

Determinants of farm diversification in integrated crop–livestock farming systems in Ghana

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Abstract

Agricultural diversification has been identified as one of the mechanisms for managing household food security and poverty in developing economies, because it can spread the risk among multiple production enterprises and provide a range of food items for the households. By examining the integrated farming systems of 608 smallholders in Ghana, this paper presents empirical evidence to support the development of effective strategies that enhance diversified farming systems. The estimated mean diversification indices were 0.45, 0.32 and 0.59 for crop, livestock and crop–livestock diversification systems, respectively. Using the Cragg two-step regression model, this paper shows that the decision to diversify and the extent of diversification are distinct decisions affected by different sets of factors. Likewise, the effect of these factors also varied across the three categories of diversification examined. Careful consideration needs to be given to the selection of factors and the methods for examining the diversification process to avoid confounding recommendations. The findings underscore the importance of households' access to tillage equipment, fertilizers, credit and market information in encouraging farmers to diversify.

Key words: agricultural diversification, integrated crop–livestock farming system, Cragg two-step model, Ghana

Introduction

Farm households in developing countries strive to achieve food security by consuming and then selling surplus household produce (Govere and Jayne, 2003). This is typical of farm households in Ghana who experience issues of food insecurity especially during the dry season. Integrated crop–livestock farming has been identified as an important mechanism to address rural household food insecurity and poverty in developing economies (Herrero et al., 2007; Food and Agriculture Organization (FAO), 2010). Globally, this type of integrated farming system produces about half the world's food (Herrero et al., 2010). In addition, it reduces the cost of total farm production by exploiting economies of scope (Chavas and Di Falco, 2012). For instance, cost savings of 14% have been identified from joint crop and livestock production rather than producing crops and livestock separately (Wu and Prato, 2006).

In Ghana, crop and livestock production systems are practiced by 90% of smallholders. However, the choices available to farmers are limited by the availability of resources such as land, labor and capital. In recent years, the options for farmers have also been limited by climatic conditions, especially erratic rainfall, drought, high temperatures and floods (Agyemang-Bonsu et al., 2008; Griebenow and Kishore, 2009; Ellis-Jones et al., 2012). These result in low crop yields and, in extreme cases, crop failure. This has a cascading debilitating effect on livestock production (Ellis-Jones et al., 2012; Ndamani and Watanabe, 2015), because pasture and crop residue, which play important roles as livestock feed in most rural settings, become limited. This leaves resource-poor farm households in Ghana suffering from income instability, inadequate food availability and increased poverty.

The relevance of agricultural diversification in reducing production and marketing risks, as well as household

income instability and its implications for food security and poverty has long been acknowledged (Ellis, 1998; Little et al., 2001; Joshi et al., 2004; Mainik and Rüschemdorf, 2010; Yan et al., 2010; Chavas and Di Falco, 2012; Kim et al., 2012; Tasie et al., 2012; Ogundari, 2013). The key benefits of agricultural diversification can then be classified into three categories: economic, social and agronomic (Johnston et al., 1995).

Economic benefits include seasonal stabilization of farm income to meet other basic needs such as education, household food security and mitigating risk. Indeed most farms are involved in multi-output diversified enterprises due to the presence of the significant uncertainty that is inherent in agriculture (Lin et al., 1974; Chavas and Di Falco, 2012). In such cases, agricultural diversification can reduce the risk exposure of farm households by optimizing income from a range of activities that are subject in different ways to varying weather and market conditions. The social benefits include more stable employment for farm workers and resources throughout the year. This can result in sustainable incomes through efficient use of resources and exploitation of comparative advantage, for example, in India (Joshi et al., 2004). Conservation of soil and water resources, reduced disease, weed and insect infestation, reduced erosion, increased soil fertility and increased yields are key determinants among the agronomic benefits of diversification (Caviglia-Harris and Sills, 2005; Iiyama et al., 2007; Mainik and Rüschemdorf, 2010).

In spite of the significant contribution of agricultural diversification in developing countries in Asia and some parts of Africa in managing production risks, studies on agricultural diversification in Ghana are minimal and have largely focused on incomes and livelihoods (Knudsen, 2007; Lay and Schüller, 2008; Aneani et al., 2011; Fausat, 2012; Senadza, 2012). With the exception of Aneani et al. (2011) who examined diversification of cocoa production, to our knowledge; there has been no study on diversification in crop production. Diversification studies on livestock are also minimal, particularly in sub-Saharan Africa (Devendra and Ibrahim, 2004; Ibrahim et al., 2009) and non-existent in Ghana. However, given that crop production is highly correlated with livestock production in sub-Saharan Africa, with nearly 60% of crops produced with livestock, this paper extends the literature on diversification by examining the factors influencing diversification in livestock and integrated crop–livestock production systems among smallholders in Ghana.

Most diversification studies have estimated and examined diversification as a joint decision-making process employing limited dependent variable models such as the logit and probit models and their extensions, as well as the Tobit models (Knudsen, 2007; Lay and Schüller, 2008; Aneani et al., 2011; Fausat, 2012; Senadza, 2012; Tasie et al., 2012). The use of such models in examining the determinants of diversification without carrying out

the appropriate tests of separability to ascertain whether diversification is indeed a joint decision or separate decisions can lead to conflicting policy recommendations. This is because examining a joint decision instead of distinct diversification decisions does not allow for a full understanding of the factors affecting the entire diversification decision-making process. By exploring the appropriate tests of separability, this paper contributes to the diversification literature by examining both the discrete decision to diversify as well as the continuous decisions concerning the intensity of diversification of crop, livestock and integrated crop–livestock systems among smallholders in Ghana. This will ensure targeted food production policies are made to correspond with the instantaneous decision to diversify as well as the extent of diversification.

The remaining sections of the paper are presented as follows. Section ‘The concept and determinants of agricultural diversification’ presents the definition of the concept of diversification and its determinants. An overview of crop–livestock production systems is presented in the section ‘Overview of crop–livestock systems in Ghana’. The research methodology is presented in the section ‘Methodology’, which includes a description of the study area, the sampling approach, the data obtained, the theoretical framework and the empirical models involved. Section ‘Empirical results’ presents the empirical results and discussion, followed by concluding comments in section ‘Conclusions and policy implications’.

The concept and determinants of agricultural diversification

Agricultural diversification refers to the shift from the dominance of one crop to production of a number of crops on a farm or in a region, to meet the ever increasing demand for food (Petit and Barghouti, 1992). In other words, agricultural diversification has meant that the farmers now concentrate on new areas of agriculture, growing alternative crops, rearing new breeds of livestock and adopting a new farming system (Joshi et al., 2006).

Chaplin (2000) and Vyas (2006) perceived diversification as consisting of three stages. The first stage reflects a cropping system that shifts away from monoculture. The second stage involves the cultivation of more than one enterprise producing a variety of crops to meet the market at different times of the year. The third stage is mixed farming involving a shift of resources from one crop (or livestock) to a larger mix of crops (or livestock) or a mix of crops and livestock. For this reason, Joshi et al. (2006) described agricultural diversification as connoting crop mix, enterprise mix and activity mix at the household level aimed at increasing household income and profit. This paper focuses on the second and third stages in diversification, as defined here. Thus, crop diversification refers to the cultivation of two or more crops

with the available productive resources. Similarly, livestock diversification is the rearing of two or more livestock types by the farmers given their available resources. Crop–livestock diversification is defined as the production of one or more crops and livestock with the available resources.

The determinants of diversification can largely be classified into demand- and supply-side categories. Specifically, such a classification includes per capita income, urbanization and population growth (Chand, 1996; Ryan and Spencer, 2001; Smith et al., 2001; Joshi et al., 2007), on the demand-side, whereas, on the supply-side, there are farm-level factors, household-level factors, biophysical factors, risk factors, infrastructure or institutions, technology and resource endowments. The characteristics of the decision-making households are largely determined by household-level factors such as age, gender, education, household dependency ratio, capital and off-farm income activities (Guvele, 2001; Shezongo, 2005; BIRTHAL et al., 2007; Van den Berg et al., 2007; Ashfaq et al., 2008; Rahman, 2008; Ibrahim et al., 2009; Abro, 2012; Tasie et al., 2012; Sichoongwe et al., 2014).

Relevant farm-level factors include the number of crops cultivated and the livestock managed by farm households, the total land area cultivated, total value of outputs, types of crops cultivated, hired and family labor, use of complementary technologies and quantity of fertilizer used (Weiss and Briglauer, 2000; Benin et al., 2004; Rahman, 2008; De and Chattopadhyay, 2010; Dzanku and Sarpong, 2010; Mesfin et al., 2011; Senadza, 2012; Sichoongwe et al., 2014). Diversification is also influenced by farmers' access to markets, distance to markets, access to extension, access to credit, membership of associations and proximity to research and extension institutions and availability of advice (Chand, 1996; Smith et al., 2001; Estache, 2003; Joshi et al., 2007; Kankwamba et al., 2012).

Several techniques have been employed to explain specialization or diversification of commodities or activities in a given time and space by a single indicator with unique strengths and weaknesses. Common among these are: the index of maximum proportion, the Herfindahl index (HI) and its related transformations, Simpson's index, the Ogive index and the Entropy index and its associated modifications (Kelley et al., 1995; Chand, 1996; Pandey and Sharma, 1996; Joshi et al., 2006). However, among these techniques, the Simpson index of diversity, the HI and the Ogive index have been widely employed in estimating agricultural diversification (Mekhora and Fleming, 2004; Joshi et al., 2006; Ashfaq et al., 2008; Ibrahim et al., 2009; Fausat, 2012; Ogundari, 2013). Simpson's index of diversity is an area-based index and measures horizontal diversification in terms of the proportionate areas allocated to different enterprises. This is appropriate and works well when estimating crop diversification. Both the HI and the Ogive index measure

diversification in terms of revenue; hence, they are suitable for estimating diversification among livestock and integrated crop–livestock systems. However, for purposes of comparison and standardization, this study employs the HI to estimate all three variants, namely, diversification among crop, livestock and crop–livestock diversification systems. Unlike the Ogive index, the HI is straightforward to interpret and lies between one (for complete specialization) and zero (for complete diversification). In addition, this index has been widely applied in measuring agricultural diversification or specialization in the economic literature, thus, enabling us to relate our results with the findings of other studies. To estimate the determinants of diversification for cross-sectional data, a number of techniques have been applied. Least-squares multiple regression models are appropriate for estimating the determinants of diversification in situations where diversification is complete within the population (Joshi et al., 2006), and has been extensively employed (Ergano et al., 2000; Ashfaq et al., 2008; Fausat, 2012; Senadza, 2012). However, in situations where diversification is not universal, ordinary least-squares estimates are inconsistent; hence, inferences from such results may be misleading (Wan and Hu, 2012).

The use of the Tobit model provides estimates of joint determinants of both discrete and continuous diversification decisions (Waithaka et al., 2007; Keelan et al., 2009; Wan and Hu, 2012). Hence, using both the probit and Tobit regression models to estimate the determinants of the probability and the extent of diversification separately, may lead to confounding policy implications. This is because, the Tobit model jointly estimates the determinants of the probability and the intensity of diversification, thus resulting in double counting the probability of diversification (Waithaka et al., 2007). Furthermore, the Tobit model assumes that the two decisions are made jointly. However, this assumption has been criticized that it may not always be reasonable because the discrete and continuous diversification decisions could be made at different stages and are likely to be influenced by different factors (Lin and Schmidt, 1984). Consequently, two-step models, the Heckman selectivity model and the Cragg model have been proposed to account for this potential problem (Mal et al., 2012; Yirga and Hassan, 2013). The Heckman model addresses selectivity bias and also requires the use of different sets of variables in each specification (Heckman, 1979). In contrast, with the Cragg model, the same set of variables can be used in both stages and assumes their effects on the two decisions are different (Cragg, 1971). Given that this is so, the decision to diversify may be preliminary to the decision on the extent to which farmers diversify. There is the need to examine whether the two decisions are joint or separate. Where the decision is jointly made the Tobit model can be used to estimate the determinants of diversification. However, where the decisions are made separately, then, the extent of diversification may be characterized by

selectivity bias. This paper conducts the separability and selectivity tests in diversification decisions. Where separability is confirmed, an additional test is conducted to examine whether the two decisions are independent of each other.

This paper assumes that the same sets of variables can affect the discrete decision to diversify and the continuous diversification decisions but affect them differently. In addition, preliminary analyses with the Heckman models revealed insignificant Mill's ratios. This has two implications: first, it indicates that selection bias is not significant in the sample; secondly, it suggests that different factors can influence the discrete decision to diversify and the continuous diversification decisions (Waithaka et al., 2007). For instance, crop–livestock farmers will decide to diversify without considering how much additional crop or livestock they intend to cultivate. Consequently, the two models can be estimated separately, thus, the use of the Cragg two-step model is appropriate for estimating the determinants of crop–livestock diversification.

Overview of crop–livestock systems in Ghana

Integrated crop–livestock systems include the production of various crops and livestock types in a mixed farming system (FAO, 2010). In Ghana, there are some complementarities in this system. For instance, crop residues are mainly used as livestock feed, especially during the dry season. Predominantly, in areas where dryness is characterized by patches of intermittent bushfires, the use of crop residues plays a critical role in livestock production. Likewise, manure is used as fertilizer on most arable land in Ghana. Manure is collected and plowed into the soil during land preparation.

In Ghana, the major crops integrated with livestock are cowpea, groundnut, soybean, rice, millet, sorghum and maize. Major livestock types in this system are cattle, sheep, goats, pigs and poultry (Karbo and Agyare, 2002). These livestock types are commonly managed in this system for various purposes. For instance, beef is a very common household meat, while goats, sheep and poultry are highly marketable and can readily be converted into cash to support household needs; hence, they are in relatively high demand. This demand is compounded during festive occasions because these animals are used for sociocultural purposes during festivals and other traditional events. However, the proportions of different livestock kept depend on the priorities of the farm households and their ability to manage them given their available resources.

A typical crop–livestock farmer in Ghana will keep at least sheep, goats or cattle, or some combination of these, in addition to the cultivation of crops such as cowpea, groundnut, maize, millet and sorghum. The

prime purpose of cultivating these crops is not to be used as feed for the animals, but, after harvesting, the crop residues are fed to the livestock. In this paper, an integrated crop–livestock system refers to a combination of any of the crops and livestock described in the previous paragraph on the same land in a given farming season.

Methodology

To examine the determinants of diversification in crop, livestock and crop–livestock systems, first indicators of diversification were computed by the Herfindah index following Pal and Kar (2012). Next the determinants of diversification were examined using the Cragg two-step model (Cragg, 1971). In the first step, the discrete decision to diversify was analyzed using the probit model. This was followed by an analysis of the extent of diversification among the diversified subsample using a truncated regression model.

Data and sampling technique

The data for this paper were collected from smallholder crop–livestock producing households in the Atebubu-Amantin (A-A) and Ejura-Sekyedumase (E-S) districts of the forest–savannah transition agroecological zone of Ghana. Multi-stage sampling was adopted to select respondents for the study. In the first stage, the forest–savannah transition agroecological zone was purposively selected for the study. The A-A and E-S districts were also selected purposively. These districts were selected on the basis of their high livestock density, the potential for integration of crop–livestock systems, market access, high poverty index and their proximity to existing good livestock-practice centers. In addition, a significant proportion of crops and livestock are produced in these districts (Ministry of Food and Agriculture, 2010). From each district, 12 communities were randomly selected. For each community, a minimum of 25 households were randomly selected from a list of crop–livestock producing households in the communities, a total of 608 farm households were interviewed.

The data were collected using structured questionnaires. The data collected included information on the crops and livestock managed, socio-economic factors, farm-level factors, institutional factors, and crop–livestock integration-related activities carried out by the farmers. Crop–livestock farmers were considered because, naturally, farmers in this system tend to diversify by producing two or more crops and/or livestock in a given cropping season. Subsequently, examining the determinants of their decision to diversify as well as the extent is essential.

Theoretical framework

The decision to diversify is centered on the theory of diversification, the basic assumption of which is rooted

in the utility maximization theory (Rahm and Huffman, 1984). Thus, the latent utility of the i th farmer for the j th diversification process is denoted by U_{ji} , where $j = 0$ or 1 if the i th farmer is ‘not diversified’ or ‘diversified’, respectively. We assume that the utility obtained from diversification depends on a vector of farm- and farmer-specific attributes, G_i , and a vector of the attributes associated with diversification, K_i , for the i th farmer.

Although the utility is a latent variable, we assume that it is a linear function of the vector of observed farm-level, farmer-related, diversification-related characteristics, institutional factors, and a random error with zero mean, as follows:

$$U_{ji} = X_i\alpha_j + e_{ji}, \quad j = 0, 1; \text{ and } i = 1, 2, \dots, n \quad (1)$$

where X_i is a $(1 \times k)$ vector of values of relevant variables to describe the utility for the i th farmer.

Given that the utilities, U_{ji} , are random, the alternative $j = 1$ will only be selected by the i th farmer if $U_{1i} > U_{0i}$ or if the unobservable (latent) random variable, $d_i^* = U_{1i} - U_{0i}$, is positive. The probability that the i th farmer practices diversification, denoted by $d_i = 1$, is a function of the explanatory variables and is expressed as:

$$\begin{aligned} P_i &= P(d_i = 1) = P(U_{1i} > U_{0i}) \\ &= P(X_i\alpha_1 + e_{1i} > X_i\alpha_0 + e_{0i}) = P(\mu_i < X_i\beta) \\ &= F(X_i\beta) \end{aligned} \quad (2)$$

where $\mu_i = e_{0i} - e_{1i}$; $\beta = (\alpha_1 - \alpha_0)$; and $F(\cdot)$ denotes the distribution function for μ_i .

Specification of the empirical model

The HI is employed to compute the crop diversification index (CDI), the livestock diversification index (LDI) and the crop–livestock diversification index (CLDI). These indices are obtained by subtracting the estimated HI from one. Accordingly, the indices have direct relationships with diversification and make the interpretation of the empirical results straightforward, such that a zero value indicates specialization and a value greater than zero signifies some measure of diversification. For standardization, the revenues (which are influenced by quantities produced, quantities sold, prices, the weather and transaction costs) from each crop or livestock enterprise were used to compute the HI.

To compute the HI, we first calculate the revenue shares of the crops and/or livestock involved in the total crop and/or livestock revenue for each sample farmer. The revenue share is expressed as:

$$S_k = \frac{R_k}{\sum_{k=1}^n R_k} \quad (3)$$

where S_k denotes the revenue share occupied by the k th crop or livestock in the total revenue for a farm’s crops, the livestock and/or the crop–livestock enterprises, respectively; R_k denotes the revenue from the k th crop or livestock enterprise for a sample farmer; $\sum_{k=1}^n R_k$

denotes the total farm revenue for the crops, the livestock and/or the crop–livestock enterprises, respectively; $k = 1, 2, \dots, n$ (number of enterprises involved in all farmers’ farming operations)

The Herfindahl index is specified as:

$$HI = \sum_{k=1}^n S_k^2 \quad (4)$$

which ranges from zero to one. The value of one indicates complete specialization (i.e., just one enterprise). For a high level of diversification, the value of the HI is likely to be small. For the special case of equal revenue shares among a total of n enterprises for a sample farmer, the values of the revenue shares would be equal to $1/n$ and the value of the HI would also be $1/n$.

The HI is computed for crops (HI_C), livestock (HI_L) and crop–livestock (HI_{CL}) farming systems. It follows that CDI, LDI and CLDI are then obtained as:

$$\begin{aligned} \text{CDI} &= 1 - HI_C; \text{LDI} = 1 - HI_L; \text{and CLDI} \\ &= 1 - HI_{CL} \end{aligned} \quad (5)$$

The sample farmers in this study consisted of those who diversified (Farmers are said to be diversified in crops, livestock and integrated crop–livestock farming systems when they obtain a CDI, LDI and CLDI > 0.5 , respectively) and those who did not. Let d_i denote the discrete decision to diversify such that $d_i = 1$ for farmers who diversified and $d_i = 0$ for non-diversified farmers. Subsequently, the extent of diversification in each category is therefore denoted by the respective indices calculated by equation (5). We assume in this paper that the two decisions were made in different stages and that the same factors had different effects on the two decisions. Consequently, the latter assumption is supported by the Cragg two-step regression model (Cragg, 1971) and has been used to explain why some crop–livestock farmers diversified and others did not as well as the observed differences in the extent of diversification in crop, livestock and crop–livestock enterprises.

Following Belotti et al. (2012), the first step of the Cragg model involves the estimation of a probit regression model for the discrete diversification decisions. Following equation (2) above, the probability that a farmer is diversified is represented by the cumulative distribution function of F for μ_i evaluated at $X_i\beta$. Assuming that the μ_i s are independently and identically distributed as standard normal random variables, we estimate the probability of diversifying using the probit model.

The second stage of the model involves the specification and estimation of the extent of diversification once the decision to diversify is made by the i th farmer. This model is defined by equation (6), which is a truncated regression model where the ε_i s are assumed to be independent and identically distributed normal random errors with mean zero and variance, σ^2 , as follows:

$$D_i | d_i^* > X_{2i}\beta + \varepsilon_i > L \quad (6)$$

where D_i is the random variable that defines diversifying (estimated by the diversification indices); d_i^* is an unobservable latent variable; L is an unobservable threshold value (For this study, L represents diversification status, i.e. diversified or not); and X_{2i} is the vector of values of independent variables that is used to explain the extent of diversification. These independent variables are denoted with the subscript 2 to differentiate them from the independent variables used to determine the first stage of the estimation (the discrete diversification decision). Although some sets of explanatory variables can be common in the two models they are expected to have separate and different effects on the discrete and continuous diversification decisions. Equation (6) is solved by maximizing the log-likelihood function using the maximum-likelihood estimator.

To substantiate the use of the two-step model, a joint decision test was conducted using the likelihood ratio test. This test involves the estimation of diversification with the probit model, the truncated model, and the Tobit model separately (Mal et al., 2012). Following Katchova and Miranda (2004), the log-likelihood values of the models were then used to compute the likelihood ratio test statistic, λ , as follows:

$$\lambda = -2(LL_{\text{Probit}} + LL_{\text{Truncated}} - LL_{\text{Tobit}}) \quad (7)$$

where LL_{Probit} , $LL_{\text{Truncated}}$ and LL_{Tobit} denote the log-likelihood functions of the probit, truncated, and Tobit regression models, respectively, for each diversification category. The estimated λ should be greater than the χ^2 critical value to justify the use of the Cragg two-step model (Katchova and Miranda, 2004; Mal et al., 2012).

Description of variables

To estimate the parameters of the models of equations (2) and (6) for the two decisions above, a set of explanatory variables is considered. These variables were selected based on empirical studies and the available database and are expected to influence the two decisions. The proceeding paragraphs discuss the nature of these variables and our expectations on their effects. *Age of household heads* is a proxy for experience in agriculture and is a major determinant in household production decisions. Given that older farmers are more likely to have access to production resources and information, they are more likely to diversify. On the other hand, younger farmers are more inclined to perceive and carry out farming as a business and a source of livelihood (FAO, 2010); thus, they are more likely to diversify to reap the benefits that come with it than older farmers who, in most instances, perceive farming as a hobby or way of life. Thus, the age variable may have either a negative or positive influence on diversification because it has had non-harmonious effects in the literature (Ashfaq et al., 2008; Sichoongwe et al., 2014).

Minimal variations have existed in the effect of *gender* on diversification. It depends largely on the gender

dominance of the household heads in the respective society and the influence of household heads in production decision-making. Subsequently, the decision to diversify is a matter of both choice and access to available resources (Sichoongwe et al., 2014). Like the northern part of the country, the forest-savannah transition agroecological zone is dominated by male household heads (Etwire et al., 2013) who are expected to have a positive influence on the decision to diversify.

The *dependency ratio*, which is the ratio of the number of active persons in the household to the number of dependants in the household, is used to represent household size and may have a mixed effect on the extent of diversification. Households with larger proportions of dependants are likely to diversify to be able to ensure stable provision of household needs, especially in terms of increasing production and diet (Benin et al., 2004). On the other hand, households with higher dependency ratio may not diversify due to inadequate household labor and other inputs needed to implement diversified farming options.

Education, introduced as a dummy variable indicating farmers who had formal education, has been found to have positive effects between education and diversification (Rahman, 2008; Ibrahim et al., 2009). Educated people are likely to be better informed about alternative crops and/or livestock adaptable to existing production conditions. In addition, educated farmers are more able to identify and explore the potentials for different sources of incomes (Ghafoor et al., 2010) from diversifying, thus are likely to have a positive influence on diversification decisions.

Off-farm income could provide farmers with additional funds for supporting production activities, but higher incomes from off-farm activities could affect the interest of the farmer and lead to diversion of resources away from farming (Rahman, 2008); hence, access to off-farm income may influence diversification either positively or negatively.

Institutional variables included in the model include distance to markets, access to credit, and access to market information, access to extension and good road network. Except for distance to markets, all the other variables are expected to have a positive influence on diversification. For instance, with access to timely credit, farmers are able to produce additional crops and/or livestock because they are able to purchase inputs and other resources needed for production. Also, a more accessible road network is likely to have positive effects on diversification. Better market and road networks reduce the transaction or marketing costs, enhancing easy and rapid disposal of produce. Subsequently, the risks of possible post-harvest losses are reduced, particularly for perishables (Joshi et al., 2004).

Distance to market is a proxy for physical access to markets and proximity to economic resources. Farmers closer to markets tend to diversify to meet the changing

market demand for various produce/products at different times of the year. Proximity to main roads and markets has also been found to increase the development of other farm enterprises (Benin et al., 2004). In addition, these variables technically affect the efficiency of the supply chain and, thus, may encourage farmers to diversify. On the other hand, it is possible that farmers at greater distances from markets or main roads diversify to meet their broad subsistence and nutritional needs (Kankwamba et al., 2012). Thus, distance to market is likely to have mixed effects on diversification.

The effects of dummy variables that represent access to extension services and access to market information were also examined in the models. These variables typically represent sources of information as well as allied improved technologies for producing additional crops and/or livestock, and could lead to increase the probability and extent of diversification (Ibrahim et al., 2009).

To explore the effect of farm-level factors on diversification, additional variables such as the use of plows, and quantity of fertilizer used as well as access to the fertilizer subsidy were included in the models. The use of plows for cultivation and the quantity of fertilizer used are expected to enhance diversification (De and Chattopadhyay, 2010; Mesfin et al., 2011). Also included in the models is a dummy variable to indicate the *ownership of land*, which is likely to have a positive influence on diversification. Farmers with limited access to land have less flexibility to allocate portions to various production activities including pasture and other livestock management practices.

To examine the role of crop–livestock integration in diversification, dummy variables to indicate the storage and feeding of crop residue are also included in the model. These variables are likely to have positive influences on both decisions. The total value of farm assets is used as a proxy for productive capital. This variable represents the value of all tools and implements used directly for the agricultural production processes, including the value of owned livestock resources. Access to farm assets is expected to empower farmers to produce different crops and/or livestock which may require specialized tools and inputs (Rahman, 2008); thus, they are likely to positively influence diversification decisions.

Empirical results

Summary statistics of variables

Table 1 presents the basic summary statistics of the variables for the sample households involved in the study. The age of household heads averaged about 44 years. Typically, the dependency ratio of farm households had an average of about 3.7 with higher percentage of male heads (76%) and 43% of heads having access to formal education. Almost 80% of the farmers were engaged in off-farm income-generating activities. Incomes from such activities are expected to be plowed back into farm

Table 1. Summary statistics for the explanatory variables.

Variable	Mean	SD
Age of the household head (years)	44	14
Gender (Male = 1; Female = 0)	0.76	0.43
Education (Yes = 1; No = 0)	0.43	0.50
Dependency ratio	3.7	2.8
Off-farm income activities (Yes = 1; No = 0)	0.76	0.43
Land ownership (Yes = 1; No = 0)	0.72	0.45
Farm assets value (GHC ¹)	2001	4.1
Hired labor (man-days ha ⁻¹)	553	947
Farm size (ha)	7	13
Share of family labor	0.43	0.31
Credit access (Yes = 1; No = 0)	0.63	0.48
Distance to markets (km)	3.5	2.7
Extension (Yes = 1; No = 0)	0.48	0.50
Access to market information (Yes = 1; No = 0)	0.26	0.44
Stable income from diversification (Yes = 1; No = 0)	0.61	0.49
District (A-A = 1; E-S = 0)	0.50	0.50
Use of plow tillage (Yes = 1; No = 0)	0.87	0.33
Good roads network	0.13	0.34
Quantity of fertilizer used (kg ha ⁻¹)	134	19
Fertilizer subsidy (Yes = 1; No = 0)	0.30	0.46
Storage of crop residue (Yes = 1; No = 0)	0.47	0.50
Feeding of crop residue (Yes = 1; No = 0)	0.55	0.50

¹ US\$1 = GHC3.924 (Ghanaian currency) or GHC1 = US\$0.255. (13/03/2016).

production activities. Farm assets were valued on average at GHC2,001.

The average hired labor was about 553 man-days ha⁻¹, whereas family labor constituted about 43%, on average, of the total labor used in production. The average total land holding was 6.8 ha, in which 72% of households owned the land used in cultivation. The use of tillage equipment (87%) was predominant among the sample farmers. Credit and extension services were accessed by 63 and 48% of the sampled households, respectively.

On average, farmers travel about 3.5 km to the nearest input and output markets. Crop–livestock integration-related variables such as the storage and feeding of crop residue were practiced by about 47 and 55% of the farmers, respectively. However, only 26% of households had access to market information. Household income stability was the major motivation for diversification among sample farmers (61%). The average quantity of fertilizer used by the sample farmers was slightly <134 kg ha⁻¹, with nearly 30% of households having access to subsidized fertilizer. About 13% of the farmers had access to good road networks.

Distributions of diversification indices

The average of the crop diversification index was 0.45, as shown in Table 2. Figure 1 shows that the crop

Table 2. Summary statistics for the crops, livestock and integrated crop–livestock diversification indices.

Diversification indices	Mean	SD
Crops diversification (CD)	0.45	0.18
Livestock diversification (LD)	0.32	0.21
Crop–livestock diversification (CLD)	0.59	0.16

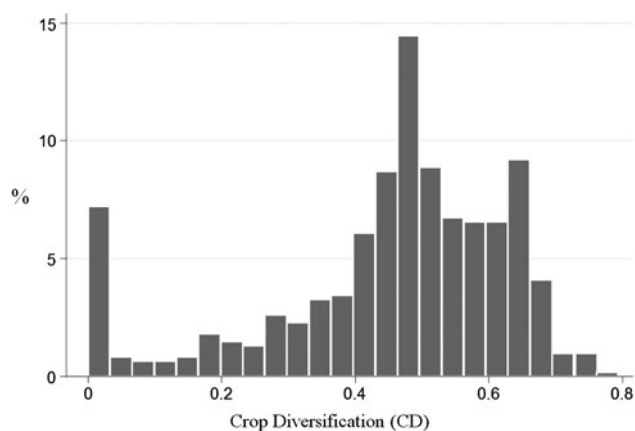


Figure 1. Distribution of the crop diversification (CD) index.

diversification index is reasonably symmetrically distributed. The majority of the farmers had values above 0.5, indicating that most of the farmers were diversified in their cropping activities. About 7% of the farmers were specialized producers growing a single crop only. The suitability of the land and other available resources to the production of specific crops or the high returns from such crops could possibly account for this finding. This result is consistent with the findings of Ogundari (2013) in a study of crop diversification of peasant farmers in Nigeria.

Similar distributions were obtained for the livestock diversification indices (Fig. 2) with an average of 0.32, as presented in Table 2. This shows that livestock diversification is relatively low and more widely dispersed. Generally, there was minimal variation in the number of livestock managed by farm households in the forest–savannah transition agroecological zone, and this could account for this distribution. Almost 18% of the farmers did not diversify their livestock production (Fig. 2).

The distribution of values of the crop–livestock diversification index for the sample farmers is shown in Fig. 3. The average crop–livestock diversification index was 0.59 with standard deviation of 0.16 (Table 2). The figure depicts a negatively skewed distribution of the index. However, with about 76% of the households having indices above 0.5, the distribution suggests a high level of crop–livestock diversification among the

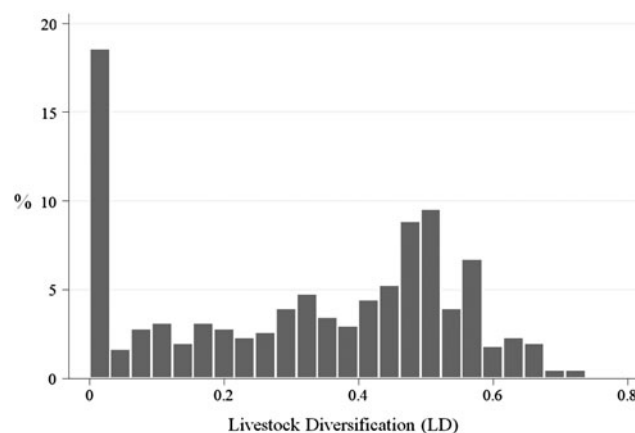


Figure 2. Distribution of the livestock diversification (LD) index.

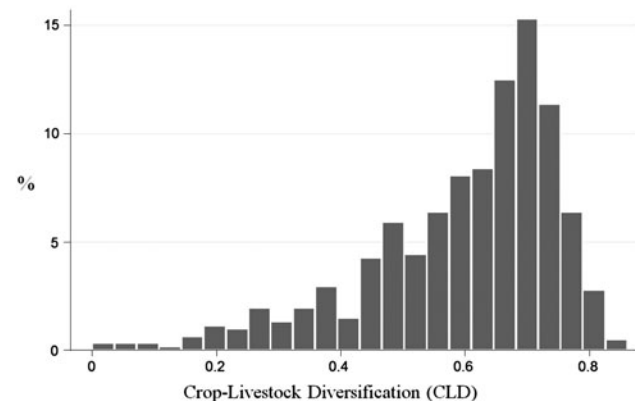


Figure 3. Distribution of the crop–livestock diversification (CLD) index.

farm households. The distributions furthermore show that the crop–livestock diversification index is greater than the indices for crop diversification and livestock diversification. Subsequently, this highlights the significance of intensification of integrated crop–livestock systems among these farm households in rural Ghana. Given the diverse nature of the distributions of the diversification indices for crop, livestock and crop–livestock, it is worth investigating the factors influencing these distributions. The following section presents a discussion on the determinants of diversification in terms of crop, livestock and crop–livestock systems.

Determinants of diversification

The likelihood ratio tests indicate that the decision to diversify and the extent of diversification occurred in two stages (see Tables 1a, 1b and 1c in Appendix 1), hence, we use of the two-step model. Although the probit and truncated models contain the same

parameters, the insignificant Mill's ratios from the Heckman models (Appendix 2), suggests that the independence assumption is satisfied, subsequently, the two decisions are independent. It implies that the continuous decision of how many crop and livestock enterprises farmers decide to adopt, does not depend on the discrete decision to diversify. The two models can be estimated separately and independently. This was evident in the results; for instance, the factors that influenced the two decisions were found not the same. Also, a given factor may be significant in the discrete decision and not significant in the continuous decision or the reverse. The estimates of the parameters of the Cragg two-step model for discrete and continuous decisions of the determinants of diversification for the three types of agricultural enterprises are presented in Table 3. The numbers of observations in Table 3 are less for the crop and livestock systems because some of the farmers were either specialized in crops or livestock production, hence, data for their activities in the other groups were not available. The results show that the discrete and continuous decisions were affected by different factors.

For crop diversification, both types of decisions were influenced by the use of tillage equipment, the quantity of fertilizer used and access to good road networks. Unlike access to good road networks, the two other variables stated above had positive effects on crop diversification. Other factors such as the fertilizer subsidy, extension and hired labor positively influenced the discrete decision, whereas negative effects were found with share of family labor and dependency ratio. Also, the continuous crop diversification decision was positively influenced by age, gender and access to market information (Table 3).

Likewise, for livestock diversification, both decisions were influenced by access to credit, market distance, market information and access to good road networks. However, differences existed in the way they influenced the two decisions. A typical example is access to market information and market distance; these both had positive effects on the discrete decisions but negative effects on the continuous decision on livestock diversification. While access to credit had positive effects on both decisions, negative effects were found with access to good road networks.

Also, the discrete decision was negatively influenced by land ownership, hired labor, and the storage of crop residue, but positively influenced by feeding of crop residue, stable income and farm size. The value of farm assets had negative effects on the continuous livestock-diversification decision.

For crop–livestock diversification, both decisions were positively influenced by the use of tillage equipment. However, other factors did influence the two decisions differently. For instance, off-farm income and farm size influenced only the discrete decision to diversify positively. The continuous decision was positively influenced by gender, access to credit, extension, access to market

information and the perception of obtaining stable incomes from diversifying.

Discussion and implications

Diversification and household decision-making processes

The estimated diversification indices of 0.45, 0.32 and 0.59 for crop, livestock and integrated crop–livestock enterprises, respectively, suggest that farm diversification is significant among smallholders in Ghana. However, these indices are low compared with that obtained in a recent study by Aneani et al. (2011) which studied the extent and determinants of crop diversification among cocoa farmers in Ghana. The differences in farmers, crops and locations could have accounted for this variation. The results of this study showed that diversification decisions may be accounted for by different sets of factors.

Within the farm-household, decision-making process, the decision to diversify (yes or no) may be preliminary to the decision on the extent to which they diversify (the numbers of crops, livestock and crop–livestock to produce). The two-step approach to examine the determinants of diversification is applied in this paper as applied in Sichoongwe et al. (2014) and Wiredu et al. (2015).

Factors affecting crop diversification

Considering crop diversification, the positive effect of extension on the discrete decision to diversify signifies the relevance of extension services and other complementary institutions in encouraging farmers to diversify. Farmers acquire relevant information on the availability of necessary resources, market prices and profitability of new crops as well as necessary complementary technologies through these institutions (Ibrahim et al., 2009; Aneani et al., 2011). Such information clears possible uncertainties about the crops and increases both the probability and the extent of crop diversification (Rahman, 2008). Other studies have found that increasing access to extension has increased the probability and the extent of crop diversification (Ibrahim et al., 2009; Mesfin et al., 2011).

In addition, farm-level factors such as the quantity of fertilizer, and the use of tillage equipment increased the probability and the extent of crop diversification. Because plowing reduces the drudgery of land preparation in terms of labor requirements and allows a greater area of land to be cultivated within a shorter period than using manual methods, crop diversification has been found to increase with access to farm implements and machinery (Mrema et al., 2008; Ibrahim et al., 2009; Mesfin et al., 2011; Sichoongwe et al., 2014). Given the available land, the ability to cultivate larger areas allows farmers to cultivate a greater range of crops.

Table 3. Determinants of diversification in the crop, livestock and crop–livestock systems.

Variable	Crop diversification				Livestock diversification				Integrated crop–livestock diversification			
	Discrete decision		Continuous decision		Discrete decision		Continuous decision		Discrete decision		Continuous decision	
	Coeff	SE	Coeff	SE	Coeff	SE	Coeff	SE	Coeff	SE	Coeff	SE
Age	0.065	0.087	0.0070*	0.0037	−0.006	0.054	−0.0028	0.0063	−0.004	0.098	−0.0036	0.0038
Gender	0.22	0.28	0.025**	0.013	−0.10	0.18	−0.013	0.021	0.22	0.30	0.022*	0.013
Education	0.21	0.26	0.003	0.010	−0.13	0.15	−0.008	0.017	0.07	0.27	0.010	0.011
Dependency ratio	−0.097**	0.043	−0.0013	0.0020	0.040	0.034	−0.0020	0.0034	0.034	0.065	0.0017	0.0023
Off-farm income	0.34	0.28	0.008	0.012	0.03	0.18	0.008	0.021	0.75***	0.28	−0.004	0.013
Land ownership	0.03	0.31	0.005	0.011	−0.41**	0.17	−0.009	0.019	−0.20	0.32	−0.002	0.012
Value of farm assets	−0.02	0.12	−0.0013	0.0030	0.015	0.048	−0.0114*	0.0061	−0.066	0.057	−0.0039	0.0032
Hired labor	2.38***	0.91	−0.0025	0.0062	−0.154**	0.075	0.005	0.011	0.29	0.30	0.0062	0.0061
Farm size	−0.07	0.17	−0.0007	0.0095	0.20*	0.12	−0.006	0.014	0.35*	0.20	−0.0015	0.0085
Family labor share	−0.72*	0.43	0.017	0.016	0.20	0.25	0.015	0.028	−0.08	0.43	0.006	0.017
Credit access	0.01	0.25	−0.007	0.010	0.92***	0.17	0.032*	0.018	0.03	0.28	0.038***	0.011
Market distance	−0.008	0.059	0.0009	0.0018	0.081**	0.033	−0.0057*	0.0032	0.055	0.059	0.0018	0.0019
Extension	0.51*	0.26	0.011	0.010	0.15	0.15	−0.019	0.018	0.10	0.27	0.031***	0.011
Market information	−0.12	0.29	0.026**	0.012	0.33*	0.19	−0.052**	0.020	0.17	0.36	0.035***	0.012
Stable income	0.09	0.27	0.029*	0.011	0.71***	0.15	0.022	0.019	0.03	0.28	0.023**	0.011
District	0.90***	0.32	0.014	0.011	0.04	0.16	0.032*	0.018	−0.70**	0.31	−0.013	0.011
Use tillage equipment	1.64***	0.32	0.073***	0.020					0.79***	0.28	0.115***	0.017
Good road network	−0.56*	0.32	−0.216***	0.016	−0.51***	0.19	−0.087***	0.029				
Fertilizer (kg)	0.88**	0.46	0.0183***	0.0063								
Fertilizer subsidy	1.15**	0.49	0.014	0.011								
Feed crop residue					0.70***	0.17	0.008	0.020				
Store crop residue					−0.61**	0.17	0.008	0.021				
Constant	−1.10	0.75	0.324***	0.037	−0.27	0.48	0.416***	0.054	0.09	0.82	0.441***	0.035
Sigma			0.11571***	0.00349			0.1808***	0.0068			0.1252***	0.0036
Number of obs.	606		563		608		511		608		593	
Wald/LR χ^2 (19)	177.44***		258.36***		143.31***		31.39**		34.99***		115.69**	
Log-likelihood	−66.48		418.07		−195.20		188.91		−52.85		390.88	

The asterisks, *, ** and ***, denote significance at the 10, 5 and 1% levels, respectively.

The quantity of fertilizer used also increased both the probability and the extent of crop diversification. Farmers who apply the recommended amount of fertilizer at the right time are more likely to increase their cropping returns. This is more prominent, especially in Ghana and other sub-Saharan Africa countries, where soil infertility is a major issue. Fertilizer availability enables farmers to improve the fertility of their land, thus making it suitable for them to increase the variety of crops they cultivate. Similar results have been obtained in India (De and Chattopadhyay, 2010); Malawi (Ndhlovu, 2011) and Zambia (Sichoongwe et al., 2014), where quantities of fertilizer use was found as a significant determinant of crop diversification.

The positive effect of the fertilizer subsidy implies that farmers with access to the fertilizer subsidy are able to obtain the recommended amounts of fertilizer at the right time for their cropping activities and, therefore, are more likely to diversify their crop production. The fertilizer subsidy ultimately results in increased fertilizer usage, which increases crop yields (Mason and Jayne, 2013) and, hence, potentially increases crop–livestock diversification.

The negative effect of access to good road networks indicates that farmers who have access to good roads tended to specialize in their crop-production activities. This is because good roads reduce the transaction costs associated with sending produce to the markets and, as a result, farmers are able to identify specific high-value crops of which they tend to increase production without necessarily diversifying. While these results contradict those of Joshi et al. (2004), this study focuses on all crops in general, whereas their study was specifically on horticultural crops. Hence, while perishability, which is highly influenced by good road networks, is a key constraint in horticulture, it may not necessarily be a major issue among crop–livestock farmers who produce largely cereals and legumes where perishability has minimal effects.

Besides these factors, other determinants such as share of family labor and dependency ratio had negative effects on the discrete decision only, suggesting that the probability of crop diversification is smaller for households with more family labor and higher numbers of dependents. The diversion of family labor into other farming activities rather than crops, as well as into off-farm income-generating activities, could possibly explain this finding. This result, however, differs from that of Culas (2006), who found that increased use of both family and hired labor positively influenced crop diversification.

The continuous decision was also influenced by gender, indicating that male farmers are more inclined to increase the extent of diversifying than female farmers. In most areas of Ghana, households with male heads have increased access to production resources, hence, influence most household production decision-making (Etwire et al., 2013) and increase the extent of crop

diversification. Also, the positive effect of age on the continuous decision implies that the extent of diversification is higher among older farmers. This may be the case because older farmers become more risk averse by diversifying and this decision may also be influenced by their past production experiences.

As expected, the perception of farmers about obtaining stable income through diversification was found to be highly significant in determining the continuous crops diversification decision. The inherent risks in agriculture, including climatic, biophysical and market-related risks, have resulted in crop diversification being used as a strategy to manage these risks (Mukherjee, 2010; Chavas and Di Falco, 2012). The risks are also reduced when farmers have access to market information which is also found to be an important positive determinant of crop diversification.

Factors affecting livestock diversification

The negative effects of land ownership on the discrete decision to diversify indicates that farmers who own their land tend not to diversify their livestock portfolios because they might have already identified crops that they grow and livestock may not be so favored because they require little land to raise. However, the probability of diversifying in livestock production tended to increase for larger amounts of land operated.

As expected, access to credit increased the probability and extent of diversifying in livestock production. This may be associated with credit relieving the financial pressure associated with acquiring necessary inputs for livestock production, such as obtaining new breeds and veterinary services, hence farmers are able to increase the numbers of livestock they keep.

Among the integrated crop–livestock practices that were included in the models, storage and feeding of crop residues had negative and positive effects, respectively, on the discrete decision of diversifying in livestock production but not on its extent. This indicates that, generally, storage of crop residues is not a common practice among smallholder farmers in Ghana. For instance, the regional baseline report of the sustainable intensification of integrated-crop small-ruminant project in West Africa (SIIC-SR, 2013) revealed that 36% of sample farmers stored their crop residues after harvest. The usual practice is to allow the crop residue to decompose after harvest which is later plowed back into the soil at the beginning of the next cropping season. Evidence indicates that the difficulty in transporting the crop residue from the farm to the house for storage is a major issue that prevents farmers from storing crop residue.

The greater the distance to markets, the more likely farmers were to diversify their livestock production but the extent of diversification decreased. The farther the farmers are from markets, the greater their transport costs both in terms of accessing inputs and also sending

their produce to the market (Ibrahim et al., 2009). Farmers tend to diversify to limit the risks associated with losses from this situation. In a related result, farmers located farther away from markets or main roads were found to diversify to meet their broad subsistence and nutritional needs (Kankwamba et al., 2012). Poor road conditions were found to decrease the probability and extent of diversification in livestock production. This corroborates with the finding that poor road conditions have been found to account for up to about 70% of total food prices in a district of Ghana (Taiwo and Kumi, 2013). This suggests that, in addition to the distances, the conditions of the roads are also crucial for enhancing livestock diversification among smallholders in Ghana.

Only the probability of livestock diversification decreased with increases in hired labor on the farms. Generally, hired labor has not been used much in livestock production in Ghana because livestock numbers were generally small among smallholders and such labor tends to be used mostly in crop activities.

Furthermore, farmers with access to market information tended to have higher probability of diversifying but less extent of diversification in livestock production. Farmers tended to concentrate their efforts and resources on the given set of livestock when they were better informed about the market situation, thereby decreasing the extent to which they diversify their livestock.

Factors affecting integrated crop–livestock diversification

The use of tillage equipment on the farms was the only variable that had significant (positive) effects on the probability and extent of diversification in crop–livestock farming systems in our study. This is probably because the use of more modern tillage equipment in land preparation for cropping enables farmers to have adequate time for greater involvement in the various livestock enterprises.

Farm size and off-farm income were the only other variables that had significant (positive) effects on the probability of diversifying in crop–livestock diversified systems. However, there were a larger number of factors that contributed significantly to increasing the extent of diversification in the crop–livestock enterprises, namely, gender, credit access, extension, market information, stable income, in addition to usage of tillage equipment, already noted.

The essential role of credit in ensuring timely acquisition of inputs and other resources necessary for production accounts for its importance in determining the extent of crop–livestock diversification. Access to credit allows farmers the flexibility to select between commodities and increase the numbers of crops and/or livestock produced. As pointed out by Aneani et al. (2011), the availability of credit in the form of loans or in-kind was found to stimulate crop diversification among cocoa farmers in Ghana.

Access to extension and market information positively influenced crop–livestock diversification. The rationale is that farmers who diversify into crop–livestock production tended to modify their production decisions to resonate with extension advice and market information even when production is ongoing. Thus, they are able to add additional crops and/or livestock to the initial commodity set to meet market demand and maximize their profits (Rahman, 2008; Mesfin et al., 2011). In addition, enhanced access to information through extension and market information equips farmers to dispel their possible doubts associated with different crops and livestock enterprises.

An additional factor that influenced the continuous decision on extent of diversification, but not the choice decision for crop–livestock diversification was gender. This implies that households with male heads are more inclined to increase their extent of crop–livestock diversification. In Ghana, in general, and in the study area, in particular, male members of households are generally the decision-makers on crop and livestock production activities. Accordingly, they have access to productive resources including land and community pasture and, therefore, are involved in major farm decision-making activities. Even in households with female heads, male members are mostly delegated to represent the households in most farm-related decision-making.

As in the case of crop diversification, income stability also contributed to increased crop–livestock diversification. Diversifying allows farmers to obtain incomes for household purposes throughout the year and this desirable situation ultimately enhances the extent to which they diversify their crop–livestock production. This has been an evident rationale in different diversification studies (Abdulai and Crole-Rees, 2001; Barrett et al., 2001; Block and Webb, 2001; Smith et al., 2001; Niehof, 2004; Seo, 2010). Income stability implies diversifying income sources, which have been found to reduce production and marketing risks (Illukpitiya and Yanagida, 2008). This result provides evidence that income stability is a significant determinant of crop–livestock diversification, in addition to crop diversification, as noted above. It furthermore implies that crop–livestock diversification in Ghana is indeed income-driven, thus identification of high-value crop–livestock combinations is essential.

Crop–livestock diversification is less prominent among farmers in the A-A district than those in the E-S district, as indicated by the negative coefficient of the district dummy variable, which had value one for the A-A district and zero for farmers in the E-S district. Largely, the E-S district is closer to research and extension services, with a range of possible agricultural development interventions. This, coupled with the existence of a large number of agricultural NGOs, gives farmers in this district enhanced access to information on the relevance of integrated crop–livestock diversification which tends to increase the probability of diversifying.

Conclusions and policy implications

In this paper, we have examined the determinants of diversification focusing on crop, livestock and integrated crop–livestock production systems among smallholders in Ghana. To the best of our knowledge, this is the first study that provides empirical evidence of the determinants of livestock diversification and integrated crop–livestock diversification. In addition, this paper is among the few to disaggregate the diversification decision-making process and apply the Cragg two-step approach to examine both the discrete and continuous diversification decisions, previously commonly analyzed as a joint decision process without conducting the necessary tests.

The results show that both discrete and continuous crop-diversification decisions were influenced by factors such as use of plow tillage, the quantity of fertilizer used and good road networks. For livestock diversification, the significant factors included access to credit, market distance, access to market information, and access to good road networks. For crop–livestock diversification, the only factor that influenced both the discrete and continuous decisions on crop–livestock diversification was the use of plow tillage.

Other factors investigated influenced one or other of the two decisions, such as age of farmers, gender, dependency ratio in the households, off-farm income, land ownership, value of farm assets, hired labor, farm size, share of family labor, access to credit, market distance, access to extension, market information, income stability, access to the fertilizer subsidy, and storing and feeding crop residues. The results obtained present important empirical outcomes with vital contributions to food production policy, research and extension, development agencies and farmers at large.

The results highlight the importance of access to information, which is largely extended to farmers through institutions such as research, extension and other agricultural projects in enhancing diversification among smallholders. Indeed, the agricultural extension services have been instrumental in promoting and disseminating production and marketing information to farmers. To boost this effort, there is the need to include diversification-related extension and information services to farmers. This could include organizing trainings on the relevant combinations of diversified systems that result in optimum synergies for farmers and, more importantly, remove possible doubts associated with the production of important crops and/or livestock. This could be accompanied by training that enhances the capacities of these institutions in terms of personnel, logistics and operating resources.

As shown by the empirical results, farmers' access to tillage equipment and fertilizer are important determinants and, hence, such access needs to be facilitated among smallholders in Ghana for them to reap the full benefits from diversification. There has been some effort by the Ministry of Food and Agriculture through the

establishment of mechanization centers where farmers can access tillage equipment. However, inadequate maintenance of the equipment leaves most of these farmers disappointed, especially at the planting season when it is most needed. Privatizing this system by partnering with interested private investors may be helpful in improving farmers' access to tillage equipment. This has the potential of improving crop–livestock diversification and, ultimately, enhancing food security and reducing poverty both at the farm household and national levels. As regards access to fertilizer, effective implementation of the existing fertilizer subsidy program to ensure timely availability at affordable prices, and within reasonable proximities, would also improve crop–livestock diversification.

The results of this study show that the discrete decision to diversify and the decision with regards to the extent of diversification are independent decisions and are not the same and, therefore, are influenced by different sets of factors. Estimation of the probability of diversifying alone does not provide sufficient understanding of the factors affecting the full decision-making process. Furthermore, it could also be misleading to assume that the two decisions are jointly made. As a result, it is imperative for future studies, particularly on agricultural diversification, to consider including appropriate tests of separability in the two decisions to determine which estimation procedure is appropriate for the data. This will obviate the trap of not sufficiently capturing the relevant sets of factors that influence the two decisions. This will allow informed recommendations that are suitable for the two decisions to be made appropriately.

Another important outcome of this paper relates to the determinants of diversification of crop, livestock and integrated crop–livestock production. This presents distinct recommendations for researchers and extension, policy and development agencies to appropriately enhance these three production systems to address issues of food security and poverty alleviation.

The empirical results highlight the importance of diversification in crop, livestock and integrated crop–livestock production systems among smallholders in Ghana. Careful consideration needs to be given by researchers, extension services, development partners and policy-makers to the factors that have been highlighted in this paper to devise better strategies for the improvement of farm production in Ghana.

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References

- Abdulai, A. and Crolerees, A.** 2001. Determinants of income diversification amongst rural households in Southern Mali. *Food Policy* 26:437–452.
- Abro, A.A.** 2012. Determinants of crop diversification towards high value crops in Pakistan. *International Journal of Business Management & Economic Research* 3:536–545.
- Agyemang-Bonsu, W., Kojo, W., Minia, Z., Dontwi, J., Dontwi, I. K., Buabeng, S.N., Baffoe-Bonnie, B., Agyemang-Yeboah, F., Buabeng, S.N., Ofori, E., Gyasi, E.A., Karikari, O., Dugan, E., Nelson, W., Naa Debei Agbey, A., Sagoe, R., Dampsey, P., Tutuah Mensah, A., Anim-Kwapong, G.J., and Frimpong, E.B.** (eds.) 2008. *Ghana Climate Change Impacts, Vulnerability and Adaptation Assessments*. Environmental Protection Agency, Accra.
- Aneani, F., Anchirinah, V., Owusu-Ansah, F., and Asamoah, M.** 2011. An analysis of the extent and determinants of crop diversification by cocoa (*Theobroma cacao*) farmers in Ghana. *African Journal of Agricultural Research* 6:4277–4287.
- Ashfaq, M., Hassan, S., Naseer, M.Z., Baig, I.A., and Asma, J.** 2008. Factors affecting farm diversification in rice–wheat. *Pakistan Journal of Agricultural Science* 45:91–94.
- Barrett, C.B., Reardon, T., and Webb, P.** 2001. Nonfarm income diversification and household livelihood strategies in rural Africa: Concepts, dynamics, and policy implications. *Food Policy* 26:315–331.
- Belotti, F., Deb, P., Manning, W., and Norton, E.** 2012. tpm: Estimating two-part models. *The Stata Journal* 20:1–13.
- Benin, S., Smale, M., Pender, J., Gebremedhin, B., and Ehui, S.** 2004. The economic determinants of cereal crop diversity on farms in the Ethiopian highlands. *Agricultural Economics* 31:197–208.
- Birthal, P.S., Joshi, P.K., Roy, D., and Thorat, A.** 2007. Diversification in Indian Agriculture towards High-Value Crops: The Role of Smallholders. IFPRI Discussion Paper 00727. International Food Policy Research Institute, Washington, DC. Available at Web site: <http://www.ifpri.org/pubs/dp/IFPRIDP00727.pdf>
- Block, S. and Webb, P.** 2001. The dynamics of livelihood diversification in post-famine Ethiopia. *Food Policy* 26:333–350.
- Cavaglia-Harris, J.L. and Sills, E.O.** 2005. Land use and income diversification: Comparing traditional and colonist populations in the Brazilian Amazon. *Agricultural Economics* 32: 221–237.
- Chand, R.** 1996. Diversification through high value crops in western Himalayan region: Evidence from Himachal Pradesh. *Indian Journal of Agricultural Economics* 41:652–663.
- Chaplin, H.** 2000. Agricultural diversification: a review of methodological approaches and empirical evidence. Available at Web site: <http://www.ilr.uni-bonn.de/agpo/rsrch/Idara/Farm/wyewp2.doc> (verified 22 January 2013).
- Chavas, J.P. and Di Falco, S.** 2012. On the role of risk versus economies of scope in farm diversification with an application to Ethiopian farms. *Journal of Agricultural Economics* 63:25–55.
- Cragg, J.** 1971. Some statistical models for limited dependent variables with application to the demand for durable goods. *Econometrica* 39:829–844.
- Culas, R.J.** 2006. Causes of farm diversification over time: An Australian perspective on an Eastern Norway model. *Australian Farm Business Management Journal* 3:1–9.
- De, U.K. and Chattopadhyay, M.** 2010. Crop diversification by poor peasants and role of infrastructure: Evidence from West Bengal. *Journal of Development and Agricultural Economics* 2:340–350.
- Devendra, C. and Ibrahim, M.** 2004. Silvopastoral systems as a strategy for diversification and productivity enhancement from livestock in the tropics. The importance of silvopastoral systems in rural livelihoods to provide ecosystem services. Second international symposium of silvopastoral systems. Universidad Autónoma de Yucatán, Mérida, 8–22.
- Dzanku, F.M. and Sarpong, D.** 2010. Agricultural diversification, food self-sufficiency and food security in Ghana—the role of infrastructure and institutions. In G. Djurfeldt, E. Aryeetey, and A.C. Isinika (ed.). *African Smallholders: Food Crops, Markets and Policy*. CAB International, Wallingford, UK, 189–213.
- Ellis, F.** 1998. Household strategies and rural livelihood diversification. *The Journal of Development Studies* 35:1–38.
- Ellis-Jones, J., Larbi, A., Hoeschle-Zeledon, I., Dugje, I., Teli, I., Buah, S., Kanton, R., Kombiok, M., Kamara, A., and Gyamfi, I.** 2012. Sustainable intensification of cereal-based farming systems in Ghana's Guinea savanna: constraints and opportunities identified with local communities. IITA report. International Institute for Tropical Agriculture, Ibadan, Nigeria.
- Ergano, K., Mehta, V.P., and Dixit, A.** 2000. Diversification of agriculture in Haryana – an empirical analysis. *Agricultural Situation in India* 57:459–464.
- Estache, A.** 2003. On Latin America's infrastructure privatization and its distributional effects. Available at Web site at SSRN: <http://ssrn.com/abstract=411942> or <http://dx.doi.org/10.2139/ssrn.411942>
- Etwire, P.M., Dogbe, W., and Nutsugah, S.K.** 2013. Institutional credit available to smallholder farmers in the northern region of Ghana. *International Journal of AgriScience* 3:502–509.
- Fausat, A.F.** 2012. Income diversification determinants among farming households in Konduga, Borno state, Nigeria. *Academic Research International* 2:555–561.
- Food and Agriculture Organization (FAO).** 2010. An international consultation on integrated crop-livestock systems for development: The way forward for sustainable production intensification. *Integrated Crop Management* 13:1–63.
- Ghafoor, A., Hussain, M., Naseer, K., Ishaque, M., and Baloch, M.** 2010. Factors affecting income and saving of small farming households in Sargodha district of The Punjab, Pakistan. *Pakistan Journal of Agricultural Engineering and Veterinary Sciences* 26:27–35.
- Govere, J. and Jayne, T.S.** 2003. Cash cropping and food crop productivity: Synergies or trade-offs? *Agricultural Economics* 28:39–50.
- Griebenow, G. and Kishore, S.** 2009. Mainstreaming environment and climate change in the implementation of poverty reduction strategies. Environment Department, Paper No. 119. The World Bank, Washington, DC.
- Guvele, C.** 2001. Gains from crop diversification in the Sudan Gezira scheme. *Agricultural Systems* 70:319–333.
- Heckman, J.J.** 1979. Sample selection bias as a specification error. *Econometrica* 47:153–161.

- Herrero, M., González-Estrada, E., Thornton, P.K., Quiros, C., Waithaka, M.M., Ruiz, R., and Hoogenboom, G.** 2007. IMPACT: Generic household-level databases and diagnostics tools for integrated crop-livestock systems analysis. *Agricultural Systems* 92:240–265.
- Herrero, M., Thornton, P.K., Notenbaert, A.M., Wood, S., Msangi, S., Freeman, H.A., Bossio, D., Dixon, J., Peters, M., and Van De Steeg, J.** 2010. Smart investments in sustainable food production: Revisiting mixed crop-livestock systems. *Science* 327:822–825.
- Ibrahim, H., Rahman, S., Envulus, E., and Oyewole, S.** 2009. Income and crop diversification among farming households in a rural area of north central Nigeria. *Agro-Science: Journal of Tropical Agriculture, Food, Environment and Extension* 8:84–89.
- Iiyama, M., Maitima, J., and Kariuki, P.** 2007. Crop-livestock diversification patterns in relation to income and manure use: A case study from a Rift Valley community, Kenya. *African Journal of Agricultural Research* 2:058–066.
- Illukpitiya, P. and Yanagida, J.F.** 2008. Role of income diversification in protecting natural forests: Evidence from rural households in forest margins of Sri Lanka. *Agroforestry Systems* 74:51–62.
- Johnston, G., Vaupel, S., Kegel, F., and Cadet, M.** 1995. Crop and farm diversification provide social benefits. *California Agriculture* 49:10–16.
- Joshi, P.K., Gulati, A., BIRTHAL, P.S., and Tewari, L.** 2004. Agriculture diversification in South Asia: Patterns, determinants and policy implications. *Economic and Political Weekly* 39:2457–2467.
- Joshi, P.K., Joshi, L., and BIRTHAL, P.S.** 2006. Diversification and its impact on smallholders: Evidence from a study on vegetable production. *Agricultural Economics Research Review* 19:219–236.
- Joshi, P.K., Gulati, A., and Cummings, R.W.** (eds). 2007. *Agricultural Diversification and Smallholders in South Asia*. Academic Foundation, New Delhi, India.
- Kankwamba, H., Mapila, M., and Pauw, K.** 2012. Determinants and spatio-temporal dimensions of crop diversification in Malawi. Project Report produced under a co-financed research agreement between Irish Aid, USAID and IFPRI, Paper.
- Karbo, N. and Agyare, W.** 2002. Crop Livestock Systems in Northern Ghana. Workshop on crop–livestock systems in dry savannas of West and Central Africa. International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria.
- Katchova, A.L. and Miranda, M.** 2004. Two-step econometric estimation of farm characteristics affecting marketing contract decisions. *American Journal of Agricultural Economics* 86:88–102.
- Keelan, C.D., Henchion, M.M., and Newman, C.F.** 2009. A double-hurdle model of Irish Households' food service expenditure patterns. *Journal of International Food & Agribusiness Marketing* 21:269–285.
- Kelley, T., Ryan, J., and Patel, B.** 1995. Applied participatory priority setting in international agricultural research: Making trade-offs transparent and explicit. *Agricultural Systems* 49:177–216.
- Kim, K., Chavas, J.P., Barham, B., and Foltz, J.** 2012. Specialization, diversification, and productivity: A panel data analysis of rice farms in Korea. *Agricultural Economics* 43:687–700.
- Knudsen, M.H.** 2007. Making a living in the cocoa frontier, Western Ghana: Diversifying incomes in a cocoa economy. *Geografisk Tidsskrift – Danish Journal of Geography* 107:29–44.
- Lay, J. and Schüler, D.** 2008. Income Diversification and Poverty in a Growing Agricultural Economy: The Case of Ghana. 39th German Development Economics Conference, Zürich.
- Lin, T.-F. and Schmidt, P.** 1984. A test of the Tobit specification against an alternative suggested by Cragg. *The Review of Economics and Statistics* 66:174–177.
- Lin, W., Dean, G.W., and Moore, C.V.** 1974. An empirical test of utility vs. profit maximization in agricultural production. *American Journal of Agricultural Economics* 56:497–508.
- Little, P.D., Smith, K., Cellarius, B.A., Coppock, D.L., and Barrett, C.** 2001. Avoiding disaster: Diversification and risk management among East African herders. *Development and Change* 32:401–433.
- Mainik, G. and Rüschemdorf, L.** 2010. On optimal portfolio diversification with respect to extreme risks. *Finance and Stochastics* 14:593–623.
- Mal, P., Anik, A.R., Bauer, S., and Schmitz, P.M.** 2012. Bt cotton adoption: A double-hurdle approach for north Indian farmers. *AgBioForum* 15:294–302.
- Mason, N.M. and Jayne, T.S.** 2013. Fertiliser subsidies and smallholder commercial fertiliser purchases: Crowding out, leakage and policy implications for Zambia. *Journal of Agricultural Economics* 64:558–582.
- Mekhora, T. and Fleming, E.** 2004. An analysis of scope economies and specialisation efficiencies among Thai shrimp and rice smallholders. Working paper series, Graduate School of Agricultural and Resource Economics, University of New England.
- Mesfin, W., Fufa, B., and Haji, J.** 2011. Pattern, trend and determinants of crop diversification: Empirical evidence from smallholders in Eastern Ethiopia. *Journal of Economics and Sustainable Development* 2:78–89.
- Ministry of Food and Agriculture.** 2010. Medium Term Agriculture Sector Investment Plan (METASIP). Statistics, Research and Information Directorate (SRID), Accra, Ghana.
- Mrema, G.C., Baker, D., and Kahan, D.** 2008. *Agricultural Mechanization in Sub-Saharan Africa: Time for a New Look*. Agricultural Management, Marketing and Finance Occasional Paper, Food and Agriculture Organization (FAO), Rome, Italy.
- Mukherjee, S.** 2010. Crop diversification and risk: an empirical analysis of Indian states. Available at Web site: <http://mpr.ub.uni-muenchen.de/35947/>
- Ndamani, F. and Watanabe, T.** 2015. Influences of rainfall on crop production and suggestions for adaptation. *International Journal of Agricultural Sciences* 5:367–374.
- Ndhlovu, D.E.** 2011. Determinants of farm households' cropland allocation and crop diversification decisions: The role of fertilizer subsidies in Malawi. Available at Web site: <http://brage.bibsys.no/xmlui/bitstream/handle/11250/187341/2010-ndhlovu.pdf?sequence=3&isAllowed=y>
- Niehof, A.** 2004. The significance of diversification for rural livelihood systems. *Food Policy* 29:321–338.
- Ogundari, K.** 2013. Crop diversification and technical efficiency in food crop production: A study of peasant farmers in Nigeria. *International Journal of Social Economics* 40:267–287.

- Pal, S. and Kar, S.** 2012. Implications of the methods of agricultural diversification in reference with Malda district: Drawback and rationale. *International Journal of Food, Agriculture and Veterinary Sciences* 2:97–105.
- Pandey, V. and Sharma, K.** 1996. Crop diversification and self-sufficiency in food grains. *Indian Journal of Agricultural Economics* 51:644–651.
- Petit, M. and Barghouti, S.** 1992. Diversification: Challenges and opportunities. *World Bank Technical Paper* 1:0253–7494.
- Rahm, M.R. and Huffman, W.E.** 1984. The adoption of reduced tillage: The role of human capital and other variables. *American Journal of Agricultural Economics* 66:405–413.
- Rahman, S.** 2008. Determinants of crop choices by Bangladeshi farmers: A bivariate probit analysis. *Asian Journal of Agriculture and Development* 5:30–14.
- Ryan, J.G. and Spencer, D.** 2001. Future Challenges and Opportunities for Agricultural R&D in the Semi-Arid Tropics. *International Crops Research Institute for the Semi-Arid Tropics*, Patancheru, India.
- Senadza, B.** 2012. Non-farm income diversification in rural Ghana: Patterns and determinants. *African Development Review* 24:233–244.
- Seo, S.N.** 2010. Is an integrated farm more resilient against climate change? A micro-econometric analysis of portfolio diversification in African agriculture. *Food Policy* 35:32–40.
- Shezongo, M.** 2005. Women's property rights in Zambia. The Strategic Litigation Workshop. Johannesburg, South Africa. Available at Web site: <http://www.cohre.org/womenlitigation/zambia.doc> (verified 7 May 2015).
- Sichoongwe, K., Mapemba, L., Ng'ong'ola, D., and Tembo, G.** 2014. The Determinants and Extent of Crop Diversification among Smallholder Farmers: A Case Study of Southern Province, Zambia. IFPRI Working paper International Food Policy Research Institute, Washington, DC.
- Smith, D.R., Gordon, A., Meadows, K., and Zwick, K.** 2001. Livelihood diversification in Uganda: Patterns and determinants of change across two rural districts. *Food Policy* 26:421–435.
- Sustainable Intensification of Integrated Crops-Small Ruminant Production Systems in West Africa (SIIC-SR).** 2013. *Regional Baseline Report*. CORAF/WECARD-AUSAID-CSIRO-CSIR-CRI (SIIC-SR).
- Taiwo, A. and Kumi, F.** 2013. An appraisal of road condition effect on rural transportation in Sekyere Central District of the Ashanti Region of Ghana. *Journal of Transportation Technologies* 3:266–271.
- Tasie, C., Ofor, U., and Wilcox, G.** 2012. Determinants of off-farm income diversification in Rivers state, Nigeria. *Wudpecker Journal of Agricultural Research* 1:331–334.
- Van den Berg, M.M., Hengsdijk, H., Wolf, J., Van Ittersum, M. K., Guanhua, W., and Roetter, R.P.** 2007. The impact of increasing farm size and mechanization on rural income and rice production in Zhejiang province, China. *Agricultural Systems* 94:841–850.
- Vyas, V.** 2006. Diversification in agriculture: Concept, rationale and approaches. In N.A. Mujumdar and U. Kapila (eds). *Indian Agriculture in the New Millennium: Changing Perceptions and Development Policy* Vol. 2. Academic Foundation, New Delhi, p. 245–256.
- Waithaka, M.M., Thornton, P.K., Shepherd, K.D., and Ndiwa, N.N.** 2007. Factors affecting the use of fertilizers and manure by smallholders: The case of Vihiga, Western Kenya. *Nutrient Cycling in Agroecosystems* 78:211–224.
- Wan, W. and Hu, W.** 2012. At-home seafood consumption in Kentucky: A double-hurdle model approach. Selected Paper for Presentation at the Southern Agricultural Economics Association Annual Meeting, Birmingham, AL. February, 2012.
- Weiss, C.R. and Briglauer, W.** 2000. Determinants and dynamics of farm diversification. FE Workingpaper 0002/Universität Kiel, Department of Food Economics and Consumption Studies.
- Wiredu, A.N., Zeller, M., and Diagne, A.** 2015. What determines adoption of fertilizers among rice-producing households in Northern Ghana? *Quarterly Journal of International Agriculture* 54(3):263–283.
- Wu, S. and Prato, T.** 2006. Cost efficiency and scope economies of crop and livestock farms in Missouri. *Journal of Agriculture and Applied Economics* 38:539–553.
- Yan, J., Wu, Y., Zhang, Y., and Zhou, S.** 2010. Livelihood diversification of farmers and nomads of eastern transect in Tibetan Plateau. *Journal of Geographical Sciences* 20:757–770.
- Yirga, C. and Hassan, R.** 2013. Determinants of inorganic fertiliser use in the mixed crop-livestock farming systems of the central highlands of Ethiopia. *African Crop Science Journal* 21:669–682.

Appendix 1.**Table 1a.** Probit, Truncated and Tobit regression estimates for crop diversification.

Variable	Probit		Truncated		Tobit	
	Coeff	SE	Coeff	SE	Coeff	SE
Age	0.065	0.087	0.0070*	0.0037	0.0066	0.0046
Gender	0.22	0.28	0.025**	0.013	0.035**	0.015
Education	0.21	0.26	0.003	0.010	0.016	0.012
Dependency ratio	−0.097*	0.043	−0.0013	0.0020	−0.0035	0.0025
Off-farm income	0.34	0.28	0.008	0.012	0.015	0.015
Land ownership	0.03	0.31	0.005	0.011	−0.002	0.014
Value of farm assets	−0.02	0.12	−0.0013	0.0030	−0.0030	0.0038
Hired labor	2.38***	0.91	−0.0025	0.0062	0.0130*	0.0076
Farm size	−0.07	0.17	−0.0007	0.0095	−0.007	0.011
Share of family labor	−0.72	0.43	0.017	0.016	−0.010	0.020
Credit access	0.01	0.25	−0.007	0.010	−0.014	0.013
Market distance	−0.008	0.059	0.0009	0.0018	0.0010	0.0022
Extension	0.51*	0.26	0.011	0.010	0.027**	0.012
Market information	−0.12	0.29	0.026**	0.012	0.028**	0.014
Stable income	0.09	0.27	0.029***	0.011	0.032**	0.013
District	0.90***	0.32	0.014	0.011	0.048***	0.013
Use tillage equipment	1.64***	0.32	0.073***	0.020	0.237***	0.020
Good road network	−0.56*	0.32	−0.216***	0.016	−0.214***	0.019
Fertilizer (kg)	0.88*	0.46	0.0183***	0.0063	0.0259***	0.0079
Fertilizer subsidy	1.15**	0.49	0.014	0.011	0.037***	0.014
Constant	−1.10	0.75	0.324***	0.037	0.130***	0.042
Number of obs.	606		563		606	
Wald/LR χ^2 (20)	177.4***		258.4***		349.5***	
Log-likelihood	−66.481		418.073		227.728	
Pseudo R^2	0.572				−3.298	
Sigma			0.1157***	0.0035	0.1477***	0.0044
Likelihood ratio statistic	247.7***					

SE denotes standard error; the asterisks, *, ** and ***, denote significant at the 10, 5 and 1% levels, respectively.

Table 1b. Probit, Truncated and Tobit regression estimates for livestock diversification.

	Probit		Truncated		Tobit	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
Age	−0.006	0.054	−0.0028	0.0063	−0.0032	0.0071
Gender	−0.10	0.18	−0.013	0.021	−0.018	0.024
Education	−0.13	0.15	−0.008	0.017	−0.019	0.019
Dependency ratio	0.040	0.034	−0.0020	0.0034	0.0009	0.0038
Off-farm income	0.03	0.18	0.008	0.021	0.008	0.023
Land ownership	−0.41**	0.17	−0.009	0.019	−0.049**	0.022
Value of farm asset	0.015	0.048	−0.0114*	0.0061	−0.0065	0.0059
Hired labor	−0.154**	0.075	0.005	0.011	−0.012	0.011
Farm size	0.20*	0.12	−0.006	0.014	0.012	0.015
Family labor share	0.20	0.25	0.015	0.028	0.027	0.031
Credit access	0.92***	0.17	0.032*	0.018	0.108***	0.020
Market distance	0.081**	0.033	−0.0057*	0.0032	0.0009	0.0035

Table 1b. (Cont.)

	Probit		Truncated		Tobit	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
Extension	0.15	0.15	−0.019	0.018	0.001	0.020
Market information	0.33*	0.19	−0.052**	0.020	−0.006	0.023
Stable income	0.71***	0.15	0.022	0.019	0.095***	0.020
District	0.04	0.16	0.032*	0.018	0.027	0.020
Good road network	−0.51***	0.19	−0.087***	0.029	−0.126***	0.029
Feed crop residue	0.70***	0.17	0.008	0.020	0.082***	0.022
Store crop residue	−0.61***	0.17	0.008	0.021	−0.060***	0.022
Constant	−0.27	0.48	0.416***	0.054	0.204***	0.060
Number of obs.	608		511		608	
Wald/LR χ^2 (19)	143.3***		31.4**		108.6***	
Log-likelihood	−195.20		188.91		−69.73	
Pseudo R^2	0.269				0.4378	
Sigma			0.1812***	0.0007	0.2284	0.0074
Likelihood ratio statistic	126.883***					

SE denotes standard error; the asterisks, *, ** and ***, denote significant at the 10, 5 and 1% levels, respectively.

Table 1c. Probit, Truncated and Tobit regression estimates for integrated crop–livestock diversification.

	Probit		Truncated		Tobit	
	Coeff	SE	Coeff	SE	Coeff	SE
Age	−0.004	0.098	−0.0036	0.0038	−0.0025	0.0046
Gender	0.22	0.30	0.022*	0.013	0.028*	0.016
Education	0.07	0.27	0.010	0.011	0.012	0.013
Dependency ratio	0.034	0.065	0.0017	0.0021	0.0015	0.0025
Off-farm income	0.75***	0.28	−0.004	0.013	0.015	0.023
Land ownership	−0.20	0.32	−0.002	0.012	−0.008	0.014
Value of farm asset	−0.066	0.057	−0.0039	0.0032	−0.0059	0.0038
Hired labor	0.29	0.30	0.0062	0.0061	0.0083	0.0074
Farm size	0.35*	0.20	−0.0015	0.0085	0.009	0.010
Family labor share	−0.08	0.43	0.006	0.017	0.002	0.020
Credit access	0.03	0.28	0.038***	0.011	0.038***	0.013
Market distance	0.055	0.059	0.0018	0.0019	0.0029	0.0023
Extension	0.10	0.27	0.031***	0.011	0.033***	0.013
Market information	0.17	0.36	0.035***	0.012	0.038***	0.015
Stable income	0.03	0.28	0.023***	0.011	0.025*	0.013
District	−0.70**	0.31	−0.013	0.011	−0.029**	0.013
Use of plow tillage	0.79***	0.28	0.115***	0.017	0.157***	0.019
Constant	0.09	0.82	0.441***	0.035	0.341***	0.041
Number of obs.	608		593		608	
Wald/LR χ^2 (22)	35.0***		115.7***		127.9***	
Log-likelihood	−52.850		390.883		250.408	
Pseudo R^2	0.2487				−0.3429	
Sigma			0.125***	0.0035	0.1518***	0.0045
Likelihood ratio statistic	175.253***					

SE denotes standard error; the asterisks, *, ** and ***, denote significant at the 10, 5 and 1% levels, respectively.

Appendix 2

Table 2a. Heckman's model of crop diversification.

Variable	Stage 1		Stage 2	
	Coeff	SE	Coeff	SE
Age	0.0069*	0.0037	0.065	0.087
Gender	0.025*	0.013	0.22	0.28
Education	0.002	0.010	0.21	0.26
Dependency ratio	−0.0012	0.0021	−0.097**	0.043
Off-farm income	0.007	0.012	0.34	0.28
Land ownership	0.005	0.011	0.03	0.31
Value of farm assets	−0.0013	0.0030	−0.02	0.12
Hired labor	−0.0032	0.0064	2.38***	0.91
Farm size	−0.0002	0.0095	−0.07	0.17
Family labor share	0.018	0.017	−0.72*	0.43
Credit access	−0.006	0.010	0.01	0.25
Market distance	0.0009	0.0018	−0.01	0.06
Extension	0.011	0.010	0.51*	0.26
Market information	0.026**	0.012	−0.12	0.29
Stable income	0.028	0.011	0.09	0.27
District	0.013	0.011	0.90***	0.32
Use tillage equipment	0.066***	0.024	1.64***	0.32
Good road network	−0.211***	0.016	−0.56*	0.32
Fertilizer	0.0179***	0.0063	0.88*	0.46
Fertilizer subsidy	0.013	0.011	1.15**	0.49
Constant	0.335***	0.041	−1.10	0.75
N	608			
Wald χ^2	229.33***			
Sigma	0.115			
Mills ratio (λ)	−0.017	0.042		

SE denotes standard error; the asterisks, *, ** and ***, denote significant at the 10, 5 and 1% levels, respectively.

Table 2b. Heckman's model of livestock diversification.

Variable	Stage 1		Stage 2	
	Coeff	SE	Coeff	SE
Age	−0.0050	0.0065	0.024	0.071
Gender	−0.018	0.022	0.26	0.22
Education	−0.019	0.017	0.23	0.20
Dependency ratio	0.0000	0.0036	−0.038	0.032
Off-farm income	−0.004	0.022	0.41**	0.22
Land ownership	−0.038**	0.019	−0.27	0.25
Value of farm asset	−0.0075	0.0051	−0.03	0.10
Hired labor	−0.008	0.010	4.00***	0.87
Farm size	0.006	0.015	0.20	0.14
Family labor share	0.027	0.028	−0.30	0.34
Credit access	0.085***	0.018	−0.28	0.20
Market distance	0.0000	0.0031	0.033	0.042
Extension	−0.008	0.018	0.30	0.21
Market information	−0.023	0.020	−0.04	0.24

Table 2b. (Cont.)

Variable	Stage 1		Stage 2	
	Coeff	SE	Coeff	SE
Stable income	0.071***	0.018	−0.19	0.22
District	0.029	0.018	0.19	0.22
Good road network	−0.096***	0.030	−1.00***	0.24
Feed crop residue	0.069***	0.022	0.57*	0.26
Store crop residue	−0.035*	0.020	−0.16	0.26
Constant	0.279***	0.061	0.12	0.58
N	608			
Wald χ^2	84.75***			
Sigma	0.201			
Mills ratio (λ)	−0.076	0.074		

SE denotes standard error; the asterisks, *, ** and ***, denote significant at the 10, 5 and 1% levels, respectively.

Table 2c. Heckman's model of integrated crop–livestock diversification.

Variable	Stage 1		Stage 2	
	Coeff	SE	Coeff	SE
Age	−0.0038	0.0046	0.054	0.084
Gender	0.021	0.016	0.31	0.25
Education	0.004	0.013	0.42	0.25
Dependency ratio	0.0026	0.0025	−0.043	0.038
Off-farm income	0.001	0.015	0.34	0.25
Land ownership	0.007	0.014	−0.21	0.29
Value of farm asset	−0.0057	0.0037	−0.045	0.074
Hired labor	0.0033	0.0077	2.12***	0.71
Farm size	0.002	0.011	0.13	0.15
Family labor share	0.018	0.021	−0.74*	0.40
Credit access	0.031**	0.013	−0.02	0.23
Market distance	0.0027	0.0022	0.019	0.050
Extension	0.024*	0.013	0.45*	0.24
Market information	0.040***	0.014	−0.16	0.28
Stable income	0.023*	0.013	−0.03	0.25
District	−0.037***	0.014	0.64**	0.29
Use of plow tillage	0.077**	0.032	2.19***	0.27
Constant	0.473***	0.053	−1.43**	0.69
N	608			
Wald χ^2	62.56***			
Sigma	0.144			
Mills ratio (λ)	−0.083	0.051		

SE denotes standard error; the asterisks, *, ** and ***, denote significant at the 10, 5 and 1% levels, respectively.