferences for various characteristics of dry beans – color, size, shape, freshness, cooking time, consistency when cooked, and the 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 color), compared to traditional varieties. Don Silvio (1993), the second RV released, is very similar to Dorado in color yet has a shorter crop cycle than that of Dorado. However, Tio Canela (1997) was expected to receive a higher farm-level price than Dorado, due to its lighter-red color (Rosas and Varela, 1996).

3. Survey methodology

3.1 Previous research

In 1993, the Bean/Cowpea CRSP funded a survey of a random sample of bean farmers (N=239) in the two main bean-growing regions of Honduras (Mideast and Northeast), as well as a survey of traders (N=57) in eight different major Honduran markets (Martel, 1995). The surveys documented adoption rates of improved bean varieties, the socioeconomic characteristic of adopters, the relative farm-level prices of different varieties, and farmers' preferences in varietal selection. This adoption survey and a complementary subsector analysis, which provided increased evidence of the importance of socioeconomic and market factors in farmer adoption of improved varieties, helped Zamorano and DICTA set future breeding priorities.

In 1996, PROFRIJOL and DICTA funded a survey of bean farmers (N=160) in Mideastern Honduras (Viana, Rodriguez, and Escoto, 1997). This study reported adoption rates for Dorado that were quite high[3] relative to those of Martel, possibly due to the heavy concentration of the sample in areas targeted by the National Bean Program (DICTA).

Drawing on the empirical results of these two studies, a study of BGYMV incidence (Morales, 1994), as well as experimental trial data, Johnson and Klass (1999) used a climate-based GIS statistical model to predict (map) BGYMV incidence over time in order to estimate the magnitude of the production losses that were averted as a result of

[3] For the Mideast region, Martel reported an adoption rate for Dorado of 27% in 1993, whereas Viana *et al.* reported an adoption rate of 50% in the same region and year.

BGYMV-resistant varieties. In addition, they used GIS to document a link between RV adoption and poverty alleviation (as reported by a recent poverty survey).

3.2 Current research

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, as well 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 traditional varieties 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 (Olancho) regions, which together account for about one-half of annual bean production in Honduras.[4]

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[4] In each of the three departments, 70 farmers were selected using the following methodology. Using bean area and production data from the 1993 Agricultural Census, a list of villages was constructed for each department which represented a cumulative of 80 percent of bean area in that department. This list was then divided into deciles by cumulative bean area, and one village from each decile was selected at random. Care was taken to ensure that the cumulative number of villages selected from a given municipality did not exceed its share of the Department's total bean area. Selected villages beyond a municipality's share were replaced by the next random selection within the decile. Thus, this sample selection method was constructed to focus upon "area" adoption rates for benefit-cost analysis, yet to ensure that village selection remained representative of the department's bean area in terms of village geography and size.

The characteristics of our respondents (Table 2) are quite similar to those in Martel's 1993 survey (in the same two regions), suggesting that our sample is representative of bean farmers in these two regions[5]. Bean producers in Honduras are predominantly small farmers, the majority of whom use fertilizer and insecticide, market at least some of their bean production, and depend upon beans as a significant important portion of their household income (Martel, 1995).

Table 2. Characteristics of Sample Farmers, Mideast/Northeast Honduras, 2000

Characteristic	Farmer Average, 2000	
	Primera	Postrera
Bean area (ha)	1.52	2.13
Average yield (kg/ha)	652	424
Applied Compound Fertilizer 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)	(N = 202)
Source: CRSP/PROFRIJOL Bean Farmer Survey, January-February 2001.		

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

[5] Our respondents' bean area is similar to those of Martel's 1993 sample, yet our respondents have a stronger market orientation and are more likely to use chemical inputs. These differences are likely due to the continuing commercialization of bean production in these two regions, as well as differences in sampling strategy; Martel stratified by valley vs. hillside farmers, while we stratified only by geographic location.

either intercropped with maize or monocropped[6]. The postrera (September/October to December/January) is a drier season, during which beans are almost exclusively monocropped[7]. The primera accounts for approximately 33% of annual national bean production, while the postrera accounts for 67% (1995-99 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 a RV, 62 % planted a TV (Table 3), and 13 % of the farmers grew both a RV and a TV. Typically, farmers who grow both an RV and a TV plant a small proportion to a TV, which is intended for home consumption – due to preferred consumption and culinary characteristics – and a larger area to an RV, intended for the market.

In *Postrera* 2000, 41 % of the respondents planted a RV, 76 % of farmers planted a TV, and 22 % planted both a RV and a TV (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 has a longer crop cycle than preferred by farmers, especially in the drought-prone postrera (Martel, 1995).

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[6] In the following analysis, intercropped area is converted to "effective monocrop bean area" given information from each respondent on his/her intercropping system. For example, a farmer with an intercrop of four rows of beans to each row of maize is assumed to have 80% "effective" area in beans for use in yield calculations.

[7] While farmers in Olancho use relay cropping for beans in the postrera, for the purposes of this paper, we assume the area to be the same as for monocropping.

Table 3. Farmer Varietal Use, Mideast and Northeast Honduras, 2000

Variety	Primera (% respondents)	Postrera (% respondents)
Tio Canela*	10.6	11.4
Dorado*	30.0	25.7
Don Silvio*	4.1	4.0
Total Resistant	46.2**	41.1**
Total Traditional	62.4**	76.2**
Sample Size	N=170	N=202

Source: CRSP/PROFRIJOL Farmer Survey, 2001 (N=210)

* BGYMV-resistant variety
** As some farmers planted more than one variety, the total is greater than 100%.

Defining small farmers as those having < 3.5 ha of total farm area, RV adoption in 2000 was neutral with respect to farm-size. Resistant variety adoption was also neutral with respect to market orientation (for both primera and postrera 2000), defining market orientation by whether or not each respondent sold beans in a given season.[8] 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 seed; 27% was obtained from a neighbor; and only 14% was obtained from government extension, an NGO, a trader, or an input supplier (Table 4).

[8] However, probit results from essay #3 of the factors influencing adoption indicate that market orientation is not neutral with respect to Dorado and Don Silvio; in fact, market participation is a statistically significant (10% level) and negative factor in use of these older RVs. The neutral result here is likely due to the fact that market participation is not a statistically significant factor in Tio Canela use, and the test in the current paper combines all RV users together.

However, RVs are not adopted neutrally with respect to the production environment. Using altitude, as well as historical knowledge of BGYMV-prone areas as a proxy for BGYMV pressure (Rosas, 2001), there is a statistical difference (α=0.04) between the adoption of RVs in "BGYMV-prone" areas (typically with altitude <1,000

Table 4. Farmer Bean Seed Source: Improved Varieties, Honduras, 2000

Seed Source	Seed (Germplasm) Planted in Postrera 2000 (%)	Original Source of this Variety (%)
Farmer-Saved Seed	59	na
Neighbors	27	57
Traders	6	10
DICTA / SAG	0	16
Zamorano	3	3
CIAT Seeds of Hope	0	2
NGO	0	0
Input Dealer	2	4
Local Market	0	3
Artisan Seed	0	0
Other	2	5
Source: CRSP/PROFRIJOL Farmer Survey, 2001		

m) 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 the seed itself, as do farmers in the valleys. Zamorano/DICTA have targeted higher altitude farmers with Catrachita[9], a non-resistant, high-yielding variety released in 1987.

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, whose benefits are estimated as the yield difference between traditional and improved technologies as observed in either experimental trials or a cross-section of survey 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, especially considering that disease frequency and intensity are fixed in experimental trials, yet under farmer conditions they may vary spatially by 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.

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[9] Analysis of the adoption and impact of Catrachita is presented elsewhere (Mather *et al.*, forthcoming).

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 RV's poorer market characteristics. 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 in the range of 15% to 20%, while for postrera 2000 (N=147) the discount is in the 10% to 15% range (Table 5). The Tio Canela price differential with respect to TVs is not significant in any of the model specifications, perhaps due to 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.

Table 5. Farmers' Bean Prices, Mideast and Northeast Regions, Honduras, 2000

Variety	Primera 2000				Postrera 2000			
	Farmer Price ($US/kg)	N	CV (%)	% price discount for MV*	Farmer Price ($US/kg)	N	CV (%)	% price discount for MV
Tio Canela	$0.47	11	31	- 4.1	$0.47	10	20	- 9.6
Dorado	$0.38	41	26	- 22.4	$0.46	27	27	- 11.5
Don Silvio	$0.32	4	14	- 34.7	$0.47	5	20	- 9.6
Catrachita	$0.52	9	32	6.1	$0.57	5	17	9.6
All Traditional Varieties	$0.49	80	27	na	$0.53	98	23	na
All Varieties	$0.46	147	30	na	$0.51	147	25	na

Source: CRSP/PROFRIJOL Farmer Survey, 2001
* Compared with TVs
CV = coefficient of variation, na = not applicable

5.3 Experimental and survey yields

In yield performance trials conducted on farmers' fields (N=53) across Honduras[10], Tio Canela averaged 1,200 kg/ha, compared to an average of 850 kg/ha for the local check–which represents a yield improvement of 41% above the local check variety (Rosas and Varela, 1996). In experimental trials under severe BGYMV pressure, RVs have yielded an average of 50% more than TVs (Rosas, 2001). In farmers' trials, Dorado yielded 20% more than the local check, and 50% more than the TV under BGYMV pressure in experimental trials.

[10] Farmer trials included a local check, typically a TV, and the farmers' choice of fertilizer application rate and management practice (the same for both Tio Canela and the TV).

However, while the mean RV yield was typically higher than that for TVs, the coefficient of variation (CV) in yield for all varieties in all years was high (ranging from 63 to 112%) (see Appendix Tables A-1 and A-2). Therefore, we could not find evidence that RVs have statistically higher yields than TVs under farmer conditions. Multi-variate regression analysis was used to test for yield differentials between RVs and TVs, controlling for numerous factors besides variety which influence yield (fertilizer use, cropping system, altitude, season, region, *etc*). However, yield regressions using OLS 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 to 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 coefficients of variation 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.[11]

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[11] Assuming that we only observe TV yields in areas of low disease pressure, then we won't observe low TV yields that would result from growing TVs in disease intense areas. Thus, the observed TV mean is higher than the true TV mean, because the TV yield distribution is truncated from below.

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 which have caused the most damage to their bean crop in the past five years. Thirty-one percent of the respondents listed the BGYMV picture as one of their two principal diseases[12]. Those who indicate 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 five years. One-half of these respondents claimed that BGYMV was a problem in both seasons, and 27 % said only in the postrera. The average frequency reported by these respondents was four out of five 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 maximize 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

[12] It should be noted RV growers are unlikely to see symptoms of BGYMV on their bean plants, even though the virus may be present (though it's presence in a RV does not result in yield loss). As we would expect, 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 four out of five years.

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 on average 50% more 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.[13] Thus, we assume that disease frequency is four out of five years, based upon the survey data, and that the average yield loss is 25 %.[14] We solve the following equation for F to estimate what adopters are willing to pay to avoid the yield risk of the TV:

$$\ln [(1 - F)Y_0] = 0.2 \ln [Y_0] + 0.2 \ln [0.85Y_0] + 0.2 \ln [0.75Y_0] + + 0.2 \ln [0.65Y_0] + 0.2 \ln [0.5Y_0]$$

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

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[13] We assume that these yield loss amounts and frequencies are constant over time, which implies that BGYMV pressure remains constant.

[14] The yield losses and frequencies are chosen based on the farmer survey results that disease losses occur 80% of the time, that breeders found that TVs experienced yields 50% below those of RVs in experimental trials under conditions of severe incidence, and so they result in an expected yield loss of 25% that is arbitrarily set to one-half that of experimental trials. Other yield loss scenarios also meet these criteria. In the absence of survey data on disease intensity and yield loss at the farm-level, we thus make conservative assumptions of yield loss to disease.

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 yields 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 (one).

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 neighbor a markup above what they would pay for a TV, the cost of seed is not a large proportion of input costs (Tshering, 2002). Although RV adopters may be able to save both labor 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), to estimate 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. No market price effects are assumed in this model, as incremental volumes of production are assumed to be exported (El Salvador imports Honduran beans regularly). The choice between an open- or closed-economy model had a small effect on the total surplus generated, based on sensitivity analysis of our model and data.

Area adoption curves were constructed for each RV using a logistic function fit to data points from the Martel's (1995) survey in 1993 and our 2001 surveys in the Mideast and Northeast regions – weighting the annual RV bean area by the seasonal and regional shares of the annual total of the two regions from the year of varietal release until 2010 (Figure 1; see Appendix). 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 four years of farmer adoption behavior, as the variety was released in 1997. However, it is clear that it is quickly 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, 31% in the postrera for the Mideast; and 34% in the primera, 22% in the postrera for the

Northeast)[15]. Thus, we project that Tio Canela will replace Dorado and Don Silvio by 2007, given Tio Canela's price advantage, relative to both of these varieties. 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 2007.

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 1987-1999 (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 due to Hurricane Mitch). The bean price series used for economic analysis is the Honduras farmgate price from 1987-1999. 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 (El Salvador and Nicaragua, a shadow market, as per Martel (1995)). Thus, we assume that the farmgate price is the best approximation to 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.

[15] Given that the Post-Hurricane Mitch seed distribution could have influenced adoption rates in 1999-2000, we use 1998 as a year more representative of the typical demand for RVs.

The CRSP and PROFRIJOL and have provided funding and training, while CIAT has provided germplasm, training, and collaboration with both DICTA and Zamorano in conducting regional field trials. Costs associated with the development of the RVs (Appendix Table A-3) begin in 1984 (the initial developmental stages of Dorado) and continue to 1997 (when Tio Canela was released).

CIAT's 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 CIAT's bean program (during the 1980-85 period)[16]. The CRSP supports the Zamorano bean program's research activities, as well as training. This analysis assumes that 60% of the CRSP support to the Zamorano bean program budget and 60% of training investments during the 1986-1997 period 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.

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

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[16] CIAT varietal development costs for this time period provided by Nancy Johnson, CIAT Economist.

Since structural adjustment in the late-1980s, improved bean varieties have primarily been extended through DICTA's artisan seed projects, Zamorano-based pilot projects, the sole private commercial seed supplier (Hondugenet, located in the capital, Tegucigalpa), commercial sales of certified seed 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 in October, 1998. 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 of 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 the period 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 in aggregate. We have assumed that average yield losses to BGYMV 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 interest, 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 DICTA's 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 disease pressure by season, elasticity of supply, and the average expected yield loss to BGYMV (Table 6). 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 elasticity of supply, assuming a higher elasticity of 1.0 % reduces the IRR to 35 %, whereas a lower elasticity of 0.4 % increases the IRR to 55 %. However, we use 0.7 % in the baseline scenario because semi-subsistence crops are generally assumed to have an inelastic elasticity of supply. The high sensitivity of our

Table 6. Sensitivity of returns to bean breeding research to changes in key parameters

Elasticity of Supply:	IRR (%)	Net Farm-level Value of Yield Loss Averted as % of Total Bean Income (%)	IRR (%)
1.0 %	34	Dorado/D.Silvio 6%; Tio Canela 15%	29
0.7 % *	41	Dorado/D.Silvio 11%; Tio Canela 20% *	41
0.4 %	55	Dorado/D.Silvio 16%; Tio Canela 25%	50
BGYMV pressure by season:	IRR (%)	Dorado Area in 2000 Replaced by Tio Canela by 2007?	IRR (%)
Postrera only *	41	Yes *	41
Primera and Postrera	48	No, area of both remain at year 2000 level	41
Discounted Benefits Extended to: (Year)	IRR (%)		
2000	40		
2005	41		
2010 *	41		
* Value used for the baseline scenario. Source: calculated by the authors			

IRR to the assumed elasticity of supply concurs with the recent work of Oehmke and Crawford (2002). 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 IRR of 29% is still quite high. We also do sensitivity analysis on 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. We also 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 three hectares 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.*, forthcoming). However, Zamorano's current breeding priorities are focused on developing varieties 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 the period 1984-2010 is 41.2 %, well above the assumed 10% opportunity cost of capital. Moreover, the adoption of RVs in Honduras has been widespread and neutral with respect to farm-size. 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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Appendix

Table A-1. Bean Yields by Variety, Primera 1998-2000, Honduras

Variety	*Primera* 2000			*Primera* 1999			*Primera* 1998		
	Yield (kg/ha)	CV (%)	N	Yield (kg/ha)	CV (%)	N	Yield (kg/ha)	CV (%)	N
Tio Canela	869	73	18	753	75	12	575	113	5
Dorado	724	66	50	923	63	50	785	72	49
Don Silvio	556	80	7	561	70	7	285	51	2
Catrachita	458	77	11	436	77	11	588	94	18
All TVs	632	65	104	701	62	102	595	84	89

Source: CRSP/PROFRIJOL Bean Farmer Survey, 2001
CV=coefficient of variation (standard deviation divided by the mean)

Table A-2. Bean Yields by Variety, Postrera 1998-2000, Honduras

Variety	*Postrera* 2000			*Postrera* 1999			*Postrera* 1998		
	Yield (kg/ha)	CV (%)	N	Yield (kg/ha)	CV (%)	N	Yield (kg/ha)	CV (%)	N
Tio Canela	537	93	23	791	53	14	190	200	7
Dorado	369	92	52	624	90	58	268	139	55
Don Silvio	552	74	8	796	46	8	389	141	2
Catrachita	211	68	10	483	80	12	165	176	19
All TVs	446	80	151	612	63	133	239	118	124

Source: CRSP/PROFRIJOL Bean Farmer Survey, 2001
CV=coefficient of variation (standard deviation divided by the mean)

Table A-3: Costs of Improved Bean Varietal Development, Honduras, 1984-1997						
	EAP [a]	EAP training [b]	PROFRIJOL [c]	DICTA [d]	CIAT [e]	TOTAL
Year	($US)	($US)	($US)	($US)	($US)	($US)
1984					112,000	112,000
1985					112,000	112,000
1986	33,985	8,022	22,314	41,407	112,000	217,728
1987	48,379	13,101	15,000	35,387		111,867
1988	59,153	19,576	15,000	56,830		150,558
1989	66,662	24,767	15,000	45,525		151,954
1990	63,777	18,346	15,000	45,559		142,682
1991	85,486	20,817	15,000	50,562		171,864
1992	64,270	22,864	15,000	48,331		150,465
1993	83,776	12,093	15,000	23,354		134,223
1994	76,696	10,282	15,000	19,009		120,986
1995	66,339	0	15,000	18,469		99,808
1996	60,181	0	15,000	17,959		93,140
1997	65,294	0	15,000	17,499		97,793

[a] Represents 60% of CRSP contribution to EAP bean program for research; includes $30,000/year for breeder's salary

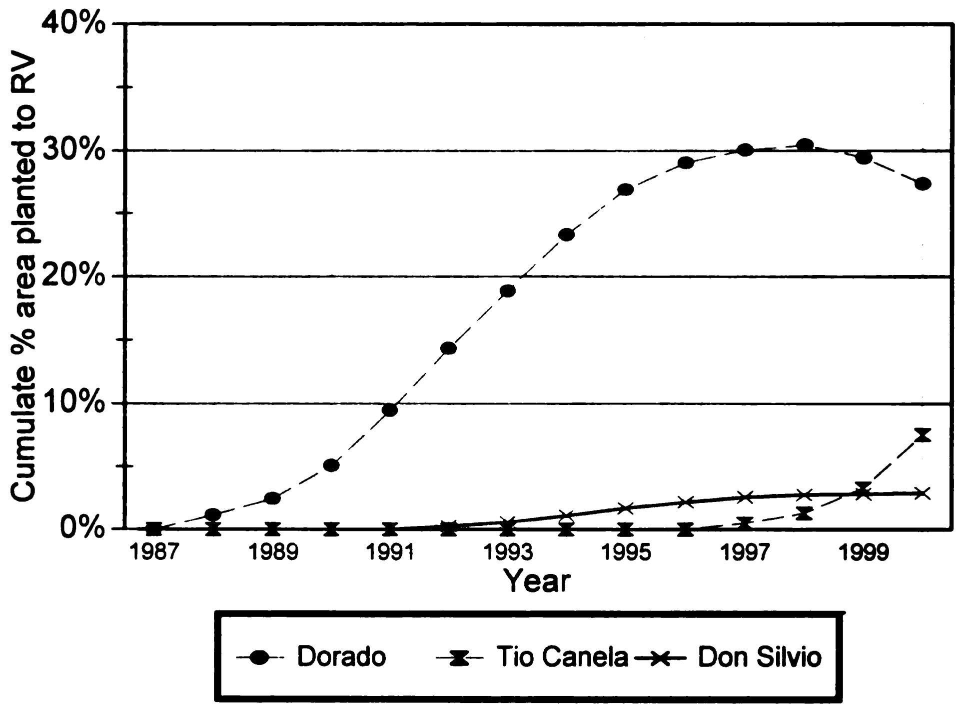
[b] Represents 60% of CRSP funding of EAP bean program for training;

[c] Represents 100% PROFRIJOL assistance to EAP and DICTA bean programs

[d] Represents 100% of DICTA's bean research and extension costs for Danli and Olancho

[e] Estimate of the cost of CIAT's bean improvement program from 1980-85 per released variety

Fig. 1: Resistant Variety Adoption
Mideast & Northeast Honduras



IMPACT ASSESSMENT OF MAINTENANCE RESEARCH TECHNOLOGIES: THE CASE OF DISEASE-RESISTANT BEANS IN HONDURAS

ESSAY TWO

1. Introduction

Conventional *ex post* impact assessment methods have typically focused on productivity enhancement technologies, whose benefits are estimated as the yield difference between traditional and improved technologies as observed in either experimental trials or a cross-section survey of 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. Various authors have used experimental trial data to estimate yield loss averted through use of a disease-resistant cultivar (Smale *et al* 1998, Morris *et al*, 1994), but experimental trials often do not well-approximate farmer conditions. This is especially true for measuring disease resistance technologies, considering that disease frequency and intensity are fixed in experimental trials, yet under farmer conditions they may vary spatially by weather patterns, altitude, and crop management practices. However, the presence of selection bias in farmer survey yield data will tend to underestimate the real benefits of disease-resistant technologies, to such an extent that Johnson and Klass (1999) recommend the use of experimental trials over survey data, even with the limitations of the trial data.

This essay proposes methodological advances that allow for the use of farm survey data to address the questions of yield loss avoidance and returns to research. The point of departure is Otsuka *et al* (1994), who use farm-level survey data to estimate the impact of RV (disease-resistant variety) rice in the Philippines. Otsuka *et al* apply a modified Heckman two-step procedure (adapted from Lee, 1978) to correct for selection bias. Lee's procedure gives unbiased and consistent estimates of parameters of the equations of interest (traditional variety (TV) yield and RV yield), which Otsuka uses to compare the mean rice yields of TVs and RVs. However, these equations represent the yield response of a given subsample of the population – TV growers in one case, and RV growers in the other. In other words, they compare the expected RV yield (conditional on RV use) with the expected TV yield (conditional on TV use). However, the more appropriate counterfactual scenario for impact analysis is unobservable – the yield that RV users would have obtained in the absence of RVs.

Extending Otsuka *et al*, this paper constructs the counterfactual to RV yields as what yields RV users would have obtained had they continued to grow TVs (i.e. the TV yield conditional on RV use). Constructing the appropriate counterfactual is especially poignant in the case of RVs (and other technologies that mitigate adverse circumstances), since it is anticipated that the TV yield profile differs significantly between RV users and TV users. Specifically, farmers adopt RVs to avoid yield losses from disease. Farmers who choose to continue to plant TVs must not experience significant yield losses, otherwise they would adopt the RV. Using farm-level survey data on disease-resistant bean yields in Honduras, a modification of Lee's two-step procedure is employed to obtain selection-corrected bean yield equations for TV and RV users. As demonstrated in the labor supply literature (Lee, 1978; Duncan and Leigh, 1980), estimation of these selection-corrected equations enables the prediction of imputed yields for each individual's unobserved varietal choice, conditional on his/her own observed characteristics. That is, the selection-corrected yield equations account for the endogenous farmer decision to adopt or not adopt RVs, and allows for meaningful prediction of TV yields (including yield loss) that those farmers adopting RVs would have gotten had the RVs not been available. Thus, the predicted TV yields of RV users can be statistically compared with predictions of RV yields to estimate the farm-level impact of disease-resistant bean varieties in Honduras, and the impact of the research that developed these varieties.

2. Model

Our principal interest in this paper is to estimate the impact of RVs by predicting the counterfactual yield of RV users -- the TV yield that RV adopters would have gotten in the absence of RVs -- and comparing this with predictions of RV yields for the same subgroup.[1] In the following model, each farmer's observed yield depends on his varietal choice, represented by equation (2). Yield Y_{Ti} is observed if the farmer grows a TV, while Y_{Ri} is observed if the farmer grows an RV. An implicit assumption of the model is that farmers are knowledgeable about the disease pressure that they face.

$$I_i = \gamma_0 + \gamma_i Z_i + e_i \qquad (1)$$

We observe:

Y_{Ri} when $I_i = 1$ if farmer grows a RV

Y_{Ti} when $I_i = 0$ if farmer grows a TV, but never both

[1] Comparing predicted TV yields with predicted (instead of actual) RV yields ameliorates the influence of measurement error on the actual yields.

$$\ln Y_{Ri} = B_{R0} + B_{Ri}X_{Ri} + u_{Ri} \qquad (2)$$

$$\ln Y_{Ti} = B_{T0} + B_{Ti}X_{Ti} + u_{Ti} \qquad (3)$$

where $\ln Y_{Ri}$ and $\ln Y_{Ti}$ are the logs of yield for individual i, X_i is a vector of personal and farm-level characteristics, and u_{Ri} and u_{Ti} are residuals. This is a switching regression model with endogenous switching, as first developed by Goldfeld and Quandt (1973) and later modified by Lee (1978).

3. The sample selection problem

Consider a population of farmers who can be identified as either adopters or non-adopters of RVs. Further assume that beans are grown in areas of high and low disease pressure, that high disease pressure leads to significant yield losses for TVs but none for RVs (Table 1), and that all farmers (at least those in high disease areas) have access to RVs. A random sample survey of this population will result in two subsamples of farmers: one with observations on RV yields, the other with observations on TV yields.

Table 1. Hypothetical yield profiles by variety and disease pressure

Disease Pressure	Scenario	
Low	# 1: TV yield = 800 kg/ha	# 2: RV yield = 800 kg/ha
High	# 3: TV yield = 600 kg/ha	# 4: RV yield = 800 kg/ha
TV = traditional variety; RV = disease-resistant variety		

If consumers prefer the culinary characteristics of TVs, then farmers in low disease areas could continue to grow TVs (Scenario # 1).[2] However, farmers in areas of high disease pressure will endogeneously select RVs (Scenario # 4) in order to avert the yield losses of TVs (Scenario # 3). For the purposes of impact assessment, the most appropriate

[2] We assume no price discounts for these scenarios. However, in the case that follows, RVs face a price discount in the market.

counterfactual for RV users is not the sample mean of TV users (Scenario # 1), but what RV users yields would have been in the absence of RVs (Scenario # 3). Therefore, failure to account for this endogeneous choice may lead to bias in the comparisons of sample mean yields by variety.

The same may be said of predictions of varietal yields from regressions, yet whether (or not) sample selection creates a statistical problem depends upon whether (or not) there are differences in both the observable and unobservable characteristics of TV and RV growers. For example, once we assume that decision to adopt an RV is not random, then the RV and TV subsamples potentially have different characteristics. Sample selection bias in this case occurs when some component of the varietal choice decision is relevant to the yield determination process; that is, when some of the determinants of the varietal decision also influence yield. Yet, when the relationship between the varietal decision and the yield determination is purely through the observables, then appropriate variables in the yield equation can control for this. Thus, sample selection bias will not occur simply because of differences in observable characteristics (Vella, 1998).

When one further assumes that unobservable characteristics (such as disease pressure) affecting the farmer's varietal decision are correlated with the unobservable characteristics affecting the yield determination process, then a relationship exists between the varietal decision and the yield determination process. If these unobservable characteristics are correlated with the observables, then the failure to include an estimate of the unobservables will lead to incorrect inference regarding the impact of the observables on yields. Thus, under these circumstances, a bias will be induced due to sample selection (*ibid*, 1998).

In the case of our survey data from Honduras, we do not observe RV (TV) yields for some farmers due to the outcome of another variable - varietal choice. Because disease pressure – and perhaps other unobservables which influence varietal choice – is not distributed randomly throughout the sample and is correlated with yield, then $E(u_i \mid$ varietal choice $\neq 0)$. If some part of the yield distribution is cut off, then estimated residuals from this model are truncated normal, and OLS estimates of yield equations are inconsistent.

To see the effects of sample selection bias more clearly, consider the following data generating process for yield:

$$\text{yield}_i = B_0 + B_1 * \text{rainfall}_i + B_2 * \text{fertilizer}_i + B_3 * \text{RV}_i + B_4 * \textit{disease pressure}_i + u_i \quad (1)$$

where: RV = 1 if farmer i grows a resistant variety, and RV=0 if not; rainfall and fertilizer use are observed variables; and *disease pressure*$_i$ is an omitted variable

In the absence of a farm-level measure of the true intensity, timing or frequency of disease pressure, and assuming that disease pressure is not distributed randomly throughout the sample, then the results of the yield regression (1) will be biased because the error term is actually $u_i + B_4 * \textit{disease pressure}_i$. Thus, the mean error will not be zero. In addition, we will encounter a further source of bias in that the omitted variable is likely correlated with the RV dummy.

Roy (1951) provided an early discussion of the problem of self-selectivity, discussing the problem of individuals choosing between two professions, hunting and fishing, based on their productivity in each activity. The observed distribution of incomes of hunters and fishermen was determined by these choices. The later discussion of the econometric consequences of self-selection bias began with studies of womens' participation in the labor force and implications for the estimation of wage equations (Gronau, 1974; Lewis, 1974). The basic idea of the two-stage estimation procedure, as first proposed by Heckman (1976) (and later extended by Lee (1976)), is to use information from a probit function of labor force participation to construct a regressor for the wage equation which serves to adjust the wage equation error term so that its expected value will be zero.

4. Estimation Procedure

The two-stage estimation procedure for each yield equation proceeds as follows. First, using all *n* observations, we estimate by ML a probit model of Z_i on I_i to obtain estimates of γ_i and γ_0.

$$I_i^* = \gamma_0 + \gamma_i Z'_i + e_i^* \qquad (4)$$

Conditional on RV use, the RV yield equation is:

$$\ln Y_{Ri} = B_{R0} + B_{Ri} X_{Ri} + \sigma_{Rei} \lambda_{Ri} + v_{Ri} \qquad \text{for Ii} = 1 \qquad (5)$$

where $E(v_{Ri} \mid Ii = 1) = 0$. The term $\lambda_{Ri} = [-f(\psi_i) / F(\psi_i)]$ is known as the inverse Mills' ratio (IMR), where f is the density function of a standard normal random variable, and F is its cumulative distribution, and where $\psi_i = \gamma_0 + \gamma_1 Z'_{i.}$. The IMR term models the truncation effect on yields associated with sample selectivity, and thus enables $E(v_{Ri} \mid Ii = 1) = 0$. The coefficient on the IMR term, σ_{Re}, is the covariance between e_i, the error term from the RV selection equation, and u_{Ri}, the error term of the RV yield equation. The actual test for selection bias in the RV yield equation is simply a t-test of whether H_0: $\sigma_{Rei} = 0$ or not. Rejection of the null indicates the presence of selection bias.

Conditional on TV use, the TV yield equation is:

$$\ln Y_{Ti} = B_{T0} + B_{Ti} X_{Ti} + \sigma_{Tei} \lambda_{Ti} + v_{Ti} \qquad \text{for } Ii = 0 \qquad (6)$$

where $E(v_{Ti} \mid Ii = 0) = 0$. The term $\lambda_{Ti} = [\, f(\psi_i) / (1 - F(\psi_i))]$.

The error term e_i in the selection equation is assumed to be distributed standard normal, and also independent of Z_i (and therefore X_i). In addition, X_i must be a strict subset of Z_i, and we must have some elements of Z_i that are not also in X_i. This means that we need a variable that affects selection but does not have a partial effect on yields (Wooldridge, 2000)[3]. Yield equations in switching regressions are commonly estimated

[3] If $z = x$, then λ_i can be highly correlated with the elements of x_i, and such multicollinearity may lead to very high standard errors for the B_i. Thus, without this exclusion restriction, it is extremely difficult to distinguish sample selection bias from a misspecified functional form for yields (Wooldridge, 2000).

either jointly (pooled) (Otsuka, 1994) or separately (Lee, 1978; Duncan and Leigh, 1980). This paper estimates the two yield equations pooled together to gain efficiency in parameter estimation. An RV dummy serves as an intercept shifter for RV users, and is interacted with some of the regressors. Thus, the expected yield for an RV user is represented by (7) while that of a TV user is represented by (8).

$$\ln Y_{Ri} \mid_{Ri} = B_{T0} + B_{R0}{*}RV + B_{Ti}X_{Ri} + B_{Ri}X_{Ri}{*}RV + \sigma_{Rei}\,\lambda_{Ri} + v_{Ri} \quad \text{for } RV=1;\ Ii = 1 \quad (7)$$

$$\ln Y_{Ti} \mid_{Ti} = B_{T0} + \qquad + B_{Ti}X_{Ti} + \qquad + \sigma_{Tei}\,\lambda_{Ti} + v_{Ti} \quad \text{for } RV=0;\ Ii = 0 \quad (8)$$

In the case of disease-resistant beans in Honduras, TV yields are expected to be truncated from below due to selection bias. That is, low TV yields caused by disease pressure are unobserved if farmers in high-disease areas switch to RVs. Thus, assuming that TV yields depend upon the level of disease pressure, then unobservable characteristics (disease pressure) will likely influence both the varietal decision (with no disease pressure, farmers prefer the TV due to its better price) and the yield determination of TVs. However, it is not clear whether (or not) the presence (or not) of disease pressure would affect RV yields. That is, RV yields under farmer conditions are expected to be about the same with or without disease pressure, *ceteris paribus*. On the other hand, given that RV yields are not often observed in non-disease areas (higher elevations) due to their price discounts relative to TVs, and that RVs are likely better suited for the conditions of valley farmers, there may well be a part of the RV yield distribution that is not observed.

Because the error term of the pooled regression has a heteroskedastic structure, we apply Huber/White's procedure to obtain robust standard errors. The final step is to calculate predictions of RV users' RV yields using the corrected RV equation (9). The counterfactual prediction is RV users' TV yields, which are calculated using the characteristics of RV users evaluated with the coefficients from the TV equation (10).

$$\ln\hat{Y}_{R_i} \mid _{R_i} = \hat{B}_{T0} + \hat{B}_{R0}*RV + \hat{B}_{T_i}X_{R_i} + \hat{B}_{R_i}X_{R_i}*RV + \hat{\sigma}_{Rei}\,\lambda_{R_i} \quad \text{for RV=1; Ii = 1 (9)}$$

$$\ln\hat{Y}_{T_i} \mid _{R_i} = \hat{B}_{T0} + \quad + \hat{B}_{T_i}X_{R_i} + \quad + \hat{\sigma}_{Rei}\,\lambda_{R_i} \quad \text{for RV=0; Ii = 1 (10)}$$

5. Background and Data

Honduras' two bean research programs, which are implemented by Zamorano (Programa de Investigaciones en Frijol, Escuela Agricola Panamericana) and DICTA (Direccion de Ciencia y Tecnologia Agricola, the Honduran National Bean Program), work in collaboration with three organizations: the USAID-funded Bean/Cowpea Collaborative Research Support Project (CRSP); the Programa Cooperativo Regional de Frijol para Centroamerica, Mexico, y El Caribe (PROFRIJOL), funded by COSUDE, the Swiss Agency for Development and Cooperation; and CIAT (Centro Internacional de Agricultura Tropical). Bean Golden Yellow Mosaic Virus (BGYMV) is the principal bean disease in Honduras, and 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 1,000 m in most growing regions of Honduras and more frequently in the drier postrera season (September/ October to December/January).

Zamorano and DICTA have developed several varieties with resistance to BGYMV (RVs), the first of which was released in 1990. However, the economic gains from yield loss averted through RV use are at least partially offset by price discounts in the market from 7 to 15 percent (Martel, 1995; Mather *et al*, 2003).

This analysis utilizes data collected through a farm-level survey of bean farmers (N=210), which was implemented by the CRSP and PROFRIJOL in January-February 2001, in collaboration with Zamorano and DICTA. The survey targeted the Mideast (El Paraiso and Francisco Morazan departments) and Northeast (Olancho) regions, which together account for about 60 % of Honduras' annual bean production. Bean producers in Honduras are predominantly small farmers, the majority of whom use fertilizer and insecticide, market at least some of their bean production, and depend upon beans for a major portion of their household income (Martel, 1995; Mather *et al*, 2003). 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[4]. The postrera (September/October to December/January) is a drier season, during which beans are the major crop and are almost exclusively monocropped. Because the whitefly population is often highest under drier conditions, BGYMV is most frequent and severe in the postrera.

Most of the sample farmers (70 percent) live in villages which have faced BGYMV pressure in the past (Table 3), and also (58 percent) live in villages which have

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

received village-level extension support, including promotion, demonstration, and/or access to RVs. RV adoption is widespread, and mean RV yields tend to be higher than those of TVs (Table 2). Yet, because of the high variance in both RV and TV yields, yields by varietal type are not statistically different (at the 5 % level).

The impact analysis of varietal development involves the estimation of the incremental change in benefits received by the farmers who have adopted the variety. In our case, we want to estimate the current yields of RV users, as well as their yields if they had not adopted an RV. However, as mentioned above, using the current TV yields of TV users as the RV users' counterfactual ignores the potential for selection bias to underestimate the benefits to RVs. Therefore, assuming that selection bias is present, the appropriate counterfactual to current RV yields is unobservable: the yields these RV growers would obtain if they were to use TVs instead. The fact that the RV survey yields and coefficients of variation are quite similar to those of TVs – given that significant price discounts exist, most farmers market beans, and adoption rates are fairly high – suggests that selection bias is indeed present, and that using current TV yields of TV users would underestimate the benefits of RVs to RV users.

Table 2. Adoption of RVs and Bean Yields by Season, 1999-2000, Honduras

Variety	Primera		Postrera	
	1999	2000	1999	2000
Varietal Use: RVs (% farmers)	45	45	41	42 [a]
TVs	64	62	67	76
Both an RV and a TV	9	7	8	18
Sample size (farmers)	N=164	N=170	N=202	N=202
Yield: RVs (mean kg/ha)	857	769	667	446
TVs (mean kg/ha)	678	632	615	459
Disaster (%) [b]	4	6	6	14
Rainfall; first month of season (avg mm) [c]	126	171	314	206
Sample size (parcels) [d]	N=188	N=203	N=242	N=268

Source: CRSP/PROFRIJOL Farmer Survey, 2001 (N=210)

[a] As some farmers planted more than one variety, the total is greater than 100%.

[b] Farmer with yield < 80 kg/ha

[c] Source: Depto. de Servicios Hidrologicos y Climatologicos, Direccion General de Recursos Hidricos, Secretaria de Recursos Naturales, Honduras

[d] Parcels aggregated at the farmer and variety level

Table 3. Characteristics of sample farmers, Honduras, 2000

Characteristic	Primera	Postrera
Bean area (mean ha)	1.30	1.58
Altitude (m)	945	913
% Farmers: in Area of Bean Golden Mosaic Virus [a] (%)	70	70
Used formula fertilizer (%)	55	48
Used Urea (%)	49	45
Used both formula and urea (%)	29	25
Intercropped (%)	14	15
Ever planted a resistant variety (PRV) (%)	67	68
% farmers living in village with extension (by type): [b]		
DICTA artisan seed program (%)	22	19
Dept. of Natural Resources (%)	35	32
Zamorano (%)	16	14
Catholic Church (%)	13	17
No extension at village level (%)	42	45
Sample size	N=170	N=202

Source: CRSP/PROFRIJOL Farmer Survey, 2001 (N=210)
[a] defined by Dr. Juan Carlos Rosas, Director, Programa de Investigaciones en Frijol, Zamorano [b] extension which includes promotion, demonstration, and/or extension of improved varieties

6. Estimation results of varietal choice function

We estimated the probit RV adoption function (Table 4) using data from four consecutive seasons: the primera and postera seasons of 1999 and 2000. Most of the elements of the adoption function are factors expected to influence bean yield such as fertilizer use, rainfall, cropping system, season, etc., as well as village dummies which help to capture non-observable agronomic factors common at the village level. Farmer socioeconomic factors such as age, education, and farmsize are not included here due to their insignificance.

Formula fertilizer use is defined as zero if the farmer used no formula fertilizer in a given season, and is defined as one if the farmer used formula in that season[5]. Variables for urea fertilizer use and combined formula and urea use are similarly constructed. Rainfall represents the total village rainfall (mm) in the first month of the given season. While rainfall during the first month of a bean season is undoubtedly an important factor in yields, the explanatory power of this rainfall data is questionable for several reasons. First, only nine rainstations across the three departments had complete data for the four seasons of production data. Thus, each of the 30 villages was assigned the value reported at the nearest rainstation to represent village rainfall. Second, the timing and distribution of rain within a month is not captured by the monthly total. Intercrop refers to any cropping system which is not monocrop (but does not include the relay system common in Olancho in the postrera, which is essentially monocrop). Disaster is a dummy to capture the influence of yields less than 80 kg/ha.

The remaining factors in the adoption function serve as exclusion restrictions – variables that affect selection but do not have a significant partial effect on yields[6]. These

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[5] We only have fertilizer use data for primera and postrera of 2000. Since this variable measures only use and not fertilizer level, and since many farmers regularly use fertilizer, we assume that fertilizer use in 1999 was the same as that observed in 2000. This assumption does not affect the test for selection bias, nor the significance or magnitude of key variables in the corrected yield equation such as RV and fertilizer use.

[6] These exclusion restriction variables were included in an OLS yield regression and determined to be insignificant at the 0.10 level.

include a dummy variable for villages in which BGYMV has been a problem in the past[7], village altitude (lower altitudes experience higher BGYMV pressure), village altitude squared, and a dummy variable for farmers who had planted an RV at some time in the past (PRV).

While a measure of a farmer's information about and access to RVs may be well-captured by village-level extension variables, these variables are not ideal exclusion restriction variables since extension presence in a village -- which in this case includes more than just information about and access to RVs – would be expected to influence (increase) yields. BGYMV is only a rough indicator of disease pressure, since more significant the intensity of disease attack and its frequency is more significant in the farmers' adoption decision. Altitude is also a rough indicator of disease pressure, as lower altitudes tend to have higher BGYMV pressure. PRV is an ideal exclusion restriction variable because it is intimately related to adoption, yet does not predict adoption perfectly due to disadoption (67 percent of the sample has planted an RV at some point, while 45 percent continue to grow an RV) and is not correlated with yields.

The estimation results (Table 4) show that the coefficient on the BGYMV dummy is positive, significant and of relatively large magnitude, which confirms the expectation that the principal benefit of RVs is expected to be the yield loss averted due to their disease resistance, and that farmers outside the BGYMV area would not likely adopt the older RVs which have significant price discounts. Also as expected, the coefficient on

[7] BGYMV area classification as designated by Dr. Juan Carlos Rosas, Director, Programa de Investigaciones en Frijol, Zamorano.

the PRV dummy is positive, significant and of sizeable magnitude. Altitude is also significant, yet it's sign is contrary to expectation as the probability of adoption is hypothesized to decrease as altitude increases.[8] The factors influencing adoption which are of principal interest to this paper are the exclusion restriction variables, none of which are significant when tested in the yield regression.

[8] While village altitude is negatively correlated (pairwise) with RV adoption, it's sign becomes positive when village dummies are included in the probit regression.

Table 4. Probit Estimates of Resistant Variety Adoption Equation, Primera and Postrera, 1999-2000

Explanatory Variables [a]	RV adoption (RV=1, TV=0)
Constant	-4.09 (-2.79)**
Season = Postrera	-0.055 (-1.20)
Year = 2000	-0.023 (-0.61)
Intercrop	0.044 (0.63)
Disaster (yield < 80 kg/ha)	0.075 (1.01)
log of Rainfall in first month of season (mm)	0.014 (0.28)
Used formula fertilizer (0=no; 1=yes)	-0.108 (-2.12)**
Used urea fertilizer (0=no; 1=yes)	0.104 (2.15)**
Used both formula & urea (0=no; 1=yes)	0.0005 (1.65)*
Village-level Extension: DICTA	0.729 (1.76)
Zamorano	-0.432 (-3.45)**
Dept of Natural Resources	-0.946 (-4.42)**
Catholic Church	-0.042 (-0.19)
BGYMV area	0.258 (1.80)*
Altitude (m)	0.006 (2.08)**
Altitude^2 (m)	-0.0000 (-1.82)*
Ever Planted Resistant Variety (PRV)	0.355 (7.81)**
[a] Does not include 30 village dummies (z stats in parentheses) ** significant at the 0.05 level * significant at the 0.10 level	N = 900 Log Likelihood = -381.47 Pseudo R2 = 0.343 Coefficients calculated as dF / dX

7. Estimation results of bean yield function

To estimate the yield function, we pooled the data over the primera and postrera seasons of 1999 and 2000 (Table 5). We assume that many factors affecting yields, such as year, cropping system, village dummies, etc., have the same effect on both TVs and RVs. However, we assume that the productivity of TVs and RVs are differentially affected by factors such as fertilizer use and season. The regressors in the yield function are nearly the same as those used in the probit function, the difference being the inclusion of the inverse Mills' ratios (IMR) and the omission of the exclusion restriction variables from the probit function.

As expected, the IMR coefficient for TVs is positive, significant at the 0.05 level and of considerable magnitude, thus indicating the presence of selection bias. The positive sign on this coefficient indicates positive selection which means that observed TV yields are higher than what would be observed (positive truncation) if a farmer randomly chosen from the whole sample were to plant a TV. The reason for this is that a farmer selected at random may be in a disease-intensive area, and thus would get lower yields, whereas such a farmer would not, in reality, plant a TV.

We did not have an *a priori* expectation for the IMR coefficient term for RVs, although it is found to be positive, significant at the 0.10 level and of smaller magnitude to that of the TV. However, because the sign on the IMR term $\lambda_{Ri} = [- f(\psi_i) / F(\psi_i)]$ is negative, while its corresponding coefficient is positive, this implies that negative selection occurs for RV growers. That is, observed RV yields are lower than they would be in the absence of the unobservables which drive RV use. An explanation for this could be that the unobservable BGYMV pressure (which may well be correlated with other unobserved disease and insect pressures to which the RVs are not resistant) which drives a farmer to experiment with RVs (PRV) tends to lower the RV yields from what they would be in disease-free areas. In addition, we do not observe many RV growers (and, thus, RV yields) in disease-free areas for two main reasons. First, farmers in areas with low to negligible BGYMV pressure will not likely grow RVs due to their market price discounts. Second, areas above 1,000 m are more remote and thus have less access to markets and extension - both of which condition access to RV seed and fertilizer.

The results of the yield function estimation corrected for selection bias compared with uncorrected OLS results are most distinctively different for the RV dummy and the constant (Table 4). The RV dummy coefficient is highly significant and large in the selection corrected estimation, whereas it is insignificant and small in the uncorrected estimation. Thus, the selection-bias correction increases the significance and magnitude of the RV dummy. All other coefficients in the yield model are essentially of the same significance and magnitude. This means that an RV farmer has higher expected yields than a TV farmer with similar characteristics.

Both corrected and uncorrected estimation show that RVs are more responsive to urea fertilizer than TVs, although the *RV*urea* coefficient is not significant at the 10% level in either equation. However, given the relative magnitude of the RV dummy and those for fertilizer response, it is clear that the principal benefit of RV use is disease resistance, not improved response to fertilizer. The coefficient for season (postrera) is negative and significant as expected, given that the postrera season is drier, has more disease pressure, and historically produces lower yields than the primera. While we would expect rainfall to increase yield, the coefficient on village rainfall (mm) is insignificant, perhaps due to the presence of village dummies and the nature of the rainfall data (explained above). While intercropping systems can result in higher bean yields, the significant and positive coefficient on *intercrop* is likely driven by two factors: most intercropping occurs in the primera (when yields are higher), and the conversion of intercropped bean area to "effective monocrop" bean area may underestimate the effective area. The inclusion of village dummies improves the explanatory and thus predictive power of the regression, as well as the estimation precision of nearly all the coefficients, although our interest in coefficients relates principally to those for the RV dummy, fertilizer use, and the IMR terms.

Table 5. Adjusted and Unadjusted OLS Estimates of Yield Equation, Primera and Postrera, 1999-2000

Explanatory Variables [a]	Corrected OLS ln(yield)	Uncorrected OLS ln(yield)
Constant	5.630 (14.74)**	5.718 (14.82)**
Season = Postrera	- 0.220 (-2.97)**	-0.238 (-3.23)**
Year = 2000	- 0.192 (-2.85)**	-0.193 (-2.85)**
Intercrop	0.245 (2.52)**	0.269 (2.81)**
Disaster (yield < 80 kg/ha)	-3.369 (-14.80)**	-3.36 (-14.69)**
log of Rainfall in first month of season (mm)	0.021 (0.29)	0.026 (0.35)
Used formula fertilizer (0=no; 1=yes)	0.206 (2.14)**	0.151 (1.64)
Used urea fertilizer (0=no; 1=yes)	0.060 (0.76)	0.098 (1.27)
Used both formula & urea (0=no; 1=yes)	- 0.0004 (-1.53)	- 0.0005 (-1.46)
RV dummy	0.552 (2.73)**	0.129 (1.10)
RV * Season = Postrera	- 0.175 (-1.52)	- 0.177 (-1.56)
RV * Year = 2000	- 0.020 (-0.18)	- 0.015 (-0.14)
RV * Disaster	- 0.554 (-1.48)	- 0.554 (-1.47)
RV * Formula Fertilizer	- 0.025 (-0.16)	- 0.013 (-0.08)
RV * Urea Fertilizer	0.155 (1.09)	0.151 (1.07)
RV * Both Formula & Urea Fertilizers	-0.0006 (-0.51)	-0.0007 (-0.54)
Inverse Mills' Ratio (TVs)	0.342 (2.51)**	–
Inverse Mills' Ratio (RVs)	0.236 (1.69)*	–
[a] Does not include 30 village dummies (t stats in parentheses) ** significant at the 0.05 level * significant at the 0.10 level	N = 900 R2 = 0.680 F(46, 854) = 16.07	N = 900 R2 = 0.678 F(44, 856) = 16.36

8. Counterfactual Predictions

Estimation of the selection corrected yield function enables the prediction of imputed yields for each individual's unobserved varietal choice, evaluating each individual's own observed characteristics at the coefficients from the alternate subsample. Finally, the predicted TV yields of RV users can be statistically compared with predictions of RV yields to estimate the farm-level impact of disease-resistant bean varieties in Honduras.

The significant coefficient on the *RV* dummy imply that the expected yield of RV users is higher than that of TV users, *ceteris paribus*. However, the more appropriate counterfactual scenario for impact analysis is the predicted yield that RV users would have obtained in the absence of RVs – the TV yield of an RV grower. The conditional counterfactual estimates the yield differential between predicted RV and TV yields for a farmer chosen at random from the RV subsample. This conditional counterfactual[9] is computed for RV growers as the sum of the selection corrected constant (common to both RV and TV growers) plus the relevant IMR coefficient multiplied by the corresponding IMR term, plus the characteristics of RV growers multiplied by the TV

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[9] The conditional counterfactual assumes that the grower has already selected into the RV subsample and includes the IMR term. Unconditional counterfactual would not assume that the grower had already selected into the RV subsample, and would not include the IMR term in the computation of predictions. While predicted yield levels vary given which counterfactual is computed (Table 6b), the percentage differential between the predicted RV yield and the predicted RV counterfactual is not affected by this choice. The reason for this is that since these differentials are calculated using predictions from the same subsample, it doesn't matter whether or not the IMR term is included. However, if we were to compute a differential between predicted RV yields (for RV users) and predicted TV yields (for TV users) – a differential across subsamples – then the counterfactual choice makes a large difference. For example, the differential between conditional predictions across subsamples are almost identical to those from OLS (605 vs. 541 kg/ha is 11%), while differentials between unconditional predictions are much larger (714 vs 476 kg/ha is 33%). Conditional differentials would thus be expected to be smaller than unconditional estimates, in which the varietal choice has not yet been made.

Table 6. Predictions of RV and TV bean yields from Corrected and Uncorrected Yield Models, 1999-2000

Comparison of Mean Predictions by Subsample	Sub-Sample Size	Corrected OLS Estimation*				Uncorrected OLS Estimation			
		Mean Predicted Yields (kg / ha)		Differential *** (%)		Mean Prediction (kg / ha)		Differential (%)	
RV vs TVcf $\vert_{RV}$ **	N=312	605	361	40	35	634	577	9	0
RV vs TVcf $\vert_{RV}$: Primera	N=145	757	418	45	42	792	666	16	12
RV vs TVcf $\vert_{RV}$: Postrera	N=167	473	313	34	28	496	501	- 1	- 9
TV vs RVcf $\vert_{TV}$ #1(adds RV, RV*fert)	N=588	541	889	- 64	- 56	568	612	- 8	- 3
TV vs RVcf $\vert_{TV}$ #2 (adds RV)	N=588	541	860	- 59	- 52	568	591	- 4	0
TV vs RVcf $\vert_{TV}$ #3 (adds RV*fert)	N=588	541	512	5	9	568	538	5	10
TV vs RVcf $\vert_{TV}$ #3 : Primera	N=245	622	641	- 3	0	652	673	- 3	0
TV vs RVcf $\vert_{TV}$ #3 : Postrera	N=343	483	421	13	17	507	441	13	17
TV vs RVcf $\vert_{TV}$ #4 (adds neither RV nor RV*fert)	N=588	541	495	9	12	568	519	9	12

* Corrected predictions include IMR coefficients and IMR terms   ** cf = counterfactual
Observed mean sample yields: RV = 673 kg/ha; RV primera = 810 kg/ha; RV postrera = 555 kg/ha
Observed mean sample yields: TV = 582 kg/ha; TV primera = 654 kg/ha; TV postrera = 531 kg/ha
*** Left differential is calculated as the ratio of the difference between sample mean yield predictions (from the mean predicted yields columns) divided by the first term; for eg., [(RV - TVcf $\vert_{RV}$) / RV] * 100. Right differential calculated as the mean of farmer differentials, calculated by the same ratio.

coefficients estimated from the TV subsample.

After obtaining predictions from each regression, the mean values of log(yield) are scaled to levels[10]. The mean predictions (Table 6) are similar to actual means, although the predicted RV yields are lower in general than actual RV yields. Two differentials are presented (Table 5); the first is calculated as the ratio of the difference between sample mean yield predictions (from the mean predicted yields columns) divided by the first term; for eg., $[(RV - TVcf|_{RV}) / RV] * 100$; while the second is calculated as the mean of farmer differentials, calculated by the same ratio, but for each farmer.

Given that we found negative selection for RV yields (mean RV yields are lower than they would be if RVs were grown in areas of no disease pressure) and positive selection for TV yields (TV yields are higher than they would be if TVs were grown in areas of high disease pressure), we would expect that differentials calculated from the selection-corrected yield equation would be larger than those from the uncorrected OLS equation. As expected, comparison of differentials by estimation technique shows that those from the corrected model are significantly larger than those from the uncorrected model (Table 5); the corrected model predicts the mean farmer differential to be 42% in the primera, and 28% in the postrera, while the uncorrected model predicts a differential of 12% and -9%, respectively for these two seasons.

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[10] The conversion of predicted log yield to level yield is exp(*scale*) * exp(ln(*yield_hat*)) where *scale* is computed as the coefficient B_0 of the regression *Yield_hat* = B_0 exp(ln(*yield_hat*)) with no constant.

Furthermore, due to market price differentials by variety, yield differentials must be adjusted in order to more accurately reflect the net gain to farmers of varietal choice. For example, the valuation of an RV grower's counterfactual (using a TV) must account for the fact that while the RV may yield more than the TV, the market price of an RV is 15% less relative to a TV[11]. Even after adjusting the differentials for market price discounts, the corrected model predicts that RV growers enjoy net income gains of 27% in the primera and 13% in the postrera compared to what they would have earned growing TVs.

However, adjusting the uncorrected model differentials for the market price discounts yields counterintuitive results: farmers growing RVs would lose 3% in net income in the primera and lose 24% in net income in the postrera relative to what they would have earned growing TVs. This result implies that RV growers do not enjoy any yield gain (yield loss averted) to compensate for the price discount (and actually lose net income in both seasons), yet continue to grow RV nevertheless. By contrast, RV differentials from the corrected model more than offset the price discount in both seasons. The conflicting results from these two models highlight the sensitivity of impact analysis of maintenance technologies to the method of econometric measurement of farm-level net benefits: using farm-level net benefits (differentials) from the corrected model yields positive aggregate benefits, whereas using differentials from the uncorrected model yields

[11] Dorado and Don Silvio, released in the early 1990s, represent 75% of current RV users. The mean price discount for these varieties is 15%. However, Tio Canela, released in 1997 and representing 25% of RV users, has a smaller farm-level price discount of 7% (Mather *et al*, 2003).

negative aggregate benefits.

Counterfactuals are also computed for TV growers as a means to test the model, by estimating a predicted TV yield and adding the RV coefficient and the RV*fertilizer coefficients (for those TV farmers who use fertilizers). While we would expect predicted differentials for TV growers to be positive -- or if negative, to not be larger than the price discount -- the model in fact predicts that TV growers would see sizeable net gains from switching to RVs. As indicated by Table 6, these results are driven by the RV coefficient, which is added to the TV counterfactual. Given that access to RVs is not likely a critical factor in the farmers' adoption decision, this result may be explained by the fact that the RVs were targeted for valley farmers, whose growing conditions are quite different from higher-altitude farmers. That is, the RV dummy represents a yield effect enjoyed by RV adopters in disease-prone areas (which may well have other disease and pest pressures beyond simply BGYMV) over and above BGYMV resistance, that the average TV grower will not enjoy. If this assumption is correct, then the more appropriate counterfactual for TV growers is #3 (Table 6), wherein we compare the mean predicted TV yield with the mean predicted TV yield which includes the fertilizer effects of RV growers. These counterfactual values appear more reasonable as predicted RV yields are not high enough to offset the RV price discount. Another explanation for the large TV differentials could be that the model consists primarily of dummy variables, and thus we may not have enough variation among the characteristics (regressors) of TV farmers to capture the differential response of TV and RV varieties to different farmer input quantities and qualities.

9. Implications for Impact Analysis

Using the economic surplus model and costs of research as outlined in paper #1, rates of return to disease-resistant bean research in Honduras are calculated for the postrera seasons 1982-2010 (Table 7), using differentials from the corrected and uncorrected models, as well as the differential derived from an expected utility framework (paper #1; Mather *et al*, 2003). The results demonstrate the significant implications of the method described in this paper for the construction of counterfactual scenarios for use in the analysis of the impact of maintenance technologies. Use of uncorrected OLS results would lead an analyst to conclude that RV use generated negligible or negative returns, while the corrected OLS results generate a high ROR. The expected utility framework provides a minimum estimate of the net farm-level benefits of RV use, which appear to have underestimated the benefits in comparison with the corrected OLS approach using sample mean differentials.

Table 7. Rates of Return to Disease-Resistant Bean Research in Honduras, Postrera Seasons 1982-2010

Method of Calculating Incremental Farm-level net benefits of RV use		Incremental net farm-level benefit of Dorado use in the postrera season, adjusted for price discount (%)	Economic Rate of Return * (%)
Expected Utility Framework **		11	41.2
Farmer Mean Differential	Corrected Model:	13	45.0
	Uncorrected Model:	- 24	–
Sample Mean Differential	Corrected Model:	19	54.5
	Uncorrected Model:	- 16	–

* Calculations use the economic surplus model as outlined in first essay.
** Framework and benefits as presented in first essay.

10. Conclusions

This paper demonstrates a method for using farm-level survey data in the construction of counterfactual scenarios for use in impact assessment of maintenance research. The method uses a modification of Lee's (1978) two-step procedure to correct for selection bias, the presence of which in farm-level survey data will likely lead to underestimation of the benefits of maintenance research (Johnson *et al*, 1999). The method is applied to test for selection bias and estimate yield differentials between RV and TV bean yields in Honduras by constructing the counterfactual to RV yields as what yields RV users would have obtained had they continued to grow TVs (i.e. the TV yield of RV users). The corrected yield model predicts that RV growers enjoy net income gains of 13 to 19 percent compared to what they would have earned growing TVs, while the uncorrected OLS model predicts that RV growers see either no income gain or even the uncorrected OLS model predicts that RV growers see either no income gain or even losses by growing RVs (relative to TVs). This application demonstrates that the implications of this method are significant for the assessment of maintenance research impacts, both at the farm-level and in terms of the ROR to research investments.

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Table 6b. Predictions of RV and TV bean yields from Unconditional and Conditional Corrected Yield Models, 1999-00

Comparison of Mean Predictions by Subsample	Sub-Sample Size	Corrected OLS Estimation without IMR				Corrected OLS Estimation with IMR			
		Mean Predicted Yields (kg / ha)		Differential [b] (%)		Mean Prediction (kg / ha)		Differential (%)	
RV vs TVcf $|_{RV}$ [a]	N=312	714	427	40	35	605	361	40	35
RV vs TVcf $|_{RV}$: Primera	N=145	882	487	45	42	757	418	45	42
RV vs TVcf $|_{RV}$: Postrera	N=167	569	376	34	28	473	313	34	28
TV vs RVcf $|_{TV}$ #1(adds RV, RV*fert)	N=588	476	782	- 64	- 56	541	889	- 64	- 56
TV vs RVcf $|_{TV}$ #2 (adds RV)	N=588	476	757	- 59	- 52	541	860	- 59	- 52
TV vs RVcf $|_{TV}$ #3 (adds RV*fert)	N=588	476	450	5	9	541	512	5	9
TV vs RVcf $|_{TV}$ #3 : Primera	N=245	546	562	- 3	0	622	641	- 3	0
TV vs RVcf $|_{TV}$ #3 : Postrera	N=343	427	371	13	17	483	421	13	17
TV vs RVcf $|_{TV}$ #4 (adds neither RV nor RV*fert)	N=588	476	436	9	12	541	495	9	12

Observed mean sample yields: RV = 673 kg/ha; RV primera = 810 kg/ha; RV postrera = 555 kg/ha
Observed mean sample yields: TV = 582 kg/ha; TV primera = 654 kg/ha; TV postrera = 531 kg/ha

[a] cf = counterfactual

[b] Left differential is calculated as the ratio of the difference between sample mean yield predictions (from the mean predicted yields columns) divided by the first term; for eg., [(RV - TVcf $|_{RV}$) / RV] * 100. Right differential is calculated as the mean of farmer differentials, calculated by the same ratio, but for each farmer.

FACTORS INFLUENCING THE ADOPTION OF DISEASE-RESISTANT BEAN VARIETIES IN HONDURAS

ESSAY THREE

1. Introduction

Improved bean varieties are one of the best ways of improving small farm household income and food security in Central America – they are scale-neutral, reproducible on-farm, and do not require complementary physical or human capital inputs (Martel et al, 2000). Previous research by Martel (1995) found that the adoption of disease-resistant bean varieties (RVs) in Honduras was neutral with respect to farm size, yet biased with respect to fertilizer use, administrative region, and topographical region. The first RVs released, Dorado (in 1990) and Don Silvio (in 1993), were more widely adopted in valleys, where disease pressure is greater, yet received market price discounts of 10 to 15 percent due primarily to their darker color. The latest RV released, Tio Canela (in 1997), purportedly has better market characteristics and thus is expected to replace Dorado and Don Silvio, as well as to be adopted in areas of lower disease pressure.

This paper builds on Martel's work by using a more recent (2001) survey to investigate the factors influencing adoption of the RVs. This survey provides a more recent snapshot of the factors influencing RV use; after ten years of extension and farmer adoption/disadoption of Dorado, and three years after the release of Tio Canela. In addition, this paper investigates the role of three additional factors in the farmer's adoption decision not included in Martel's analysis: extension, market participation, and ambient adoption rates. These additional variables can inform policy makers and breeders in new ways about the kinds of farmers adopting or not adopting RVs, and especially regarding whether or not Tio Canela's better relative market characteristics are borne out by farmer adoption by both Dorado/Don Silvio growers and previously non-RV growers.

Literature on seed systems and technology adoption in developing countries offers various explanations for non-adoption of improved crop varieties by farmers (Feder *et al*, 1985; Tripp, 1997). Two of the more common explanations which are relevant to improved bean varieties include: lack of information about improved varieties and/or lack of access to improved seed; and secondly, inappropriate or unprofitable technology (i.e. experimental results are not representative of farmer agronomic and/or economic conditions). Access factors include extension programs, which affect farmers' information and access to improved seed, as well as farmer-to-farmer exchange, which is represented by the local RV adoption rate. Because Honduras' bean seed system is highly informal, access to information about new varieties and seed itself could be a constraint to more widespread adoption of RVs. Although farmer seed exchange is common, it may take considerable time to achieve extensive coverage, and between and even within communities, seed exchange mechanisms may not be equitable (Tripp, 1997). Breeding factors affect the agronomic and economic performance of the RVs under farmer conditions and include the level of disease resistance and the market acceptance of the RVs.

In this paper, farm survey data from Honduras are used in probit analysis to investigate the significance and magnitude of "access" factors vs. "varietal/breeding" factors in the adoption of disease-resistant bean varieties in Honduras. The results of the probit analysis have implications for whether factors under the control of breeders or policy-makers would have more leverage to alleviate remaining constraints to more widespread adoption of improved bean varieties in Honduras, or whether a combination of actions is most complementary to greater adoption.

2. Background

2.1 Organizations

Honduras' two bean research programs, which are implemented by Zamorano (Programa de Investigaciones en Frijol, Escuela Agricola Panamericana) and DICTA (Direccion de Ciencia y Tecnologia Agricola, the Honduran National Bean Program), work in collaboration with three organizations: the USAID-funded Bean/Cowpea Collaborative Research Support Project (CRSP); the Programa Cooperativo Regional de Frijol para Centroamerica, Mexico, y El Caribe (PROFRIJOL), funded by COSUDE, the Swiss Agency for Development and Cooperation; and CIAT (Centro Internacional de Agricultura Tropical). This paper utilizes data from a farm-level survey of bean farmers (N=210) that was implemented by the CRSP and PROFRIJOL in January-February 2001, in collaboration with Zamorano and DICTA. The survey targeted the Mideast (El Paraiso and Francisco Morazan departments) and Northeast (Olancho) regions, which together account for about one-half of annual bean production in Honduras.

2.2 BGYMV-Resistant Bean Varieties

Bean Golden Yellow Mosaic Virus (BGYMV) is the principal bean disease in Honduras, and one of the main production constraints in Honduran valleys (Martel, 1995). The virus is transmitted by the whitefly species <u>Bemisia tabaci</u>, which is normally found below 1,000 meters in all growing regions of Honduras and more frequently in the drier postrera season (September/October to December/January). Zamorano and DICTA have developed several varieties with resistance to BGYMV, the first of which was released in 1990 (Dorado), the second (Don Silvio) in 1993. However, the economic gains from yield loss averted through use of Dorado or Don Silvio are at least partially offset by price discounts in the market of approximately 15 percent (Martel, 1995; Mather *et al*, 2001). The newest RV (Tio Canela), released in 1997, faces a smaller market price discount of about 7 percent (Mather *et al*, 2001). While two other RVs include DICTA 113 and DICTA 122, their adoption rates to date are negligible (*ibid*, 2002).

2.3 Seed Distribution Channels

RV bean seed is disseminated through various channels, although 57 % of RV adopters first obtain seed from neighbors (Mather *et al*, 2001). While DICTA supported an artisan seed program in the early 1990s, this program was relatively small in scale, and focused on Dorado. Both Zamorano and Hondugenet sell certified seed directly to farmers, which is packaged in 50 lb bags and sold exclusively from Zamorano's campus and Hondugenet's facilities in Tegucigalpa (the capital). Zamorano and the Department of Natural Resources each have additional extension services in some villages which involve RV promotion, demonstration, and/or access to seed. Zamorano's extension work has primarily promoted Tio Canela. In addition, various NGOs, such as the Catholic Church, distribute improved seed to project participants and support the development of local farmer seed banks across the country, although they are typically less active in the Mideast and Northeast than in other regions.

2.4 Post-Mitch Seed Distribution

Following the devastation caused by hurricane Mitch in October 1998, the USAID-funded Post-Mitch Agricultural Recovery for Honduras project represented the most significant extension of improved bean technology since the public extension service was eliminated in the late 1980s. With funding from USAID and the British Department for International Development, Zamorano and 10 independent farmers with irrigation and seed production experience were contracted to multiply a total of 97 mt of RV bean seed (Tio Canela, Dorado, and Don Silvio–approximately equal amounts of each variety) in the *verano* season (December to May), which was then distributed in 10 lbs bags by 41 NGOs to small- and medium-size farmers for planting in 1999 during the *primera* (May/June to July/August), the rainy season, and *postrera* (September/ October to December/January), a drier season (EAP, 2000; Mainville, 2000). A separate component of this USAID project also funded demonstration plots throughout the country in 1999-2000, which helped to introduce farmers to RVs and Zamorano's recommended management practices and complementary inputs. While this project may have exposed many farmers to improved varieties for the first time, only 9% of our sample received RV seed from Zamorano or an NGO after Mitch. However, this is not surprising since much of the NGO assistance was targeted to other regions of Honduras, which were hit harder (and are generally poorer) than Mideast and Northeast Honduras.

2.5 Survey Farmers

Bean producers in Honduras are predominantly small farmers, the majority of whom use fertilizer and insecticide, and market at least some of their bean production

(Tables 1a and 1b). Most of the sample farmers (70 percent) live in villages which have faced BGYMV pressure in the past (Table 1b), and also which have benefitted from extension activities including promotion, demonstration, and/or access to RVs (58 percent). These data suggest that the characteristics of RV and TV growers are quite similar. Honduran farmers typically plant two crops during the year. In the primera, maize is the principal crop[1], and beans are either intercropped with maize or monocropped.[2] During the postrera, beans are almost exclusively monocropped. Because the whitefly population is often highest under drier conditions, BGYMV is most frequent and severe in the postrera. The adoption analysis that follows only considers the postrera season, as this is the primary bean production season and nearly all of the sample farmers planted in the postrera.

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[1] Typically, farmers plant beans in the primera in order to multiply seed for their postrera planting.

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

Table 1a. Characteristics of Sample Bean Farmers, Postrera 2000, Honduras

Characteristic	RV Adopters [a] (N=79)	Nonadopters (N=123)	All farmers (N=202)
	(Mean or %)		
Farm size (ha)	12.8	10.8	11.5
Bean area (ha)	2.35	2.28	2.14
Education (years in school)	3.2	2.9	3.01
Age (years)	49	49	49
Altitude (m)	832 [b]	964 [b]	913
Expected September rainfall (mm)	216	212	214
Used formula fertilizer (%)	44	50	48
Used urea fertilizer (%)	53 [c]	40 [c]	45
Used both formula and urea (%)	28	23	25
Used no fertilizer (%)	31	33	32
Used insecticide (%)	75 [b]	64 [b]	68
Used fungicide (%)	17 [d]	34 [d]	20
Intercropped (%)	23 [d]	11 [d]	15

Source: CRSP/PROFRIJOL Farmer Survey, 2001 (N=210)
[a] 19% of farmers used both an RV and a TV (N=38)
[b] significantly different (5% level) across RV use using two-sided t-test
[c] significantly different (10% level) across RV use using two-sided t-test
[d] significantly different (10% level) across RV use using one-sided t-test

Table 1b. Characteristics of Sample Bean Farmers, Postrera 2000, Honduras

Characteristic	RV Adopters[a] (N=79)	Nonadopters (N=123)	All farmers (N=202)
	(Mean or %)		
Marketed beans (%)	56	63	60
Sold 1 to 50% of harvest (%)	21	21	21
Sold > 50% of harvest (%)	34	42	39
% farmers in village with BGYMV [b] (%)	84 [e]	62 [e]	70
% farmers in village with extension: [c]			
DICTA artisan seed program (%)	24 [g]	15 [g]	19
Dept. of Natural Resources (%)	32	32	32
Zamorano (%)	16	12	14
Catholic Church (%)	18	16	17
Received RV seed from Post-Mitch org (%)	13 [e]	2 [e]	6
No extension at village level (%)	46	40	42
Planted an RV, Postrera '96	49 [e]	7 [e]	24
Mean village RV adoption rate, Postrera '95 [d]	29 [e]	15 [e]	20
Mean village RV adoption rate, Postrera '98 [d]	37 [e]	19 [e]	26

Source: CRSP/PROFRIJOL Farmer Survey, 2001 (N=210)
[a] 19% growers used both an RV and a TV (N=38) [b] defined by Dr. J.C. Rosas, Director, Programa de Investigaciones en Frijol, Zamorano [c] extension which includes promotion, demonstration, and/or extension of improved varieties [d] calculated for each farmer as the ratio of RV users to non-RV users in his/her village (N=7), not including the farmer
[e] significantly different (5% level) across RV use using two-sided t-test
[f] significantly different (10% level) across RV use using two-sided t-test
[g] significantly different (10% level) across RV use using one-sided t-test

3. Adoption Model

In the following probit analysis, adoption of an RV is defined as planting an RV in postrera 2000. The adoption model builds from Martel's (1995) logit model specification of Dorado adoption, which included such variables as: age, education, farm size, fertilizer use, administrative and topographical region. This paper not only uses a more recent farmlevel survey, but also three additional variables in the varietal decision model: market participation, extension, and the village RV adoption rate. In addition, this adoption analysis will differentiate between the older RVs (Dorado and Don Silvio) and the newest RV (Tio Canela) because of the expected differential influence on farmers' varietal choice with respect to market participation, extension, and village RV adoption rates.

A majority of survey farmers market at least some of their postrera harvest (Table 2), with two-thirds of postrera bean sellers selling more than half their harvest (Mather *et al*, 2001). Market participation may affect a farmer's varietal choice depending upon his/her expected yield loss to disease as well as his/her risk preferences. For example, given that sizeable price discounts for RVs exist in the market, farmers in low-disease pressure areas who sell beans would not likely grow RVs because the potential yield loss averted through RV use would not compensate for the income lost to the market price discount. In this case, participation in the market (and the level of participation) would be expected to negatively affect a farmer's decision regarding RV use. In addition, according to our survey results, current RV users (and RV disadopters) prefer the culinary characteristics of the traditional varieties (Mather *et al*, 2001). Therefore, farmers who don't sell beans – net bean buyers or subsistence farmers – would only grow RVs if their expected disease losses put the household below their threshold consumption requirements. On the other hand, assuming that the expected yield losses in disease-intense areas are greater than the market price discount, then market participation by farmers in these areas would not be expected to have a negative effect on adoption (although we cannot say whether the expected effect for these farmers would be negligible or positive).

We use two terms to measure the effect of market participation on adoption. The first, a dummy for "low participation" sellers who sold between 1 to 50% of their postrera 2000 harvest, represents those farmers who are likely selling unexpected surplus from their production over and above that intended for home consumption. The second, a dummy for "high participation" sellers who sold more than 50% of their postrera 2000 harvest, represents farmers who produce and market beans as a cash crop, or farmers who have no choice but to sell at harvest to repay input or other loans (and must later purchase beans for home consumption on the market).

We also include village-level dummies for those villages which received extension including promotion, demonstration, and/or access to RVs. DICTA extension is expected to have a positive influence on Dorado/Don Silvio[3] adoption, whereas Zamorano extension is expected to have a positive influence on Tio Canela adoption. To capture the effect of the Post-Mitch seed distribution, we include a dummy for those

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[3] From this point on, "Dorado" will refer to both Dorado and Don Silvio. These varieties were both released in the early 1990s, promoted by DICTA and face similar market price discounts.

farmers who received RV seed from a Post-Mitch program NGO. In place of Martel's topographical region variable (valley vs. mountains), we use a village dummy for areas which have been known to have faced BGYMV pressure in the past. We also add village-level altitude as a separate measure of disease pressure.

In the Dorado probit, village RV adoption rates for postrera 1995 are used as yet another measure of historical BGYMV pressure in the village. The village RV adoption rate in 1995 should be a good indicator of long-term expected disease pressure, since farmers would not likely continue to grow the old RVs – regardless of market participation status – unless their expected disease losses were in excess of the price discount (or in excess of subsistence requirements). Thus, villages with higher adoption rates of these old RVs in 1995 very likely had high levels and frequency of BGYMV pressure that same year.

The village RV adoption rate is computed for each farmer as the ratio of RV adopters in a given village to non-adopters (not including the farmer). Given this form of calculation, this variable also serves as a proxy measure of the given farmer's informal access to both RV seed as well as information about RV's agronomic and market performance under local conditions. Thus, the village RV adoption rate proxies the extent to which farmer-to-farmer exchange of information and seed influences RV adoption. The informal nature of the bean seed system in these regions of Honduras is highlighted by the fact that in postrera 2000, 89% of the sample farmers either planted saved seed (59%) or obtained seed from a neighbor (29%), while only 14% was obtained from government extension, an NGO, a trader, or an input supplier together (Mather *et al*, 2001). Because the DICTA artisan seed program was most active in the early 1990s, and because many current Dorado growers had adopted the variety by 1996, we chose the postrera 1995 season for the village-level RV adoption rate to estimate the relative influence in 1995 of extension (DICTA), village-level farmer-to-farmer information and seed access, and village-level disease pressure (both proxied by the village-level RV adoption rate, postrera 1995) on current Dorado use.

As just mentioned, current Dorado use is likely to be highly correlated with prior use (*i.e.*, most Dorado growers in 2000 are not new adopters). Thus, we include a dummy for those farmers who grew an RV in postrera 1996 (RV_96), in order to capture unobservable farmer characteristics which may have influenced RV adoption prior to 1996.

In the Tio Canela probit, village RV adoption rates for postrera 1998 are used as another measure of historical BGYMV pressure in the village. Given that adoption of RVs up to postrera 1998 involved primarily Dorado and Don Silvio, this use of the village adoption rate is principally as a measure of historical disease pressure. We chose the postrera 1998 season because this planting occurred one month before Hurricane Mitch hit Honduras (in October, 1998). This timing gives us a measure of RV use by village prior to the Post-Mitch RV seed distribution, and also prior to widespread Tio Canela dissemination (Tio Canela was released in 1997). To capture the effect of the Post-Mitch RV seed distribution in 1999, we include a separate dummy in the regression for farmers who received RV seed from the Post-Mitch program.

If Tio Canela has better agronomic and/or market performance than the older RVs, we would expect Tio Canela to be adopted both in areas with lower village RV adoption rates, as well as in historically disease-intense areas (as a replacement for the older RVs). Thus, we would expect that Tio Canela adoption would be less influenced by market participation and disease pressure than that of Dorado. For a proxy of farmer-to-farmer exchange of Tio Canela seed and information, we compute a village-level Tio Canela adoption rate for postrera 1999.

4. Estimation of adoption equations

4.1 Dorado

We estimate two probits for both Dorado and Tio Canela; one with the RV_96 dummy and one without. The following discussion of estimation results refers to the specifications which include the RV-96 dummy, unless otherwise indicated. Martel's (1995) logit model, based on a 1993 survey, found Dorado adoption to be neutral with respect to education and farm size, positively correlated with fertilizer use, the mideast region (El Paraiso and Francisco Morazan departments), and valley topography, and negatively associated with age. The results of our probit models[4] (Table 2) show that the adoption of Dorado (N=52) and Don Silvio (N=8) (all referred to as Dorado from here on) is neutral with respect to farm size, which concurs with Martel (1995). Another point of concurrence is that our dummy indicator for disease pressure (BGYMV) is positively correlated with Dorado use, yet our continuous indicator (altitude) is surprisingly positive

[4] We apply Huber/White's procedure to obtain robust standard errors for each probit.

Table 2. Probit Estimates of Dorado Adoption, Postrera, 2000

Factors	Dorado [a] Adoption (Dorado=1, other=0)	
Department = F.Morazan	0.140 (1.10)	0.070 (0.58)
Department = Olancho	0.029 (0.22)	0.063 (0.46)
Tio Canela	-0.234 (-2.74)***	—
Dorado [a]	—	- 0.231 (-2.98)***
Education (years)	0.027 (2.14)**	0.021 (1.69)*
Age (years)	0.002 (0.60)	0.001 (0.37)
ln (Farm size) (ha)	0.019 (0.81)	0.005 (0.21)
Formula Fertilizer (0=no; 1=yes)	-0.290 (2.76)***	- 0.287 (-2.78)***
Urea Fertilizer (0=no; 1=yes)	0.017 (0.18)	- 0.033 (-0.35)
Both Formula and Urea (0=no; 1=yes)	0.132 (0.85)	0.236 (1.41)
Insecticide (# of applications)	0.073 (3.32)***	0.071 (3.38)***
Fungicide (# of applications)	- 0.020 (-0.63)	- 0.021 (-0.68)
Intercropped (0=no; 1=yes)	0.186 (1.63)*	0.175 (1.51)
ln (Expected September rainfall) (mm)	0.351 (1.92)**	0.265 (1.43)
ln (Altitude) (m)	- 0.060 (-0.35)	0.062 (0.34)
BGYMV area (0=no; 1=yes)	0.168 (1.54)	0.238 (2.50)***
Sold 1 to 50% of harvest (0=no; 1=yes)	- 0.031 (-0.39)	- 0.052 (-0.67)
Sold 51 to 100% of harvest (0=no; 1=yes)	- 0.155 (-2.09)**	- 0.141 (1.83)*
Village-level Extension: DICTA	0.278 (2.44)**	0.169 (1.54)
Zamorano	0.092 (0.81)	0.077 (0.61)
Dept of Natural Resources	-0.134 (-1.64)*	- 0.122 (-1.63)*
Catholic Church	0.204 (1.50)	0.139 (1.05)
Received Post-Mitch RV seed '99	0.057 (0.40)	- 0.032 (-0.24)
Village RV adoption rate, Postrera '95 (%)	0.775 (4.51)***	0.531 (2.97)***
Planted an RV, Postrera '96	—	0.465 (5.00)***
[a] includes Don Silvio (N=8) *** significant at the 0.01 level ** significant at the 0.05 level * significant at the 0.10 level Coefficients calculated as dF / dX (z stat in parentheses)	N = 202 Wald chi2(20) = 68.8 prob > chi2 = 0.0000 Log Likelihood= -82.1 Psueudo R2 = 0.322	N = 202 Wald chi2(20) = 99.2 prob > chi2 = 0.0000 Log Likelihood= -71.7 Psueudo R2 = 0.408

Table 3. Probit Estimates of Tio Canela Adoption, Postrera, 2000

Factors	Tio Canela Adoption (T.Canela=1, other=0)	
Department = F.Morazan	0.125 (1.52)	0.117 (1.47)
Department = Olancho	0.132 (2.10)**	0.138 (2.21)**
Tio Canela	—	—
Dorado [a]	- 0.069 (-2.68)***	- 0.074 (-3.13)***
Education (years)	0.007 (1.83)*	0.007 (1.79)*
Age (years)	- 0.000 (-0.26)	- 0.000 (-0.34)
ln (Farm size) (ha)	0.006 (0.61)	0.004 (0.37)
Formula Fertilizer (0=no; 1=yes)	0.019 (0.52)	0.016 (0.46)
Urea Fertilizer (0=no; 1=yes)	0.098 (2.11)**	0.094 (2.05)**
Both Formula and Urea (0=no; 1=yes)	- 0.061 (-1.83)*	- 0.058 (-1.82)**
Insecticide (# of applications)	0.015 (2.08)**	0.016 (2.26)**
Fungicide (# of applications)	0.013 (1.72)*	0.011 (1.58)
Intercropped (0=no; 1=yes)	0.062 (1.14)	0.066 (1.22)
ln (Expected September rainfall) (mm)	-0.051 (-0.83)	-0.066 (-1.08)
ln (Altitude) (m)	0.086 (1.60)	0.090 (1.70)*
BGYMV area (0=no; 1=yes)	0.016 (0.46)	0.014 (0.43)
Sold 1 to 50% of harvest (0=no; 1=yes)	0.014 (0.40)	0.009 (0.29)
Sold 51 to 100% of harvest (0=no; 1=yes)	- 0.016 (-0.51)	- 0.018 (-0.64)
Village-level Extension: DICTA	0.005 (0.16)	0.001 (0.02)
Zamorano	0.098 (1.32)	0.113 (1.46)
Dept of Natural Resources	- 0.038 (-1.52)	- 0.042 (-1.79)*
Catholic Church	- 0.049 (-1.56)	- 0.049 (-1.67)*
Received Post-Mitch RV seed '99	0.278 (2.97)***	0.177 (2.33)***
Village RV adoption rate, Postrera '98(%)	0.106 (1.92)*	0.100 (1.88)*
Village T.Canela adopt. rate, Pos '99 (%)	0.298 (1.93)**	0.260 (1.76)*
Planted an RV, Postrera '96	—	0.064 (1.69)*
[a] includes Don Silvio (N=8) *** significant at the 0.01 level ** significant at the 0.05 level * significant at the 0.10 level Coefficients calculated as dF / dX (z stat in parentheses)	N = 202 Wald chi2(20) = 59.7 prob > chi2 = 0.0001 Log Likelihood= -46.1 Psueudo R2 = 0.356	N = 202 Wald chi2(20) = 56.8 prob > chi2 = 0.0003 Log Likelihood= -45.2 Psueudo R2 = 0.369

and insignificant.

In contrast to Martel, our results indicate that there is no longer a regional disparity in Dorado adoption (northeast region adoption no longer significantly lags that of the mideast), age is not significantly correlated with adoption (and its sign is positive), and education has a significant and small positive effect on adoption. A more interesting contrast is that our results show that formula fertilizer use has a significant and negative effect on adoption (Martel did not distinguish between different types of fertilizer). However, the effect of urea use is insignificant and of much smaller magnitude, while there is a positive (yet insignificant) effect of combined urea and formula use on adoption.

The coefficient on a dummy indicating Tio Canela use is unsurprisingly significant, large, and negative. If Tio Canela does outperform the old RVs in agronomic and/or market acceptance terms, we would expect to see old RV users switch to Tio Canela. However, Tio Canela was only recently released, 19% of current old RV users in our sample had not heard of Tio Canela, and 48% indicated that they did not have access to seed or sufficient information about the variety.[5] The coefficients of both market participation dummies are negative, as expected, and the magnitude of the "high" market participation dummy is larger than that of the "low" market participation dummy. However, only the "high" participation coefficient is statistically significant (10% level),

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[5] "No access" was defined as those growers who indicated that they: a) had heard of Tio Canela; and b) responded to the question of why they hadn't planted Tio Canela by saying either that they didn't have access to the seed or didn't know enough about the variety.

and the magnitude is not large compared with other variables. This implies that market participation has served as a significant disincentive to Dorado adoption.

The RV-96 dummy itself is highly significant and of large magnitude, as expected. This dummy captures the influence of unobserved variables related to the farmer's characteristics and production environment in 1996 that were associated with his decision to use an RV in that year. The inclusion of the RV-96 dummy has little effect on the variables mentioned above – such as education, age, farm-size, fertilizer use, *etc.* – which lends credibility to the interpretation of these coefficients as either their marginal effect on new RV adoption since 1996 or their effect on continued RV use.

The coefficient on the village RV adoption rate (postrera 1995) is positive, significant at the 1% level, and is also the largest in magnitude. In addition, the dummy for historical BGYMV pressure is also significant and of considerable magnitude. Together, these results demonstrate that the older RVs are more likely to be used in areas of historical BGYMV pressure. The fact that the coefficient on the BGYMV dummy is of much smaller magnitude than that on village RV adoption rate in 1995 demonstrates the impreciseness of using one category to describe disease pressure that varies by frequency, intensity, and timing over space and time.

The inclusion of the *RV-96* dummy is more pronounced on the RV seed and information access variables: the village RV adoption rate for 1995 and DICTA extension. In the model without *RV-96*, the coefficient on DICTA is 0.278 and significant at the 5% level, while that for the village RV adoption rate for 1995 is 0.775 and significant at the 1% level. However, the DICTA coefficient in the model with *RV-*

96 is not significant[6] and is nearly half the size at 0.169, while the village RV adoption rate in 1995 is still significant at the 1% level but is smaller at 0.531. The reason for this change is that the effect of DICTA extension on current Dorado use is diminished once we account for the effect of DICTA extension on RV use in 1996 (RV_96). Thus, we are modeling two channels of influence on current Dorado use. First, DICTA extension in the early 1990s influenced early adoption (RV_96), which has resulted in continued Dorado use for some farmers. Second, DICTA extension increased RV seed information and access in some villages, which, over time, increased the potential for farmer-to-farmer exchange both in those and other villages. Likewise, the effect on current Dorado use of a village's RV adoption rate in 1995 is diminished once we account for the effect that this village RV adoption rate has on RV use in 1996 (RV_96).

These results suggest that while farmer-to-farmer exchange has a larger effect on farmer adoption than does extension, extension plays a role in helping to jump-start the dissemination process. This is consistent with the descriptive statistics cited above concerning the informal nature of the bean seed system in Honduras. Finally, the effect of the Post-Mitch program (a farmer-specific, not village level variable) is not significant for Dorado adoption because most of our sample farmers who received RV seed from a Post-Mitch program received Tio Canela, and those who received Dorado seed were already Dorado growers.

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[6] Although the coefficient on DICTA extension is not significant once RV_96 is included, RV_96 and DICTA are jointly significant at the 1% level in a LR test.

4.2 Tio Canela

The following discussion of Tio Canela estimation results refers to the specifications which include the *RV-96* dummy, unless otherwise indicated. The results of our probit model for Tio Canela (Table 3) show that its adoption (N=22) is neutral with respect to farm size, education, and age.[7] In contrast with Dorado, there is a slight regional disparity in Tio Canela adoption (adoption is 14% more likely in Olancho). In addition, Tio Canela adoption shows nearly the opposite correlation with fertilizer use from that of Dorado. The coefficient on formula fertilizer use is of negligible magnitude and is insignificant, the effect of urea use is significant (5% level) and positive, and that of combined urea and formula use on adoption is significant (10% level) and negative, but of small magnitude.

The coefficient of the dummy indicating continued Dorado use is negative, as expected, although only half the magnitude of the corresponding coefficient (for Tio Canela) in the Dorado adoption function. As mentioned above, nearly two-thirds of current Dorado growers do not have sufficient information about and/or seed access to Tio Canela. The coefficients of both market participation dummies are highly insignificant and small in magnitude. This implies that, in contrast to Dorado, the smaller market discount for Tio Canela has not served as a significant deterrent to its adoption.

A more significant contrast to Dorado is seen in the coefficients on disease pressure variables. The coefficient on the historical BGYMV pressure dummy is

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[7] Although the coefficient on education is significant at the 10% level, its magnitude is negligible.

insignificant and of negligible magnitude (while the same coefficient in the Dorado probit is 0.238 and significant at the 1% level), which indicates that Tio Canela is being adopted outside of traditionally disease-intense areas. Even more striking, the coefficient on the village RV adoption rate for 1998 is significant (10% level) but of much smaller magnitude than that of Dorado (0.10 for Tio Canela compared with 0.53 for Dorado). This offers further evidence that farmers in lower-disease pressure areas are adopting Tio Canela, while also suggesting that some Dorado growers are switching to Tio Canela. Further contrast between Dorado and Tio Canela adoption is seen in the magnitude of the RV_96 variable, which is 0.47 for Dorado and 0.064 for Tio Canela. Thus, while some Tio Canela adopters were previously Dorado users, the unobserved factors that explained Dorado use in 1996 are still very important in explaining current Dorado use, yet have little influence on Tio Canela adoption.

The variables which measure RV seed access and information – Post-Mitch RV seed, Zamorano extension, and village-level Tio Canela adoption rate in postrera 1999 – are correlated in various ways. First, Zamorano multiplied the seed for the Post-Mitch NGO dissemination, and many of these NGOs work in the same villages where Zamorano has previously offered extension. Second, as was the case with DICTA extension and Dorado use in villages, we would expect that extension would lead to higher village adoption rates. In addition, our Post-Mitch dummy only captures the direct effect of this program – those farmers who received seed direct from a Post-Mitch NGO in 1999. Yet, other farmers may have received Post-Mitch program RV seed in 2000 indirectly through program participants (in 1999). Thus, the village Tio Canela adoption rate in 1999 may also capture an indirect effect of Post-Mitch seed dissemination.

Unsurprisingly, the effect of the Post-Mitch program is significant (5% level) because several of the Tio Canela users in our sample received the variety for the first time from the Post-Mitch program.[8] The effect of Zamorano village-level extension is positive, of a magnitude similar to that of the Post-Mitch program, yet is insignificant.[9] However, Zamorano extension is correlated (0.41) with the variable for village-level Tio Canela adoption rate in 1999, and these two variables are jointly significant at the 1% level in a LR test.[10] Given that the market participation and disease pressure variables are either insignificant or small in magnitude, the fact that the largest coefficient in the model is the village-level Tio Canela adoption rate in 1999 suggests that the main constraint to increased Tio Canela adoption is increased seed information and access.

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[8] It is not clear why the magnitude of the Post-Mitch dummy coefficient diminishes from 0.278 to 0.177 when the RV_96 dummy is included in the regression (when no other variable coefficient in the model experiences notable changes). This implies that some unobservable factors that explain RV use in 1996 also explain how or why the farmer has access to the Post-Mitch NGO program.

[9] It is not surprising that the Zamorano extension magnitude is smaller (0.11) than that of the Post-Mitch program (0.177) because the latter is a farmer-level variable (indicating whether or not the farmer himself received RV seed) whereas the former is a village-level variable (indicating whether or not the village received RV demonstration, information, and/or seed access).

[10] When the village Tio Canela 1999 adoption rate is not included in the model, the coefficient on Zamorano extension is much larger at 0.220 and is significant at the 1% level. However, the Post-Mitch dummy actually becomes insignificant and declines in magnitude to 0.108.

4.3 Breeding Factors

With respect to breeding factors, the influence of market price discounts for Dorado are reflected in the negative effect of market participation on Dorado adoption. In addition, the large magnitude of the coefficient for the 1995 village RV adoption rate, and the smaller but significant coefficient on the BGYMV dummy, indicate that Dorado is primarily used in areas of historically high disease pressure due its market price discount. By contrast, there is no significant effect of market participation on Tio Canela adoption, the BGYMV dummy for Tio Canela is insignificant, and the effect of the 1998 village RV adoption rate for Tio Canela adoption is much smaller, all of which demonstrate that Tio Canela is being adopted both in areas of high and low disease pressure.

4.4 Access Factors

With respect to access to Dorado, DICTA extension presence in a farmer's village has a much smaller effect on the probability of Dorado adoption (about one-fourth) than the village RV adoption rate in postrera 1995. However, Zamorano extension presence has only half the effect on the probability of Tio Canela adoption compared with the village Tio Canela adoption rate in postrera 1999. These results are not surprising given that Dorado was released over 10 years ago, and extension typically has a larger effect early in the dissemination process (as is seen with Tio Canela). At this point in time, access to Dorado is not a principal constraint to increased Dorado impact as 61% of our survey respondents have planted Dorado at one point, and only 16% of those who haven't planted it indicate that they never did so due to lack of seed and/or information (Mather *et* *al*, 2001). On the other hand, Zamorano extension would be expected to have a large effect on adoption (relative to farmer-to-farmer exchange) at this early stage of its dissemination process. Tio Canela has only been planted by 21% of the survey respondents, and 47% of those who haven't planted cite lack of seed and/or information as the reason. Given that the coefficients of the market participation and disease pressure variables in the Tio Canela probit are either insignificant or small in magnitude, the main constraint to increased Tio Canela adoption seems to be increased seed information and access.

5. Conclusions

In this paper, farm survey data from Honduras are used in probit analysis to investigate the significance and magnitude of "varietal/ breeding" factors vs. "access" factors in the adoption of disease-resistant bean varieties in Honduras. The results indicate that increased adoption of Dorado and Don Silvio are more constrained by poor market characteristics (breeding factors) than lack of access to seed and information. Yet, farmers' continuing use of Dorado since the early 1990s – primarily in areas of historically high disease pressure – demonstrates the positive farm-level benefits of yield loss averted due to its disease resistance. However, the poor market characteristics of these early-generation RVs, reflected in average price discounts of 15% relative to TVs, has constrained adoption primarily to disease-intense areas. In addition, the market price discounts have reduced the net income gains for Dorado users.

By contrast, the results of analysis of Tio Canela adoption (released in 1997) indicate that the market acceptance (breeding) aspects of the variety appear to be improved over those of Dorado, as Tio Canela is being adopted in areas of both historically high and low disease pressure. However, the principal constraint to further impact of Tio Canela is information and seed access. With increased access, current Dorado users would be expected to switch to Tio Canela and enjoy larger net incomes due to Tio Canela's smaller price discounts. In addition, the adoption of Tio Canela outside of traditionally high-disease pressure areas implies that Tio Canela offers positive net benefits for growers in low-disease pressure areas as well.

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CONCLUSIONS

1. Economic impact of disease-resistant bean research in Honduras

This research uses a recent farm-level survey (2001) in the two principal bean-producing regions of Honduras to estimate the adoption rates of disease-resistant bean varieties, the farm-level benefits of adoption, and the *ex post* rate of return to bean research in Honduras from 1982-2010. The results demonstrate 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 the period 1982-2010 is 41.2 %. Survey results show that adoption of RVs is widespread; 42% of sample bean farmers used an RV in the postrera season of 2000. Moreover, the adoption of disease-resistant bean varieties in Honduras has benefitted primarily small farmers. Therefore, these results support previous claims that improved bean varieties are an ideal means by which to improve small farm household income and food security in Central America – they are scale-neutral, reproducible on-farm, and do not require complementary physical or human capital inputs (Martel *et al*, 2000).

2. Methodological contributions

This research also demonstrates two methodological contributions for the use of farm-level survey data in the construction of counterfactual scenarios in impact assessment of maintenance research. The first approach uses farm-level and experimental trial data within an expected utility framework to value the farm-level benefits of disease-resistant varieties. This method estimates that adopters gain the equivalent of 7 to 16% (depending on the variety) in bean income from the yield loss averted through RV use. This calculation represents the minimum expected net gain for adopters, as it solves the expected utility framework for the point at which TV users would switch to RV use. The robustness of the high aggregate rate of return to bean research mentioned above is supported by the use of this minimum expected net farmlevel gain for adopters in its calculation.

The second method uses a modification of Lee's (1978) two-step procedure to correct for selection bias (Heckman, 1979; Goldfeld and Quandt, 1973), whose presence in farmlevel survey data will likely lead to underestimation of the benefits of maintenance research (Johnson *et al*, 1999). The method is applied to test for selection bias and estimate yield differentials between RV and TV bean yields in our survey data from Honduras by constructing the counterfactual to RV yields as what yields RV users would have obtained had they continued to grow TVs (*i.e.*, the TV yield of RV users). The corrected yield model predicts that RV growers enjoy net income gains of 13 to 19% in the postrera season, compared to what they would have earned growing TVs; while the uncorrected OLS model predicts that RV growers see either no income gain or even losses by growing RVs (relative to TVs). This application demonstrates that the implications of this method are significant for the assessment of maintenance research impacts.

3. Factors influencing the adoption of RVs

Finally, this research also uses the farm survey data in probit analysis to investigate the significance and magnitude of "varietal/ breeding" factors vs. "access" factors in the adoption of disease-resistant bean varieties in Honduras. The results indicate that adoption of Dorado and Don Silvio are more constrained by poor market characteristics (breeding factors) than lack of access. Yet, farmers' continuing use of Dorado since the early 1990s – primarily in areas of historically high disease pressure – demonstrates the positive farmlevel benefits of yield loss averted due to its disease resistance. However, its poor market characteristics, reflected in average price discounts of 15% relative to TVs, results in little adoption – and thus apparently no net income benefits – for growers outside of these high-disease areas, as well as reduced net income gains for Dorado users themselves.

By contrast, the results of analysis of Tio Canela adoption (released in 1997) indicate that the market acceptance (breeding) aspects of the variety appear to be much improved over those of Dorado, as Tio Canela is being adopted in areas of both historically high and low disease pressure. However, the principal constraint to further impact of Tio Canela is information and seed access (a policy aspect). With increased access, current Dorado users would be expected to switch to Tio Canela and enjoy larger net incomes due to Tio Canela's smaller price discounts. In addition, the adoption of Tio Canela outside of traditionally high-disease pressure areas implies that Tio Canela offers positive net benefits for growers in low-disease pressure areas as well.

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