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Opportunities Seized, Opportunities Missed: Differences in the Economic Impact of Bean Research in Five Latin American Countries

by

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OPPORTUNITIES SEIZED, OPPORTUNITIES MISSED: DIFFERENCES IN THE ECONOMIC IMPACT OF BEAN RESEARCH IN FIVE LATIN AMERICAN COUNTRIES

by

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Any errors are our own.

EXECUTIVE SUMMARY

Over the past 20 years, the national systems in Central America and Ecuador have sustainably invested in research to improve varieties of common bean. Previous research has focused on estimating economic benefits realized by new adopters who replace traditional varieties with improved varieties (type I gains). However, recent literature has demonstrated the importance of also estimating the economic benefits realized by current adopters who replace old improved varieties (IVs) with new IVs (type II gains). This study provides estimates of adoption rates of improved varieties in four countries in Central America (Costa Rica, El Salvador, Honduras, Nicaragua) and Northern Ecuador, and calculates the economic benefits realized by new adopters who replace traditional varieties with improved varieties (type I gains) and current adopters who replace old IVs with new IVs (type II gains).

Results suggest that the adoption rates of IVs in 2010 ranged from 46% in Honduras (lowest) to 82% in Nicaragua (highest). New adopters obtain 12-18% yield gains from replacing traditional varieties with IVs (type I gains), and current adopters obtain 0.49-1.68% yield gain per year by replacing older IVs with newer IVs (type II gains). Benefit/cost analysis indicates that returns to investments were negative in Costa Rica and positive elsewhere, with a regional NPV of US$358 million and IRR of 32%. Results indicate the importance of research networks and spillover benefits that small countries derive through research collaboration. They reiterate the significance of consumer preferences in explaining adoption (or dis-adoption) of IVs, and highlight the importance of two types of benefits farmers derive from sustained investments in breeding research and the seed system.

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ACRONYMS

B/C CRSP	Bean/Cowpea Collaborative Research Support Program
CIAT	International Center for Tropical Agriculture
CNP	*Consejo Nacional de Producción*, Costa Rica (National Production Council)
COSUDE	Swiss Agency for Development and Cooperation
CPI	Consumer Price Index
CV	Coefficient of Variation
ECAR	Central American Adaptation and Yield Trial
ESPAC	*Encuesta de Superficie y Producción Agropecuaria Continua* (the continuous agricultural survey on area and production)
FAO	Food and Agriculture Organization
INIAP	National Institute of Agricultural Research, Ecuador
IRR	Internal Rate of Return
IVs	Improved Varieties
Line ID	line identification
MSU	Michigan State University
NARS	National Agricultural Research Systems
NGOs	Non-Governmental Organizations
NPV	Net Present Value
NSO	National Statistical Office
PIF	*Programa de Investigaciones en Frijol*, Zamorano, Honduras
PRONALEG-GA	*Programa Nacional de Leguminosas y Granos Andinos*
PS	Producer Surplus
R&D	Research and Development
TS	Total Surplus
U.S.	United States
US$	U.S. Dollar
USAID	U.S. Agency for International Development
USDL	United States Department of Labor
VIDAC	Central American Adaptation Nursery

1. INTRODUCTION

One of the most common approaches for analyzing welfare effects of agricultural research in a partial-equilibrium framework is the use of economic surplus analysis (Alston, Norton, and Pardey 1998). The literature on returns to investment is extensive. For example, Alston et al. (2000) assembled 292 studies for the period 1953-1999 reporting 1,886 rates of return estimates. This paper demonstrates the wide use of surplus concepts to address the following research question—what are the benefits of public investments in a research program?

The economic surplus approach to addressing this question involves estimating two key parameters—the size of the adoption of a research output and the average effect size, which measures the effect of a research output per unit of adoption compared with a counterfactual. In the literature, it is common to find a mix of methods used to estimate these two parameters. This includes methods based on data from farmer surveys, agricultural trials, secondary sources (e.g., seed sales data) and expert elicitations (e.g., Mather et al. 2003; Pardey et al. 2006; Mooney 2007; Maredia, Bernsten, and Ragasa 2010). In this paper, a combination of expert elicitations and econometric analysis of agricultural trial data was used to estimate the economic impact of investments in bean breeding research in Costa Rica, El Salvador, Honduras, Nicaragua, and northern Ecuador.

Over the past 20 years, the National Agricultural Research Systems (NARS) in these focused countries, in collaboration with international research institutions, have invested in research to improve varieties of common bean (*Phaseolus vulgaris* L.) with the aim of providing farmers with improved varieties that are disease resistant and have better agronomic characteristics than traditional varieties.

Much of the returns-to-research literature has focused specifically on varietal improvement research (Maredia, Bernsten, and Ragasa 2010). Most of the studies estimate rates of return to investments in varietal improvement research based on estimated benefits accruing to farmers who switch from a (low-yielding) traditional variety to a (high-yielding) improved variety (Griliches 1958; Marasas, Smale, and Singh 2003; Mather et al. 2003; Mooney 2007). In the literature, these are referred to as type I benefits (Byerlee and Traxler 1995). However, as a research program matures and generates new and better improved varieties (IVs), the adopter farmers also experience type II benefits by replacing their old IVs with new (possibly higher-yielding) IVs. Many studies have estimated this additional type II benefits from long-term investments in varietal improvement research by using experimental yield data (Byerlee and Traxler 1995; Pardey et al. 2006; Maredia, Bernsten, and Ragasa 2010). In this study, we estimated the economic benefits accruing to farmers from both type I and type II gains.

Among Central American countries, the bean research programs closely collaborate with each other under the leadership of the regional bean-breeding program at the Pan-American School of Agriculture University (Zamorano) located in Honduras and several spillover varieties have been released in more than one country. In addition, the bean research programs in this region mostly use the same pool of genetic materials (i.e., meso-American bean lines) to develop IVs of beans. Thus, for Central America, in addition to a per country economic analysis, a regional analysis was carried out. For Ecuador, since there is only one player conducting bean research and the pool of genetic materials is different (i.e., Andean types), the impact analysis was conducted separately.

In what follows, we first discuss the bean research programs and varieties released for each country. Second, we explain the analytical framework implemented in this paper. Third, we describe the sources of data. Then we present the estimates of adoption rates of IVs and explain the benefits from this technology adoption through yield gains derived from replacing (a) traditional varieties with IVs (type I gains) and (b) old IVs with new IVs (type II gains), and input these benefits into a surplus model to estimate the economic impact of bean research. We finalize the discussion with a few concluding remarks.

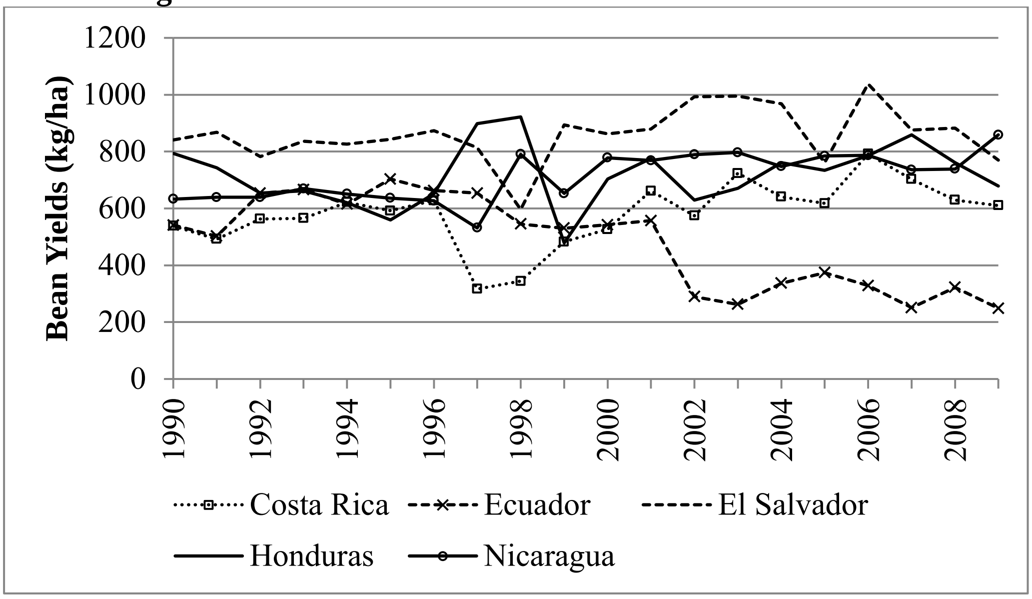
2. BEAN SUBSECTOR, BEAN RESEARCH AND VARIETIES RELEASED, AND ADOPTION OF IMPROVED VARIETIES

2.1. The Bean Subsector

FAOSTAT trade data for the period 2000-2009 show that Nicaragua and Ecuador are the only net bean exporters─the remaining three countries in this study are net bean importers (FAOSTAT 2011). While in Central America, Nicaragua is generally considered the *bean basket* for the region, Ecuador's main bean-export partner is Colombia. Recent aggregate yield data show that yields have varied over time (Figure 1). For the period of 1990-2009, yields averaged 581 kg/ha (CV[1]=0.20) in Costa Rica; 479 kg/ha (CV=0.33) in Ecuador; 860 kg/ha (CV=0.11) in El Salvador; 717 kg/ha (CV=0.15) in Honduras; and 713 kg/ha (CV=0.12) in Nicaragua (estimation of yields including recently available data show minimal differences compared to these yield estimates, if any).

Most of the variation in yields has been due to weather-related factors (Key Informants 2010a). In Ecuador, the *Programa Nacional de Leguminosas y Granos Andinos*' (PRONALEG-GA) bean research primarily focuses on developing bush-type beans targeted for mono-cropping systems and adopted by farmers in the northern region (Key Informants 2010a). The FAOSTAT's dry-bean data reported in Figure 1 is an aggregate for the whole country and does not distinguish between monocropped and intercropped bean data. The National Statistical Institute of Ecuador, thru its *Encuesta de Superficie y Producción Agropecuaria Continua* (ESPAC, the continuous agricultural survey on area and production) reports detailed bean data since 2002. At the national level, ESPAC and FAOSTAT report the same yield levels for 2002-2009. However, for the same period dry bean yields for northern

Figure 1. National Bean Yields (kg/ha) in Costa Rica, Ecuador, El Salvador, Honduras, and Nicaragua



Source: FAOSTAT 1990-2009.

[1] CV = coefficient of variation. Estimated by dividing the standard deviation by the mean.

Ecuador averaged 619 kg/ha vs. 302 kg/ha at the national level, and yields averaged 655 kg/ha for monocropped beans vs. 194 kg/ha for intercropped beans (ESPAC 2011; FAOSTAT 2011), implying that the yield trend observed at the country level for Ecuador do not reflect yields in northern Ecuador, which is the focus region of the bean research program analyzed in this paper (estimation of yields including recently available data show minimal differences compared to these yield estimates, if any).

The fact that the yield trend has been constant in some countries does not suggest that bean research has had no positive effect on (aggregate) production. Morris and Heisey (2003) note that, over time, most successful crop breeding programs generate genetic gains in yields. However, genetic yield gains have two components: (a) increased yield potential, which is observable because yields are higher, and (b) increased biotic and abiotic stress resistance, which is aimed at avoiding losses from stresses (yields may not be higher; instead, losses are averted in the presence of stresses). Therefore, without bean research, it is possible that in these countries, yields could have been much lower over time. Because of this, it is important to empirically estimate if improved bean varieties released over time show genetic yield gains and document the economic impact of investments in bean research in the past two decades.

2.2. Bean Research and Varieties Released

The bean research network of Central America was started under *Profrijol*, a regional bean research network established in 1981 by the International Center for Tropical Agriculture (CIAT) and supported by the Swiss Agency for Development and Cooperation (COSUDE). *Profrijol* was the only bean research network conducting bean research in Central America during the 1980s and 1990s. In 1996, Zamorano, using funds from the Bean/Cowpea (B/C) Collaborative Research Support Program (CRSP) and *Profrijol*, was given the mandate to lead efforts to breed small red beans for the region. Zamorano's bean program has provided leadership to the region's bean research network since 2002, after COSUDE's funding to *Profrijol* ended and CIAT's participation in the region was drastically reduced. This network currently includes NARS from Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Puerto Rico, and Haiti. One of the major contributions of *Profrijol* was the establishment of regional bean nurseries (or trials), which are still used. In these nurseries, lines from different breeding programs are put together and distributed to collaborators in the region for testing (J.C. Rosas, personal communication 2010). The regional nurseries include the VIDAC (Central American Adaptation Nursery) and ECAR (Central American Adaptation and Yield Trial). The information generated is used to select lines adapted to a wide range of environments and to eventually release a variety. Currently, Zamorano's bean program is responsible for preparing and distributing these nurseries and compiling the data provided by the collaborators.

In Ecuador, the PRONALEG-GA program, under the national institute of agricultural research (INIAP), is in charge of conducting bean-breeding activities. PRONALEG-GA consolidated its activities in 1990 and since 1994 has supported other government experimental stations throughout the country (INIAP 2009). In the 1990s, the PRONALEG-GA program collaborated with *Profriza*, an Andean bean research network established by CIAT and supported by COSUDE.[2] During this period, PRONALEG-GA depended on CIAT

[2] *Profriza* was established following the Central American model of *Profrijol*. Both programs were coordinated by CIAT and supported by COSUDE.

to generate new varieties (i.e., no crosses were made in Ecuador). Although PREDUZA, a Dutch organization provided external funding to PRONALEG-GA from 2000-2004 (Mooney 2007), since 2003, the CRSP has been the major external supporter for bean research in Ecuador. Through this collaboration, PRONALEG-GA has been able to make its own bean crosses, which has reduced its germplasm-dependence on other institutions (Key Informants 2010a). Currently, PRONALEG-GA collaborates with international institutions (e.g., CIAT, Michigan State University), and with local NGOs and local farmers groups to develop new bean IVs adapted to local conditions. PRONALEG-GA has three main nurseries for testing advanced lines under farmer conditions: (1) *Prueba*, (2) *Comprobación,* and (3) *Producción*. As stated below, data from the ECAR (Central America) and PRUEBA (Ecuador) trials were used to estimate the type II yield gains for this study.

Between 1990 and 2010, 90 bean varieties (all market classes) were released in the five countries of interest (Table 1). However, some of the varieties released in Central America were released in several countries, usually with a different name in each country. The lines which were released as varieties in more than one country (here we report the line identification (ID) since this was the same across countries) were: *DOR 364* (four countries), *EAP 9510-77* and *MD 30-75* (five countries each), *SRC 2-18-1* (three countries), and *EAP 9510-1, DOR 390* and *DOR 482* (two countries each) (Table 2). Hence, 78 genetically unique varieties were released in all five countries. From all IVs, most varieties were small reds or large reds (56 of 90), followed by red mottled varieties (10 of 90), and black varieties (8 of 90) (Tables 1 and 2). Further, in all countries except Nicaragua, more than 50% of the IVs were released in the last decade and at least 52 of the 90 varieties were developed using (direct or indirect) CRSP funding (Table 1). As Tables 1 and 2 show, over the past two decades, most IVs were released in Ecuador, followed by Honduras, Costa Rica, Nicaragua, and far behind El Salvador.

While the Central American bean programs have focused on developing mostly small reds and black bean varieties, PRONALEG-GA's efforts in Ecuador have focused on developing varieties of several market classes. However, the three main market classes in Ecuador are: red mottled (38% of varieties belong to this market class), yellow (23% of varieties), and white (12%) (Table 2). This study focuses on estimating benefits for small red and red mottled improved bean varieties in Central America and northern Ecuador, respectively.

Table 1. Improved Bean Varieties (IVs) Released between 1990-2010

	Country					
Number of…	Costa Rica	El Salvador	Honduras	Nicaragua	Ecuador	Total
IVs released between 1990-2010	18	9	21	16	26	90
IVs released in the 1990s	8	4	5	9	10	36
IVs released in the 2000s	10	5	16	7	16	54
Small red IVs	12	9	21	14	n.a.	56
Red mottled IVs	n.a.	n.a.	n.a.	n.a.	10	10
IVs developed with CRSP funds	9	5	17	4	17	52
Average # of IVs released/year	0.9	0.45	1.05	0.8	1.3	4.5

Source: Authors.

n.a. = not applicable

CRSP = Collaborative Research Support Program (includes Bean/Cowpea and Dry Grain Pulses CRSP).

Table 2. Improved Bean Varieties Released between 1990-2010, by Country and Market Class

Country	Market Class	Variety Name /a	Line ID /a,b	Year released
Costa Rica	Black	Puricise	BAT 76	1993
	Black	UCR 52	DOR 390	1994
	Black	CIAT 95	MUS 181	1995
	Black	Guaymí	MUS 106	1996
	Black	UCR 55	NJBC-20601-1-CM(71)	2000
	Red	Changuena	MR 13652-39	2006
	Red	Curre	MPCR 202-26-1	2006
	Red	Gibre	MPCR 202-30-2	2006
	Red	**Tongibe**	**BCH 9901-14**	2007
	Red	Disquis	MR 14215-9	2009
	Small red	**UCR 50**	**DOR 364**	1992
	Small red	UCR 51	DOR 474	1993
	Small red	Chirripó Rojo	DOR 489	1995
	Small red	Maleku	RAB 572	1996
	Small red	Bribri	MD 23-24	2000
	Small red	**Cabécar**	**EAP 9510-77**	2003
	Small red	**Telire**	**EAP 9510-1**	2004
	White	Surú	MEB 2232-29	2009
El Salvador	Small red	**CENTA Cuscatleco**	**DOR 364**	1989
	Small red	DOR 582	DOR 582	1993
	Small red	CENTA Costeño	DOR 585	1995
	Small red	ROJO Salvadoreño 1	DOR 482	1997
	Small red	CENTA 2000	MD 30-75	2000
	Small red	**CENTA San Andrés**	**EAP 9510-77**	2002
	Small red	**CENTA Pipil**	**PRF 9653-16B-3**	2005
	Small red	**CENTA Nahuat**	**SRC 2-18-1**	2008
	Small red	**CENTA C.P.C.**	**PPB 11-20 MC**	2008
Honduras	Small red	**Dorado**	**DOR 364**	1990
	Small red	Don Silvio	DOR 482	1992
	Small red	Tío Canela 75	MD 30-75	1996
	Small red	DICTA 113	DICTA 113	1997
	Small red	DICTA 122	DICTA 122	1997
	Small red	**Amadeus 77**	**EAP 9510-77**	2003
	Small red	**Carrizalito**	**EAP 9510-1**	2003
	Small red	**Cedrón**	**PTC 9557-10**	2003
	Small red	**Cayetana 85**	**PRF 9653-16B-2A**	2003
	Small red	Macuzalito	PPB 9911-44-5-13M	2004
	Small red	Palmichal 1	PRF 9707-36	2005
	Small red	Nueva Esperanza 01	DICZA 9801	2005
	Small red	**Cardenal**	**MER 2226-41**	2007
	Small red	**Deorho**	**SRC 2-18-1**	2007
	Small red	Victoria	SRS 56-3	2007
	Small red	**Don Cristóbal**	**SRC 1-12-1-8**	2007
	Small red	Conan 33	PRF 9653-25B-1	2007
	Small red	Quebradeño	IBC 307-7	2009
	Small red	**La Majada AF**	**IBC 301-182**	2009
	Small red	**Briyo AM**	**IBC 306-95**	2009
	Small red	Milagrito	F0243	2009
Nicaragua	Black	INTA Nueva Guinea	DOR 390	2001
	Black	INTA Cardenas	DOR 500	2001
	Dark red	INTA Masatepe	DOR 582	1990
	Dark red	INTA Fuerte Sequia	SX 14825-7-1	2009
	Light red	**INTA Rojo**	**EAP 9510-77**	2002

Country	Market Class	Variety Name /a	Line ID /a,b	Year released
	Red	INTA Estelí	CM-12214-25	1990
	Red	INTA Precoz	SRC 2-18	2006
	Red	INTA Pueblo Nuevo JM	MR 13046-28-SM4	2006
	Small red	ESTELI 90A	CNIGB 1-90	1990
	Small red	ESTELI 90B	CNIGB 2-90	1990
	Small red	ESTELI 150	CNIGB 3-90	1990
	Small red	COMPAÑIA 93	PVA 692	1993
	Small red	**DOR 364**	**DOR 364**	1993
	Small red	CNIGB 93	DOR 391	1994
	Small red	COMPAÑIA	RAB 463	1996
	Small red	INTA Canela	MD 30-75	2001
Ecuador	Black	Afroandino	INIAP-482	2010
	Cranberry	Vilcabamba	INIAP-413	1993
	Cream (Bayo)	Chaupeño	INIAP-419	1998
	Purple Mottled	La Concepción	INIAP-424	2004
	Red	Bolívar*	INIAP-421	1999
	Red Kidney	Colorado	INIAP-472	1990
	Red Kidney	Boliche	INIAP-473	2003
	Red Mottle	Imbabello	INIAP-411	1991
	Red Mottle	Toa*	INIAP-412	1993
	Red Mottle	**Yunguilla**	**INIAP-414**	1993
	Red Mottle	Je.Ma.	INIAP-418	1996
	Red Mottle	Doralisa	INIAP-474	2003
	Red Mottle	**Yunguilla**	**INIAP-414**	2004
	Red Mottle	**Libertador**	**INIAP-427**	2007
	Red Mottle	**Paragachi Andino**	**INIAP-429**	2009
	Red Mottle	**Portilla**	**INIAP-430**	2009
	Red Mottle	**Rojo del Valle**	**INIAP-481**	2010
	White	Blanco Imbabura	INIAP-417	1996
	White	Blanco Belen	INIAP-422	2003
	White	Blanco Fanesquero	INIAP-425	2004
	Yellow	Canario	INIAP-416	1995
	Yellow	Canario	INIAP-423	2003
	Yellow	Canario Siete Colinas*	INIAP-426	2004
	Yellow	Canario del Chota	INIAP-420	2005
	Yellow	Canario Guarandeno	INIAP-428	2007
	Yellow	Rocha	INIAP-480	2009

Source: Authors.

/a. Varieties included in the multiple regression analysis are in bold. Data for all varieties released to date were not available in the nursery used for analysis.

/b. Line ID is the identification of the variety during the breeding process. Same Line ID means the varieties are the same.

* Denotes climbing varieties, all others are bush-type varieties.

3. ANALYTICAL FRAMEWORK FOR ESTIMATING THE ECONOMIC BENEFITS DERIVED FROM INVESTMENTS IN BEAN RESEARCH

3.1. The Economic Surplus Approach

In this study, the total benefits derived from investments in bean research were estimated using surplus concepts, where the benefits were given by the change in total surplus (Δ *TS*) due to the release and adoption of new bean varieties. Griliches (1958) used *ex-post* surplus analysis to estimate the realized social rate of return of private and public investments in research and development of hybrid corn in the United States. Since then, many studies have reported measures of the returns to agricultural research and development (R&D) using surplus concepts (for e.g., Akino and Hayami 1975; Byerlee and Traxler 1995; Marasas, Smale, and Singh 2003; Mather et al. 2003; Pardey et al. 2006; Mooney 2007; Maredia, Bernsten, and Ragasa 2010).

The rationale for the use of economic surplus models is straightforward and a large body of literature explains this approach (see for example Alston, Norton, and Pardey 1998). Although the research-induced technical changes in the bean sub-sector could affect different sectors of the economy (e.g., labor markets), it was assumed that these secondary effects were exogenous and were not addressed in the analysis. For each country, a small open economy surplus model was used. The assumption of an *open* economy was appropriate because the studied countries trade (export and import) beans with each other and with other countries in the world. Similarly, the term *small* was fitting because the bean supply of each country does not influence international prices.

In the small open economy set up, the demand curve is assumed perfectly elastic and all benefits accrue to producers because there is no research-induced reduction in price (Alston, Norton, and Pardey 1998). Therefore, the change in total surplus (Δ *TS*) equals the change in producer surplus (Δ *PS*). Following Maredia and Byerlee (2000), Mather et al. (2003), and Mooney (2007), it was assumed that the supply curve was linear and that its shift (due to technological change) was parallel. One potential problem of this assumption is that the benefits from a parallel shift may be overestimated (almost twice) if the supply shift is indeed pivotal (Alston, Norton, and Pardey 1998). However, assuming parallel shifts was appropriate in this context because previous studies have shown that (a) adoption of IVs is scale-neutral (Mather et al. 2003) and (b) the production technology of bean producers is relatively homogeneous (Mooney 2007).

Thus, for this study, the formula for estimating research benefits was given by:

$$\Delta \text{TS} = \Delta \text{PS} = \text{P}_0 \times \text{Q}_0 \times \text{K}_t \,(1 + 0.5\, \text{K}_t\, \varepsilon), \qquad (1)$$

where P_0 is the exogenous market price for beans, Q_0 is the initial quantity produced before bean research, K_t represents the shift in the supply curve for each year, and ε represents the supply elasticity (Alston, Norton, and Pardey 1998). The most critical variable in Equation (1) is the supply-shift parameter K (Maredia, Bernsten, and Ragasa 2010), represented by:

$$K = A * k, \qquad (2)$$

where A is the share of the bean area planted to improved bean varieties and k is the research-induced yield advantage of new bean varieties; that is, the yield gains. As discussed above, there are two types of yield gains derived from the use of improved varieties: type I, which occurs in areas where improved varieties replace traditional varieties (i.e., new adopters of IVs), and type II, which occurs in areas where new improved varieties replace old improved varieties (i.e., current adopters replace old IVs with new IVs) (Byerlee and Traxler 1995).

Economists have estimated the supply shift parameter (representing type I or type II gains) in different ways using experimental and farm level data (see for example Mather et al. 2003; Pardey et al. 2006; Mooney 2007; Maredia, Bernsten, and Ragasa 2010). In the analytical model used in this paper, the shift in the supply curve resulting from type I gains was represented by:

$$K_t^I = (A_t - A_b) * k^I \quad , \tag{3}$$

where A_t is the adoption rate at time t, A_b is the adoption rate in the base year (i.e., 1996), and k^I is the yield gain associated with replacing traditional varieties with improved varieties, obtained from previous research and assumed to be constant through time. Total type I benefits from varietal improvement in country r at time t were given by Equation (4), which measures the economic benefit of farmers who replace their traditional varieties with improved varieties (i.e., new adopters):

$$\text{Type I } \Delta PS_{rt} = P_{rt} \times Q_{rt} \times K^I_t (1 + 0.5\, K^I_t\, \varepsilon) \tag{4}$$

Research-induced type II yield gains were defined as:

$$K^{II}_t = A_{t-1} * [(1 + \lambda)^s - 1], \tag{5}$$

where K^{II}_t measures the benefit from new bean IVs released over time and adopted by farmers who were already adopters in previous time period (A_{t-1}), and λ is the yield gain associated with replacing old IVs by new IVs, assumed to grow over time at a rate equal to s. The total type II benefits from varietal improvement in country r at time t were given by:

$$\text{Type II } \Delta PS_{rt} = P_{rt} \times Q_{rt} \times K^{II}_t (1 + 0.5\, K^{II}_t\, \varepsilon) \tag{6}$$

Following Byerlee and Traxler (1995), the total benefits from varietal improvement in country r at time t were given by the sum of type I and type II benefits; that is, the sum of Equations (4) and (6).

After the stream of program benefits and costs were estimated, two economic measures were used to estimate the returns to research in each country: Net Present Value (NPV) and Internal Rate of Return (IRR). These measures are useful because they compress the annual flows of benefits and costs into a summary statistic by aggregating the flows over time, which allows comparison and evaluation of alternative investments (Alston, Norton, and Pardey 1998). The cost data used for NPV and IRR estimations reflect a 6-year lag between when breeding starts and when a variety is released because bean-breeding programs usually take five to seven years to develop and release a new bean variety, and multiply and distribute seed. Therefore, while costs were only included for the period 1991-2009, benefits were accounted from 1997 until 2015. This gave an 18-year period for which benefits were evaluated, which is consistent with the period of evaluation used in previous research (Mather et al. 2003; Mooney 2007).

3.2. The Model for Estimating Yield Gains for Type II Benefits

This study relied on varietal yield trials to estimate type II yield gains. Following Maredia, Bernsten, and Ragasa (2010), the yield gains of variety *i* in location *j* and year *t*, Y_{ijt}, are estimated by ordinary least squares using the following regression model:

$$Y_{ijt} = \alpha + \sum_{t=1}^{T-1} \beta_t D_t + \sum_{i=1}^{I-1} \gamma_i D_i + \sum_{j=1}^{J-1} \delta_j D_j + \sum_{r=1}^{R-1} \pi_r D_r + \mu_t , \tag{7a}$$

where D_t are the dummy variables for each year, D_i are the dummy variables for each variety included in the yield trial dataset (i.e., equal to one if Y_{ijt} corresponds to yields of variety *i*; zero otherwise), D_j are dummy variables for each location included in the dataset within each country *r*, D_r are dummy variables for each country, u_t are error terms, and α, β_t, γ_i, δ_j, and π_r are the estimated coefficients.

However, this model can only be estimated with a complete dataset; that is, when there is consistency in the locations and the set of varieties evaluated (Maredia, Bernsten, and Ragasa 2010). This was not the case for this study since the locations where the trials were grown were not always the same and/or the set of varieties was different depending on the location where the trials were evaluated. Therefore, the model in Equation (7a) was modified to:

$$Y_{it} = \alpha + \sum_{t=1}^{T-1} \beta_t D_t + \sum_{i=1}^{I-1} \gamma_i D_i + \sum_{r=1}^{R-1} \pi_r D_r + \mu_t , \tag{7b}$$

where Y_{it} is the yield of variety *i* (averaged across all locations within a country) in year *t*. Although averaging across locations did not allow us to estimate the effect of the genotype by environment interaction, each year the breeding programs usually use the same format (i.e., average yields across locations) to report their results; therefore, averaging yields across locations is consistent with the approach used by bean breeders in making their selection decisions. For Ecuador, dummies for countries were not included because the trials were not conducted in other countries. Therefore, for Ecuador, Equation (7b) became:

$$Y_{it} = \alpha + \sum_{t=1}^{T-1} \beta_t D_t + \sum_{i=1}^{I-1} \gamma_i D_i + \mu_t \tag{7c}$$

Since the models in Equations (7b and 7c) were estimated with an intercept, and to avoid the dummy variable trap, one dummy variable for a) each year (the first year of data), b) each variety (the oldest variety), and c) each country (except Ecuador) were excluded from the regression. Once the parameters were estimated, the fitted values ($\hat{Y}_{it}$) for the experimental yields of each variety for every year were computed. Using these (fitted) values provided more accurate estimates of the yield effect because they take into account the year effect on variety *i*; that is, they adjust the mean upwards or downwards to reflect the fact that variety *i* may have not been tested in high- or low-yielding years (Maredia, Bernsten, and Ragasa 2010).

The predicted yields from Equations (7b and 7c) were used to estimate the effect of a vintage variable (i.e., year of release) V_i on yield gains, using the following simplified vintage models (adapted from Maredia, Bernsten, and Ragasa 2010) that include the year of release as an explanatory variable:

$$\ln(\hat{Y}_{it}) = \alpha + \sum_{t=1}^{T-1} \beta_t D_t + \sum_{r=1}^{R-1} \pi_r D_r + \lambda V_i + \mu_t \quad \text{for small red IVs in Central America} \qquad (8a)$$

$$\ln(\hat{Y}_{it}) = \alpha + \sum_{t=1}^{T-1} \beta_t D_t + \lambda V_i + \mu_t \quad \text{for red mottled IVs in northern Ecuador,} \qquad (8b)$$

where V_i is the year in which variety *i* was released and ln ($\hat{Y}_{it}$) is the natural log of the fitted values from Equation (7b) for the Central American data and from Equation (7c) for the Ecuadorian data. Therefore, the relative (percent) per year yield increase is given by:

$$100 \; d\ln(\hat{Y}_{it})/dV_i = 100 \; \lambda \qquad (9)$$

After the per year yield gain (λ) was estimated using Equations (8a and 8b), the research-induced yield advantage was weighted by the yearly cumulative adoption rate of IVs. Further, the research-induced yield advantage was assumed to grow at a compound rate; i.e., $k_t^{II} = (1 + \lambda)^s$, where λ is the yield gains from new bean IVs and $s = (t - 1996)$.

Economic benefits from type II yield gains were estimated for two scenarios: an actual scenario using the actual adoption rates (the *with* bean research scenario) and a counterfactual scenario where yields and adoption rates were assumed constant at a base year (the *without* bean research scenario).

4. DATA

4.1. Harvested Area and Production of Small Reds and Red Mottled Beans

The data used in this study were obtained from both primary (i.e., experimental trials yield data, key informant interviews) and secondary sources. For each country, information about yearly bean area harvested, production, and yields were obtained from the Food and Agriculture Organization's (FAO) statistical database FAOSTAT. FAOSTAT's area harvested and production data were compared to data from the national statistical offices (NSO) of each country for years with available data (data from NSOs were not available for all years). The differences between FAOSTAT and NSO average harvested area were statistically significant at the 5% level only for Costa Rica─FAOSTAT's average was slightly higher. In contrast, the differences in average bean quantity produced were not statistically significant at the 10% level for any country. FAOSTAT data were used because it was available for all years within the period of interest (i.e., 1991-2009). For years after 2009, the area harvested was assumed as the average of the previous five years (i.e., 2005-2009).

While FAOSTAT's dry bean data refers to bush beans in Central America, these data refers to both bush and climbing beans in Ecuador. Since our interest was only on bush beans, the data published by Ecuador's NSO (the ESPAC survey, only available for 2002-2009 at the time of the analysis) were used to estimate the share of dry bean production attributed to each bean type. We estimated that, between 2002-2009, approximately 51% of the national dry bean production corresponded to bush beans (this share does not change when data for recent years is also included in this estimation). Further, given that breeding efforts have been concentrated in northern Ecuador (i.e., provinces of Carchi and Imbabura), the same data (ESPAC) were used to estimate the share of total bean production coming from this region. We estimated that, between 2002-2009, approximately 39% of the national bush bean production came from this region (this share does not significantly change when data for recent years is included in the estimation). These two percentages were used to estimate bush-bean production in northern Ecuador using FAOSTAT data and the shares were assumed constant over time.

One final adjustment was made to FAOSTAT data before using it. Given that our interest was in small red beans in Central America and red mottled beans in northern Ecuador, key informants were asked to estimate the share of production coming from these two market classes in 2010. While 97% of El Salvador's and 95% of Honduras' bean production corresponds to small red beans, 85-90% of production corresponds to this market class in Nicaragua and small reds account for only 20-30% of Costa Rica's bean production (Key Informants 2010a). Further, Mooney (2007) estimated that in northern Ecuador, 68.4% of the bean area is planted to red mottled beans. These shares were used to estimate small red and red mottled bean production in Central America and Ecuador, respectively, and these shares were assumed constant over time.

4.2. Price Data

The price data for Central American countries were obtained from the '*Consejo Nacional de Producción*' (National Production Council, CNP) of Costa Rica (CNP 2011), which compiles and publishes price data for the Central American countries of interest, in U.S. Dollars (US$). The CNP price data used were the real monthly wholesale price for small red beans, averaged over a calendar year and across countries. Thus, a unique price was used across all Central American countries.

For Ecuador, the price data for red mottled beans came from previous research for years prior to 2004 (reported in real yearly values) and from the Central Bank of Ecuador (CBE 2011) for 2004 onwards. The Central Bank of Ecuador reports data on the value of bean exports and total quantity exported. This information was used to estimate the free on board price for the period of 2004 to September 2011.

To estimate real (discounted to 2009) prices, the United States (U.S.) consumer price index (CPI) was used because all prices were reported in US$. The CPI was obtained from the U.S. Department of Labor (USDL), Bureau of Labor Statistics and refers to the U.S. city average of all items in the index for all urban consumers (USDL 2011). For years after 2010, the price was assumed as the average of the previous five years (i.e., 2006-2010). The average real bean price for 1997-2010 was highest for Central American countries (US$984/MT) and lowest for Ecuador (US$673/MT). While average real price ranged from US$518/MT to US$1,412/MT in Central American countries, the average real price ranged from US$566/MT to US$1,039/MT in Ecuador.

4.3. Supply Elasticity and Discount Rate

The supply elasticity parameter, ε, was assumed equal to 0.7. Since no primary research on supply elasticity exists for the countries of interest, this parameter was assumed identical to that used by Mather et al. (2003). Mooney (2007) also used an identical elasticity parameter to that of Mather et al. (2003) in his bean study in Ecuador. In general, the short-run and intermediate supply responses of a semi-subsistence crop like beans are generally assumed inelastic (Mather et al. 2003). Therefore, assuming a supply elasticity parameter equal to 0.7 seemed appropriate in this context. Further, a 4% real discount rate was used. Recent literature (Alston, Norton, and Pardey 1998; Bazelon and Smetters 2001; Maredia, Bernsten, and Ragasa 2010) suggests that using real discount rates (adjusted for inflation) is appropriate when evaluating long-term profitability of projects and suggest discount rates in the 3-5% range. Maredia, Bernsten, and Ragasa (2010) used a 4% discount rate to evaluate the benefits of bean research in Michigan. Thus, the discount rate used in this study is comparable to discount rates in previous studies.

4.4. Adoption Rates and Diffusion Curves

To estimate varietal adoption, logistic diffusion curves were generated. To generate these curves, three parameters were used: (1) *Current adoption rates of IVs* (A_t), (2) *Base year adoption rates of IVs* (A_b) and (3) *Maximum adoption rate of IVs* (A^{MAX}).

Current adoption rates of IVs, A_t: The current adoption rates were obtained from bean breeders using a structured questionnaire and methodology for soliciting expert opinion, and reflect 2010 levels of adoption of IVs (of the market classes of interest) in each country. Breeders were asked to name the five most widely used IVs in 2010 and the respective share of bean area planted to these IVs. However, only in Honduras were breeders able to name up to five most widely planted IVs. In all other countries, they named only three IVs as the most widely planted. To estimate the total adoption rate of IVs, the individual adoption rates were added up for each country. Although Maredia, Bernsten, and Ragasa (2010) used bean seed sales data to estimate adoption rates in Michigan, U.S., this approach was deemed not appropriate in the Latin American context because most farmers do not purchase seed. Instead, bean farmers in Latin America generally store part of their harvest to use as seed in the next planting season. Further, although breeders' estimations of adoption rates may be overestimated, the breeders interviewed estimated adoption rates taking into consideration farmers' re-use of grain as seed and adoption rates published in previous studies when available (i.e., Honduras and Ecuador).

Base year adoption rates of IVs, A_b: The assumed base year for this study was 1996, which is when investments in collaborative bean research for the period 1991-2010 first generated IVs. These adoption rates were obtained from previous research (i.e., the literature).

Maximum adoption rate of IVs, A^{MAX}: Since bean research was considered a mature industry in the countries of interest, it was assumed that the 2010 adoption rates were approaching the maximum level of adoption for most countries. The logistic diffusion curve formula requires that A^{MAX} be different than A_t; thus, the maximum adoption rate was assumed to be two percentage points above the 2010 adoption rates for all countries except Costa Rica. Since adoption of small red IVs in Costa Rica has slightly decreased over time, A^{MAX} was assumed to be two percentage points above the base year (1996) adoption rate, when adoption peaked (i.e., the curve depicts a decreasing adoption rate).

4.5. Yield Gains

As previously discussed, there can be two types of yield gains from adopting IVs: Type I and Type II. Type I gains were estimated using available data on *k* from previous research conducted in Honduras by Mather et al. (2003) and in Ecuador by Mooney (2007). For Honduras, k^I was assumed equal to 11.5%, the average of the values reported by Mather et al. (2003). Since no other studies have empirically estimated *k* in the remaining Central American countries, Mather et al. (2003) estimation of *k* was also used for these countries. Given that the most widely grown IV across the Central American countries in 2010 (i.e., *EAP 9510-77*) was tested and released in all these countries (under different names), has wide adaptability, and was released almost at the same time across these countries (Table 2), this assumption seems adequate. For Ecuador, Mooney (2007) estimated that adopters enjoy 18.4% lower unit costs when planting IVs (vs. traditional varieties) in northern Ecuador. Thus, k^I was assumed equal to 18.4% for northern Ecuador.

Type II gains were estimated based on the experimental yield data obtained from two bean breeding programs: (i) the *Programa de Investigaciones en Frijol* (PIF) of Zamorano in Honduras, which compiles data for Central American countries, and (ii) the *Programa Nacional de Leguminosas y Granos Andinos* (PRONALEG-GA) of INIAP in Ecuador. In Central America, PIF distributes and collects data on several trials that are tested across the region. The trial data used for this study in this region came from the ECAR trial (Central American Adaptation and Yield Trial), which included data for the period 1999-2009. In Ecuador, PRONALEG-GA also implements several trials and the trial data used in this study came from the PRUEBA trial (Spanish for *TEST*), which included data for the period 2004-2009.

4.6. Research Costs

Obtaining research investment information was challenging. Bean breeding program leaders were asked to identify their 2010 external funding sources and how much they received from each source. In addition, they were asked to estimate the amount of funding they received during the last ten years from large donors. Funding provided by large donors for several years was easily available. However, program leaders found it difficult to estimate their annual core budget. Since Zamorano's breeding program supplies breeding lines to all NARS in Central America, the costs of generating these materials were all imputed to Zamorano. Although this may overestimate Zamorano's costs, it is impossible to attribute these costs to the different programs that benefit from this service.

To estimate the core budget for each program, program leaders were asked how many staff members their programs employed in 2010 and the share of their time devoted to bean-related activities to estimate their full time equivalent. Further, they were asked to provide this information by degree (e.g., Ph.D, M.Sc.) and state whether the number of staff has increased/decreased/remained constant over the last decade. This information was used along with average wage data obtained from different sources (Key Informants 2010a; O. Mejia, personal communication 2012) to estimate full time equivalent researchers' costs.

Given that improved varieties of several market classes have been released in Costa Rica and Ecuador, the total research costs were weighted to reflect the proportion invested in the development of small red and red mottled bean varieties in each of these countries, respectively. For Costa Rica, the share of small red IVs released in the country during the last two decades was used to weight total research costs as to reflect the amount invested on breeding small red IVs. In contrast, for northern Ecuador, the Principal Investigator for the MSU-PRONALEG-GA project provided an estimate of the share of the total research costs devoted to developing red mottled IVs. In contrast, for all other countries in this study, total research costs were not weighted since either no other market classes have been released during the period of evaluation or almost the entire bean production in the country corresponds to small red beans.

5. RESULTS AND DISCUSSION

5.1. Adoption of Improved Varieties over Time

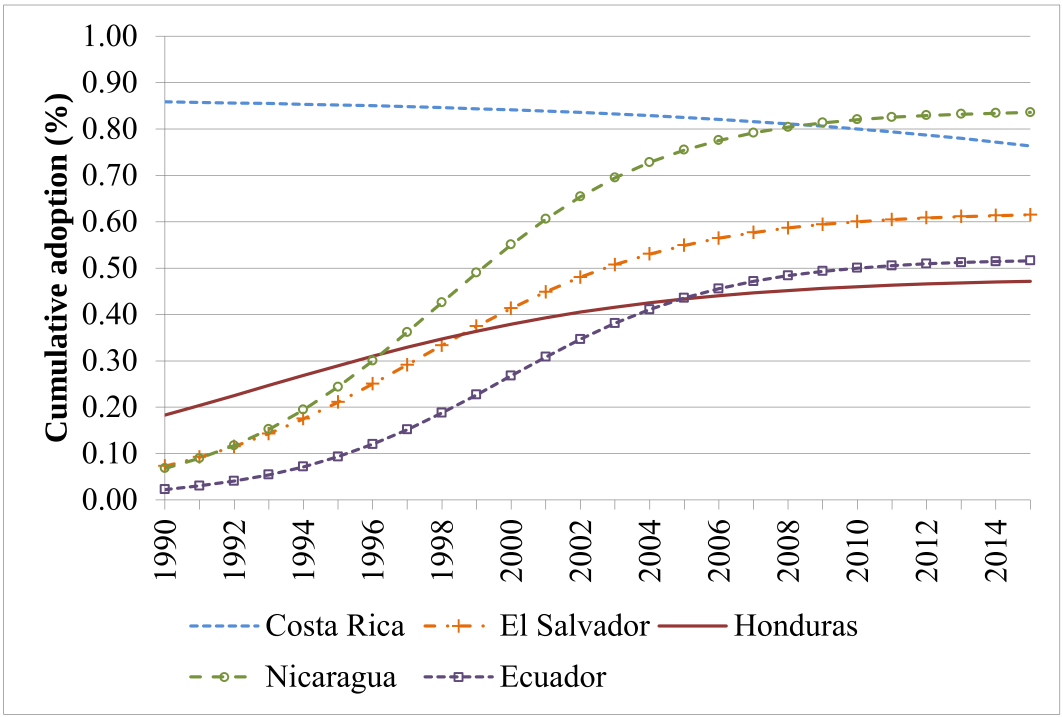
Although 90 improved bean varieties have been released in the past two decades in the five countries of interest, at any given time bean farmers generally grow a mix of varieties (that include traditional and improved varieties). In four of the countries, breeders named three IVs as the most widely grown IVs in 2010, with the exception being Honduras where breeders named five IVs being widely grown in 2010 (though two IVs were by far the most widely grown). Although some of the IVs currently grown were released many years ago, most were recent releases. For example, while *Tío Canela 75*, released in 1996 in Honduras (Table 2), was still grown in 2010 in this country, its adoption rate was low (3.5% of the bean area) compared to *Deorho*, released in 2007 and with an estimated adoption rate of 23% (Key Informants 2010a). Thus, over time, new IVs generally phase out old IVs as they become available. To estimate the country-level adoption rate in 2010, the individual adoption rates were added up for each country. Although total adoption could be disaggregated by variety for 2010, this was not possible for 1996.

While the information of adoption rates for 2010 was obtained from expert opinions through personal interviews, adoption rates for 1996 were obtained from different sources. For 2010, it was estimated that 80%, 60%, 46%, and 82% of the bean area planted to small red varieties in Costa Rica, El Salvador, Honduras, and Nicaragua, respectively, was planted with small red IVs. Similarly, for northern Ecuador, it was estimated that 50% of the bean area grown with red mottled, bush-type varieties was grown with red mottled IVs (Key Informants 2010a). Further, in Central America, the line *EAP 9510-77*─developed by national research systems using Bean/Cowpea and Pulse CRSP partial support and released under a different name in each country (i.e., *Cabécar* in Costa Rica, *CENTA San Andrés* in El Salvador, *Amadeus 77* in Honduras, and *INTA Rojo* in Nicaragua)─was widely planted across all four Central American countries and accounted for an estimated 49.7% (or 235,028 ha) of the total area harvested to beans in 2009.

For 1996, the country-level adoption rates for Costa Rica, El Salvador, and Nicaragua were assumed at 85%, 25%, and 30%, respectively, based on estimates from previous research conducted in this region (CIAT 2001). Similarly, it was assumed that IVs were grown in 31% of the small red bean area in Honduras (Mather 2003) and 12% of the red mottled bean area in northern Ecuador (Mooney 2007) in 1996. The adoption rates in these two points in time were used to estimate logistic diffusion curves over time (Figure 2).

As Figure 2 shows, for most countries, total adoption of improved bean varieties has increased since 1996. In contrast, adoption rates of bean IVs in Costa Rica may have slightly decreased over time. A few reasons may explain this. First, in 1996, the *Consejo Nacional de Producción* (CNP), then the government unit in charge of grain purchases stopped regulating market prices. Bean imports drastically increased after this market reform. This may have reduced the farmer incentive to produce beans, thus reducing the area they plant (Key Informants 2010a). Second, it is likely that farmers that remained in the bean production business may have continued or shifted to produce landraces, which are light red beans for which there is a strong consumer preference, instead of growing IVs that have darker seed compared to landraces (Key Informants 2010a). In Costa Rica, the supply chain works differently than in other countries in the region.

Figure 2. Total Adoption Rates of Improved Bean Varieties (Small Reds and Red Mottled) over Time-1990-2015



Source: Generated by the authors.

Currently, most farmers sell beans to packers/processors who then sell beans through supermarkets, where final consumers purchase them (Key Informants 2010b). Since farmers mainly sell to bean packers/processors, these packers highly influence which varieties farmers grow. When some of these packers/processors were asked about the market classes they prefer, they mentioned that, for red beans, they only buy light reds because that is the market class consumers prefer. Further, they do not give price discounts (as in other countries in the region) for dark red beans; instead, they do not buy them (Key Informants 2010b). This suggests that to increase adoption of red IVs, the bean program should continue improving the market value (i.e., color) of new red IVs to conform to market preference for light red beans. Finally, while adoption of IVs has increased most rapidly in Nicaragua, Ecuador, and El Salvador, IVs have been adopted at a slower rate in Honduras. However, up to 1995, adoption was higher in Honduras compared to all other countries with increasing diffusion curves.

5.2. Estimation of Genetic Yield Gains

The main focus of the study was on estimating type II yield gains, using experimental yield data. The advantage of using experimental yield data is that most variables that influence yields are deliberately held constant; hence, the differences in yields reflect the effect of the variety *per se* (Pardey et al. 2006). The disadvantage of using experimental data is that experimental yields are usually higher than farmers' yields. However, Pardey et al. (2006) note that using experimental yields may be appropriate because farmers' yields are affected by many factors (e.g., weather, change in relative price of inputs and outputs) and, although experimental treatments (e.g., fertilizer levels) may change over time and among locations, this variability is smaller than the variability of farmers' yields. Further, it is proportional yield gains, not yield levels that are relevant in this study.

The vintage model described in equation (8a) was estimated for Central America as a region (all four countries together due to data limitations to estimate this equation for each country separately) and for Honduras separately (since enough observations were available for Honduras). Descriptive statistics of experimental yields are included in Table 3 and the results of the vintage models (i.e., Equation 8a for Central America as a region and Honduras separately, and Equation 8b for Ecuador) are reported in Table 4.

For Central America, while only 13 of the 45 varieties released between 1990-2010 were reported in the ECAR dataset (Table 3), 12 of the 13 varieties were released post 1999 (year when data were first available) and they represent 35% of the small red IVs released since 1999 (see Table 2 for a list of varieties). The small number of released varieties found in this dataset was possibly because: (a) it is likely that national programs also released varieties tested in different (national) nurseries, which were not included in the ECAR trial; (b) since the data were only available from 1999, it is probable that all varieties released prior to 2002 were evaluated in this trial before 1999, with the exception of *DOR 364*, which is used as a universal control; and (c) bean programs in the region did not provide data to Zamorano every year. While the average experimental yield (1999-2009) was 2,125 kg/ha, yields were highly variable, ranging from an average of 1,400 kg/ha to 3,140 kg/ha (Table 3).

Table 3. Estimated Mean Yields (Kg/Ha) and Other Statistics of Red Bean (Central America) and Red Mottled (Ecuador) Varieties Using Experimental Trial Data from the ECAR (1999-2009) and PRUEBA (2003-2010) Datasets

Year of release	Variety Name / Line ID	N	Mean yield (kg/ha)	Std. Dev.	Std. Err.	Minimum	Maximum
Central America							
1989	DOR 364	35	2,011	786	133	523	3,954
2002	EAP 9510-77	5	1,963	237	106	1,704	2,292
2003	EAP 9510-1	10	2,216	839	265	912	4,118
2003	Cayetana 85	3	1,922	90	52	1,863	2,026
2003	Cedron	11	1,972	720	217	1,057	3,534
2005	CENTA Pipil	12	2,248	823	237	1,179	3,658
2007	Tongibe	5	1,983	590	264	1,303	2,895
2007	Cardenal	2	2,005	324	229	1,776	2,235
2007	Don Cristobal	4	2,490	1,122	561	1,634	4,010
2007	SRC 2-18-1	9	2,272	764	255	1,446	3,460
2008	CENTA C.P.C.	3	1,890	352	203	1,683	2,297
2009	La Majada	3	2,357	678	391	1,744	3,086
2009	Briyo AM	6	2,294	726	297	1,383	3,257
Average			2,125	619	247	1,400	3,140
Ecuador							
2004	Yunguilla	7	1,138	578	219	531	1,979
2007	Libertador	2	1,305	127	90	1,215	1,395
2009	Paragachi Andino	6	1,102	432	176	495	1,716
2009	Portilla	8	1,256	564	199	551	2,052
2010	Rojo del Valle	3	1,460	649	374	720	1,932
Average			1,252	470	212	702	1,815

Sources: Programa de Investigaciones en Frijol Metadata, Zamorano, Honduras; INIAP/PRONALEG-GA Metadata, Ecuador.

Table 4. Linear Regression Results of the Vintage Models Using Experimental Yields of Improved Bean Varieties (IVs) Released in Central America (ECAR Dataset, 1999-2009) and Ecuador (PRUEBA Dataset, 2003-2010)

	Central America (small red IVs) /a		Honduras (small red IVs) /b		Ecuador (red mottled IVs) /c	
	N = 108		N = 88		N = 26	
	Prob > F = 0.000		Prob > F = 0.000		Prob > F = 0.000	
	R-squared = 0.9565		Adj. R-squared = 0.9616		Adj. R-squared = 0.9491	
Variables	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Year dummy variables (1=Yes):						
2000	0.09	***0.000	0.08	***0.000	n.a.	
2001	0.38	***0.000	0.39	***0.000	n.a.	
2002	-0.03	0.227	-0.07	***0.005	n.a.	
2003	0.36	***0.000	0.38	***0.000	n.a.	
2004	0.12	***0.000	0.13	***0.000	0.58	***0.000
2005	-0.10	***0.006	-0.06	**0.028	1.28	***0.000
2006	0.14	***0.000	0.15	***0.000	0.57	***0.000
2007	0.12	***0.000	0.11	***0.000	0.87	***0.000
2008	0.34	***0.000	0.34	***0.000	0.35	***0.000
2009	0.21	***0.000	0.20	***0.000	1.19	***0.000
2010	n.a.		n.a.		0.81	***0.000
Country dummy variables (1=Yes):						
Costa Rica	-0.42	***0.000	-0.46	***0.000	n.a.	
El Salvador	-0.33	***0.000	-0.30	***0.000	n.a.	
Guatemala	-0.91	***0.000	-0.92	***0.000	n.a.	
Nicaragua	-0.31	***0.000	-0.30	***0.000	n.a.	
Vintage variable (year of release)	0.0049	***0.000	0.0056	***0.000	0.0168	*0.051
Constant	-2.11	0.124	-3.48	**0.012	-27.46	0.106

Sources: Programa de Investigaciones en Frijol Metadata, Zamorano, Honduras; INIAP/PRONALEG-GA Metadata, Ecuador.
*, **, *** indicates the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively.
n.a. = not applicable (i.e., variable not included in the regression).
/a, /b. Year 1999 and country Honduras were excluded from the regression to avoid the dummy trap.
/a. Robust standard errors used to estimate p-values because variances are not equal (Prob > Chi2 = 0.0451).
/c. Year 2003 excluded to avoid the dummy trap.

For Ecuador, five of the 10 red mottled varieties released between 1990 and 2010 were reported in the PRUEBA dataset (Table 3). All five varieties represent 100% of the red mottled varieties released since 2004 (see Table 2 for a list of varieties), which allowed comparing yield gains from varieties released since 2004 (i.e., recent varieties). While the average experimental yield (2003-2010) was 1,252 kg/ha, yields were highly variable, ranging from an average of 702 kg/ha to 1,815 kg/ha (Table 3).

The results of the vintage model regression for Central America as a region (Table 4), interpreted as the yield gains of small red IVs released over time in the region as a whole, suggest that the gain in yield potential from varieties released in the region from 1989 to 2009 averaged 0.49%. This percent is consistent with previous research that estimated bean yield gains in Michigan (Maredia, Bernsten, and Ragasa 2010). These results, combined with the information in Table 3, indicate that, in Central America, the gain in yield potential averaged roughly 10 kg/ha/year.

Similarly, the results of the vintage model regression for Honduras (Table 4), which only include data of varieties released in Honduras, suggest that the gain in yield potential from varieties released in Honduras from 1989 to 2009 averaged 0.56%, or roughly 12 kg/ha/year. The results of the vintage model regression for Ecuador (Table 4) suggest that the gain in yield potential from red mottled varieties released in Ecuador from 2004 to 2010 averaged 1.68% (or roughly 21 kg/ha/year), which is slightly higher than expected and much higher than the gains found for Central America and Honduras. In all three regressions, the dummy variables for year were highly significant, suggesting great variability in yields over time. Similarly, in Central America, there was great variability in yields across countries where the trials were tested.

5.3. Measuring Costs, Benefits and Estimating Returns To Investments in Bean Research

The stream of costs, valued in constant 2009 U.S. Dollars show that Nicaragua had the highest average annual real cost associated with the development of red bean varieties (US$373,668/year), followed by Honduras (US$167,170/year), El Salvador (US$142,380/year), Costa Rica (US$128,005/year), and far behind Ecuador, with the lowest average annual real cost associated with the development of red mottled bean varieties (US$39,532/year). Most of the costs reported for Nicaragua relate to salaries (87%, on average). In contrast, the average research cost per hectare planted with IVs per year was highest for Costa Rica (US$24/ha with IVs/year), followed by Ecuador (US$17/ha with IVs/year), Honduras (US$3.88/ha with IVs/year), El Salvador (US$3.50/ha with IVs/year), and Nicaragua (US$3.19/ha with IVs/year).

The estimates of bean yield gains, in combination with estimations of adoption rates, annual bean prices, elasticity of supply, and the annual quantity of bean produced of the market classes of interest were used to estimate the value of benefits realized at the farm level for the period of 1997-2015 for each country of interest. Then, the annual research costs and a real discount rate of 4% were used to estimate the NPV and IRR to bean research investments in each country (called the *base scenario*).

A sensitivity analysis was conducted to test the robustness of the results. Given that the main parameters are mutually dependent (e.g., adoption rates likely depend on yields), varying each parameter separately and considering all combinations possible may not be adequate. Thus, in addition to the *base scenario* estimations of NPV and IRR, two other scenarios (*A* and *B*) were evaluated. For this, the following parameters from the *base scenario* were modified as follow: *Scenario A*, type II yield gains, and 2010 adoption rates were simultaneously modified to reflect a +10% difference from the *base scenario*. In *Scenario B*, type II yield gains and 2010 adoption rates were simultaneously modified to reflect a -10% difference from the *base scenario*. In both scenarios, all other parameters were held constant. Additionally, the minimum type II yield gains and 2010 adoption rates needed to recover investment (i.e., when NPV=0, or break-even values) were estimated separately (e.g., type II yield gains were changed until NPV=0, while holding all other variables constant). Finally, for the *base scenario*, a 10% discount rate was also used to study the sensitivity of the results to this parameter.

Table 5 includes the summary of the NPV and IRR findings. Details on these estimations are found in the Appendix. Results from the *base scenario* suggest that in all countries except

Costa Rica, investments in bean research have been profitable and provided a return well above the assumed opportunity cost of capital because the NPV was positive and the IRR was greater than the discount rate used. When the discount rate was increased to 10% for countries with positive returns (i.e., all except Costa Rica), NPV was also greater than zero, suggesting that the results were not greatly affected by the discount rate. The largest returns to investment for the *base scenario* were observed for Nicaragua (US$214 million), followed by El Salvador (US$78 million), Honduras (US$58 million), Ecuador (US$11 million), and Costa Rica (US$-2 million). These returns represent a producer surplus of US$73, US$84, US$63, US$196, and US$26 per hectare planted with IVs per year in Nicaragua, El Salvador, Honduras, Ecuador, and Costa Rica, respectively

There were two reasons for the high returns observed in Nicaragua: (1) the area planted to beans has more than doubled since 1996 and (2) adoption of improved varieties has greatly increased since 1996 due to investments made by donors and the government, especially after hurricane MITCH in 1998. Since this study did not include these costs, these benefits were likely overestimated. The modest economic impact for Ecuador was due to the small area planted to beans in northern Ecuador and the deficient formal seed system, which has limited farmers' access to high-quality bean seed. To overcome this limitation, PRONALEG-GA is promoting alternative ways to produce and sell high quality, low-cost bean seed through seed producers located in villages across different regions. However, PRONALEG-GA's efforts have most likely had limited impact because the amount of seed produced and sold has been relatively small and its limited resources have not allowed to scale up these initiatives.

Table 5. Summary of Net Present Value (NPV) and Internal Rates of Return (IRR) Estimations of Investments on Bean Research in Central America and Ecuador, 1991-2015

	Scenario (in constant 2009 US$)						For 1997-2015
	Base		Scenario A		Scenario B		Producer surplus per ha per year
Country	NPV(US$)	IRR	NPV(US$)	IRR	NPV(US$)	IRR	
Costa Rica	-2,016,054	-5%	-1,610,978	-3%	n.e.	n.e.	26
El Salvador	77,510,816	40%	93,170,299	43%	62,688,130	37%	84
Honduras	58,250,437	34%	73,724,174	37%	43,698,030	31%	63
Nicaragua	214,002,964	42%	254,621,317	45%	175,583,202	39%	73
Ecuador	10,920,047	37%	13,216,135	39%	8,832,204	35%	196
Central American countries	347,748,163	32%	419,904,813	35%	281,969,362	32%	72
All countries	358,668,210	32%	433,120,948	35%	290,801,566	32%	74

Source: Generated by the Author.

NOTES: n.e. = not estimated.

Scenario A assumes a 10% increase over estimations of Type II yield gains and 2010 adoption rates simultaneously.

Scenario B assumes a 10% decrease over estimations of Type II yield gains and 2010 adoption rates simultaneously.

Surplus per hectare per year estimated by dividing each year's total surplus (base scenario) by the area planted with IVs.

The net losses found for Costa Rica were due to the fact that (a) the area planted to beans has decreased since 1996 (and only the red-bean share was included in the estimations) and (b) the adoption rates between 1996 and 2010 have also decreased. Therefore, net losses were expected. Although this was true for small red beans, it is possible that positive gains could be found for black beans because (a) most farmers have adopted the black bean IVs *Brunca* (released in 1982) and *Guaymi* (released in 1996) and (b) the area planted to black IVs is much larger than the area planted to red beans (Key Informants 2010a). However, estimating the economic impact of black beans for Costa Rica was not possible because only a few varieties have been released recently and available experimental data did not include yield information for these varieties.

As a region (i.e., Costa Rica, El Salvador, Honduras, Nicaragua, and northern Ecuador), investments in bean research were profitable, generating a net present value of more than US$358 million, most of which came from Central American countries, particularly Nicaragua. This is due to the fact that Nicaragua is the largest bean producer in the region and the adoption rates in this country were relatively high in 2010. Further, the governments of Nicaragua, Honduras, and El Salvador have implemented (free or subsidized) seed distribution programs that have increased adoption rates and, thus, contributed to the observed (and large) economic benefits. While the benefits derived from type II gains accounted for less than one-half of the change in total surplus in El Salvador (42%) and Nicaragua (39%), Type II benefits accounted for more than 50% of the change in total surplus in Honduras (61%) and Ecuador (53%). The estimated IRR for the region was 32%, which more than offsets the opportunity cost of capital.

The sensitivity analysis shows that, for countries with positive returns to investment, these returns are also positive in both *scenarios A* and *B*. In contrast, for Costa Rica, returns are still negative in the optimistic scenario (*scenario A*). Although there were no type I benefits in Costa Rica because farmers have dis-adopted IVs over time (thus there are no new adopters), the realized type II yield gains were not enough to recover investments in bean research.

As mentioned above, break-even values for λ and adoption rates were also estimated. In Costa Rica, the NPV would be zero (break-even value for λ) if the value of λ were 114% higher than estimated; that is, if $\lambda = 1.048\%$. Further, the results suggest that for all other countries, even if $\lambda=0$ (hence type II gains = 0), the NPV would still be positive. This was because adoption of IVs was assumed to increase (at the *base scenario* rate) over time, generating enough type I benefits (from new adopters) to realize positive NPV values. It was not possible to estimate break-even values for adoption rates in 2010 for these four countries (with positive returns) since, even if the 2010 adoption rate was only 1% above the 1996 adoption rate (e.g., 26% in El Salvador in 2010 instead of 60%), NPV would still be positive. This was because even with a small increase in adoption of IVs over time, both type I and type II benefits were realized, and these were large enough to offset the cost of research. Finally, as the 2010 adoption rate decreased (and got closer to the 1996 adoption rate), the share of the benefits derived from type I gains became smaller and that of type II gains became larger.

6. CONCLUDING REMARKS

Between 1990 and 2010, the National Agricultural Research Systems in Honduras, El Salvador, Nicaragua, Costa Rica, and Ecuador, in collaboration with international partners, have released seventy-eight genetically unique IVs, 45 of these were small reds, and 10 were red mottled varieties. The adoption rates of IVs for 2010 ranged from 46% in Honduras to 82% in Nicaragua. The economic impact of the adoption of this steady flow of higher yielding improved bean varieties is the focus of this paper. There are several lessons that can be drawn from the analysis and results presented in this paper.

First, small countries derive important spillover benefits through collaboration with countries in a similar agro-ecological region. This study found that in Central America, because of their small size and limited human and financial resources, the national bean programs function as a collaborative network, thus facilitating the exchange of germplasm within the region. This collaboration has generated several spillover benefits, including access to a greater number of locations to test lines, several varieties released in more than one country, and greater access to technical and financial assistance.

Second, key to the success of Central America's bean research program was the establishment of *Profrijol*—especially its network of regional bean nurseries, which are currently being implemented with partial support from the Dry Grain Pulses Collaborative Research Support Program (CRSP). In addition, the regional network has helped increase collaboration between breeding programs in the region, strengthen the national bean programs, and reduce crop losses caused by the bean golden yellow mosaic virus. Currently, Zamorano's bean program is responsible for supplying germplasm to regional collaborators through the regional nurseries. Especially over the past decade, the CRSP's financial support (through Zamorano's bean program) has been critical to sustaining the collaboration among former *Profrijol* members.

Third, in economic analysis it is important to account for two types of benefits farmers derive from sustained investments in crop breeding research─type I and type II. Type I gains are experienced when farmers replace traditional varieties with improved varieties (i.e., new adopters) and type II gains are experienced by farmers (i.e., current adopters) when they replace old improved varieties with new improved varieties. The benefits derived from type II gains ranged from 40-60% of total benefits in the focused countries. In countries where the adoption of IVs is expanding rapidly, type I benefits will dominate. However, as the breeding programs mature and release a constant flow of higher yielding varieties, the importance of type II gains increases. This study has demonstrated the importance of estimating both these sources of economic benefits and the methodology of doing so.

Fourth, the benefits realized from investments in crop breeding research depend on the capacity of the seed system to facilitate both type I and type II gains. Currently, government interventions in Honduras, El Salvador, and Nicaragua to distribute bean seed have played a major role in increasing the adoption of IVs in these countries. However, the seed provided to farmers is either subsidized or free, which is not sustainable in the long term. Therefore, alternative ways to produce and commercialize low-cost high-quality seed is key to ensuring a sustainable access to IVs by new and current adopters. The bean seed system is the most deficient in Ecuador. In order to increase seed production, financial assistance would likely be required because PRONALEG-GA's human and financial resources are stretched thin.

Financial support from the Government of Ecuador and donors will be key to find alternatives to overcome this bottleneck.

Fifth, this study reiterates the importance of consumer and market class preferences in explaining adoption or lack of adoption of IVs. For example, the adoption rates of small red IVs in Costa Rica showed a declining trend over the study period. This can be partially explained by the strong consumer preference for light red beans (which is the color of traditional red bean varieties), while most red IVs available in Costa Rica had dark seed. It is likely that this has driven adoption rates down at the same time when the total area planted to beans was declining rapidly due to market reforms. These results suggest that in Costa Rica, to increase adoption rates, future bean research on small red varieties should give priority to developing varieties that are more acceptable to farmers (i.e., with better market value) and consumers. Further, since black beans is the most widely produced market class in Costa Rica, increased efforts should be devoted to develop new black varieties.

Finally, breeding programs generally provide additional benefits not captured in the economic benefits presented in this study. For example, these programs develop new varieties that have traits not reflected in yields (e.g., maturity, color, growing habit), provide training services for future plant breeders, and are responsible for germplasm conservation, among others. These additional benefits are important despite the fact that it is not possible to put an economic value to them.

APPENDIX

Table A1. Costa Rica: Base Scenario Net Present Value (NPV) and Internal Rate of Return (IRR) Calculations for Improved Small Red Bean Varieties, 1991-2015

Year	Period	Area harvested (ha)	Production (mt)	Adoption rate (%)	λ growth (%)	Kt		Supply Elasticity e	Real Price (US$/mt)	Change in TS		Research Costs (US$, real)	Net Benefit (US$)
						Type I	Type II			Type I	Type II		
1991	-5	17,395		0.86						0	0	158,619	-158,619
1992	-4	15,790		0.86						0	0	153,984	-153,984
1993	-3	14,758		0.85						0	0	149,508	-149,508
1994	-2	14,217		0.85						0	0	145,776	-145,776
1995	-1	14,081		0.85						0	0	141,758	-141,758
1996	Base	8,119	4,063	0.85						0	0	137,692	-137,692
1997	1	11,040	5,524	0.85	0.0049	0.000	0.004	0.7	1,412	0	32,530	134,604	-102,074
1998	2	9,280	4,643	0.85	0.0098	0.000	0.008	0.7	1,212	0	47,026	132,540	-85,513
1999	3	9,063	4,535	0.84	0.0148	0.000	0.012	0.7	1,152	0	65,598	129,676	-64,078
2000	4	7,707	3,856	0.84	0.0197	0.000	0.017	0.7	960	0	62,027	132,136	-70,110
2001	5	5,828	2,916	0.84	0.0247	0.000	0.021	0.7	867	0	52,980	129,454	-76,474
2002	6	5,522	2,763	0.84	0.0298	0.000	0.025	0.7	857	0	59,643	96,711	-37,068
2003	7	5,212	2,608	0.83	0.0348	0.000	0.029	0.7	518	0	39,709	123,918	-84,209
2004	8	4,087	2,045	0.83	0.0399	0.000	0.033	0.7	804	0	55,228	121,616	-66,389
2005	9	4,087	2,045	0.82	0.0450	0.000	0.037	0.7	880	0	67,993	118,514	-50,521
2006	10	3,509	1,756	0.82	0.0501	0.000	0.041	0.7	728	0	53,576	115,666	-62,091
2007	11	3,004	1,503	0.82	0.0552	0.000	0.045	0.7	901	0	62,410	113,295	-50,885
2008	12	2,757	1,379	0.81	0.0604	0.000	0.049	0.7	1,411	0	97,578	109,907	-12,329
2009	13	3,944	1,974	0.81	0.0656	0.000	0.053	0.7	963	0	103,044	86,725	16,319
2010	14	3,460	1,731	0.80	0.0708	0.000	0.057	0.7	1,109	0	111,747		111,747
2011	15	3,460	1,731	0.79	0.0761	0.000	0.061	0.7	1,022	0	110,027		110,027
2012	16	3,460	1,731	0.79	0.0813	0.000	0.065	0.7	1,022	0	116,877		116,877
2013	17	3,460	1,731	0.78	0.0866	0.000	0.068	0.7	1,022	0	123,579		123,579
2014	18	3,460	1,731	0.77	0.0920	0.000	0.072	0.7	1,022	0	130,109		130,109
2015	19	3,460	1,731	0.76	0.0973	0.000	0.075	0.7	1,022	0	136,444		136,444
		In constant 1991 US$:			NPV =	-956,905				*In constant 2009 US$:*		NPV =	-2,016,054
												IRR =	-5%

Source: Estimations made by the Author. See Table Notes in Table A6.

Table A2. El Salvador: Base Scenario Net Present Value (NPV) and Internal Rate of Return (IRR) Calculations for Improved Small Red Bean Varieties, 1991-2015

Year	Period	Area harvested (ha)	Production (mt)	Adoption rate (%)	λ growth (%)	Kt		Supply Elasticity e	Real Price (US$/mt)	Change in TS		Research Costs (US$, real)	Net Benefit (US$)
						Type I	Type II			Type I	Type II		
1991	-5	75,097		0.09						0	0	196,108	-196,108
1992	-4	76,795		0.12						0	0	190,377	-190,377
1993	-3	72,110		0.14						0	0	184,843	-184,843
1994	-2	72,042		0.17						0	0	180,228	-180,228
1995	-1	58,801		0.21						0	0	179,485	-179,485
1996	Base	65,659	51,920	0.25						0	0	174,337	-174,337
1997	1	80,495	63,652	0.29	0.0049	0.005	0.001	0.7	1,412	427,014	110,126	170,427	366,714
1998	2	75,709	59,866	0.33	0.0098	0.010	0.003	0.7	1,212	696,425	207,818	163,864	740,379
1999	3	72,178	57,074	0.37	0.0148	0.014	0.005	0.7	1,152	944,756	324,292	160,323	1,108,724
2000	4	76,659	60,618	0.41	0.0197	0.019	0.007	0.7	960	1,098,834	431,117	155,110	1,374,841
2001	5	82,624	65,335	0.45	0.0247	0.023	0.010	0.7	867	1,303,870	580,788	150,818	1,733,841
2002	6	80,707	63,819	0.48	0.0298	0.026	0.013	0.7	857	1,461,830	734,146	109,713	2,086,264
2003	7	81,362	64,337	0.51	0.0348	0.030	0.017	0.7	518	996,931	560,563	107,269	1,450,226
2004	8	84,432	66,764	0.53	0.0399	0.032	0.020	0.7	804	1,749,924	1,094,180	104,486	2,739,618
2005	9	82,989	65,624	0.55	0.0450	0.034	0.024	0.7	880	2,011,168	1,389,285	101,062	3,299,391
2006	10	84,758	67,022	0.56	0.0501	0.036	0.028	0.7	728	1,786,251	1,354,845	97,904	3,043,192
2007	11	91,785	72,579	0.58	0.0552	0.038	0.031	0.7	901	2,490,189	2,062,075	95,193	4,457,072
2008	12	102,529	81,075	0.59	0.0604	0.039	0.035	0.7	1,411	4,483,899	4,032,474	91,673	8,424,700
2009	13	100,940	79,818	0.59	0.0656	0.040	0.038	0.7	963	3,083,689	2,997,390	92,000	5,989,079
2010	14	92,600	73,224	0.60	0.0708	0.040	0.042	0.7	1,109	3,313,509	3,465,898		6,779,408
2011	15	92,600	73,224	0.60	0.0761	0.041	0.046	0.7	1,022	3,096,535	3,471,581		6,568,116
2012	16	92,600	73,224	0.61	0.0813	0.041	0.049	0.7	1,022	3,128,228	3,745,398		6,873,627
2013	17	92,600	73,224	0.61	0.0866	0.042	0.053	0.7	1,022	3,152,659	4,017,819		7,170,478
2014	18	92,600	73,224	0.61	0.0920	0.042	0.056	0.7	1,022	3,171,444	4,289,200		7,460,644
2015	19	92,600	73,224	0.61	0.0973	0.042	0.060	0.7	1,022	3,185,860	4,559,919		7,745,779
		In constant 1991 US$:			NPV =	36,789,922			*In constant 2009 US$:*			NPV =	77,510,816
												IRR =	40%

Source: Estimations made by the Author. See Table Notes in Table A6.

Table A3. Honduras: Base Scenario Net Present Value (NPV) and Internal Rate of Return (IRR) Calculations for Improved Small Red Bean Varieties, 1991-2015

Year	Period	Area harvested (ha)	Production (mt)	Adoption rate (%)	λ growth (%)	Kt Type I	Kt Type II	Supply Elasticity e	Real Price (US$/mt)	Change in TS Type I	Change in TS Type II	Research Costs (US$, real)	Net Benefit (US$)
1991	-5	104,272		0.20						0	0	258,564	-258,564
1992	-4	67,996		0.23						0	0	211,207	-211,207
1993	-3	79,202		0.25						0	0	197,282	-197,282
1994	-2	111,700		0.27						0	0	171,351	-171,351
1995	-1	64,859		0.29						0	0	125,563	-125,563
1996	Base	79,043	57,718	0.31						0	0	111,262	-111,262
1997	1	78,850	57,577	0.33	0.0056	0.002	0.002	0.7	1,412	180,694	141,196	122,252	199,638
1998	2	74,881	54,679	0.35	0.0112	0.004	0.004	0.7	1,212	285,269	245,432	129,429	401,272
1999	3	106,064	77,449	0.36	0.0169	0.006	0.006	0.7	1,152	555,813	524,885	135,488	945,209
2000	4	114,671	83,734	0.38	0.0226	0.008	0.008	0.7	960	641,461	662,847	164,462	1,139,846
2001	5	72,568	52,990	0.39	0.0283	0.010	0.011	0.7	867	439,057	494,904	168,242	765,718
2002	6	132,661	96,870	0.41	0.0341	0.011	0.013	0.7	857	911,342	1,117,124	155,937	1,872,529
2003	7	99,005	72,295	0.42	0.0399	0.012	0.016	0.7	518	457,807	608,424	160,481	905,751
2004	8	98,347	71,814	0.43	0.0457	0.013	0.019	0.7	804	768,922	1,104,652	156,797	1,716,777
2005	9	111,916	81,722	0.43	0.0515	0.014	0.022	0.7	880	1,026,258	1,589,168	169,698	2,445,728
2006	10	121,600	88,794	0.44	0.0574	0.015	0.025	0.7	728	975,038	1,622,924	164,844	2,433,117
2007	11	133,000	97,118	0.45	0.0634	0.016	0.028	0.7	901	1,382,603	2,467,031	212,451	3,637,183
2008	12	133,000	97,118	0.45	0.0693	0.016	0.031	0.7	1,411	2,246,392	4,285,946	205,016	6,327,322
2009	13	98,856	72,186	0.46	0.0753	0.017	0.034	0.7	963	1,176,031	2,393,291	155,897	3,413,425
2010	14	119,674	87,388	0.46	0.0813	0.017	0.037	0.7	1,109	1,681,314	3,640,993		5,322,306
2011	15	119,674	87,388	0.46	0.0874	0.018	0.040	0.7	1,022	1,583,663	3,641,281		5,224,944
2012	16	119,674	87,388	0.47	0.0935	0.018	0.043	0.7	1,022	1,611,759	3,926,310		5,538,070
2013	17	119,674	87,388	0.47	0.0996	0.018	0.046	0.7	1,022	1,635,459	4,212,450		5,847,909
2014	18	119,674	87,388	0.47	0.1057	0.018	0.050	0.7	1,022	1,655,416	4,499,600		6,155,016
2015	19	119,674	87,388	0.47	0.1119	0.019	0.053	0.7	1,022	1,672,195	4,787,722		6,459,917
		In constant 1991 US$:			NPV =	27,648,128				*In constant 2009 US$:*		NPV =	58,250,437
												IRR =	34%

Source: Estimations made by The Author. See Table Notes in Table A6.

Table A4. Nicaragua: Base Scenario Net Present Value (NPV) and Internal Rate of Return (IRR) Calculations for Improved Small Red Bean Varieties, 1991-2015

Year	Period	Area harvested (ha)	Production (mt)	Adoption rate (%)	λ growth (%)	Kt Type I	Kt Type II	Supply Elasticity e	Real Price (US$/mt)	Change in TS Type I	Change in TS Type II	Research Costs (US$, real)	Net Benefit (US$)
1991	-5	98,368		0.09						0	0	490,362	-490,362
1992	-4	88,139		0.12						0	0	476,032	-476,032
1993	-3	100,300		0.15						0	0	462,196	-462,196
1994	-2	98,786		0.19						0	0	450,657	-450,657
1995	-1	120,677		0.24						0	0	438,237	-438,237
1996	Base	104,509	67,653	0.30						0	0	425,668	-425,668
1997	1	117,694	76,187	0.36	0.0049	0.007	0.001	0.7	1,412	762,195	158,191	416,120	504,266
1998	2	165,025	106,827	0.43	0.0098	0.014	0.004	0.7	1,212	1,879,670	460,346	409,738	1,930,278
1999	3	180,351	116,748	0.49	0.0148	0.022	0.006	0.7	1,152	2,954,150	847,761	400,884	3,401,027
2000	4	194,773	126,084	0.55	0.0197	0.029	0.010	0.7	960	3,517,663	1,173,653	387,847	4,303,468
2001	5	201,338	130,333	0.61	0.0247	0.035	0.014	0.7	867	4,016,351	1,544,826	377,116	5,184,060
2002	6	218,311	141,321	0.65	0.0298	0.041	0.018	0.7	857	4,999,838	2,197,405	323,952	6,873,290
2003	7	252,934	163,733	0.69	0.0348	0.045	0.023	0.7	518	3,910,834	1,946,442	317,584	5,539,692
2004	8	202,692	131,210	0.73	0.0399	0.049	0.028	0.7	804	5,282,203	2,951,336	309,346	7,924,193
2005	9	236,473	153,078	0.75	0.0450	0.052	0.033	0.7	880	7,173,491	4,462,568	299,208	11,336,851
2006	10	199,953	129,437	0.78	0.0501	0.055	0.038	0.7	728	5,249,426	3,608,318	289,858	8,567,886
2007	11	202,613	131,159	0.79	0.0552	0.057	0.043	0.7	901	6,814,754	5,140,042	281,831	11,672,965
2008	12	209,269	135,468	0.80	0.0604	0.058	0.048	0.7	1,411	11,294,234	9,289,222	271,410	20,312,046
2009	13	217,518	140,808	0.81	0.0656	0.059	0.053	0.7	963	8,166,618	7,283,424	271,650	15,178,392
2010	14	213,165	137,990	0.82	0.0708	0.060	0.058	0.7	1,109	9,339,858	8,987,250		18,327,108
2011	15	213,165	137,990	0.83	0.0761	0.060	0.062	0.7	1,022	8,700,616	8,992,551		17,693,167
2012	16	213,165	137,990	0.83	0.0813	0.061	0.067	0.7	1,022	8,765,976	9,692,501		18,458,477
2013	17	213,165	137,990	0.83	0.0866	0.061	0.072	0.7	1,022	8,814,450	10,388,869		19,203,319
2014	18	213,165	137,990	0.83	0.0920	0.061	0.077	0.7	1,022	8,850,324	11,083,067		19,933,391
2015	19	213,165	137,990	0.84	0.0973	0.062	0.081	0.7	1,022	8,876,828	11,776,409		20,653,237
			In constant 1991 US$:		NPV =		101,574,886			*In constant 2009 US$:*		NPV =	214,002,964
												IRR =	42%

Source: Estimations made by The Author. See Table Notes in Table A6.

Table A5. Ecuador: Base Scenario Net Present Value (NPV) and Internal Rate of Return (IRR) Calculations for Improved Red Mottled Bean Varieties in Northern Ecuador, 1991-2015

Year	Period	Area harvested (ha)	Production (mt)	Adoption rate (%)	λ growth (%)	Kt		Supply Elasticity e	Real Price (US$/mt)	Change in TS		Research Costs (US$, real)	Net Benefit (US$)
						Type I	Type II			Type I	Type II		
1991	-5	6,983		0.03						0	0	22,827	-22,827
1992	-4	6,970		0.04						0	0	21,763	-21,763
1993	-3	7,185		0.05						0	0	28,098	-28,098
1994	-2	8,599		0.07						0	0	37,864	-37,864
1995	-1	7,759		0.09						0	0	31,751	-31,751
1996	Base	8,489	7,287	0.12						0	0	29,341	-29,341
1997	1	8,534	7,326	0.15	0.0168	0.006	0.002	0.7	600	25,598	8,868	28,903	5,562
1998	2	7,533	6,467	0.19	0.0339	0.012	0.005	0.7	600	48,464	19,965	27,246	41,183
1999	3	7,762	6,663	0.23	0.0513	0.020	0.010	0.7	600	79,158	38,566	23,406	94,318
2000	4	6,427	5,517	0.27	0.0689	0.027	0.016	0.7	600	90,857	52,038	7,480	135,415
2001	5	7,207	6,187	0.31	0.0869	0.035	0.023	0.7	600	130,154	87,051	12,295	204,910
2002	6	8,333	7,153	0.35	0.1051	0.042	0.032	0.7	600	181,461	140,667	13,626	308,501
2003	7	7,996	6,864	0.38	0.1237	0.048	0.043	0.7	600	201,042	179,159	44,755	335,446
2004	8	7,036	6,040	0.41	0.1426	0.053	0.054	0.7	659	216,854	220,264	57,762	379,355
2005	9	8,455	7,258	0.44	0.1618	0.058	0.066	0.7	740	318,152	365,169	57,749	625,572
2006	10	7,353	6,312	0.46	0.1813	0.062	0.079	0.7	753	299,596	385,360	55,944	629,012
2007	11	6,607	5,671	0.47	0.2011	0.065	0.092	0.7	626	234,840	335,885	61,120	509,605
2008	12	6,106	5,241	0.48	0.2213	0.067	0.104	0.7	566	203,029	320,610	131,810	391,828
2009	13	6,085	5,223	0.49	0.2418	0.069	0.117	0.7	839	308,033	533,634	57,375	784,292
2010	14	6,921	5,941	0.50	0.2627	0.070	0.129	0.7	1,039	442,028	835,322		1,277,350
2011	15	6,921	5,941	0.51	0.2839	0.071	0.142	0.7	765	329,964	676,782		1,006,747
2012	16	6,921	5,941	0.51	0.3055	0.072	0.154	0.7	765	333,394	738,908		1,072,302
2013	17	6,921	5,941	0.51	0.3274	0.072	0.167	0.7	765	335,929	801,361		1,137,290
2014	18	6,921	5,941	0.51	0.3497	0.073	0.179	0.7	765	337,796	864,319		1,202,115
2015	19	6,921	5,941	0.52	0.3724	0.073	0.191	0.7	765	339,168	927,959		1,267,126
			In constant 1991 US$:		NPV =	5,183,118			*In constant 2009 US$:*			NPV =	10,920,047
												IRR =	37%

Source: Estimations made by the Author. See Table Notes in Table A6.

Table A6. Notes for Table A1 through Table A5

Country	Notes
Costa Rica	Area harvested is 25% of total area harvested to reflect only red bean production (i.e., excludes other market classes). Yield for 1996 estimated as the average yields of 1994-1998, using FAOSTAT data. λ=0.0049 (Type II gains); Type I gains=11.5% (from Mather et al. 2003). Price is the average price for Central American countries.
El Salvador	Area harvested is 97% of total area harvested to reflect only red bean production (i.e., excludes other market classes). Yield for 1996 estimated as the average yields of 1994-1998, using FAOSTAT data. λ=0.0049 (Type II gains); Type I gains=11.5% (from Mather et al. 2003). Price is the average price for Central American countries.
Honduras	Area harvested is 95% of total area harvested to reflect only red bean production (i.e., excludes other market classes). Yield for 1996 estimated as the average yields of 1994-1998, using FAOSTAT data. λ=0.0056 (Type II gains); Type I gains=11.5% (from Mather et al. 2003). Price is the average price for Central American countries.
Nicaragua	Area harvested is 87.5% of total area harvested to reflect only red bean production (i.e., excludes other market classes). Yield for 1996 estimated as the average yields of 1994-1998, using FAOSTAT data. λ=0.0049 (Type II gains); Type I gains=11.5% (from Mather et al. 2003). Price is the average price for Central American countries.
Ecuador	Area harvested is 13.5% of total of dry bean area harvested in the country to reflect only red mottled (i.e., excludes other market classes) bush-bean production in the provinces of Carchi and Imbabura. Yields in northern Ecuador are 35% higher (estimated from ESPAC data) than country-level yields. Thus, FAOSTAT yields data were multiplied by 1.35 to reflect yields in northern Ecuador and yield for 1996 estimated as the average of 1994-1998. λ=0.0168 (Type II gains); Type I gains=18.4% (from Mooney 2007).
For all countries	For 2010-2015, area harvested assumed as the average of the previous five years (i.e., 2005-2009). For 2011-2015, price assumed as the average of the previous five years (i.e., 2006-2010). Discount rate=4%. Production estimated by multiplying area harvested in each year times the base year (i.e., 1996) yields.

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