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Abstract

Community-based management (CBM) of village poultry aims to foster development and reduce poverty in Benin by disseminating five technologies for improving village poultry farming. We develop a theoretical model to analyze multiple technology adoption decisions that takes into account the interrelations between the technologies. Estimates from multivariate probit models indicate significant interrelations between the five adoption decisions. We show how the estimation results, and particularly the different types of marginal effects, can be utilized to deeply analyze the interrelations between adoption decisions. CBM successfully promoted the adoption of various technologies. Some adoption decisions indicate farmers' general openness towards new technologies.

Key words: Community-Based Management, Technology adoption, Multivariate probit, Village poultry, Benin, West Africa.

JEL codes: Q12, Q16, C31, C35, O13, O14

1. INTRODUCTION

Village poultry, also termed traditional poultry, is a widespread traditional activity in most developing countries, and a significant source of meat and protein. Indeed, more than 90% of rural families in developing countries, including the poor and landless, keep at least one poultry species (i.e. chickens, ducks, guinea fowl, geese or pigeons, see Gueye, 2005 and Mack *et al*., 2005). The production process is usually rudimentary with partial or total scavenging and minimal care (no vaccination, little or no feeding, etc.). Accordingly, productivity is very low (growth rates, number of eggs per hen, quantity of meat, etc.). For instance, in Benin, the average productivity of local hens is 50 eggs per year with an average weight of 40 g compared to 220 eggs with an average weight of 60 g for hens of modern breeds (DE/MAEP, 2008).

Despite its low productivity, village poultry plays an important role in income generation and poverty reduction. Indeed, various impact studies in South Asia have demonstrated that the income from the sale of poultry products is used to finance children's schooling and to begin the process of asset accumulation (Alders & Pym, 2009). In Benin, village poultry enables farmers to overcome times of hardship during the annual cycle, when the garners are empty, by selling poultry in order to buy cereals for family consumption (Gbaguidi, 2001). Income from the sale of poultry products also facilitates investments in other business enterprises (e.g. food processing, crop production) and in other livestock such as small ruminants and cattle (Clarke, 2004). Recognizing this role, the government of Benin and various development agencies (e.g. the Danish International Development Agency) have supported the modernization of traditional village poultry production. The projects implemented for this purpose mainly rely on the community, where the community represents all village dwellers regardless of their ethnic group or religion.

This community-based management (CBM) of traditional poultry is an approach that involves the installment of a "village poultry interest association" in each "experimental" village, i.e. a village that participates in CBM. The members of these associations often hold weekly meetings either to receive training in some basic techniques of poultry management, or to exchange their experience, especially regarding problems in poultry farming as well as their solutions (Sodjinou *et al*., 2012). Two members of each association, selected on the basis of their educational level and reputation within the community, received training in the techniques of poultry vaccination and treatment against major diseases. The role of these two members, named ‘village poultry vaccinators’ (VPVs), is to compensate for the lack of private or state veterinarians who are often less interested in village poultry farming (see Sodjinou *et al*., 2012).

By focusing on CBM, development agencies aim to help villagers to think together and to share their experiences of poultry production. By doing so, projects are expected to encourage changes in the farmers’ behavior regarding village poultry farming, notably the adoption of technologies that improve productivity such as poultry vaccination, the construction of henhouses and chick-houses using locally available materials, the use of improved or supplementary feed, and improved cockerels. The ultimate goal is to move village poultry farming from the rudimentary level to a stage where it can play an important part in the generation of income for rural households.

However, the introduction of these new technologies was only partially successful. Indeed, some of them (e.g. henhouses) were widely used by poultry keepers, while others (e.g. improved cockerels) were not very successful. The successful and efficient dissemination of the technologies requires detailed knowledge about the factors that hamper or encourage the farmers’ adoption decisions. This information is important in order to be able to prioritize the measures within CBM programs and to gain an insight into ways to increase the awareness and use of village poultry improvement technologies. Hence, the objective of this study is to analyze the effects of socioeconomic and institutional factors, including community-based management, on the adoption of these technologies.

When farmers face multiple innovations, they consider the way these different technologies interact and take these interdependencies into account in their adoption decisions (Velandia *et al*., 2009). Ignoring these interdependencies can lead to inconsistent policy recommendations (Marenya & Barrett, 2007). Hence, we develop a theoretical model of technology adoption decisions that takes the interrelations between these technologies and the adoption decisions into account and we show how this model can be econometrically estimated. In contrast to most previous studies that analyze technology adoption decisions separately, we analyze all five adoption decisions simultaneously using the multivariate probit method. This not only improves the precision of the estimation results and provides consistent standard errors of the estimates, but also enables us to analyze the interrelations between the five adoption decisions. We show how the estimation results, and particularly the estimated correlation coefficients and the various types of marginal effects, can be utilized to gain a deep insight into the interrelations between the different adoption decisions. In fact, we are the first to demonstrate how the various types of marginal effects for multivariate probit models can be used to obtain detailed information on the interrelations between technology adoption decisions.

The following section describes the methodology. Section 3 presents a descriptive analysis of the qualitative and quantitative data obtained in this study. The results of the multivariate probit model are presented, interpreted, and discussed in section 4. The paper ends with section 5, which presents some conclusions and implications.

2. METHODOLOGY

2.1. Modeling the adoption of village poultry improvement technologies

Two types of technology adoption exist, namely individual (farm-level) adoption and aggregate adoption (Feder *et al*., 1985). This study targets the adoption of village poultry improvement technologies at the farm-level, where the adopter of a given technology is the person who is using the technology at the time of the survey (i.e. agricultural campaign 2008-2009). The adoption of the following five different technologies was analyzed: vaccination, improved feeding, the construction of henhouses and chick-houses, and improved cockerels.

When it comes to the adoption of a new technology, farmers are faced with choices and tradeoffs. Differences in adoption decisions are often due to the fact that farmers have different cultures, different resource endowments, different objectives, different preferences, and different socio-economic backgrounds (Tambi *et al*., 1999). It follows that some farmers adopt the new technology while others do not. In such a context, farmers' decisions regarding the adoption of innovation can be explained using the theory of the maximization of expected utility. Following this theory, a farmer will adopt a given new technology if the expected utility obtained from the technology exceeds that of the old one (Chebil *et al*., 2009).

Let U_{im1} represent the expected utility that a given farmer i would receive from adopting a new technology m and U_{im0} the expected utility gained from using the alternative or old technology. The i^{th} farmer adopts the new technology m if $U_{im1} > U_{im0}$. For each farmer i, we can write the expected utility difference $\left(y_{im}^*\right)$ between adopting and not adopting technology m as a function of observed characteristics x_{im} and unobserved characteristics z_{im} (Verbeek, 2004). Furthermore, we expect that the expected utility difference depends on the use of other technologies, because technologies might be complements or substitutes. Hence, we obtain the utility difference:

$$y^*_{im} = U_{im1} - U_{im0} = f\left(x_{im}, z_{im}, y_{i\tilde{m}}\right), \tag{1}$$

where $y_{i\tilde{m}} = \left(y_{i1}, \ldots, y_{im-1}, y_{im+1}, \cdots, y_{iM}\right)'$ is a vector of zeros and ones indicating whether other technologies are used and M is the total number of technologies. Thus, for a given technology m, the breeder i is faced with a choice between two alternatives: adopting the new technology ($y_{im} = 1$, i.e. when $y^*_{im} > 0$) or not adopting it ($y_{im} = 0$, i.e. when $y^*_{im} \leq 0$).

Usually, when the adoption decision is binomial, a binary choice model such as probit or logit regression is used to assess the determinants of adoption. However, in this study, we analyze more than one adoption decision. Given our specification of utility differences in equation (1) and assuming a linear functional form of $f(.)$, we get the following equation system:

$$\begin{aligned} y^*_{i1} &= \beta_1' x_i + \gamma_1' z_i + \delta_1' y_i \\ &\vdots \\ y^*_{iM} &= \beta_M' x_i + \gamma_M' z_i + \delta_M' y_i , \end{aligned} \tag{2}$$

where x_i is a vector that includes all observed characteristics in at least one of $x_{i1}, \ldots, x_{iM}$, z_i is a vector that includes all unobserved characteristics in at least one of $z_{i1}, \ldots, z_{iM}$, $y_i = \left(y_{i1}, \ldots, y_{iM}\right)'$ is a vector that indicates which technologies are currently in use, and $\beta_1, \ldots, \beta_M$, $\gamma_1, \ldots, \gamma_M$ and $\delta_1, \ldots, \delta_M$ are parameter vectors, where the mth element of each δ_{im} is zero for m=1,…,M.[1] We can re-write equation system (2) in matrix form:

$$y^*_i = \beta\, x_i + \gamma\, z_i + \delta\, y_i , \tag{3}$$

where $\beta = \left(\beta_1, \ldots, \beta_M\right)'$, $\gamma = \left(\gamma_1, \ldots, \gamma_M\right)'$ and $\delta = \left(\delta_1, \ldots, \delta_M\right)'$ are parameter matrices, where all diagonal elements of δ are zero. Defining $\varepsilon^*_i = y_i - y^*_i$ and replacing y_i by $y^*_i + \varepsilon^*_i$ in (3), we get the following simultaneous equation system:

[1] Please note that if one or more variables in x_{im} or z_{im} are not included in x_i or z_i, respectively, the corresponding coefficient(s) in β or γ, respectively, can be set to zero.

$$y_i^* = \beta x_i + \gamma z_i + \delta y_i^* + \delta \varepsilon_i^* . \tag{4}$$

Solving this system for y_i^*, we get the following reduced form:

$$y_i^* = (I-\delta)^{-1} \beta x_i + (I-\delta)^{-1} \gamma z_i + (I-\delta)^{-1} \delta \varepsilon_i^* , \tag{5}$$

where I is an $M \times M$ identity matrix.

Given that z_i and ε_i^* are unobserved, we can estimate the following system as a multivariate probit model:

$$y_i^* = \beta^* x_i + \varepsilon_i , \tag{6}$$

$$y_{im} = 1 \text{ if } y_{im}^* > 0 \text{, and 0 otherwise,}$$

$$\varepsilon_i \sim N_M [0, V],$$

where $\beta^* = (I-\delta)^{-1} \beta$ is the coefficient matrix to be estimated and $\varepsilon_i = (I-\delta)^{-1} \gamma z_i + (I-\delta)^{-1} \delta \varepsilon_i^*$ is the vector of disturbance terms, which is assumed to follow a multivariate normal distribution with mean 0 and variance-covariance matrix V. As we normalize all variances of the disturbance terms (diagonal elements of matrix V) to unity, the off-diagonal elements of V can be interpreted as correlations between the disturbance terms. Our specification has two important implications for the estimation. First, all observed explanatory variables in x_i should be included in all equations, because even if a variable does not have a direct effect on y_{im}^* and thus, is not included in x_{im} so that the corresponding coefficient in β is zero, the corresponding coefficient in β^* is not necessarily zero. Second, it is very likely that the disturbance terms of the individual equations $\varepsilon_i = (\varepsilon_{i1}, \ldots, \varepsilon_{iM})$ are mutually correlated (i.e. the off-diagonal elements of V are non-zero), because they all depend on the same terms $\varepsilon_i^* = (\varepsilon_{i1}^*, \ldots, \varepsilon_{iM}^*)$ and the same set of unobserved characteristics (z_i) , even if the different technologies are affected directly by different unobserved characteristics, i.e. $z_{im} \neq z_{in}$ for $m \neq n$. However, it is very likely that some unobserved characteristics $([z_i]_j)$ exist that affect the adoption decisions of many technologies $([z_i]_j \in z_{im}$ for many $m \in 1, \ldots, M)$, e.g. general openness to new technologies and risk attitudes, resulting in even stronger correlations between the disturbance terms of the individual equations.

Hence, the adoption of several technologies should be analyzed with a multivariate probit model rather than with separate univariate probit models, because the former can account for correlations between the disturbance terms.

The main problem for the utilization of the multivariate probit model is the evaluation of the likelihood function and its derivatives, because this requires the computation of *M*-variate integrals of the *M*-variate normal distribution, which is analytically impossible (Greene, 2008). To overcome this problem, various methods have been suggested in the literature, including the GHK (Geweke-Hajivassiliou-Keane) simulator, Stern simulators or simulated likelihood methods. Börsch-Supan & Hajivassiliou (1993) showed that the GHK simulator is the most efficient method in terms of the variance of the estimators of probabilities. It also has many desirable features in the case of multivariate normal models with limited dependent variables, notably, the simulated probabilities are unbiased and bounded between 0 and 1 and the probabilities are continuous and differentiable functions of the parameters of the model (Börsch-Supan & Hajivassiliou, 1993).

These types of simulators for estimating multivariate probit models are available in the econometric software NLOGIT version 4.0 (Greene, 2007) and in the R statistical environment (R Development Core Team, 2012) with the add-on package "mvProbit" (Henningsen, 2012). In this study, we use the R package "mvProbit" with 5000 simulation draws of the GHK algorithm to compute integrals of the multivariate normal distribution.[2]

2.2. Factors affecting innovation adoption and hypotheses

Farmers' decisions to adopt a given new agricultural technology in preference to old or alternative technologies depend on various factors. In this study, the explanatory variables include the village status (experimental or non-experimental village), the region, the breeder's gender, age and education, household size, and access to credit. These variables are listed in Table 1 along with hypotheses on how each characteristic might affect the adoption of village poultry technologies.

We do not use the participation in CBM as an explanatory variable in the adoption model, because this is clearly an endogenous decision variable and hence, would cause inconsistent estimates of the effects of all explanatory variables. In contrast, we include the *village status*, with "1" for experimental villages and "0" otherwise, as an explanatory variable in the

[2] The R code used for this analysis is presented in Appendix B.

adoption model. This variable is clearly exogenous, because it cannot be influenced by individual farmers. Hence, the coefficients of the *village status* measure the combined effect of living in an experimental village and having the option to participate in CBM. Having the option to participate in CBM implies that the farmers have much better possibilities to obtain information on and be trained in the new technologies, which should increase the probability that they adopt these technologies. Even farmers who are not participating in CBM, but who live in experimental villages are exposed to the new technologies more often than farmers who live in non-experimental villages, as they certainly talk to their participating neighbors about the new technologies while they may also see their neighbors adopt the technologies. Hence, farmers in experimental villages are expected to have a higher propensity to adopt the new technologies regardless of whether they participate in CBM or not, i.e. the sign of this variable is expected to be positive.

Table 1. Hypothesized determinants of breeders' decision to adopt poultry improvement technologies

Variables	Measure	Expected effect	Rationale
EXPVIL	1=experimental village, 0=otherwise	+	Breeders in experimental villages have more information about the new technologies
REGION	1=North, 0=South	±	Cultural, agro-climatic and economic differences
GENDER	1=male, 0=female	+	Females often have less labor available and the introduction of new technologies often requires additional labor
AGE	Age of the breeder (years)	+	Producers become increasingly open to new technologies until a certain age after which their openness declines
AGE2	Square of AGE (years^2)	-	
EDUC	1=formal education, 0=otherwise	+	Education increases the ability to understand and benefit from new technologies
HHSIZE	Persons in household	+	Labor availability increases the potential benefits from new technologies, because new technologies often require additional labor
CREDIT	1=obtained credit, 0=otherwise	+	Breeders who have access to credit are more likely to have sufficient financial means to introduce new technologies

A dummy variable is included for the *region* (1=North and 0=South), which allows us to control for cultural differences (North = mainly Muslim, South = mainly Christian), as well as agro-climatic and economic differences that could affect the likelihood of adopting the new technologies. This variable can either have a positive or negative effect on the adoption of the new technologies.

We use the gender of the person who usually takes care of the poultry flock rather than the gender of the head of the household (the conventional practice in most adoption studies) as the explanatory variable (1=male, 0 = female). This allows us to assess the behavior of female breeders regarding the adoption of village poultry improvement technologies in female-headed as well as male-headed households. In rural areas of Benin, female farmers often have financial, land and labor constraints. Thus, we assume that they will be less likely to adopt the technologies, i.e. the variable *gender* is expected to have a positive sign.

Sall *et al*. (2000) use *age* as a proxy for farming experience and argue that knowledge gained over time from working in an uncertain production environment may help to evaluate information, thereby influencing adoption decisions. Rogers (2003) shows that there is inconsistent evidence about the relationship between age and the adoption of agricultural innovations. He argues that about half of the many studies on the adoption of innovations show no relationship between age and the adoption of innovations; a few indicated that young producers are more likely to adopt innovations, while some found that old farmers are more likely to adopt innovations. In this study, the relationship between age and adoption is expected to be positive for young farmers and negative for old farmers. In other words, we expect that producers become increasingly open to new technologies until a certain age, after which their openness decreases. To allow for this nonlinear relationship, the square of the breeder's age is included as an additional explanatory variable in the adoption model.

According to Rogers (2003), farmers with better *education* are often earlier adopters of new technologies, because they are more able to gather information on new technologies and to exploit their benefits. Hence, this variable (1 = successfully completed at least one year of schooling; 0 = otherwise) is supposed to have a positive influence on the adoption of village poultry technologies.

We use *household size* as a proxy for the availability of family labor. Adopting a new technology often implies a need for additional labor. For instance, Feder *et al*. (1985) argue that new technologies may increase the seasonal demand for labor, so that adoption is less attractive for farm households with limited availability of family labor. Hence, we expect household size to have a positive effect on the adoption of poultry technologies.

The *access to credit* is expected to have a positive effect on the adoption of various village poultry technologies, because the introduction of new technologies often requires short-term or long-term investments. The main problem, however, is that measuring access to credit is not an easy task. Doss (2006) argues that the best measure is if the producer has a source of available credit, i.e. a loan for which the producer is eligible, at a reasonable cost, in terms of time and money. However, such a measure is often unavailable, but one solution is to include a measure of whether the farmer has ever received credit (Doss, 2006). This measure is still not perfect, but it is a better measure of access to credit than the simpler question of whether the farmer has received credit in the current period (Doss, 2006). Therefore, we use this solution for measuring access to credit in our study. However, this measure may still be somewhat endogenous to the adoption of a specific technology, which could cause inconsistent estimates. Despite this potential problem, credit has been included as an explanatory variable in many adoption studies (Doss, 2006). In order to verify the robustness of our estimation results, we re-estimate the multivariate probit model without the variable *access to credit*, although this might cause inconsistent results due to an omitted variables problem. However, if the removal of this variable does not significantly affect the coefficients and the marginal effects of the other explanatory variables, we can assume that the results are robust to a potential endogeneity of our measure of access to credit.

2.3. Marginal effects

As the coefficients of (multivariate) probit models cannot be reasonably interpreted, we calculated two types of marginal effects: marginal effects on the unconditional expectations of the dependent variables and marginal effects on the conditional expectations of the dependent variables.

The unconditional expectation of a dependent variable y_{im} is:

$$E[y_{im}] = \Phi(\beta_m^* x_i), \quad (7)$$

where $\Phi(.)$ denotes the cumulative distribution function of the univariate standard normal distribution and β_m^* is the *m*th row of the coefficient matrix β^*, which indicates the probability that the *m*th technology is adopted while disregarding all other technology adoption decisions. Hence, the marginal effect of an explanatory variable x_{ij} on the unconditional expectation of a dependent variable y_{im}, i.e. $\partial E[y_{im}]/\partial x_{ij}$, shows how an explanatory variable affects the general tendency to adopt an innovation before a farmer has finally decided which innovations (s)he will adopt. Furthermore, this marginal effect indicates the total effect of an explanatory variable on the expectation of the dependent variable (corresponding to $\beta^* = (I - \delta)^{-1} \beta$), which includes both the direct effect (corresponding to β) and the indirect effect through other technologies (corresponding to $\beta^* - \beta$).[3]

The conditional expectation of a dependent variable y_{im} depends on the other adoption decisions $y_{i\tilde{m}} = (y_{i1}, \ldots, y_{im-1}, y_{im+1}, \ldots, y_{iM})$ and can be calculated by:

$$E[y_{im} \mid y_{i\tilde{m}}] = \frac{\Phi^M \left(\lambda_1 \beta_1' x_{i1}, \ldots, \lambda_M \beta_M' x_{iM}, V^*\right)}{\Phi^{M-1}\left(\lambda_1 \beta_1' x_{i1}, \ldots, \lambda_{m-1} \beta_{m-1}' x_{im-1}, \lambda_{m+1} \beta_{m+1}' x_{im+1}, \ldots \lambda_M \beta_M' x_{iM}, V_{im}^{**}\right)}, \quad (8)$$

where $\Phi^M(.)$ denotes the cumulative distribution function of the *M*-variate standard normal distribution, $\lambda_{in} = 2y_{in} - 1 \forall n \neq m$, $\lambda_{im} = 1$, $V_i^* = \Lambda_i V \Lambda_i$, Λ_i is an *M*×*M* diagonal matrix with elements $\lambda_{i1}, \ldots, \lambda_{iM}$ on its diagonal, and V_{im}^{**} is equal to matrix V_i^* with the *m*th row and the *m*th column removed.[4] The conditional expectation indicates the probability that the *m*th technology is adopted given that the other technology adoption decisions have been made and are $y_{i1}, \ldots, y_{im-1}, y_{im+1}, \ldots, y_{iM}$. Hence, the marginal effect of an explanatory variable x_{ij} on the conditional expectation of a dependent variable y_{im}, i.e. $\partial E[y_{im} \mid y_{i\tilde{m}}] / \partial x_{ij}$, shows how an explanatory variable affects the adoption decision of a single innovation given that the other adoption decisions have been made. Given that the adoption decisions regarding all other technologies are held constant, these marginal effects only indicate the direct effects of the explanatory variables on the expectations of the dependent variables, i.e. disregarding the indirect effects through other technologies. We have calculated the marginal effects on the conditional expectations of the dependent variables based on three different assumptions about the adoption of the other technologies:

[3] For instance, assume that an explanatory variable influences the profitability of technology *m* but not the profitability of technology *n* so that it has a direct effect on the adoption of technology *m* but no direct effect on the adoption of technology *n*. However, the explanatory variable can have an indirect effect on the adoption of technology *n*, if the adoption of technology *m* influences the profitability of technology *n*.

[4] We have derived the formula for calculating the conditional expectations of the dependent variables of a multivariate probit model (equation 8) as a generalization of the formula for bivariate probit models given in Greene (1996, p. 3).

- assuming that all other dependent variables are zero $\left(y_{i1} = \ldots = y_{im-1} = y_{im+1} = \ldots = y_{iM} = 0\right)$, the marginal effects show how an explanatory variable affects a single specific adoption decision given that no other innovations have been adopted, e.g. in the initial situation before any innovation has been adopted. Hence, these marginal effects indicate how development programs could get farmers to start adopting new technologies;
- assuming that all other dependent variables are as observed, the marginal effects show how an explanatory variable affects a single specific adoption decision given that all other adoption decisions have been made and all these adoption decisions are as observed. Hence, these marginal effects are closest to the farmers' adoption decisions at the time of the data sampling; and
- assuming that all other dependent variables are one $\left(y_{i1} = \ldots = y_{im-1} = y_{im+1} = \ldots = y_{iM} = 1\right)$, the marginal effects show how an explanatory variable affects a single specific adoption decision given that all other innovations have been adopted. Hence, these marginal effects indicate which factors influence the decision of a breeder who has adopted most technologies to also adopt the last technology.

We have computed all these marginal effects using the finite-difference method and the decomposition proposed by Greene (1996, p. 4) in order to improve the computational efficiency. The computation of the marginal effects of dummy variables was done by taking the difference between two expectations of a dependent variable computed with the dummy variable being zero and one, respectively, because the smallest possible increment of a dummy variable is from zero to one rather than an infinitesimal small real number. This has the advantage that the marginal effects of dummy variables can be easily and consistently interpreted, e.g. males have *ceteris paribus* an X% higher probability than women of adopting the mth technology, while this interpretation is not true if the marginal effect of a dummy variable is calculated as a partial derivative or with the finite-difference method using a very small difference.

Given that the marginal effects differ between observations, we present both the marginal effects calculated at the sample mean and the mean marginal effect over all observations. The standard errors of all marginal effects are computed with the Delta method based on partial derivatives that are obtained using the finite-difference method. We have implemented all these computations in the R package “mvProbit”.

2.4. Data collection

The data used in this study were collected in two provinces of Benin: Donga in the North and Mono in the South. In each province, two districts where poultry-based interventions have been implemented during the past decade were selected. In each of the four districts, discussions with resource-persons (development agents, extension agents and researchers) enabled us to identify all experimental villages (i.e. villages where CBM was implemented, in total between eight and 10 villages in each district) and some non-experimental villages which fulfill the same criteria that were used by the project coordinators to select the experimental villages.[5] Based on these results, two experimental villages and one non-experimental village were randomly selected in each of the four districts.

Hence, in total, eight experimental villages and four non-experimental villages were selected for the study. Subsequently, a census of all households that were involved in poultry production was taken and 30 households in the experimental villages and 15 households in the non-experimental villages were randomly selected. In the experimental villages, the sample is made up of participant households and non-participant households. In each household, all members that produce poultry were interviewed (see Table 2). If the household had two or more members (e.g. wife and husband) who separately cared for different flocks of poultry, all poultry-keeping household members were interviewed separately. For this reason, the sample size (405) of the poultry breeders is higher than the number of households surveyed (303).

The survey was carried out in two complementary steps. In the first step, qualitative data were collected through focus group discussions as well as individual interviews. These data mainly concern farmers’ perceptions of various poultry improvement technologies and CBM of village poultry. Based on the conclusions taken from the qualitative data, we collected quantitative data about the farmers’ characteristics and those that are specific to their farms, economic factors and the institutional settings.

[5] The criteria that were used by the project coordinators to select the experimental villages included "social cohesion" (i.e. no open conflict between village dwellers and not highly politically influenced), high community interest in poultry production, high incidence of poverty (as identified by the National Institute for Statistics), and no negative experience with other development projects (e.g. conflict with development agent).

Table 2. Distribution of the sample according to the participation in CBM

Region	Non-participant of non-experimental village	Non-participant of experimental village	Participant	Total
South	51	84	93	228
North	39	55	83	177
Total	90	139	176	405

3. DESCRIPTIVE DATA ANALYSIS

Our sample includes 405 poultry breeders, with females representing about 42% of the interviewed producers (Table 3). The proportion of females is somewhat higher in experimental villages (45%) than in non-experimental villages (31%) but there is no statistically significant difference between participants in CBM (48%) and non-participants in experimental villages (42%). The proportion of breeders with a formal education is 33% in the entire sample and there is no statistically significant difference between experimental villages (32%) and non-experimental villages (36%). However, the proportion of breeders with a formal education is significantly higher among participants (38%) than among non-participants in experimental villages (25%). The proportion of producers who had received a loan was much higher among participants in CBM (78%) than among non-participants in experimental and non-experimental villages (5% and 6%, respectively). This indicates that the participation in CBM improves access to credit. The household size and the age of the breeder do not differ significantly between experimental and non-experimental villages or between participants and non-participants in experimental villages.

As mentioned above, the adoption of the following five technologies was analyzed: vaccination of village poultry, improved feeding, henhouse and chick-house construction, and improved cockerels. The adoption rates for participants in CBM as well as non-participants in CBM both in experimental and non-experimental villages are presented in Table 4.

Table 3. Some characteristics of poultry-keepers according to the participation in CBM

			Number of obs.	Gender, % males	Age, years	Formal edu. %	Household size	Credit %
Total		a	405	57.8	44.0	32.6	8.0	36.8
Non-exper. village		b	90	68.9	43.0	35.6	7.8	5.6
Exper.	all	c	315	54.6	44.3	31.7	8.1	45.7
vil-	non-part.	d	139	57.6	43.0	24.5	8.2	5.0
lage	particip.	e	176	52.3	45.3	37.5	8.0	77.8
P values	b – c	f	405	0.016	0.486	0.497	0.552	<0.001
of inde-	b – d	g	229	0.084	0.991	0.070	0.444	0.863
pen-	b – e	h	266	0.009	0.240	0.756	0.723	<0.001
dence	d – e	i	315	0.350	0.142	0.014	0.639	<0.001
tests	b – d – e	j	405	0.034	0.266	0.039	0.737	<0.001

Note: Pearson's Chi-squared test is used to test the independence of categorical variables (gender, formal education, and credit); one-way tests and Student's t-tests are used to test the independence of continuous variable (age and household size).

Table 4. Proportions of the breeders who adopted the new technologies (in percent)

	Non-participant of non-experimental village	Non-participant of experimental village	Participant	Total
Number of observations	90	139	176	405
Methods of poultry diseases treatment				
Vaccination	31.1	36.7	63.6	47.2
- thereof vaccination only	21.1	28.8	52.8	37.6
- thereof traditional and vaccination	10.0	7.9	10.8	9.6
Appreciation of the vaccination (by breeders who vaccinate their birds)				
Satisfied breeders	56.8	85.3	84.2	80.5
Poultry feeding				
Improved feed	6.7	21.6	50.0	30.6
Poultry housing				
Possess chick-house	16.7	13.7	46.6	28.6
Possess henhouse	47.8	59.0	89.8	69.9
Breeding stock				
Possess improved cockerels	5.6	8.6	13.6	10.1

3.1. Vaccination

In the study area, the only vaccination used for village poultry is against Newcastle Disease (ND). This vaccination is performed by VPVs and sometimes by veterinarians. About 47% of the breeders vaccinate their poultry (Table 4). The proportion of participants in CBM who vaccinate their birds (64%) is approximately twice the proportion among non-participants of experimental and non-experimental villages (37% and 31%, respectively). These rates of poultry vaccination were considerably higher than the average value found at the national level (11 % in 2008/9, DE/MAEP, 2009). The high rate of poultry vaccination in experimental villages can be explained by the fact that this innovation received high priority among the interventions suggested by the communities themselves in order to reduce village poultry mortality (Koudande, 2006). Therefore, this technology was expected to have a high adoption rate.

Some producers only use vaccination (38%), while other farmers combine vaccination and traditional treatment methods (10%). Producers who combined vaccination with traditional treatment methods did not find that vaccination fully protected their birds from becoming sick. Therefore, they combined vaccination with other remedies which they found to have a preventive effect in their specific local context (Thomsen, 2005). Traditional methods of village poultry disease treatment are based on plants or various products purchased at local markets. The plants most frequently used by the interviewed farmers are bitterleaf (*Vernonia amygdalina*), chili pepper (*Capsicum frutescens*) and basil (*Ocimum basilicum*). The products usually purchased at the market include products normally used for the treatment of human diseases and glutamate (a white powder often used for seasoning sauces).

The high adoption rate of vaccination can also be explained by general satisfaction with the vaccination. Indeed, amongst the farmers who vaccinated their birds, eight out of 10 were satisfied with it, which may be because it increases the survival rate of birds (Sodjinou *et al*., 2012) and even reduces the gap in profitability between indigenous poultry breeds and exotic poultry breeds (Rodríguez *et al*., 2011). The satisfaction rate with the vaccination is much higher in experimental villages (84-85%, both for participants and non-participants in CBM) than in non-experimental villages (57%). However, this also means that about 19% of all breeders who vaccinated their birds were dissatisfied with the VPVs' interventions for various reasons. First, certain producers complained that the VPVs are not always available, which is mainly due to the fact that VPVs do not receive a basic salary, but are only paid for their services. Second, in the surveyed villages in Northern Benin, producers blamed the VPVs for not respecting appointments. Third, some VPVs do not have equipment to store the vaccines and hence, they often do not have vaccines and antibiotics available when the farmers need them. Fourth, VPVs often have to travel long distances from the village to buy vaccine and they therefore often increase the price of the vaccine to cover the travel and purchase costs. This means that the producers are less able to purchase the vaccines because of their low financial power. Fifth, during the focus group discussions, producers stated that some VPVs do not master the timing of poultry vaccination, e.g. they vaccinate the birds when some are already infected or are ill, which may actually increase the mortality rate of the birds. Hence, these mistakes made by the VPVs reduce the farmers' motivation to use vaccination. Thomsen (2005) reports similar results and states that VPVs sometimes wait until they hear rumors of an approaching epidemic before they announce a campaign. There is also disagreement between breeders and VPVs regarding the best time to vaccinate, as breeders may have insufficient money when VPVs decide to run a vaccination campaign (Thomsen 2005). These results show that producers who have already adopted vaccination also have several disincentives to continue vaccination. These disincentives can be reduced, e.g. by continually training VPVs (e.g. every year), but also by sensitizing the producers. Indeed, the future adoption of this technology by current non-adopters will partly depend on the improvements in performance experienced by farmers who use vaccination.

3.2. Improved Feed

Traditionally, products such as chopped cassava, corn, bran of corn, rice, millet/sorghum, beans, *gari* (flour from cassava) by-products, snails, and worms are used to feed village poultry, while termites and crushed cereals are used to feed chicks. The so-called improved feed consists of a combination of various locally available products such as milled corn, bones, snail shell, small fish, soy, salt, and peanut oil by-products, which are ground down before being fed to the birds. About 31% of all breeders provide their birds with improved feed, but this figure is 50% amongst the participants in CBM. Improved feed is used much less by non-participants, particularly in non-experimental villages. Indeed, only 7% of the non-participants in non-experimental villages make improved feed for their birds, compared to approximately 22% of non-participants in experimental villages.

3.3. Henhouses and chick-houses

During the implementation of CBM, a model of a henhouse and a chick-house (both built from locally available materials) was often suggested to the producers. Henhouses are made of clay or oil palm branches, while chick-houses are made of ribs of palm and are often coneshaped. Overall, about 29% of the breeders owned chick-houses, while the figure was 47% for participants in CBM compared to 14% and 17% for non-participants in experimental and non-experimental villages, respectively. Overall, about 70% of poultry-keepers owned henhouses, while the figure was 90% for participants in CBM compared to only 48% of farmers in non-experimental villages.

According to the strategy used by the CBM projects, each producer could adapt the suggested henhouse model to his or her own conditions and financial means. Put differently, farmers were not obliged to adopt the model type suggested by these projects. By allowing breeders to adapt henhouses (and chick-houses) to their personal circumstances, the projects left room for variability in the construction of these structures. According to Adegbola (2010), the perceived investment cost and ease of use are often the main reasons for modifying a given technology. However, the farmers who adopted henhouses complied with certain structural features necessary for optimal functioning, notably some form of ventilation and a door allowing people to enter for cleaning purposes.

3.4. Improved cockerels

In order to improve the performance of the indigenous chickens (e.g. increase the quantity of eggs and meat produced), cockerels with improved genetics were introduced. Almost 14% of the participants in CBM had improved cockerels, which was much larger than the proportion in the non-experimental villages (6%).

4. ANALYSIS OF THE TECHNOLOGY ADOPTION DECISIONS

In our initial multivariate probit model, the variables AGE and AGE^2 neither separately nor jointly had a significant effect on the adoption of any of the five different technologies.[6] Hence, we re-estimated the model without these two variables. The estimated coefficients and the corresponding marginal effects are presented in Tables 5 and 6, respectively. *t* tests, Wald tests, and Likelihood Ratio (LR) tests unanimously indicated that the disturbance terms are significantly correlated across adoption decisions and hence, that the multivariate probit model is superior to separate univariate probit models (see Table 7 and Appendix Table A.1).

[6] *t* tests, Wald tests, and Likelihood Ratio (LR) tests unanimously indicated that neither the AGE variable nor the AGE^2 variable nor both variables jointly influenced any of the adoption decisions. The results of some Wald tests and LR tests are given in Appendix Table A.1.

4.1. The effect of community-based management on the adoption of the technologies

The introduction of CBM in experimental villages (variable EXPVIL) significantly increased the adoption of henhouses. If the breeders had not adopted any of the five technologies, CBM increased the incidence of henhouses by approximately 20 percentage points. However, the more technologies the breeders adopted, the smaller the effect of CBM. Furthermore, CBM increased the use of improved feed, but in contrast to its effect on henhouse building, CBM's effect on using improved feed increased with the adoption of other technologies. CBM significantly increased the general consideration of vaccination, while the actual direct effects of CBM on vaccination were only of considerable size if some but not all other technologies had already been adopted, but even then these effects were not statistically significant. This indicates that CBM had a significant indirect effect on the adoption of vaccination through the adoption of other technologies (see section 4.5).

Table 5. Estimates of multivariate probit model for adoption decisions of poultry improvement technologies

Variable	Measure	Vaccination	Improved feed	Henhouse	Chick-house	Improved cockerel
Constant		-0.774*** (0.219)	-1.928*** (0.292)	-0.774*** (0.251)	-1.539*** (0.260)	-1.930*** (0.503)
EXPVIL	1=experiment-tal village	0.346** (0.176)	0.938*** (0.247)	0.615*** (0.188)	0.096 (0.233)	0.378 (0.426)
REGION	1=North, 0=South	0.379** (0.157)	-0.855*** (0.197)	0.334* (0.172)	-0.948*** (0.191)	-1.038*** (0.391)
GENDER	1=male, 0=female	0.021 (0.155)	0.034 (0.177)	0.485** (0.195)	0.451** (0.175)	0.080 (0.235)
EDUC	1=formal education	0.545*** (0.159)	0.523*** (0.174)	0.228 (0.186)	0.095 (0.179)	0.276 (0.271)
HHSIZE	persons in household	-0.013 (0.018)	0.049*** (0.019)	0.009 (0.020)	0.072*** (0.018)	0.062**(0.026)
CREDIT	1=obtained credit	0.751*** (0.160)	0.855*** (0.174)	1.003*** (0.223)	0.926*** (0.173)	0.040 (0.241)

Number of observations = 405
Log likelihood function = -894.216
( ): Figures in parenthesis are standard errors
*** Significant at 1%, ** Significant at 5%, * Significant at 10%

Table 6. Marginal effects on the adoption of poultry improvement technologies

Variable	Marginal effect[a]	Vaccination	Improved feed	Henhouse	Chick-house	Improved cockerel
EXPVIL	unc sm	0.137 *	0.241 ***	0.217 ***	0.030	0.046
	unc ma	0.122 *	0.230 ***	0.191 ***	0.027	0.053
	cond-0 sm	0.097	0.008	0.221 ***	-0.028	0.035
	cond-0 ma	0.082	0.021	0.187 ***	-0.036	0.039
	cond sm	0.049	0.113 ***	0.221 ***	-0.091	0.016
	cond ma	0.038	0.168 ***	0.130 *	-0.082	0.050
	cond-1 sm	-0.015	0.297 *	0.035	-0.109	0.089
	cond-1 ma	-0.008	0.258 *	0.052	-0.104	0.092
REGION	unc sm	0.150 *	-0.259 ***	0.106 *	-0.286 ***	-0.140 ***
	unc ma	0.134 *	-0.230 ***	0.095 *	-0.259 ***	-0.147 ***
	cond-0 sm	0.197 ***	-0.031	0.247 ***	-0.066 *	-0.075 *
	cond-0 ma	0.184 ***	-0.043 *	0.221 ***	-0.073 *	-0.077 *
	cond sm	0.272 ***	-0.195 ***	0.247 ***	-0.264 ***	-0.022
	cond ma	0.217 ***	-0.223 ***	0.191 ***	-0.187 ***	-0.087 *
	cond-1 sm	0.229 ***	-0.341 ***	0.090 *	-0.144	-0.201 *
	cond-1 ma	0.223 ***	-0.305 ***	0.101 *	-0.143	-0.201 *
GENDER	unc sm	0.008	0.011	0.160 *	0.140 ***	0.011
	unc ma	0.007	0.009	0.141 ***	0.127 ***	0.013
	cond-0 sm	0.002	-0.006	0.163 *	0.014	0.004
	cond-0 ma	0.003	-0.013	0.142 *	0.020	0.004
	cond sm	0.017	-0.038	0.163 *	0.107 *	0.000
	cond ma	0.010	-0.042	0.109 *	0.089 *	-0.002
	cond-1 sm	0.015	-0.060	0.044	0.109	-0.017
	cond-1 ma	0.015	-0.050	0.056	0.101 *	-0.012
EDUC	unc sm	0.213 ***	0.175 ***	0.072	0.031	0.042
	unc ma	0.191 ***	0.151 ***	0.064	0.027	0.046
	cond-0 sm	0.194 ***	0.006	0.062	-0.008	0.027
	cond-0 ma	0.172 ***	0.015	0.051	-0.011	0.030
	cond sm	0.168 *	0.063	0.062	-0.028	0.013
	cond ma	0.143 ***	0.080 *	0.035	-0.028	0.036
	cond-1 sm	0.104 *	0.117 *	0.007	-0.051	0.069
	cond-1 ma	0.102 *	0.098 *	0.014	-0.047	0.068
HHSIZE	unc sm	-0.005	0.016 ***	0.003	0.023 ***	0.009 *
	unc ma	-0.004	0.014 ***	0.003	0.021 ***	0.010 *
	cond-0 sm	-0.008	0.001	-0.005	0.004	0.005
	cond-0 ma	-0.008	0.003	-0.004	0.005 *	0.005
	cond sm	-0.012	0.009 *	-0.005	0.020 ***	0.001
	cond ma	-0.009	0.010 *	-0.004	0.014 ***	0.005
	cond-1 sm	-0.010 *	0.016 *	-0.003	0.012	0.011
	cond-1 ma	-0.009 *	0.013 *	-0.003	0.012	0.011
CREDIT	unc sm	0.291 ***	0.286 ***	0.291 ***	0.311 ***	0.006
	unc ma	0.275 ***	0.257 ***	0.278 ***	0.288 ***	0.006
	cond-0 sm	0.254 ***	0.002	0.270 ***	0.033	-0.011
	cond-0 ma	0.235 ***	0.007	0.245 ***	0.046	-0.016
	cond sm	0.232 ***	0.049	0.270 ***	0.204 ***	-0.011
	cond ma	0.205 ***	0.071	0.167 ***	0.164 ***	-0.038
	cond-1 sm	0.152 *	0.140 *	0.042	0.177 *	-0.090
	cond-1 ma	0.152 *	0.123 *	0.061	0.170 *	-0.081

(a) "unc" indicates marginal effects on the unconditional expectations; "cond-0" indicates marginal effects conditional on all other dependent variables being zero; "cond" indicates marginal effects conditional on all other dependent variables being as observed; "cond-1" indicates marginal effects conditional on all other dependent variables being one; "sm" indicates marginal effects calculated at the sample mean; and "ma" indicates the mean marginal effects over all breeders.
*** Significant at 1%, ** Significant at 5%, * Significant at 10%

Finally, our results indicate that CBM did not have an effect on the use of chick-houses or improved cockerels. In summary, CBM was particularly successful in encouraging technological laggards[7] to build henhouses, moderately advanced breeders to vaccinate their chickens, and first movers to provide improved feed. In other words, the modernization process can be best supported by the construction of henhouses, followed by vaccination and then the use of improved feed.

The positive effect of CBM on the adoption of technology is consistent with our initial hypothesis formulated in section 2.2) and implies that producers from experimental villages are more likely to adopt new technologies than their counterparts from non-experimental villages. This can be explained by the fact that CBM promotes contact between producers, which facilitates discussions about production methods based on the participants' experiences (e.g. the effect of henhouses, improved feed, and vaccination on the birds' survival rate, see Sodjinou *et al*., 2012).

Another explanation for the positive effect of CBM on the adoption of various innovations is that the networks which arise from the implementation of the approach not only reduce the cost of accessing information for small-scale farmers, but also expose farmers to the technologies and make them aware of their benefits. Indeed, in rural Africa in general, and particularly Benin, farmers often have limited access to public extension services. The situation is even more complicated for poultry producers as extension agents are often uninterested in this type of farming. In such circumstances, farmers often obtain information about new technologies through cooperative or farmer association meetings (Adegbola, 2010). This is confirmed by the finding of Boahene *et al*. (1999) who showed that small-scale farmers with limited resources tend to invest in their social networks for information rather than in extension services. Collaboration through social networks allows farmers to obtain the same level of knowledge at a lower cost (Zirulia, 2012).

4.2. Regional location and the adoption of the technologies

The adoption of all village poultry improvement technologies is significantly influenced by the region of residence. For instance, village poultry keepers in the north of the country, *ceteris paribus*, are considerably more likely to adopt poultry vaccination than the breeders in

[7] We define "technological laggards" as breeders who have not yet adopted any technology, "moderately advanced breeders" as breeders who have adopted some but not all technologies, and "first movers" as breeders who have adopted nearly all new technologies.

the south. This is surprising given the fact that the price of vaccine (per dose) is lower in the south (on average FCFA 29) than the north (about FCFA 49). However, there are three further factors that explain the different vaccination rates between the two regions. First, in the north, farmers are more involved in cattle rearing where vaccination is frequently used. Therefore, farmers in the north have more knowledge about the vaccination of animals and are therefore more confident with the use of the technology. Second, the two regions use different vaccine supply systems. In the north, VPVs have formed networks (or associations) that purchase vaccine (and other veterinary products) from private veterinarians for distribution to their members, which may well improve breeders' access to such treatments. Third, VPVs obtain higher profits from vaccination in the north (FCFA 1938 for 100 chickens) than in the south (FCFA 487 for 100 chickens, see Appendix Table A.2), which probably means that VPVs in the north are more likely to try to persuade farmers to vaccinate their birds. Also, the VPVs' monthly gross margin can reach FCFA 15,000 in the north compared to FCFA 2,500 in the south, because the number of vaccinations per village is generally higher in the north.

Breeders in the north are significantly less likely to adopt improved feed. For a typical farmer, the (conditional) probability to use improved feed is, *ceteris paribus*, around 20 percentage points higher in the south than in the north. However, for farmers who have not adopted any other technology, the difference between the north and south is much smaller. The difference between the two regions can be explained by the fact that food processing (mainly maize and cassava) is much more practiced in the south than the north. Thus, farmers in the South have better access to the compounds needed for making improved feed than their counterparts in the north; a situation which they capitalize on if they are generally open to and have already adopted other innovations.

Furthermore, farmers in the north are, *ceteris paribus,* significantly more likely to have a henhouse, but are significantly less likely to have a chick-house or improved cockerels.

4.3. The effect of socioeconomic factors on the adoption of the technologies

The gender of the breeder significantly influences the adoption of henhouses and chick-houses. The adoption rate of henhouse is *ceteris paribus* approximately 15 percentage points higher amongst male breeders than it is amongst female breeders, while the adoption rate of chick-houses only depends on the breeder's gender if some other technologies have already been adopted. The result that male producers are more likely to provide shelter for their birds than female breeders can be explained by the fact that many women do not dare to build henhouses and chick-houses without help from males and hence, their decisions to adopt henhouses or chick-houses depend on the willingness of males to help them. Consequently, women tend to have smaller and weaker henhouses than men.

The difference between males and females regarding the adoption of henhouses may also be explained by the prestige associated with henhouses, which is sought by men. Thus, a large and attractive looking henhouse may act as an important social status symbol for some men, who are therefore more willing to invest the necessary funds and time into its construction (Rogers, 2003: Thomsen, 2005). This is not the case for women for whom the keeping of village poultry is mostly about making money, or reinforcing their social positions (e.g. participation in decision making in their household). Therefore, a henhouse has a mainly functional purpose (Thomsen, 2005).

Gender had no significant effect on the adoption of village poultry vaccination, improved feed or improved cockerels, which means that, *ceteris paribus*, male and female farmers made the same adoption decisions for these technologies.

Education had no effect on the adoption of henhouses, chick-houses or improved cockerels, but had a positive and significant effect on the adoption of vaccination and improved feed. For technological laggards, the adoption rate of vaccination was *ceteris paribus* almost 20 percentage points higher among breeders who had a formal education. However, the effect of education on the adoption of vaccination declined as the breeder’s experience with other technologies increased, but the effect is still 10 percentage points for first movers. The effect of education on the use of improved feed is considerably smaller and negligible in the initial state when no other technologies have been adopted and increases to around 10 percentage points for first movers. In fact, education not only facilitates easy access to information, but also improves farmers’ capacity to evaluate the benefits of a new technology. As noted by Boahene *et al*. (1999), highly educated breeders incur lower information costs as they are able to evaluate and understand information much more easily than uneducated farmers. Therefore, an improvement in the education level of producers can increase the adoption of village poultry improvement technologies.

Household size has a positive and statistically significant effect on the adoption rate of improved feed and chick-houses, which generally increases by 1-2 percentage points with each additional household member. This positive effect can be explained by the fact that these two technologies require daily labor, which is more available in larger households. However, the effects on improved feed and chick-houses are very small for technological laggards. The effect of household size on vaccination is slightly negative while the effect on the adoption of improved cockerels is slightly positive although both effects are only partially statistically significant. Household size clearly does not affect the adoption of henhouses.

4.4. The effect of other institutional factors on the adoption of the technologies

Access to credit has a positive and statistically significant effect on all technologies except improved cockerels. The adoption rates of vaccination and henhouse are generally increased by more than 20 percentage points, but the more technologies that have been adopted, the less significant the effect. In contrast, access to credit only increases the adoption rate of chick-houses if other technologies have already been adopted. In general, access to credit makes more farmers consider improved feed, but it only directly affects the actual adoption decisions of first movers. This indicates that access to credit has a considerable indirect effect on the adoption of improved feed through the adoption of other technologies (see section 4.5).

The positive effect of access to credit on the adoption of village poultry improvement technologies is consistent with Feder *et al*. (1985) who argue that access to credit is an important determinant for the adoption of new technologies. Indeed, access to credit facilitates the acquisition of technology by small farmers who, in general, have limited financial liquidity. This implies that improving producers' access to credit will increase the adoption of poultry vaccination, henhouses, chick-houses, and (indirectly) improved feed. This improvement can be achieved through the implementation of a poultry-oriented microcredit system. The first credit granted for poultry farming could be used for henhouse construction, which is a launch pad for the adoption of other technologies (see section 4.1). Repayment of the loan should start about six months after it has been granted to give the farmers time to produce their first marketable products.

Our study shows that the analyzed factors, except for the region, hardly influence the decision of whether to adopt improved cockerels or not and that improved cockerels were not widely adopted (compared to the four other technologies analyzed in this study, see Table 4). This has various reasons, e.g. low resistance to diseases and the socio-cultural role of indigenous poultry. Indeed, Chrysostome & Sodjinou (2005) showed that "improved cockerels operation", financed by the Beninese Government, has had mixed results. On the one hand, the weight of indigenous chickens and the number of eggs laid increased. However, the main drawback of this operation was that it did not take into account the failures of similar operations carried out in the 1960s when the introduction of new genes[8] seriously affected the phenotypic diversity, which is highly valued in rural areas (Chrysostome & Sodjinou, 2005). Thus, chickens with red, white or black plumage which are sought after for traditional and ritual ceremonies became rare. Some farmers, therefore, consciously abandoned cockerels of modern breeds or killed them. Moreover, the crossbreed obtained from the first generation was not sufficiently adapted to traditional poultry rearing practices and the birds' low level of resistance resulted in high loss rates (Chrysostome & Sodjinou, 2005). As stated by Chatterton & Chatterton (1982), the problem might have been in the communication between farmers, governmental institutions and researchers, because governmental workers and researchers often underestimate the role of farmers in the improved cockerels transfer process. Smallholder farmers are often socially conservative and risk-averse and only take risks that allow them to cope with the vagaries of the weather and markets, behavior which extension services sometimes find illogical (Chatterton & Chatterton, 1982). Kryger *et al.* (2010) argued that if development agencies do not consider the social and cultural aspects of smallholders' poultry rearing, there is a risk that they will fail to provide village poultry keepers with the appropriate assistance. This is because village dwellers do not only act on the basis of economic rationales, but also seek to fulfill their social and cultural obligations (Kryger *et al.*, 2010). This applies, for example, to different plumage colors which are highly valued in rural areas for traditional ceremonies (Sodjinou, 2011), something which may be missed by development agencies if they do not undertake a multidisciplinary study prior to the introduction of the technology. The problem could also be related to profitability. Indeed, in an *ex ante* evaluation of interventions in village poultry systems in Ethiopia, Udo *et al.* (2006) showed that crossbreeding had a highly negative impact on net returns (-148%). All these constraints explain the fact that improved cockerels are not widely adopted in village poultry farming.

[8] The main breeds used were Rhode Island Red and Plymouth Rock.

4.5. Interrelations between adoption decisions

The technology adoption decisions of small-scale poultry farmers in Benin were evaluated through a multivariate probit model that facilitated an assessment of the possible links between the adoption decisions of five different village poultry improvement technologies. The utilization of this model was justified by the theoretical model and the expectation that unobserved explanatory variables exist (e.g. general openness to new technologies) that affect more than one adoption decision and that the adoption of a given technology may drive the adoption of other technologies and vice versa. Our results indicated that analyzing all adoption decisions simultaneously is much more efficient than analyzing each adoption decision separately, i.e. the results of our multivariate probit model are more precise than the results from separate traditional probit models.

The correlations between adoption decisions in the data (y_{im}), between the disturbance terms of the different technology adoption decisions (ε_{im}) and between the (unconditional) expected outcomes predicted by our multivariate probit model $(E[y_{im}] = \Phi(\beta_m^* x_i))$ are presented in Table 7. Nearly all these coefficients of correlation are positive. Furthermore, half of the correlations between the disturbance terms are statistically significantly positive while the disturbance terms of each single adoption decision are significantly correlated with the disturbance terms of at least one other adoption decision. This means that unobserved factors that influence the adoption decision of one technology influence the adoption decision of at least one other technology in the same direction and/or that some adoption decisions are complementary.

Table 7. Correlation between the disturbance terms in the adoption model as well as between the adoption decisions in the data

	Vaccination	Improved feed	Henhouse	Chick-house
Improved feed	0.335***	---	---	---
	0.532***			
	0.589***			
Henhouse	0.202***	0.366***	---	---
	0.099	0.605***		
	0.913***	0.584***		
Chick-house	0.123**	0.397***	0.321***	---
	0.126	0.468***	0.601***	
	0.424***	0.873***	0.492***	
Improved cockerel	0.020	0.168**	0.024	0.312***
	0.126	0.239	-0.018	0.534***
	-0.086	0.673***	-0.009	0.680***

Note: In each cell, the first value is the correlation between two adoption decisions in the data measured by the "phi" coefficient of correlation for binary variables suggested by Yule (1912), which is numerically identical to Pearson's coefficient of correlation (Krus, 2010, p. 84f); the second value represents Pearson's coefficient of correlation between the disturbance terms of two adoption decisions; the third value represents Pearson's coefficient of correlation between the (unconditional) expected outcomes predicted by our multivariate probit model.

In some cases, the correlation between the disturbance terms is stronger than the corresponding correlation between the expected outcomes predicted by our model (e.g. henhouse – chick-house). This indicates that these interrelations between the adoption decisions are mainly driven by common unobserved factors (e.g. general openness and attitudes towards new technologies) or complementarities between the technologies. However, in several other cases, the correlation between the expected outcomes is stronger than the correlation between the disturbance terms (e.g. henhouse – vaccination), which indicates that the interrelations between the adoption decisions are predominantly driven by common observed factors (e.g. experimental village, region, access to credit).

The disturbance terms of the adoption decisions of improved feed and chick-house in particular are highly correlated with nearly all other disturbance terms, which indicates that these adoption decisions, which require the lowest initial investment of labor and capital, are good indicators of the farmers' general openness and attitudes towards new technologies. Hence, observed factors that generally have a large effect on the adoption of improved feed and/or chick-houses (e.g. REGION, HHSIZE, CREDIT) have a much smaller effect if farmers are not open to new technologies and have not adopted any of the analyzed technologies (see Table 6).

Furthermore, there is a high mutual correlation between the disturbance terms of the adoption of the henhouse, chick-house, and improved feed. In other words, producers who shelter their birds are more likely to give them improved or supplementary feed and vice versa. This interrelationship is probably derived from complementarity between these technologies, because farmers who shelter their birds are engaged in a process of behavioral change, i.e. the phasing out of the scavenging system. This obliges them to feed their birds in order to compensate for the feed that the birds used to find for themselves in nature. Chrysostome & Sodjinou (2005) report that the increase in the flock size in villages where farmers provided improved feed to their poultry but which did not have henhouses, caused conflicts between breeders and agriculturalists whose farms were close to poultry flocks. In fact, the increase in the flock size resulted in massive damage to corn and other crops. According to Chrysostome & Sodjinou (2005), before the introduction of CBM, these conflicts were solved amicably but jealousy and massive damage to crops by poultry led agriculturalists to use poisoned seeds, which resulted in many poultry deaths. These events could explain the fact that farmers who adopt henhouses tend to adopt improved feed and vice versa. This explanation is confirmed by the conditional marginal effects of CBM on improved feed, which are only significantly positive if other technologies (predominantly henhouses) have already been adopted (see Table 6). In short, farmers are less likely to adopt improved feed if they do not use other technologies, notably henhouses, chick-houses or vaccination. As the effect of introducing CBM in an experimental village on henhouse building is very high for farmers who have not adopted any other technologies, promoting henhouse building is an appropriate initial measure of CBM which can serve as a launch pad for other technologies (particularly chick-houses and improved feed).

In contrast to other technologies, the decision to adopt improved cockerels is not significantly correlated with other technologies (except chick-houses). This means that the adoption of improved cockerels is nearly unrelated to vaccination, improved feeding, and henhouse possession.

4.6. Robustness check – possible endogeneity of CREDIT variable

Furthermore, as stated in section 2.2), we re-estimate the multivariate probit model without *access to credit* as the explanatory variable in order to verify the robustness of our estimation results to a potential endogeneity of our measure of access to credit (see Appendix Tables A.3 and A.4). In general, the estimates are rather similar and the coefficients that are significant in the full model are also significant in the restricted model. In other words, the withdrawal of the variable CREDIT does not change the level of significance of other variables. However, the interpretation of the results of these two models is different, because the "*ceteris paribus*" condition includes a constant CREDIT variable in the full model but not in the restricted model. Given that the proportion of breeders with access to credit is considerably higher in experimental villages than in non-experimental villages, the coefficients and marginal effects of variable EXPVIL now also include the indirect effect through better access to credit. Therefore, the estimated positive effect of experimental villages on the adoption decisions (except for improved cockerels) is moderately greater in the restricted model than in the full model. As access to credit is also slightly correlated with the region and the breeder's gender (breeders in the north and female breeders have better access to credit), the coefficients and marginal effects of variables REGION and GENDER are somewhat affected by the removal of variable CREDIT: particularly the gender differences regarding the adoption of henhouses and chick-houses decrease because the hesitation amongst females regarding construction is partly off-set by their better access to credit.

4.7. *Robustness check – estimation without non-participants in experimental villages*

In our basic model and the above-described robustness check, the effect of variable EXPVIL measures the average effect on breeders in experimental villages, which consists of the direct effect of CBM on participants and the indirect spill-over effects on non-participants in experimental villages. In order to separately assess the direct effect of CBM on participants, we re-estimated our models without observations from non-participants in experimental villages (see Appendix Tables A.5 to A.8). Most estimates are rather similar to our initial estimates, although the statistical significances are lower in several cases due to a smaller number of observations. As expected, the coefficients and marginal effects of the EXPVIL variable are considerable greater, because they only measure the direct effect of participating in CBM, which is much larger than the indirect spill-over effect on non-participants in experimental villages.[9]

[9] In the models with access to credit as an explanatory variable, the estimates of the effects of access to credit are considerable smaller in the model without observations from non-participants in experimental villages than in our basic model. This is probably derived from the correlation between the variables EXPVIL and CREDIT, which is particularly high in the sample without observations from non-participants in experimental villages.

5. CONCLUSION

The objective of this study was to analyze the adoption of village poultry improvement technologies and particularly to assess the effect of community-based management programs on farmers' adoption decisions. In general, CBM successfully boosted the adoption of various village poultry improvement technologies, mainly because it promotes the creation of information networks among farmers. This indicates that when farmers have the information and technical support through an approach based on the community, i.e. CBM, they can overcome traditional poultry farming behavior to increase their income and reduce poverty. The main policy implication of this result is that the government or development actors can boost the modernization of village poultry production by investing in information dissemination and assistance on village poultry improvement technologies in particular through community-based approaches, e.g. through the establishment of poultry interest groups and the provision of training for village poultry vaccinators (VPV).

The adoption of village poultry technologies also depends on the breeder's education as well as on access to resources, notably labor and credit. Indeed, CBM-based poultry improvement programs often include micro-credit programs that are tailored to poultry production (e.g. the repayment does not start immediately but at the end of the production cycle), which further increase the positive impact of these programs on the modernization of village poultry production.

Our results show that the different adoption decisions are not independent, and hence, analyzing all adoption decisions simultaneously using a multivariate probit model provides much more precise estimates than analyzing each adoption decision separately. Furthermore, the joint analysis of all adoption decisions allowed us to get a deep insight into the interrelations between the adoption decisions. For instance, the adoption decisions that require the lowest initial investments of labor and capital (improved feed and chick-houses) can be used as indicators of the farmers' general openness and attitudes towards new technologies. Furthermore, the success of CBM-based village poultry improvement programs can be improved by first focusing on henhouse construction, then on vaccination, and finally on improved feed. Given that henhouses, vaccination, and improved feed significantly increase the survival rate of chicken (Sodjinou *et al*, 2012), CBM clearly increases the income-generating capacity of small-scale poultry breeders through the increased adoption of these technologies.

Finally, we demonstrated that our proposed theoretical model is well suited for simultaneously analyzing multiple technology adoption decisions. Estimated by the multivariate probit method, the estimation results, and particularly the different types of marginal effects, can be utilized to get a deep insight into the interrelations between the different adoption decisions.

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Appendix

A. Additional tables

Table A.1: statistical tests

Test of variable(s)	Wald test			LR test		
	Chi^2	DF	P-val.	Chi^2	DF	P-val.
AGE^2	3.354	5	0.6456	5.0292	5	0.4123
AGE and AGE^2	7.897	10	0.6389	10.595	10	0.3899
CREDIT	65.107	5	$1.1 \cdot 10^{-12}$	76.206	5	$5.2 \cdot 10^{-15}$
Correlation between disturbance terms	235.62	10	$<2 \cdot 10^{-16}$	152.26	10	$<2 \cdot 10^{-16}$

Table A.2. Village Poultry Vaccinator's profitability of vaccinating 100 birds (FCFA)

Region	Purchase price	Selling price	Transport and other costs	Gross margin	Profit
North	2666.7	4911.1	306.1	2244.4	1938.3
South	2260.0	2866.7	120.0	606.7	486.7
Total	2481.8	3981.8	221.5	1500.0	1278.5

Table A.3. Estimates of multivariate probit model without access to credit as explanatory variable

Variable	Measure	Vaccination	Improved feed	Henhouse	Chick-house	Improved cockerel
Constant		-0.690*** (0.213)	-1.763*** (0.285)	-0.635*** (0.235)	-1.384*** (0.258)	-1.923*** (0.491)
EXPVIL	1=experiment-tal village	0.615*** (0.165)	1.218*** (0.241)	0.909*** (0.179)	0.467** (0.216)	0.397 (0.411)
REGION	1=North, 0=South	0.517*** (0.150)	-0.615*** (0.168)	0.490*** (0.158)	-0.703*** (0.178)	-1.028*** (0.366)
GENDER	1=male, 0=female	-0.115 (0.150)	-0.096 (0.169)	0.288* (0.162)	0.301* (0.169)	0.069 (0.233)
EDUC	1=formal education	0.594*** (0.157)	0.562*** (0.168)	0.294* (0.176)	0.153 (0.173)	0.276 (0.262)
HHSIZE	persons in household	-0.016 (0.017)	0.040** (0.017)	0.003 (0.020)	0.061*** (0.017)	0.061** (0.025)
Corre-lations between distur-bance terms	Vaccination		0.595*** (0.076)	0.208** (0.090)	0.255*** (0.098)	0.128 (0.130)
	Improved feed			0.670*** (0.076)	0.539*** (0.074)	0.230* (0.128)
	Henhouse				0.658*** (0.078)	0.003 (0.141)
	Chick-House					0.504*** (0.110)

Number of observations = 405, Log likelihood function = -932.319
( ): Figures in parenthesis are standard errors
*** Significant at 1%, ** Significant at 5%, * Significant at 10%

Table A.4. Marginal effects based on multivariate probit model without access to credit as explanatory variable

Variable	Marginal effect[a]	Vaccination	Improved feed	Henhouse	Chick-house	Improved cockerel
EXPVIL	unc sm	0.239 ***	0.302 ***	0.334 ***	0.141 *	0.048
	unc ma	0.225 ***	0.298 ***	0.315 ***	0.136 *	0.055
	cond-0 sm	0.158 ***	0.007	0.294 ***	-0.009	0.032
	cond-0 ma	0.143 *	0.019	0.264 ***	-0.011	0.036
	cond sm	0.101	0.118 ***	0.294 ***	-0.027	0.015
	cond ma	0.087	0.187 ***	0.172 ***	-0.035	0.040
	cond-1 sm	0.021	0.341 ***	0.036	-0.047	0.059
	cond-1 ma	0.028	0.305 ***	0.055	-0.043	0.063
REGION	unc sm	0.204 ***	-0.194 ***	0.162 ***	-0.223 ***	-0.139 ***
	unc ma	0.191 ***	-0.183 ***	0.151 ***	-0.214 ***	-0.145 ***
	cond-0 sm	0.228 ***	-0.023	0.292 ***	-0.049 *	-0.083 *
	cond-0 ma	0.224 ***	-0.034 *	0.280 ***	-0.052 *	-0.086 *
	cond sm	0.325 ***	-0.184 ***	0.292 ***	-0.235 ***	-0.027
	cond ma	0.265 ***	-0.212 ***	0.230 ***	-0.166 ***	-0.093 *
	cond-1 sm	0.238 ***	-0.290 ***	0.085 *	-0.090	-0.211 *
	cond-1 ma	0.233 ***	-0.265 ***	0.088 *	-0.090	-0.211 *
GENDER	unc sm	-0.046	-0.031	0.098 *	0.098 *	0.010
	unc ma	-0.042	-0.029	0.090 *	0.093 *	0.011
	cond-0 sm	-0.054	-0.004	0.108	0.009	0.006
	cond-0 ma	-0.048	-0.012	0.100	0.013	0.006
	cond sm	-0.036	-0.045	0.108	0.082	0.001
	cond ma	-0.034	-0.055	0.074	0.072	0.003
	cond-1 sm	-0.018	-0.073	0.029	0.075	-0.001
	cond-1 ma	-0.018	-0.064	0.037	0.072	0.002
EDUC	unc sm	0.232 ***	0.193 ***	0.096 *	0.051	0.042
	unc ma	0.219 ***	0.176 ***	0.089 *	0.049	0.046
	cond-0 sm	0.203 ***	0.004	0.075	-0.007	0.027
	cond-0 ma	0.187 ***	0.013	0.063	-0.009	0.030
	cond sm	0.176 ***	0.062	0.075	-0.033	0.014
	cond ma	0.155 ***	0.080 *	0.041	-0.032	0.036
	cond-1 sm	0.101 *	0.115 *	0.007	-0.043	0.062
	cond-1 ma	0.103 *	0.101 *	0.013	-0.039	0.062
HHSIZE	unc sm	-0.006	0.013 *	0.001	0.020 ***	0.009 *
	unc ma	-0.006	0.012 *	0.001	0.019 ***	0.010 *
	cond-0 sm	-0.009	0.001	-0.006	0.003	0.005
	cond-0 ma	-0.009	0.002	-0.006	0.004 *	0.006
	cond sm	-0.014 *	0.008 *	-0.006	0.018 ***	0.002
	cond ma	-0.011 *	0.009 *	-0.006	0.013 ***	0.006
	cond-1 sm	-0.011 *	0.014 *	-0.002	0.009	0.012 *
	cond-1 ma	-0.010 *	0.011 *	-0.003	0.009	0.012 *

Note: explanations are given below Table 6.

Table A.5. Estimates of multivariate probit model without observations from non-participants in experimental villages

Variable	Measure	Vaccination	Improved feed	Henhouse	Chick-house	Improved cockerel
Constant		-0.689*** (0.250)	-1.855*** (0.343)	-0.965*** (0.343)	-1.565*** (0.303)	-2.335*** (0.577)
EXPVIL	1=experiment-tal village	0.570** (0.278)	1.343*** (0.336)	1.393*** (0.316)	0.831*** (0.318)	0.941** (0.468)
REGION	1=North, 0=South	0.245 (0.208)	-0.677*** (0.252)	0.370 (0.265)	-0.849*** (0.234)	-1.038** (0.438)
GENDER	1=male, 0=female	-0.147 (0.199)	-0.224 (0.253)	0.804** (0.329)	0.353 (0.220)	0.202 (0.373)
EDUC	1=formal education	0.649*** (0.213)	0.758*** (0.246)	0.242 (0.292)	0.237 (0.230)	0.318 (0.378)
HHSIZE	persons in household	-0.004 (0.022)	0.034 (0.023)	0.006 (0.030)	0.076*** (0.021)	0.097** (0.038)
CREDIT	1=obtained credit	0.467* (0.0277)	0.509* (0.287)	0.381 (0.399)	0.197 (0.270)	-0.543* (0.325)
Corre-lations between distur-bance terms	Vaccination		0.618*** (0.102)	0.023 (0.141)	0.037 (0.147)	0.233 (0.199)
	Improved feed			0.546*** (0.151)	0.413*** (0.116)	0.281 (0.267)
	Henhouse				0.457*** (0.137)	-0.149 (0.344)
	Chick-House					0.626*** (0.141)

Number of observations = 266, Log likelihood function = -569.7002
( ): Figures in parenthesis are standard errors
*** Significant at 1%, ** Significant at 5%, * Significant at 10%

Table A.6. Marginal effects based on multivariate probit model without observations from non-participants in experimental villages

Variable	Marginal effect[a]	Vaccination	Improved feed	Henhouse	Chick-house	Improved cockerel
EXPVIL	unc sm	0.224 *	0.377 ***	0.416 ***	0.281 ***	0.105 *
	unc ma	0.208 *	0.359 ***	0.383 ***	0.262 ***	0.128 *
	cond-0 sm	0.176	0.002	0.419 ***	0.004	0.054
	cond-0 ma	0.153	0.008	0.371 ***	0.002	0.077
	cond sm	0.118	0.090	0.419 ***	0.125	0.007
	cond ma	0.074	0.184 *	0.272 ***	0.058	0.099
	cond-1 sm	-0.018	0.237	0.206	-0.028	0.182
	cond-1 ma	-0.005	0.216	0.224	-0.016	0.182
REGION	unc sm	0.096	-0.221 ***	0.094	-0.300 ***	-0.138 *
	unc ma	0.084	-0.186 ***	0.082	-0.264 ***	-0.150 ***
	cond-0 sm	0.147	-0.008	0.195 *	-0.119	-0.043
	cond-0 ma	0.139	-0.017	0.163 *	-0.109	-0.058
	cond sm	0.207 *	-0.104	0.195 *	-0.265 ***	-0.004
	cond ma	0.159 *	-0.174 *	0.136 *	-0.168 *	-0.088 *
	cond-1 sm	0.152 *	-0.265	0.096	-0.055	-0.214 *
	cond-1 ma	0.152 *	-0.222	0.112 *	-0.056	-0.204 *
GENDER	unc sm	-0.057	-0.076	0.219 ***	0.128 *	0.027
	unc ma	-0.049	-0.061	0.179 ***	0.111	0.031
	cond-0 sm	-0.045	-0.006	0.261 *	-0.008	0.022
	cond-0 ma	-0.034	-0.016	0.217 ***	-0.008	0.032
	cond sm	0.007	-0.062	0.261 *	0.084	0.003
	cond ma	-0.008	-0.100 *	0.177 ***	0.067	0.035
	cond-1 sm	0.001	-0.193 *	0.171	0.017	0.056
	cond-1 ma	0.005	-0.167	0.182	0.015	0.059
EDUC	unc sm	0.246 ***	0.264 ***	0.061	0.088	0.045
	unc ma	0.220 ***	0.213 ***	0.053	0.077	0.051
	cond-0 sm	0.224 ***	0.003	0.049	0.010	0.014
	cond-0 ma	0.198 ***	0.012	0.038	0.008	0.018
	cond sm	0.182 *	0.063	0.049	0.034	0.002
	cond ma	0.142 *	0.123 *	0.022	0.013	0.022
	cond-1 sm	0.061	0.177	-0.002	-0.009	0.048
	cond-1 ma	0.066	0.138	0.002	-0.007	0.046
HHSIZE	unc sm	-0.001	0.011	0.001	0.028 ***	0.013 ***
	unc ma	-0.001	0.009	0.001	0.024 ***	0.015 ***
	cond-0 sm	-0.004	0.000	-0.004	0.008	0.005
	cond-0 ma	-0.004	0.001	-0.003	0.007	0.007
	cond sm	-0.005	0.003	-0.004	0.024 ***	0.001
	cond ma	-0.005	0.005	-0.002	0.015 *	0.010 *
	cond-1 sm	-0.007	0.005	0.000	0.004	0.022 *
	cond-1 ma	-0.007	0.004	0.000	0.004	0.021 *
CREDIT	unc sm	0.182 *	0.168 *	0.100	0.072	-0.076 *
	unc ma	0.168	0.143 *	0.089	0.063	-0.087 *
	cond-0 sm	0.183 *	0.001	0.096	0.038	-0.051
	cond-0 ma	0.170	0.004	0.078	0.042	-0.073
	cond sm	0.150	0.030	0.096	0.061	-0.009
	cond ma	0.131	0.075	0.044	0.067	-0.109 *
	cond-1 sm	0.081	0.154	-0.009	0.075	-0.227
	cond-1 ma	0.087	0.130	-0.003	0.066	-0.206

Note: explanations are given below Table 6.

Table A.7. Estimates of multivariate probit model without access to credit as explanatory variable and without observations from non-participants in experimental villages

Variable	Measure	Vaccination	Improved feed	Henhouse	Chick-house	Improved cockerel
Constant		-0.680*** (0.243)	-1.818*** (0.324)	-0.950*** (0.310)	-1.560*** (0.298)	-2.314*** (0.548)
EXPVIL	1=experiment-tal village	0.891*** (0.189)	1.668*** (0.260)	1.639*** (0.276)	0.978*** (0.248)	0.593 (0.420)
REGION	1=North, 0=South	0.334* (0.197)	-0.564** (0.228)	0.434* (0.244)	-0.814*** (0.226)	-1.099*** (0.382)
GENDER	1=male, 0=female	-0.151 (0.199)	-0.208 (0.248)	0.779*** (0.289)	0.351 (0.217)	0.162 (0.355)
EDUC	1=formal education	0.598*** (0.210)	0.688*** (0.234)	0.217 (0.283)	0.216 (0.220)	0.397 (0.354)
HHSIZE	persons in household	-0.003 (0.022)	0.033 (0.022)	0.006 (0.029)	0.076*** (0.021)	0.092*** (0.034)
Corre-lations between distur-bance terms	Vaccination		0.633*** (0.095)	0.046 (0.144)	0.054 (0.143)	0.145 (0.180)
	Improved feed			0.563*** (0.131)	0.411*** (0.112)	0.186 (0.210)
	Henhouse				0.460*** (0.137)	-0.192 (0.308)
	Chick-House					0.610*** (0.152)

Number of observations = 266
Log likelihood function = -576.6052
( ): Figures in parenthesis are standard errors
*** Significant at 1%, ** Significant at 5%, * Significant at 10%

Table A.8. Marginal effects based on multivariate probit model without access to credit as explanatory variable and without observations from non-participants in experimental villages

Variable	Marginal effect[a]	Vaccination	Improved feed	Henhouse	Chick-house	Improved cockerel
EXPVIL	unc sm	0.344 ***	0.449 ***	0.497 ***	0.324 ***	0.073
	unc ma	0.329 ***	0.436 ***	0.459 ***	0.304 ***	0.084 *
	cond-0 sm	0.287 ***	0.002	0.493 ***	0.014	0.055
	cond-0 ma	0.265 ***	0.009	0.435 ***	0.015	0.064
	cond sm	0.210 *	0.104 *	0.493 ***	0.150	0.007
	cond ma	0.157 *	0.224 ***	0.301 ***	0.088	0.059
	cond-1 sm	0.034	0.344 *	0.206	0.004	0.081
	cond-1 ma	0.052	0.311 *	0.227	0.012	0.089
REGION	unc sm	0.130 *	-0.186 *	0.112 *	-0.289 ***	-0.151 ***
	unc ma	0.116 *	-0.158 *	0.098 *	-0.255 ***	-0.163 ***
	cond-0 sm	0.175 *	-0.007	0.209 *	-0.100	-0.071
	cond-0 ma	0.166 *	-0.014	0.176 *	-0.089	-0.085
	cond sm	0.238 *	-0.099	0.209 *	-0.252 ***	-0.008
	cond ma	0.180 *	-0.167 *	0.144 *	-0.159 *	-0.101 *
	cond-1 sm	0.172 *	-0.277 *	0.100	-0.040	-0.222 *
	cond-1 ma	0.171 *	-0.237 *	0.115 *	-0.041	-0.214 *
GENDER	unc sm	-0.059	-0.071	0.214 ***	0.127 *	0.022
	unc ma	-0.052	-0.058	0.176 ***	0.110 *	0.025
	cond-0 sm	-0.051	-0.005	0.258 *	-0.008	0.028
	cond-0 ma	-0.039	-0.014	0.214 ***	-0.008	0.038
	cond sm	0.001	-0.059	0.258 *	0.082	0.004
	cond ma	-0.011	-0.096	0.171 ***	0.068	0.028
	cond-1 sm	0.004	-0.190	0.169	0.019	0.036
	cond-1 ma	0.008	-0.165	0.181	0.017	0.040
EDUC	unc sm	0.228 ***	0.240 ***	0.056	0.080	0.060
	unc ma	0.206 ***	0.198 ***	0.048	0.070	0.066
	cond-0 sm	0.206 ***	0.002	0.047	-0.003	0.039
	cond-0 ma	0.185 *	0.009	0.036	-0.005	0.045
	cond sm	0.165 *	0.056	0.047	0.019	0.006
	cond ma	0.130 *	0.112 *	0.023	-0.001	0.047
	cond-1 sm	0.057	0.163	0.005	-0.023	0.089
	cond-1 ma	0.063	0.129	0.009	-0.019	0.086
HHSIZE	unc sm	-0.001	0.011	0.002	0.028 ***	0.013 ***
	unc ma	-0.001	0.009	0.001	0.024 ***	0.015 ***
	cond-0 sm	-0.004	0.000	-0.003	0.007	0.007
	cond-0 ma	-0.004	0.001	-0.003	0.006	0.009
	cond sm	-0.005	0.003	-0.003	0.023 ***	0.001
	cond ma	-0.004	0.005	-0.002	0.015 *	0.010 *
	cond-1 sm	-0.006	0.008	0.000	0.004	0.019 *
	cond-1 ma	-0.006	0.006	0.000	0.003	0.019 *

Note: explanations are given below Table 6.

B. R-Script used for the analysis

Warning: the execution of all these commands might take up to several days.

```
# load R package "mvProbit"
library( "mvProbit" )

# read data set
dat <- read.csv( "AdoptionData.csv" )

# ML estimation using the BHHH algorithm
estResult <- mvProbit(
   cbind( VACCIN, FEED, HENHOUSE, CHICKHOU, COCK ) ~
   REGION + GENDER + EDUC + CREDIT + HHSIZE + EXPVIL,
   data = dat, method = "BHHH",
   algorithm = "GHK", nGHK = 5000 )
summary( estResult )

# ML estimation using the BHHH algorithm, with AGE
estResultAge <- mvProbit(
   cbind( VACCIN, FEED, HENHOUSE, CHICKHOU, COCK ) ~
   REGION + GENDER + AGE + EDUC + CREDIT + HHSIZE + EXPVIL,
   data = dat, method = "BHHH",
   algorithm = "GHK", nGHK = 5000 )
summary( estResultAge )

# ML estimation using the BHHH algorithm, with AGE + AGE^2
estResultAge2 <- mvProbit(
   cbind( VACCIN, FEED, HENHOUSE, CHICKHOU, COCK ) ~
   REGION + GENDER + AGE + AGE2_100 + EDUC + CREDIT + HHSIZE + EXPVIL,
   data = dat, method = "BHHH",
   algorithm = "GHK", nGHK = 5000 )
summary( estResultAge2 )

# ML estimation using the BHHH algorithm, without credit
estResultNoCredit <- mvProbit(
   cbind( VACCIN, FEED, HENHOUSE, CHICKHOU, COCK ) ~
      REGION + GENDER + EDUC + HHSIZE + EXPVIL,
   data = dat, method = "BHHH",
   algorithm = "GHK", nGHK = 5000 )
summary( estResultNoCredit )

# ML estimation of each adoption decision separately
estResultSep1 <- glm( VACCIN ~ REGION + GENDER + EDUC + CREDIT + HHSIZE +
   EXPVIL, data = dat, family = binomial( link = "probit" ) )
summary( estResultSep1 )
estResultSep2 <- glm( FEED ~ REGION + GENDER + EDUC + CREDIT + HHSIZE +
   EXPVIL, data = dat, family = binomial( link = "probit" ) )
summary( estResultSep2 )
estResultSep3 <- glm( HENHOUSE ~ REGION + GENDER + EDUC + CREDIT + HHSIZE +
   EXPVIL, data = dat, family = binomial( link = "probit" ) )
summary( estResultSep3 )
estResultSep4 <- glm( CHICKHOU ~ REGION + GENDER + EDUC + CREDIT + HHSIZE +
   EXPVIL, data = dat, family = binomial( link = "probit" ) )
summary( estResultSep4 )
estResultSep5 <- glm( COCK ~ REGION + GENDER + EDUC + CREDIT + HHSIZE +
   EXPVIL, data = dat, family = binomial( link = "probit" ) )
summary( estResultSep5 )
```

```
# statistical tests (using R packages "car" and "lmtest")
library( "car" )
library( "lmtest" )

# test significance of AGE^2 in general model
# Wald-test
lht( estResultAge2,
   c( "b_1_4 = 0","b_2_4 = 0", "b_3_4 = 0", "b_4_4 = 0", "b_5_4 = 0" ) )
# LR test
lrtest( estResultAge2, estResultAge )

# test common significance of AGE + AGE^2 in general model
# Wald-test
lht( estResultAge2, c( "b_1_3 = 0", "b_1_4 = 0", "b_2_3 = 0", "b_2_4 = 0",
   "b_3_3 = 0", "b_3_4 = 0", "b_4_3 = 0", "b_4_4 = 0",
   "b_5_3 = 0", "b_5_4 = 0" ) )
# LR test
lrtest( estResultAge2, estResult )

# test significance of CREDIT in model without AGE + AGE^2
# Wald-test
lht( estResult,
   c( "b_1_4 = 0","b_2_4 = 0", "b_3_4 = 0", "b_4_4 = 0", "b_5_4 = 0" ) )
# LR test
lrtest( estResult, estResultNoCredit )

# test of multivariate probit against separate univariate probit models
# Wald-test
lht( estResult,
   c( "R_1_2 = 0", "R_1_3 = 0", "R_1_4 = 0", "R_1_5 = 0", "R_2_3 = 0",
      "R_2_4 = 0", "R_2_5 = 0", "R_3_4 = 0", "R_3_5 = 0", "R_4_5 = 0" ) )
# LR test
estResultSep <- list( maximum = logLik( estResultSep1 ) +
   logLik( estResultSep2 ) + logLik( estResultSep3 ) +
   logLik( estResultSep4 ) + logLik( estResultSep5 ) )
attr( estResultSep$maximum, "df" ) <- 5 * 7
class( estResultSep ) <- "maxLik"
lrtest( estResultSep, estResult )


# unconditional marginal effects, calculated at all observations
margEffUncObs <- margEff( estResult,
   addMean = TRUE, calcVCov = TRUE )
summary.data.frame( margEffUncObs )
printCoefmat( summary( margEffUncObs )[ 12151:12180, ] )

# unconditional marginal effects, calculated at the mean
margEffUncMean <- margEff( estResult, atMean = TRUE, calcVCov = TRUE )
print( margEffUncMean )
summary( margEffUncMean )


# conditional marginal effects, calculated at all observations
# assuming that all other dependent variables are as observed
margEffCondObs <- margEff( estResult,
   cond = TRUE, addMean = TRUE, calcVCov = TRUE, returnJacobian = TRUE,
   algorithm = "GHK", nGHK = 5000 )
printCoefmat( summary( margEffCondObs )[ 12151:12180, ] )
```

```
# conditional marginal effects, calculated at the mean
# assuming that all other dependent variables except henhouse are zero
margEffCondMeanH <- margEff( estResult, cond = TRUE, atMean = TRUE,
   othDepVar = c( 0, 0, 1, 0, 0 ), calcVCov = TRUE,
   algorithm = "GHK", nGHK = 5000 )
summary( margEffCondMeanH )


# conditional marginal effects, calculated at all observations
# assuming that all other dependent variables are zero
margEffCondObs0 <- margEff( estResult,
   cond = TRUE, addMean = TRUE, othDepVar = 0, calcVCov = TRUE,
   returnJacobian = TRUE, algorithm = "GHK", nGHK = 5000 )
printCoefmat( summary( margEffCondObs0 )[ 12151:12180, ] )

# conditional marginal effects, calculated at the mean
# assuming that all other dependent variables are zero
margEffCondMean0 <- margEff( estResult, cond = TRUE, atMean = TRUE,
   othDepVar = 0, calcVCov = TRUE,
   algorithm = "GHK", nGHK = 5000 )
summary( margEffCondMean0 )


# conditional marginal effects, calculated at all observations
# assuming that all other dependent variables are one
margEffCondObs1 <- margEff( estResult,
   cond = TRUE, addMean = TRUE, othDepVar = 1, calcVCov = TRUE,
   returnJacobian = TRUE, algorithm = "GHK", nGHK = 5000 )
printCoefmat( summary( margEffCondObs1 )[ 12151:12180, ] )

# conditional marginal effects, calculated at the mean
# assuming that all other dependent variables are one
margEffCondMean1 <- margEff( estResult, cond = TRUE, atMean = TRUE,
   othDepVar = 1, calcVCov = TRUE, algorithm = "GHK", nGHK = 5000 )
summary( margEffCondMean1 )
```