Chapter 16

Agroforestry Adoption By Smallholders

D. Evan Mercer and Subhrendu K. Pattanayak
USDA Forest Service and Research Triangle Institute

Agroforestry is a joint forest production system whereby land, labor, and capital inputs are combined to produce trees and agricultural crops (and/or livestock) on the same unit of land. Although existing for centuries (maybe millennia) as an array of traditional land use practices in the tropics, agroforestry emerged in the late 1970s as a modern, improved tropical land use system suitable for scientific study, replete with its own international research center, the International Center for Research in Agroforestry (ICRAF) and journal, Agroforestry Systems. During the 1990s, interest in agroforestry in temperate regions increased rapidly when the scientific community discovered the complex land management systems developed by rural landowners in North America and Europe, including forest farming, alley cropping, shelterbelts, riparian buffers, and silvopastural systems (Lassoie and Buck 1999).

Despite some impressive scientific and technological advances, agroforestry rural development efforts in the 1980s and 1990s were frequently unsuccessful (Nair 1996). Although agroforestry projects failed for a number of different reasons, one common factor was the inadequate attention given to socioeconomics in the development of systems and projects (Current et al. 1995). Beginning in the mid-1990s, agroforestry leaders argued for increased emphasis on research to understand the agroforestry adoption decision process (Mercer and Miller 1998, Sanchez 1995). For example, former Director General of ICRAF, Pedro Sanchez (1995: 24), stated that "the need to develop predictive understanding of how farm households make decisions regarding land use is as essential as developing a predictive understanding of the competition between tree and crop roots."

Sills and Abt (eds.), Forests in a Market Economy, 283–299.

As a result, agroforestry adoption studies have proliferated recently (Pattanayak et al. [forthcoming]). Most of these studies use dichotomous choice (logit or probit) regression models to explain how various characteristics of farmers, farms, and development projects influence the adoption decision. Unfortunately, many of these recent studies fail to link their empirical analyses to underlying theory. Rather, they often just report a number of factors that are correlated with adoption of specific technologies in specific locations, which does little to promote a general predictive understanding of the farm household decision-making process.

In this chapter, we develop a model of the adoption decision process using microeconomic theory and illustrate its econometric application with two case studies in the Philippines and Mexico. These case studies examine different types of agroforestry systems in sites that contrast ecologically, socially, and culturally.

1. REVIEW OF EMPIRICAL STUDIES ON AGROFORESTRY ADOPTION[1]

A large and growing literature addresses the adoption of agricultural technologies and technological change as engines for economic development. Examples include the seminal survey by Feder et al. (1985) and a recent study of sustainable agricultural intensification by Clay et al. (1998). More recently, the study of agroforestry adoption has intensified as governments, donor agencies, and scientists search for technologies that will be adopted by farmers to generate economic growth while protecting ecological capital. Consequently, we draw on the general technology adoption literature to identify clusters of factors that empirically explain adoption behavior and compare these to recent empirical analyses of agroforestry adoption.

The broader literature reveals five categories of determinants of technology adoption: economic incentives, biophysical conditions, risk and uncertainty, household preferences, and resource endowments. These are not mutually exclusive because of correlation and complementarity between factors within categories and because different empirical applications often use the same variables to proxy different factors. In addition, researchers have developed conflicting conceptual and empirical arguments regarding the way in which several variables (e.g., plot size and tenure) influence adoption. For each of the five general categories, we discuss the expected direction of influence, based on our review and summary of 26 empirical analyses of agroforestry (for details see Pattanayak et al. [forthcoming]). We then use this information to develop a stylized economic model of farmer adoption in section 2.

1. Market incentives (*I*) include factors that explicitly lower costs and/ or produce higher benefits from technology adoption and as such are the standard economic determinants of adoption. The empirical literature suggests that adoption is positively influenced by variables such as expected yield increases and share of income from farming. Unfortunately, explicit market data such as prices are lacking in most analyses. Often market data are absent because the studies focus on subsistence economies where markets are thin and proxies for price are usually not available, or the studies are so limited geographically and/or temporally that there is little variability of the available market data among respondents.
2. Biophysical conditions (*Z*) such as soil quality, steepness of farmland, and plot size influence the physical production process. Since these conditions directly impact production costs and returns, they are implicitly economic determinants of adoption. Our review shows that adoption is more likely on farms with steep plots. As in much of the broader literature, the correlation with plot size is ambiguous, perhaps because of the confounding influence of scale economies and resource constraints. Based on the few studies that have included soil quality variables, we see a similar ambiguity. Again, this might reflect the desire to protect good-quality land being confounded by complacency because of sufficient soil resources.
3. Risk and uncertainty (*R*) relates to the market and institutional environment under which decisions are made. Short-term risk (e.g., fluctuations in commodity prices and rainfall) and long-term risk (e.g., tenure insecurity) influence the adoption decision and process. Our review shows an unambiguous and consistent result for the tenure variable: landowners are more likely than tenants to adopt agroforestry and other conservation technologies. We also found that previous experiences and familiarity with agroforestry/conservation investment projects, possibly because of information disseminated through extension services or community group membership, were positively correlated with adoption.
4. Household preferences (*H*) are a placeholder for the broad category of household-specific influences such as risk tolerance, intrahousehold homogeneity, and conservation attitude. Since preferences are difficult to measure explicitly, they are usually proxied with sociodemographic variables such as age, gender, and education. Our assessment of the literature shows adoption is more likely in a household with a higher education level and greater proportion of males. The male effect could

reflect the endowment effect discussed next. By and large, age is an insignificant explainer of adoption.

5. Resource endowment (L) measures the decision makers' abilities to employ resources necessary for implementing the technology. Asset holdings and wealth measures such as land, labor, livestock, and savings are examples of resource endowments. Our review shows the consistent and unambiguous positive influence of wealth on agroforestry adoption and conservation investments.

2. THEORY OF FARMER ADOPTION

Using household production theory as a conceptual framework (Amacher et al. 1993, Pender and Kerr 1998) and the five broad determinants of adoption discussed above, we develop a model of agroforestry adoption as an investment choice. Consider a representative farm household that maximizes its utility, U, which is assumed to be a concave, continuous, twice-differentiable function of agricultural commodities, Q_C, (e.g., rice/corn) and household time inputs, Y_C (e.g., leisure). The function is conditioned by household preferences that are proxied by sociodemographics, H. Utility maximization is subject to three constraints (time input endowment, technology, and cash income). The household time input constraint implies that the sum of own input supply of time, Y_P (labor), and own input consumption of time, Y_C (leisure), cannot exceed the household time endowment, Y_E, which is conditioned by household characteristics, H.

Agricultural outputs, Q_P, are assumed to be a convex, continuous production function, F, of Y_P. Productivity depends on household resource endowments, L, such as land, tools, money, human capital, and economic incentives provided by the government, such as subsidies. The biophysical characteristics of the farm, Z, also mediate the production technology. A typical cash constraint requires household expenditures on agricultural commodities and inputs to be less than or equal to the sum of agricultural profits, π, which depend on market prices, P_Y, and exogenous income, E. The household's budget constraint combines a typical cash income constraint with the endowment constraint such that expenditures are equal to the sum of the monetary equivalent of the household input endowment, agricultural profits, and exogenous income; this sum is the "Beckerian" full income (Strauss 1986).

Following Amacher et al. (1993), adoption of agroforestry requires joint investments of money, labor, and land to acquire agroforestry capital. That is, labor and money are collectively embodied in the amount of land dedicated to agroforestry. As described above, this joint investment is conditioned by the resource endowments and biophysical conditions faced by the household. Agroforestry (L_{AF}) can therefore be conceived as one among many sets of coordinated investments that produce an annual rate of return, r, to enhance overall well-being. Since the returns to agroforestry occur in the future, households consider the expected stream of income net of consumption (I) or the market-based incentives, in choosing between alternate investments. These expectations are based on the household's assessment of the relative importance of agroforestry income to total farm income, which depends on risks and uncertainty, R, in the short and long terms. Mathematically, the household's utility-maximization problem is expressed with the Lagrangian in equation 16.1.

$$\begin{aligned} Max\ E\{[U(Q_C, Y_C; H) \ &+\ \lambda(\pi + E - P_Y Y_P - rL_{AF}) \\ &+\ \mu(Q_P, Y_P; L_{AF}, Z) + \eta(Y_E - Y_C - Y_P)], R\} \end{aligned} \qquad 16.1$$

The objective is to maximize expected utility by choosing levels of inputs (including land) and outputs. The first-order conditions with respect to Q_C, Y_C, Q_P, Y_P, and L_{AF} have the standard Marshallian equimarginal interpretations when households choose the level of agroforestry technology that maximizes total utility.

Consider the choice facing household i when deciding whether to adopt agroforestry. The utility-maximizing household compares its expected net utility with and without adoption (EU_i*). A reduced form version of this net utility is given by equation 16.2:

$$EU_i^* = \alpha_I I_i + \alpha_L L_i + \alpha_R R_i + \alpha_Z Z_i + \alpha_H H_i + \varepsilon_i \qquad 16.2$$

where I_i, L_i, R_i, Z_i, and H_i are as defined above. Note that I_i captures market incentives because net income is a function of explicit and implicit prices of outputs and inputs of the agroforestry process. Since the true net utility function is unknown, we treat the estimated function as random by including the error term ε_i.[2] Although EU_i* is not directly observable, the researcher can observe the owner-manager's adoption decision. Let L_{AFi} be an indicator of whether the household i adopts agroforestry ($L_{AFi} = 1$) or not ($L_{AFi} = 0$), so that

$$L^*_{AFi} = 0 \text{ if } EU_i^* \le 0 \quad and \quad L^*_{AFi} = 1 \text{ if } EU_i^* > 0 \qquad 16.3$$

Depending on the assumptions regarding the distribution of the error term in equation 16.2, this structural relationship can be estimated using a variety of methods. In most analyses of binary choice data, probit or logit models are estimated assuming either a normal or logistic distribution, respectively, for the error term (Maddala 1983). That is,

$$\text{Prob}(L^{*}_{AFi} = 1) \quad = \quad \Phi(\alpha_I I + \alpha_L L + \alpha_R R + \alpha_Z Z + \alpha_H H) \qquad 16.4$$

where $\Phi(.)$ is the cumulative distribution function and I, L, R, Z, and H are the explanatory variables in equation 16.2 and α is a vector of parameters to be estimated. Although one might expect different predictions from the logit and probit models for samples with very few positive responses for the dependent variable ($y = 1$), or very few nonresponses ($y = 0$) and very wide variation in important independent variables, usually the two models produce similar results. In fact, little theoretical justification exists for choosing between the probit and logit models (Greene 1997). To investigate the determinants of agroforestry adoption, our two case studies empirically estimate equation 16.4 with binary adoption data from the Philippines and Mexico with probit (Philippines) and logit (Mexico) regression models.

3. EMPIRICAL ANALYSES OF AGROFORESTRY ADOPTION

We present two case studies of adoption of tree planting by small farmers in the Philippines and Mexico as examples of using empirical analysis to test the predictions of the theory of adoption. These case studies provide ecological, social, and cultural contrasts as well as contrast in the types of agroforestry systems being promoted. For example, land is a major constraint for Filipino farmers, with an average farm size of 2.63 ha on steeply sloped land, resulting in high erosion rates under traditional agricultural systems. In Mexico, however, the absolute amount of land is not a constraint because the average farm size is 48 ha on relatively flat slopes. Inadequate and highly variable rainfall and very thin, poor soils are major ecological constraints to corn-based agricultural production in the Mexico site. Labor, seeds, seedlings, and fertilizers constrain production in both Mexico and the Philippines. Thus, the main objective for the agroforestry projects in the Philippines was erosion control to facilitate long-term agricultural production from small, steeply sloped plots, and in Mexico, the primary objectives were to develop systems to reduce farm production risk, improve total farm productivity, and reduce pressures on natural forests.

The Philippines case study examines the factors influencing farmers' decisions to adopt contour hedgerow systems, a form of alley cropping, to reduce the negative impacts of soil erosion. Contour hedgerows are a set of agroforestry practices in which food crops are planted between hedges of woody perennials established along the contours of sloping upland farm plots. Prunings from the hedgerow trees or shrubs are placed at the up-slope base of the hedges to trap the eroding soil so that over time natural terraces are formed. The hypothesized benefits of contour hedgerows are erosion control, enhanced soil nutrient availability, weed suppression, and enhanced fuel and fodder production. However, the hedgerows may also produce increased demand for scarce labor and skills, loss of annual cropping area, difficulty in mechanizing agricultural operations, and excessive competition with the crops for soil nutrients, light, and water (Nair 1993).

In the Mexico case study, low and sporadic corn production with traditional *milpa* (slash and burn) systems on thin soils and inadequate rainfall led to the search for tree-based systems to improve long-term productivity and reduce the risk of catastrophic agricultural failure. Hence, this study examines factors influencing farmers' decisions to plant trees in a variety of different systems. Projects offered timber trees and/or fruit trees to farmers who agreed to plant the trees in association with agricultural crops in 1 hectare agroforestry plots (Snook and Zapata 1998). The projects' objectives were to provide short-, medium-, and long-term production, starting with annual crops, followed by fruits and finally timber.

3.1 The Philippines: Leyte in the Eastern Visayas

Two villages, Visares and Cagnocot, on the island of Leyte, Eastern Visayas, were the sites for the Philippines case study. Both sites are hilly and subject to significant erosion. Visares has a pronounced maximum rainy period in December but no dry season, while Cagnocot receives even rainfall throughout the year except for the dry months of February to April. The soils are acidic, varying from sandy loam to extremely clayey. Ipil-ipil (*Leucaena leucocephala*) and kakawate (*Gliricidia sepium*) are the two primary tree species used as hedgerows. Both communities engage in fishing, carpentry, and other nonfarm activities, and Visares has a rudimentary rattan furniture industry introduced by a U.S. Agency for International Development project. The Philippines data were collected in 1993 and 1994 through a socioeconomic survey of 277 agricultural households. Two questionnaires, one on socioeconomic and agronomic characteristics and the other on farm budgets, were administered to each household. Descriptive statistics for the Philippines case study are in table 16.1. The average farm covered 2.63 ha sitting on a 28% slope and produced an annual income of 10,500 pesos (US$402), accounting for 58% of total household income. The average education across household members was 2 years. The head of the average farm household had lived in the village for 33 years. While 66% of respondents had planted trees on their farms, only 31% had previously constructed contour hedgerows. Sixty two percent of the respondents reported owning the plots they farmed.

Table 16.1. Descriptive statistics for Philippines case study (n = 277)

Variable Description	Mean	Standard Deviation
Average education (years)	1.90	1.17
Number of labor days in farming	83.30	88.2
Annual agricultural profits (US$)	402.00	617
Percent of income from farm agriculture	57.70	34.0
Farm size (ha)	2.63	3.47
Made contour hedgerows on your farm? (yes = 1, no = 0)	0.31	0.47
Ever planted trees on farm? (yes = 1, no = 0)	0.66	0.48
Heard of contour hedgerow farming? (yes = 1, no = 0)	0.77	0.42
Received training in contour hedgerows (yes = 1, no = 0)	0.19	0.39
Extent of assistance from project official [a]	0.10	0.20
Steepness of farmland (degree)	28.6	15.7
Length of residency in the village (years)	33.0	15.5
Distance from home to fields (minutes)	18.5	23.5
Tenant? (yes = 1, no = 0)	0.38	0.43
Member of farmer or community development group (yes = 1, no = 0)	0.50	0.66

[a] The extent of assistance is measured as the normalized sum of dummy variables where each dummy measures the receipt of one of four types of assistance (cash, technical information, labor, and seeds) from project staff.

3.2 Mexico: Calakmul Biosphere Reserve, Campeche

This case study site is located in the buffer zone of the 723,000-ha (1.7 million-acre) Calakmul Biosphere Reserve in southeastern Campeche, Mexico. Contiguous with the Maya Biosphere Reserve in Guatemala, the Calakmul Biosphere Reserve was created in 1989 to protect the last great frontier in Mexico to which Mexicans continue to migrate in search of land for farming. The Calakmul region comprises a municipality (Calakmul), the core bioreserve area where settlement is prohibited, a buffer zone of 72 communities (15,000 inhabitants), and a few privately owned properties (Bosque Modelo 1997). In the communities, called *ejidos,* each member family has equal rights to the use of communal forest and agricultural lands. *Ejidos* vary in size from 100 to 50,000 ha and from 10 to 150 members. The allotment for each family's agricultural use varies from 25 to 50 ha. Communal forest areas vary from 250 to 25,000 ha per *ejido*.

Data were collected in winter of 1998 via in-person interviews of a stratified random sample (by *ejido*) of farmers in the buffer zone of the Calakmul Biosphere Reserve. The final sample consisted of 176 farmers in 15 separate *ejidos*. Casey et al. (1999) provide details on field logistics and data gathering. Descriptive statistics for the variables used for the analysis of the Mexican case study are in table 16.2. The average farmer is 38 years old with 4 children and an annual income of US$1,510. The education level of the farmers is very low; 60% had not finished primary school, only 29% had finished primary school, and only 11% had finished secondary school. Ninety-four percent of respondents immigrated to Calakmul from outside the state of Campeche, with the average farmer having immigrated to Calakmul 11 years ago. The average farmer received 48.2 ha of land on joining the *ejido*, 39.7 ha of which was originally under primary forest cover and 8 ha under secondary fallow. Farmers had harvested an average 9.9 ha of forests with an average 28 ha currently under forest cover, 19 ha under fallow, and 4.8 ha in *milpa*. While 67% of respondents had established an average of 1.27 ha of nonagroforestry tree plantings since joining the *ejido*, only 31% (55) reported establishing agroforestry systems on an average plot size of 1.15 ha. Forty-seven percent of respondents had previous experience with an agricultural or forestry development project, and 79% reported an interest in participating in future agroforestry development projects.

Table 16.2. Descriptive statistics for Mexican case study (n = 176)

Variable description	Mean	Standard Deviation
Age of farmer (years)	38.31	13.76
Secondary education (1 = yes; 0 = no)	0.11	0.31
Total farm income (US$/year)	$1510	$1638
Timber income (US$/year)	$118	$486
Immigrant from outside Campeche (1 = yes; 0 = no)	0.94	0.23
Length of residency in Calakmul (years)	10.97	6.33
Distance to fields from house (km)	2.81	2.22
Farm size (ha)	48.16	25.25
Non-agroforestry tree plantings (ha)	1.27	2.54
Forestry experience (1 yes; 0 = no)	0.29	0.46
Previous project experience (1 = yes; 0 = no)	0.47	0.50
Interest in planting more trees (1 = yes; 0 = no)	0.79	0.40

3.3 Empirical findings

3.3.1 Leyte, Philippines: Building Contour Hedgerows

The results of the probit analysis for contour hedgerow adoption are presented in table 16.3. The dependent variable is the probability of being a contour hedgerows adopter (0 = nonadopter, and 1 = adopter); 86 respondents (31%) had constructed hedgerows (y = 1). The overall model fit the data well as indicated by the high χ^2, Veall-Zimmerman pseudo R^2 statistics, and the percentage of correct predictions (84%). The signs of statistically significant regressors have theoretical and intuitive appeal. Statistical significance of variables can be determined by studying the probability values (p-values) reported in column 3. The marginal effects (or probabilities) on adoption from a unit increase in independent variables (calculated at the means) are reported in column 4.

Table 16.3. A probit model of agroforestry adoption in Leyte, the Philippines (n = 277)

Variable	Coefficient	P-Value	Marginal Effect
Constant	-2.83	0.000	-0.721
Ever planted trees on farm? (yes = 1, no = 0)	1.87	0.000	0.365
Heard of contour hedgerow farming? (yes = 1, no = 0)	0.46	0.137	0.104
Percent of income from farm agriculture	0.53	0.143	0.134
Distance from home to fields (minutes)	-0.01	0.034	-0.003
Steepness of farmland (degree)	0.01	0.092	0.003
Length of residency in the village (years)	-0.02	0.031	-0.004
Tenant? (yes = 1, no = 0)	-0.67	0.029	-0.169
Labor in farming (days)	0.002	0.087	0.001
Average education of household head	-0.01	0.905	-0.003
Received training (yes = 1, no = 0)	1.72	0.000	0.569
Member of community group (yes = 1, no = 0)	0.28	0.106	0.072
χ^2 (11) statistic	159	0.000	
Veall-Zimmerman pseudo R^2	0.66		
% Correctly predicted	84		

Those households that have historically planted trees on their own farms and are familiar with agroforestry are more likely to adopt. Households which earn a greater percentage of their income from agriculture and which live closer to their agricultural fields are more likely to adopt. Agroecological needs also influence the adoption choice, and we find that households farming steeper lands are more likely to adopt. The length of residency indicates that households that have lived in the area for a long time are less likely to adopt. The coefficient on the tenant variable shows that tenants are less inclined to make long-term soil conservation investments. Labor endowments, proxied by the number of days in farming, are positively correlated with the adoption choice.

We do not find a significant relationship for education, possibly due to limited statistical variation in our sample. If a household received training in making hedgerows, it is very likely to adopt agroforestry. The variable indicating membership in community organizations is positively related with adoption. To the extent that community organizations provide information on new technologies and infrastructural support, membership in such groups and direct training should encourage adoption. Finally, as in many rural development projects, greater project assistance appears to have a substantial impact on the adoption of agroforestry technology. Unfortunately, project assistance is correlated with other variables, such as tenant and training, and causes interpretation problems due to multicollinearity.

We do not report the model with the assistance variable (see Pattanayak and Mercer 2002), but do find that it is positively correlated with adoption. In other results not reported here, prices of outputs (banana and corn) and inputs (labor and seed) were not statistically correlated with the adoption decision. This may be due to inadequate variability in prices. Looking across the column of marginal probabilities, we find that familiarity with the technology, either through previous personal experience with planting or through training by extension agents, has the highest impact on the probability of adoption. This suggests that efforts to minimize the uncertainty regarding new technologies may have significant payoffs.

3.3.2 Campeche, Mexico: Planting Timber and Fruit Trees

Table 16.4 presents the results of the maximum likelihood estimation of the logit regression model. The dependent variable, whether or not the farmer had established an agroforestry system, is regressed against the list of explanatory variables in table 16.2; 55 of the 176 respondents (31%) had established an agroforestry system ($y = 1$).

The χ^2 (12) statistic and pseudo R^2 suggest that the estimated model fits the data reasonably well; 74.43% of all responses were predicted correctly. Statistical significance of variables is identified by the p-value (probability value) reported in column 3. The effects of the independent variables on the logit or log odds of adopting agroforestry are reported as odds ratios in column 4.[3]

Six variables are significant at or below the 5% level (farm income, distance to fields, immigrant, previous project experience, nonagroforestry tree plantings, and interest in planting more trees). Age, education, and farm size are significant at the 6% to 11% level. Timber income is significant at the 18% level. The length of residency in Calakmul is not significantly different from zero. Signs for all variables are intuitively credible, with higher probabilities of adoption being positively correlated with age, education, income, length of residency, forestry experience, previous agricultural or forestry project experience, and interest in more tree planting. The greater the distance that farmers have to walk to their fields, the larger the income from timber harvesting, the larger the farm size, and the more hectares in tree plantations, the less likely that farmers will adopt agroforestry. Immigrants from outside Campeche also have a lower probability of adopting agroforestry than those immigrating from inside Campeche.

Table 16.4. Logit regression model of agroforestry adoption in Campeche, Mexico

Variable	Coefficient	P-value	Odds Ratio
Constant	-0.119	0.927	—
Age of farmer (years)	0.026	0.078	1.026
Education (1 = secondary; 0 = no secondary)	1.039	0.106	2.827
Immigrant (1 = yes; 0 = no)	-2.380	0.004	0.092
Length of residency (years)	0.0113	0.727	1.011
Total farm income	0.0004	0.029	1.000
Timber income	-0.0002	0.179	0.999
Size of farm (ha)	-0.018	0.073	0.982
Distance to fields (km)	-0.244	0.018	0.784
Non-agroforestry tree plantings (ha)	-0.161	0.046	0.851
Interest in planting more trees (1 = yes; 0 = no)	1.073	0.051	2.924
Forestry experience (1 = yes; 0 = no)	0.638	0.123	1.893
Previous project experience (1 = yes; 0 = no)	0.878	0.024	2.407
χ^2 (12) statistic	41.20	0.0000	
Pseudo R^2	0.189		
% Correctly predicted	74%		
N	176		

4. CASE STUDY FINDINGS IN CONTEXT

Next, we examine the results from the two case studies in the context of the categories of factors influencing adoption identified in the literature in section 1 and theory in section 2.

1. Market Incentives. In both the Philippines and Mexico studies, higher farm incomes are positively correlated with adoption. Likewise, in both case studies, increasing distance from home to fields results in lower probability of adoption, since increasing distance to fields increases the cost of adopting the new technology. Although only significant at a p-value of 18%, increasing income from timber harvests in Mexico is negatively correlated with agroforestry adoption. Unfortunately, in both case studies as in most agroforestry adoption studies, market data was either unavailable or insufficiently variable to be included in the analyses.

2. Biophysical Conditions. In the Philippines study, the steepness of farmland is significantly and positively correlated with adoption. In the Mexico case study, since there is very little variation in the biophysical conditions facing respondents, they are not included in the empirical modeling.
3. Risk and Uncertainty. Tenure is usually a very strong predictor of adoption, because lack of tenure suggests a risk of not being able to reap the long-term benefits from installing agroforestry systems. In the Philippines, respondents who did not own the land they were farming were significantly less likely to adopt agroforestry than owners. In Mexico, since all farmers operate under the same community (*ejido*) tenure system, tenure was not a variable. Several variables are associated with reducing uncertainty of new technologies. In the Philippines these variables include previous experience, knowledge, membership in community groups, training, and assistance, all of which significantly raised the probability of adoption. In Mexico as well, previous experience with rural development projects and with forestry are significant and positive as predicted.
4. Household Preferences. Different cultural, educational, and life experiences are expected to lead to different preferences for investing in new production methods, and we observe stark differences between the Philippines and Mexico in this category. In the Philippines, education is insignificant, but the length of residency in the village is significant and positive. In Mexico, however, education is significant at the 10% level and positively associated with adoption, while length of residency was insignificant. In addition, the age of Mexican farmers is significant and positively related to adoption. Immigrants from outside of Campeche are significantly less likely to adopt a new technology like agroforestry, perhaps reflecting increasing risk aversion for more distant immigrants. The impact of immigrant status on adoption suggests that the people of the Campeche share a knowledge base of the local soils, plants, and climate and generally adopt a modified version of the autochthonous natural resource management system common throughout the area.
5. Resource Endowments. In the Philippines, the proxy for labor endowment is positively and significantly correlated with adoption. Moreover, assistance, which included cash allowances, also increases the probability of adoption. In the Mexico study, two measures of land endowments—the total size of the farm and the size of nonagroforestry tree plantings—are both significant and

negatively related to likelihood of adoption. Farmers who control more land and who have planted more hectares in trees appear to perceive less need to adopt more intensive land use systems like agroforestry.

5. CONCLUSIONS

In this chapter, we develop a theoretical model of agroforestry adoption based on neoclassical economics, household production theory, and a review of the literature of empirical studies of adoption of agricultural and agroforestry innovations. The literature review reveals five general categories of factors shown to influence agroforestry adoption: market incentives, biophysical conditions, risk and uncertainty, household preferences, and resource endowment. We test these factors with two empirical case studies. In the Philippines study, we use a probit model to examine adoption of contour hedgerows on steep slopes to reduce the high erosion rates associated with traditional agricultural practices. In the Mexican case, we use a logit regression model to analyze adoption probabilities on flat land with very thin, poor soils and inadequate and sporadic rainfall. The results of the case studies confirm many of the predictions from the theory developed in section 2 and the literature review in section 1.

The literature review and our case studies also reveal several concerns with the recent studies on agroforestry adoption behavior. First, the majority of empirical studies examine agroforestry adoption as a snapshot in time, whereas agroforestry adoption is a dynamic process that occurs over a long time period as farmers experiment with agroforestry, incorporate it into their farming enterprise, or abandon it all together. Seldom will all households adopt any technology, even over the longest time period. Therefore, the adoption process might be modelled as a logistic or sigmoid function of time, with the rate of adoption and the final level of adoption as critical variables. The adoption studies to date (including the case studies in this chapter) only provide information on which farmers adopt agroforestry early on and can only show us which households to begin with when introducing new projects or programs. However, understanding the rate of adoption over time and the final expected level of adoption is necessary for assessing the potential benefits of new projects or programs. Unfortunately, we are unaware of any empirical research that rigorously analyzes the time dimension of adoption for agroforestry. This is likely due to the lack of data sets with adequate time series.

Second, the majority of adoption studies are limited in scope geographically as well as temporally. Like our case studies, most adoption studies are limited to a small number of sites within a limited geographic area. This is one of the factors limiting the inclusion of market data in many analyses, such as the case studies presented here. To really understand the adoption process, we need studies that compare adoption across a wide variety of communities that vary culturally, ecologically, and economically. Unfortunately, conducting surveys over extended geographic areas is costly and time consuming. An alternative approach is to use meta-analytic methods to analyze a large group of previous studies that as a group provide the needed variation (Cook et al. 1992).

Third, returning to a point made by Feder et al. (1985), if the technology is nondivisible, it takes on a dichotomous form at the individual level and a continuous form at the aggregate. For a divisible technology, the measure of adoption will likely be continuous and include examples such as the amount or share of farm area utilizing the technology. However, except for a study by Caviglia and Kahn (2001) that employs a Heckman selection model of agroforestry adoption, most studies typically estimate dichotomous data models and do not tackle the extent of adoption.

Fourth, the majority of recent studies (including our two case studies) apply standard logit or probit methods to the binary adoption data. Yet, a variety of alternative econometric techniques are available that apply different estimation approaches (such as linear probability, generalized method of moments) and/or make fewer assumptions about the distribution of the error term or about the estimation process (such as semi- and nonparametric approaches). It remains to be seen whether the results of agroforestry adoption studies are robust to the econometric methods applied.

Finally, recent studies have explored the usefulness of stated preference methods such as conjoint analysis to examine how and why farmers choose different types of agroforestry systems (Casey et al. 1999, Zinkhan et al. 1997). While most studies use past behavior (or binary adoption data) as a predictor of future adoption, the stated preference methods are well positioned to evaluate *ex ante* plans for tree planting. Collectively, these points indicate that additional study is needed to analyze the robustness of agroforestry adoption models to the analytic and econometric methods employed.

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[1] This review draws from ongoing research conducted by the authors and collaborators. We started with a set of 56 articles on adoption of agricultural and forestry technology by smallholders. Ultimately, based on the criteria of (1) empirical analysis and (2) focus on agroforestry and soil-water conservation investments, we narrowed our list down to 26 studies. The details of our meta-analytic review are presented in Pattanayak et al. (forthcoming).

[2] Randomness exists potentially because of unobserved attributes, instrumental variables, measurement errors, and taste variations (see Feather and Amacher 1994).

[3] Each additional increment of the independent variable increases the odds of adoption by $e^{(\beta)}$. These values are calculated as odds ratios: the amounts by which the odds favoring adoption ($y = 1$) are multiplied with each 1-unit increase in that independent variable assuming all other independent variables remain constant.