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Poisson Count Models to Explain the Adoption of Agricultural and Natural Resource Management Technologies by Small Farmers in Central American Countries

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ABSTRACT

Evaluations of the factors influencing the adoption of agricultural and natural resource management technologies among small farmers in developing countries have been mostly limited to qualitative discussions or simple descriptive statistics resulting in superficial and inconclusive findings. This study introduces the use of Poisson Count Regressions as a statistically appropriate procedure to analyze certain common types of adoption data. It uses them to assess the impact of key socio-economic, bio-physical, and institutional factors on the adoption of integrated pest management, agroforestry, and soil conservation technologies among small farmers in three Central American countries: Costa Rica, Panama, and El Salvador.

Key Words: *agroforestry, evaluation of development projects, integrated pest management, poisson count regressions, soil conservation, technology adoption.*

International development agencies, national and local governments, and non-governmental organizations have and are investing significantly in developing countries to transfer sustainable agriculture and natural resource technologies to small farmers living on steeply sloped and degraded lands (Byrnes; Kaimowitz). Soil conservation, agroforestry and integrated pest management projects have attempted to transfer technologies to reduce the degradation of natural resources and simultaneously improve farmers' incomes.

Evaluating the impact of these projects by quantifying the levels of technology adoption and assessing the socioeconomic, bio-physical and institutional factors that influence adoption is critical to improving their efficiency. However, few have been rigorously evaluated due to limited funding, lack of data and/or suitable methodological approaches. A review of 21 Central American technology transfer projects funded by different international donor agencies and administered by CATIE

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(Tropical Agriculture Research and Education Center) during the last 10 years shows that typically less than 2 percent of the project budgets was dedicated to formal evaluation activities. As a result, evaluations are mostly qualitative descriptions of general trends of technology adoption.

When funding has been provided for evaluations, their scope has been limited by the lack of data and suitable methodological approaches. The most commonly applied methods, bivariate statistical analysis and multiple ordinary least squares (OLS) models (Current, Lutz and Scherr; Gómez; Melgar; Quirós), have not allowed researchers to effectively quantify the relationships between bio-physical, socioeconomic, and institutional variables and the levels of technology adoption. A key limiting factor in these approaches has been that the dependent variables (i.e. the field measurements of farm level adoption) are rarely continuous, making the OLS estimation technique inefficient.

Binomial Probit or Logit models may be more suitable, although the dependent variables (i.e. adoption levels) are often not truly binomial in developing countries (Pérez; Melgar). To use the binomial models, applied economists and other social scientists working in developing countries have artificially lumped adoption levels into two categories (1 = full adoption, 0 = no adoption at all), inducing statistically undesirable measurement errors (Judge *et al.*).

This study is the first to explore the use of Poisson Count Regression models to analyze technology adoption. The objective is to evaluate the adoption of agricultural and natural resource technologies by small farmers in developing countries, and illustrate the use of Poisson Count Regression models in analyzing adoption data. In these models the dependent variable, adoption, is assumed to be an integer-valued gradient. The explanatory variables are the socioeconomic characteristics of the farmers, the bio-physical characteristics of their farms and institutional factors associated with the extension effort. Poisson Count Regressions are used to evaluate three technology transfer projects in Central America: integrated pest management in Costa Rica, agroforestry systems in Panama, and soil conservation in El Salvador.

The Need for Count Models

In developing countries the adoption of improved agricultural or natural resource management technologies by small, subsistence farmers is not a straightforward process. Most technologies consist of several practices that have been designed to work together but which can be used individually. Farmers seldom adopt all the practices, or even individual practices as recommended, but modify them according to their means and perceived needs (Nelson; Quirós). Therefore, measurements of adoption in developing countries are often categorically ordered variables, undertaking values such as "none, low, average, high and total". In the projects evaluated in this study, for example, adoption was ranked by independent investigators into as few as three categories in the case of agroforestry and as many as eight categories in the case of soil conservation technologies. Under those circumstances, OLS is not the ideal choice statistically. The OLS procedure performs best when the dependent variable Y, and therefore the regression error-term, is continuous (i.e., can take on any integer or non-integer value) and normally distributed. Otherwise, more efficient estimation methods can be found. Further, if OLS techniques are used under small sample and non-normal dependent variable conditions, the statistical inferences made with the estimated models are invalid (Judge *et al.*).

In some studies (Melgar), adoption was originally measured as an ordered count variable and later transformed into a binomial variable by, for example, assigning a value of 1 when adoption was high or total and 0 otherwise. Then, binomial Logit or Probit models (Aldrich and Nelson) were fitted. A problem with this approach is the measurement error induced in the dependent variable. A stepwise or partial adoption process cannot be measured by a dichotomous dependent variable (Monardes).

Dichotomous choice models are only theoretically appropriate when adoption is truly binomial, as is often the case in the more homogeneous, technology-driven and resource-abundant production systems characteristic of developed countries. In contrast, empirical evidence suggests that the adoption of agricultural and natural resource management technologies by small farmers in developing countries occurs as a gradient, at sequential levels. Complete technological packages are seldom adopted (Bentley and Andrews; Byerlee and Polanco). Another negative consequence of applying OLS when the dependent variable is categorical is that there is no guarantee that the model's parameter estimators will be unbiased. The estimated model will also yield inconsistent dependent-variable predictions (Pindyck and Rubinfeld).

The Poisson Count Model

The recently developed Event Count Duration Regression Models (ECDR) (King 1989a) can be useful in analyzing adoption data from developing countries. These models assume that the dependent variable results from a counting of events using positive integer numbers. This process implies an ordering scheme like that observed when measuring adoption. ECDR specifications have been applied to model and predict the rate of occurrence of wars in countries or regions, based on the values taken by macroeconomic, policy and social explanatory variables (King, 1987). More recently, count models have been proposed for recreation demand analysis (Gillig, Ozuma, and Griffin). ECDR models in this case have the advantage of predicting the expected level of adoption by a farmer, given the type of extension program in which the farmer participated and his/her socioeconomic profile. Quantifying the impact of each independent variable on the level of adoption is also straightforward. In the Poisson Event Count Regression model (King, 1989b):

$$(1) \quad E[Y_i] = \exp^{\{\beta X_i\}} \qquad (i = 1, \ldots, n)$$

where $E[Y_i]$ is the expected value of the dependent variable for the ith observation, exp the exponential function, β is a 1 by k vector of parameters, X_i is a k by 1 vector with the values of the k independent variables in the ith observation and n is the number of observations. Equation (1) can be used to predict the expected level of adoption given the value taken by the vector of independent variables X_i.

Two broad types of explanatory variables are often included in technology adoption studies—*qualitative,* modeled through dichotomous (dummy) variables, and *quantitative,* integer or non-integer valued. Their relative impact on the dependent variable is calculated differently. Notice that equation (1) can also be expressed as:

$$(2) \quad E[Y_i] = \exp^{\{\beta_1 X_{1i}\}}\exp^{\{\beta_2 X_{2i}\}} \ldots \exp^{\{\beta_k X_{ki}\}} = \exp^{\{\beta_j X_{ji}\}}C_j \qquad (i = 1, \ldots, n)$$

where j can take any one value from 1 to k and identifies a specific explanatory variable and C_j is a constant representing the product of the remaining exponential terms in (2). For dichotomous explanatory variables, if $X_{ji} = 0$, $E[Y_i] = C_j$, and when $X_{ji} = 1$, $E[Y_i] = \exp^{\{\beta_j\}} C_j$. Therefore:

$$(3) \quad 100 \times (\exp^{\beta_j} - 1)$$

calculates the percentage change on $E[Y]$ when X_j goes form zero to one, for all observations (i). In general, for independent variables that take several integer values, the percentage change in the expected level of adoption when X_j goes from X_{j1} to X_{j2} can be calculated as:

$$(4) \quad 100 \times (\exp^{\{\beta_j X_{j2}\}} - \exp^{\{\beta_j X_{j1}\}})/(\exp^{\{\beta_j X_{j1}\}})$$

For quantitative explanatory variables the elasticity estimate at X_{ji} is given by:

$$(5) \quad (\partial E[Y_i]/\partial X_{ji})(X_{ji}/E[Y_i]) = \beta_j X_{ji}$$

A final advantage of the Poisson Event Count Regression models is that, if appropriate, two or more regression equations can be jointly estimated using a Seemingly Unrelated Regression (SUR) specification, which potentially increases estimation efficiency by taking advantage of the correlation among the dependent variables in the different equations.

The Technology Transfer Projects

Pérez conducted an adoption study of an Integrated Pest Management (IPM) project in Costa Rica. The project promoted two improved pest management technologies among tomato farmers in the Grecia and Valverde Vega counties, province of Alajuela, Costa Rica. Technology "A" was for the production of tomato seedlings free of the geminivirus transmitted by the white fly (*Bemisia tabaci*). Technology "B" involved the rational use of pesticides to control tomato fruit worms (*Heliothis zea*) using economic thresholds.

A randomly selected sample of 43 farmers from the list of the extension agency of the Ministry of Agriculture (MAG) in Grecia was monitored. It included organized and non-organized groups of farmers who were approached with combinations of different extension techniques, including field lectures, written materials and demonstrative plots. Technology 'A' practices included using seedbeds, using the recommended soil mix, using paper cups as containers for growing and transplanting the seedlings, using any protective cover on the seedbed or using the recommended protective structure on the seedbed. Technology 'B' practices included sampling, using the recommended sampling method, applying an economic action threshold and using the proper mix of pesticides for controlling the fruit worms.

The adoption levels of the two IPM technologies were monitored, recording the number of practices adopted by each farmer six months after the extension activities ended. The potential range of adoption was from 0 to 5 practices for Technology "A", and from 0 to 4 practices for Technology "B". A variety of socio-economic, biophysical, and institutional data about the farmers, farms and the extension programs was collected (Table 1). This is a typical situation in which the SUR version of the Poisson Regression is suitable for increasing estimation efficiency.

Gómez conducted a study on the adoption of Agroforestry System Technologies (AST) in Panama. He evaluated 50 farm-families within the areas of influence of the "Agroforestry Project for Community Development" (INRENARE/CARE) and the "Project for Food Production and Community Development in Marginal Lands" (MIDA/WFP), in the provinces of Coclé, Herrera and Los Santos. These projects promoted agroforestry practices among small farmers for almost six years, including wood lots, intercropping with trees in degraded sites and on moderate to steep slopes and using trees as live fences and windbreaks, depending on specific farm-site soil, slope, and agronomic conditions. Intercropping involved rice, creon and cassava production. The most commonly recommended tree species were fast growing and multi-purpose: pine (*Pinus caribaea*), eucalyptus (*Eucalyptus camaldulensis*), acacia (*Acacia mangium*) and leucaena (*Leucaena leucocephala*).

In this case adoption was classified on three levels: *high* for the farmers who initially adopted at least one of the agroforestry practices proposed, followed the technical guidelines provided by the project's personnel and later increased areas or established other agroforestry practices; *medium* for the farmers who initially adopted at least one of the agroforestry practices proposed and adequately maintained it, but did not increase areas or adopted other agroforestry practices; and *low* for the farmers who adopted an agroforestry practice but had completely abandoned it by the time of the evaluation. Data on biophysical, socioeconomic and institutional factors were also collected (Table 1).

Melgar conducted an evaluation of a Soil Conservation project in the Río Las Cañas watershed, El Salvador. CATIE, the Lempa River Hydroelectricity Commission, the Ministry of Agriculture, and the USAID (United States Agency for International Development) bilateral mission in El Salvador implemented this project from 1991 through 1995. The extension phase involved working primarily with farmer leaders, establishing demonstration and trial plots using a variety of soil conservation practices: contour ditches and drainage systems, live and stone barriers and fences, or-

Table 1. Adoption levels and values taken by some of the independent variables in the Integrated Pest Management (IPM), Soil Conservation and Agroforestry Systems Technology Transfer Projects.

IMP Technology A		IPM Technology B		Agroforestry		Soil Conservation	
Category	Freq.	Category	Freq.	Category	Freq.	Category	Freq.
Variable: Technology Adoption Level							
0	12	0	14	1	19	1–3	4
1	3	1	10	2	17	4–6	6
2	8	2	11	3	14	7–9	7
3	9	3	5	—	—	10–12	5
4	5	4	3	—	—	13–15	11
5	6	5	—	—	—	16–18	14
—	—	—	—	—	—	19–21	7
—	—	—	—	—	—	22–24	18
Variable: Formal (School) Education							
0–3 Years	11	0–3 Years	11	0–3 Years	15	1(None)	16
4–6 Years	26	4–6 Years	26	4–6 Years	31	2(Element.)	42
7–12 Years	6	7–12 Years	6	7–12 Years	4	3(High Sch.)	14
Variable: Farm Ownership							
0(No)	26	0(No)	26	0(No)	22	0(No)	9
1(Yes)	17	1(Yes)	17	1(Yes)	28	1(Yes)	63
Variable: Access to Hired Labor							
0(No)	27	0(No)	27	—	—	0(No)	35
1(Yes)	16	1(Yes)	16	—	—	1(Yes)	37
Variable: Access to Credit							
0(No)	27	0(No)	27	0(No)	23	0(No)	—
1(Yes)	16	1(Yes)	16	1(Yes)	27	1(Yes)	—
Variable: Previously Adopted New Technology							
0(No)	25	0(No)	25	0(No)	16	0(No)	—
1(Yes)	18	1(Yes)	18	1(Yes)	34	1(Yes)	—
Variable: Farm Size (Ha's)							
0.1–0.5	14	0.1–0.5	14	0.1–2.5	14	0.1–1.0	26
0.6–1.0	19	0.6–1.0	19	2.6–5.0	13	1.1–2.0	21
1.1–3.9	6	1.1–3.9	6	5.1–20.0	14	2.1–5.0	21
4.0–8.0	4	4.0–8.0	4	20.1–100.0	9	5.1–28.0	4
Variable: Frequent Contact with Extension Agents							
0(No)	15	0(No)	15	0(No)	12	1 Visit	11
1(Yes)	28	1(Yes)	28	1(Yes)	38	2 Visits	23
—	—	—	—			3 Visits	38
Variable: Training Intensity (Level or Years in Project)							
1	14	1	14	1	21	1–2 Years	30
2	10	2	10	2	14	3 Years	22
3	19	3	19	3	15	4 Years	20

ganic fertilizers, individual terraces, agroforestry practices, and fuel-efficient wood stoves.

Near the end of the project, Melgar conducted an adoption survey with a random sample of 72 farmers. He calculated an adoption level for each farmer by weighting each practice adopted by the assessed quality (high = 1, average = ⅔ or low = ⅓) with which it had been adopted, and dividing the weighted sum by the total number of practices recommended for that particular farm. Therefore, the possible adoption levels ranged from zero to 100 percent, but could only take a limited number of discrete values within that range. He also collected data on biophysical, socioeconomic and institutional factors (Table 1).

Results: Adoption of Integrated Pest Management Technologies

According to the Poisson Count Regression, three variables have a statistically significant impact on the adoption of both IPM technologies at the 10-percent level: belonging to a community organization, having access to credit, and having access to hired labor (Table 2). Using equation (3), it is estimated that the adoption levels among farmers that belong to a community organization are 80 percent higher than those among farmers that do not, in the case of Technology "A", and 140 percent higher for Technology "B". Farmers with access to credit are likely to have adoption rates between 90 and 225 percent higher, when all other factors are held constant. This confirms the empirical observations in the literature about the importance of access to credit for technology adoption in developing countries (Monardes). Hired labor availability is a key limiting factor in the adoption of both IPM technologies. It has an approximately 100-percent impact on the adoption of either one of these technologies.

The variables cropping system, years of formal education, recent adoption of a new technology and farm size also have a statistically significant impact on the adoption of Technology "A" at the 10-percent level. A 40-percent difference in the level of adoption is detected depending on the type of cropping system used by the farmer, indicating that Technology "A" is more compatible with one of the two cropping systems prevailing in the area. Formal education shows a positive and considerable effect on adoption. For instance, using equation (4), it is calculated that a full high school education increases the predicted adoption level by 60 percent in relation to only having a third-grade education.

Having recently adopted a new technology nearly doubles the predicted adoption levels. With limited resources available for technology transfer, it might be justifiable to focus extension efforts on former adopters. Alternatively, this result implies that convincing a farmer to accept an improved technology for the first time can be a good investment because it will facilitate the transfer of other technologies in the future. As farm size increases, it becomes more difficult to summon the amount of labor needed for the practices recommended in Technology "A", regardless of the availability of family or hired labor. A farmer who only grows one hectare of tomatoes is likely to adopt twice the number of practices of a farmer who grows five hectares. Technology "A" is more suitable for small farmers with sufficient family and hired labor availability.

The distribution of written extension materials (in addition to a standard field talk and exercise with all farmers) can not be shown to have an impact on the adoption of either IPM technology at the 10-percent level of statistical certainty. This must be assessed with caution since the magnitude of type II error is unknown. The additional field extension activity of visiting demonstrative plots, however, is predicted to have increased the adoption of IPM Technology "B" by over 200 percent. Interestingly, the farmer's educational level showed an impact on the adoption of IPM Technology "A" but not "B", which included relatively complex practices such as sampling and the use of economic thresholds.

There is wide variability in net farm income within the sample, from 35,000 Costa Rican Colones a month (about U.S. $190), which is below the official poverty level, to over 185,000 (or U.S. $1,000). This variable

Table 2. Estimates, Asymptotic Standard Error Estimates and Significance Levels for the Parameters of the Poisson Count Regression Models of the Adoption of Integrated Pest Management (IPM) Technologies in Alajuela, Costa Rica.

The Integrated Pest Management Technology A			
Variable	Param. Est.	S.E. Est.	Sig. Lev.
Intercept	−0.5483	1.5459	—
Farmer belonged to a community organization (1 = Yes, 0 = No)	0.6022	0.2438	+1**
Farmer received written extension materials (1 = Yes, 0 = No)	0.2401	0.2725	+1
Farmer visited a demonstrative plot (1 = Yes, 0 = No)	−0.3739	0.3752	+1
Cropping system based on transplanting seedlings (1 = Yes, 0 = No)	−0.5113	0.1977	2**
Number of years of formal education the farmer had had	0.0513	0.0401	+1*
Farmer adopted a new technology in recent past (1 = Yes, 0 = No)	0.6579	0.2836	+1**
Farmer frequently consulted with extensionists (1 = Yes, 0 = No)	0.0276	0.1738	+1
Farmer's age (Years)	0.0387	0.0761	2
Age squared	−0.00013	0.0009	2
Farmer's years of experience growing tomatoes	−0.0417	0.0305	2
Experience squared	0.0004	0.0009	2
Farmer's access to credit (1 = Yes, 0 = No)	0.6544	0.2487	+1**
Net farm income (1000 Colones/month)	−0.0076	0.0055	2
Farmer owns the farmland (1 = Yes, 0 = No)	0.1821	0.285	+1
Farmer's access to hired labor (1 = Yes, 0 = No)	0.6754	0.2285	+1**
Farm size (Hectares)	−0.2712	0.1137	−1**
The Integrated Pest Management Technology B			
Variable	Param. Est.	S.E. Est.	Sig. Lev.
Intercept	−7.4814	1.8234	—
Farmer belonged to a community organization (1 = Yes, 0 = No)	0.8839	0.3728	+1**
Farmer received written extension materials (1 = Yes, 0 = No)	−0.9428	0.5179	+1
Farmer visited a demonstrative plot (1 = Yes, 0 = No)	1.184	0.5824	+1**
Number of years of formal education the farmer had had	−0.0389	0.0857	+1
Farmer adopted a new technology in recent past (1 = Yes, 0 = No)	0.3586	0.4501	+1
Farmer frequently consulted with extensionists (1 = Yes, 0 = No)	0.3795	0.3457	+1
Farmer's age (Years)	0.2165	0.0712	2**
Age squared	−0.00196	0.0008	2**
Farmer's years of experience growing tomatoes	0.1766	0.064	2**
Experience squared	−0.0041	0.0015	2**
Farmer's access to credit (1 = Yes, 0 = No)	1.1823	0.4174	+1**
Net farm income (1000 Colones/month)	−0.0132	0.0051	2**
Farmer owns the farmland (1 = Yes, 0 = No)	0.6209	0.3299	+1**
Farmer's access to hired labor (1 = Yes, 0 = No)	0.7507	0.3549	+1**
Farm size (Hectares)	−0.0197	0.122	2

Note: Param. Est indicates the parameter estimate; *SE. Est.* indicates the asymptotic standard error estimate; in *Sig. Lev.*, 1 or 2 indicates whether the alternative hypothesis was specified as one or two-tailed respectively; in the case of 1-tailed alternatives, + or − indicates the assumed sign of the parameter under the alternative hypothesis; ** and * indicate statistical significance at the 95 and 90 percent levels, respectively, according to asymptotic t-tests. Since the SUR version of the model was used in this case, the t-tests involve $2n - k_1 - k_2 - 1 = 86 - 17 - 16 - 1 = 42$ degrees of freedom.

Table 3. Estimates, Asymptotic Standard Error Estimates, and Significance Levels for the Parameters of the Poisson Count Regression Models of the Adoption of Agroforestry System Technologies in in Coclé, Herrera and Los Santos, Panama.

Agroforestry System Technologies			
Variable	Param. Est.	S.E. Est.	Sig. Lev.
Intercept	−0.2682	0.1742	—
Farmer receiving technical advice on agroforestry (1 = Yes, 0 = No)	0.071	0.1062	+1
Farmer participated in agroforestry short course (1 = Yes, 0 = No)	0.0537	0.0867	+1
Farmer previously received technical assistance (1 = Yes, 0 = No)	−0.0043	0.0918	+1
Farm size (hectares)	0.002	0.0018	+1
Number of years of formal education the farmer had had	0.0341	0.0177	+1*
Farmer's years of experience with tree planting	0.0852	0.0195	2**
Experience squared	−0.0034	0.0007	2**
Farmer's frequent contact with other farmers (1 = Yes, 0 = No)	−0.2282	0.0721	2**
Farmer's frequent contact with extensionists (1 = Yes, 0 = No)	0.0633	0.1322	+1
Farmer's access to credit (1 = Yes, 0 = No)	0.0203	0.0721	+1
Farmer adopted a new technology in recent past (1 = Yes, 0 = No)	0.5023	0.0916	+1**
Farmer's desired area of agroforestry systems in future (hectares)	0.027	0.0586	+1
Farmer had title to the land (1 = Yes, 0 = No)	0.1598	0.0917	+1**
Intensive land use at farm (1 = Yes, 0 = No)	0.0122	0.0848	−1

Note: Param. Est. indicates the parameter estimate; *S.E. Est.* indicates the asymptotic standard error estimate; in *Sig. Lev.*, 1 or 2 indicates whether the alternative hypothesis was specified as one or two-tailed respectively; in the case of 1-tailed alternatives, + or − indicates the assumed sign of the parameter under the alternative hypothesis; ** and * indicate statistical significance at the 95 and 90 percent levels, respectively, according to asymptotic t-tests.

shows a negative effect on adoption, which is statistically significant in the case of IPM Technology "B". This suggests that although farmers are willing to borrow to improve their production systems, their farm income will be mostly destined for consumption. The common notion that poorer farmers are less likely to adopt improved technologies is not supported by the data. On the contrary, needy farmers might be more eager to adopt new technologies if they have access to credit.

Farmland ownership is predicted to have a positive effect on the levels of adoption of both IPM technologies and a statistically significant impact in the case of Technology "B," implying an 85-percent increase in adoption rates due to land ownership. The coefficients of age and age squared and experience and experience squared are also statistically significant in Technology "B". Age and experience have a positive influence on adoption up to 53 and 21 years, respectively, after which they begin to have a negative effect. The model (Equation 2) predicts, for example, that the level of adoption of a 53-year-old farmer with 21 years of experience will be three times as high as the level of adoption of a 38-year-old farmer with only 10 years of experience.

Whether the farmer frequently receives advice from an extension worker shows no impact on the adoption of either IPM technology. If farmers have obtained good results when using previous "expert" advice, they should be more willing to accept it again. However, mixed past experiences could cancel out this effect and explain the lack of significance of this variable.

Results: Adoption of Agroforestry Systems

The results of analyzing adoption with the Poisson Count Regression (Table 3) can be compared with previous findings in the literature, specifically the qualitative assessment of Current, Lutz and Scherr. A key objective of that World Bank-funded study of over 21 agroforestry projects in six Central American and Caribbean countries was to determine the factors that influence the adoption of agroforestry systems in these countries. The present study finds five variables with a significant impact on adoption at the 10-percent level: education, experience with tree planting, frequent contact with other farmers, recent adoption of an improved technology, and land tenure.

Farmers with an elementary-school education have 25-percent higher adoption rates than farmers without any formal education. A high school education increased adoption rates by an additional 25 percent. This variable is not discussed in Current, Lutz and Scherr. Farmers in this case had lower educational levels that those in the Costa Rican IPM study; many were illiterate. Education appears to be an important determinant of technology adoption, especially if the target population is poorly educated.

This agroforestry project was implemented exclusively through farmer and community organizations. Therefore, the effect of this factor on adoption could not be evaluated. However, as in the Costa Rican IPM study, the predicted adoption rates for farmers that have recently adopted improved technologies is higher, 65 percent in this case. There are further similarities with the results of the IPM study. The variables "frequent contact with extensionists" and "previous use of technical assistance" do not show a statistically significant impact on adoption. The variables representing the type and degree of extension assistance received by farmers through the project (field demonstrations, and short courses in this case) are not statistically significant at the 10-percent level either.

The former conflicts with the observation of Current, Lutz and Scherr that levels and types of extension-based technical assistance have an important influence on the adoption of agroforestry practices in Central America. The results of the present study do not imply that training and extension is unnecessary. The agroforestry project was a community-organized effort and, as in the case of the IPM project, all of the participating farmers received a basic level of instruction and support. The issue of what types of extension methods and intensities of training are necessary and economically justifiable, however, deserves more rigorous attention.

Land tenure shows a statistically significant impact on adoption; however, its predicted impact on the levels of adoption is a modest 17 percent. This is somewhat consistent with the conclusion of Current, Lutz and Scherr that, contrary to common beliefs, a lack of formal land title does not strongly influence the adoption of agroforestry practices. His explanation for this is that most farmers, in spite of not having formal title to their land, feel secure about their long-term rights.

The number of years of experience with forestry showed a statistically significant and empirically meaningful non-linear influence on adoption, which reaches a maximum at 12.5 years. Ten years of experience are predicted to increase adoption levels by more than 65 percent. This is also compatible with the conclusion of Current, Lutz and Scherr that most farmers in Central America assimilate agroforestry systems gradually over time, and that in most cases significant degrees of adoption are only observed after five to 10 years.

Access to credit does not show a statistically significant impact on the adoption of agroforestry practices in this case. This is consistent with the conclusion of Current, Lutz and Scherr that the access to formal lines of credit does not greatly impact adoption because most small-scale farmers do not use credit, especially for labor which is the major input in most agroforestry systems. However, it must be noted that most of the farmers in the Panama project received many of the required inputs (seed, fertilizers, tools, etc.) free, as an incentive for participation (Gómez).

The area of agroforestry systems desired in the future could be a proxy for the likelihood of adoption. It shows a positive but non-significant effect. The intensity of land use at the farm does not appear to be a limiting factor for the adoption of agroforestry system technologies in this case either. This variable has not been specifically evaluated in other studies. Farm size appears to have a positive effect

Table 4. Estimates, Asymptotic Standard Error Estimates and Significance Levels for the Parameters of the Poisson Count Regression Models of the Adoption of Soil Conservation Technologies in in the Río Las Cañas Watershed, El Salvador.

Soil Conservation Technologies			
Variable	Param. Est.	S.E. Est.	Sig. Lev.
Intercept	4.4224	0.1067	—
Number of years the farmer participated in project	0.0155	0.0093	+1**
Distance from the farm to the main road (kilometers)	−0.0089	0.0127	−1
Farm area under cultivation (hectares)	−0.0014	0.0019	−1
Number of working-age children in the farm family	0.0122	0.0041	+1**
Farmer's educational level (none/basic/advanced)	0.0121	0.0207	+1
Farmer's age (years)	−0.0162	0.0754	2
Age squared	0.0033	0.0186	2
Farmer works of the farm (1 = Yes, 0 = No)	0.0160	0.0237	−1
Farmer owns the farmland (1 = Yes, 0 = No)	−0.0408	0.0282	2
Farmer's access to hired labor (1 = Yes, 0 = No)	0.0159	0.0224	+1
Number of crops grown	0.0130	0.0081	+1*
Number of visits made by extension agents to the farm	0.0150	0.0142	+1
Number of incentives provided to the farmer	−0.0204	0.0175	+1

Note: Param. Est indicates the parameter estimate; *S.E. Est.* indicates the asymptotic standard error estimate; in *Sig. Lev.*, 1 or 2 indicates whether the alternative hypothesis was specified as one or two-tailed respectively; in the case of 1-tailed alternatives, + or − indicates the assumed sign of the parameter under the alternative hypothesis; ** and * indicate statistical significance at the 95 and 90 percent levels, respectively, according to asymptotic t-tests.

on adoption, although this cannot be concluded at the 10-percent level of statistical certainty. The apparently positive relation is consistent with the qualitative conclusions of Current, Lutz and Scherr.

Results: Adoption of Soil Conservation Technologies

The results of the Poisson Count Regression analysis of the factors influencing the adoption of soil conservation practices (Table 4) are discussed here and compared with related findings in the literature. These include bivariate evaluation of this same project (Melgar), a study on the adoption of soil conservation practices in Central America (Lutz, Pagiola and Reiche) and two site-specific studies in El Salvador (Sain and Barreto) and the Dominican Republic (Witter, Robothan and Carrasco). This study identifies three factors that have a statistically significant impact on the adoption of the soil conservation practices promoted by the Río Las Cañas project at the 10-percent level: the number of years participating in the project, the number of children in the farm family, and the number of crops grown.

Farmers participating for the entire four years of the project show adoption rates 5 percent higher than those of farmers participating only one year, which could be considered an empirically relevant change given that the average adoption level in this case is 80 percent. Using bivariate evaluations, which must be interpreted with caution (Judge *et al.*) Melgar and Sain and Barreto concluded that length-of-participation has a positive impact on the adoption of soil conservation practices. This factor is not explicitly discussed in Lutz, Pagiola and Carrasco.

The number of working-age children in the farm-families averages five and ranges from zero to 13. Every additional child in the family increases adoption rates by about two percent. This is explained by the need for labor to establish and maintain the labor-intensive soil conservation structures. Other studies have concluded that child labor is a valuable asset for a family in developing countries, which explains the high number of children per family. Lutz, Pagiola and Carrasco note that labor availability is a key determinant in the adoption of soil conservation practices.

The number of crops grown has a positive and statistically significant effect on adoption. The participating farmers were growing between one and six different crops, 2.5 on average. The difference in the expected adoption level for a farmer growing one crop versus one growing six crops is seven percent, which is an empirically meaningful increase from the observed average of 80 percent. Diversified cropping systems might be more compatible with the establishment and maintenance of soil conservation structures due to agronomic (soil management) reasons or because diversified systems are a longer-term economic investment than monocultures. This factor has not been discussed in the literature.

Only nine of the 72 farmers participating in the project were not the landowners (Table 1). They show slightly higher adoption levels. Participation in this project was encouraged but voluntary. Therefore, these nine farmers may have had a special motivation to improve the land they were farming. Some of them were granted land-usage rights by the landowners in exchange for establishing soil conservation structures (Melgar). This finding is consistent with the result in the agroforestry systems case study and Current, Lutz and Scherr's conclusion that land tenure does not foster adoption. Napier identifies land tenure as an important factor influencing the adoption of soil conservation practices in developing countries. In Central America, however, Lutz, Pagiola and Carrasco did not find evidence to support that hypothesis. They argue that the significant returns obtained from the investment in soil conservation in the short-run make the land-tenure consideration irrelevant.

Other statistically non-significant variables include the distance from the farm to the main road, the number of extension visits, farm size, the farmer's age and education, and the number and types of incentives provided. General literature on technology transfer in developing countries conceptually argues that these variables may influence adoption, depending on specific circumstances. Lutz, Pagiola and Carrasco conclude that the furnishing of incentives has increased adoption in some cases, but has decreased it in others, especially in the long run.

The time factor could explain why incentives are not associated with higher adoption in the present study. The furnishing of incentives may increase the likelihood of initial participation and, if distributed throughout the early stages of the project, as it was done in this case, keep unconvinced farmers involved. Soil conservation structures, however, demand continuous maintenance to avoid deterioration. The non-significance of incentives can be understood considering that more than 60 percent of the farms were evaluated three years or more after initiating participation. Furnishing temporary incentives does not appear to influence long-term adoption.

Conclusions and Recommendations

The application of multiple regression models specially designed to analyze the type of data usually encountered in technology adoption surveys in developing countries, specifically the Poisson Count Regression, allows for a statistically efficient and sound evaluation of the various complex factors affecting technology adoption by small farmers in these countries. Some general conclusions can be drawn from the three case studies analyzed as a whole. Participation in community organizations/farmer activities is positively related to technology adoption. Farmers that have previously adopted new technologies are more likely to do so again. Depending on the type of technology, factors such as access to credit, hired/family labor availability, education, farm size and the type of cropping system (including the degree of crop diversification) can also be important determinants of adoption. Depending on the situation, the farmer's age and experience with agriculture/forestry can have a non-linear effect on adoption, increasing it at first but eventually showing a detrimental impact on adoption rates.

The effectiveness of the extension services is an important and frequently debated issue in developing countries. Exposure to technical assistance (frequent contact with extensionists and number of visits made by extensionists) always showed a positive and, in two out of four cases, a statistically significant impact on adoption rates. Whether land tenure affects the adoption of improved technologies is another important and disputed question in developing countries. This variable also always showed a positive effect on adoption, which was statistically significant in three of the four cases analyzed.

The study finds mixed evidence about a third critical issue: the effectiveness of increased levels of training intensity on adoption. They appear to have no impact in the case of agroforestry systems, but the number of years participating in the soil conservation project significantly increased adoption. Receiving written extension materials showed a positive statistically significant impact on the adoption of IPM Technology "A", but the additional visiting of demonstrative plots did not, while the opposite was observed in the case of IPM Technology "B". The effect of this variable perhaps depends on the type and quality of the different levels of training offered in a given project and on the kind of technology that is being transferred.

Finally, the study concludes that a higher net farm income and the furnishing of incentives do not appear to have a positive impact on technology adoption. It is recommended that more research be conducted on the factors affecting the adoption of sustainable agriculture and natural resource management technologies using data from other well-documented projects and Poisson Count Regressions. Also, there is a need for research to assess the marginal costs and benefits of a select sample of prototype technology transfer projects from the many that are being carried out throughout the developing world. These projects are using an array of extension strategies combining multiple techniques that imply widely different degrees of training intensity and per-unit costs, without any information about the corresponding marginal benefits.

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