Building farmers' capacity for innovation generation: what are the determining factors?

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Abstract

Innovation is essential for agricultural and economic development, especially in today's rapidly changing global environment. While farmers have been recognised as one of the key sources of innovation, many studies on agricultural innovations continue to consider farmers as adopters of externally-driven innovations only. Based on cross-sectional data from 409 farm households, this study, in contrast, analyses the innovation-generating behaviour among rural farmers in northern Ghana. Inspired by two innovation theories – induced innovation and innovation systems – we focus on the determinants of innovation behaviour. Employing recursive bivariate probit and endogenous treatment-regression models which control for selection bias, we find that participation in Farmer Field Fora, a participatory extension approach with elements of the innovation systems perspective, is a key determinant of innovation behaviour in farm households. Other important determinants are education, climate shocks and risk preferences. These results are robust to alternative specifications and estimation techniques. We conclude that policies for the generation of innovations among farmers should focus on education, and on building innovation capacity through institutional arrangements that permit interactions and learning between stakeholders.

Keywords: Determinants; Farmer Field Fora; farmer innovation; Ghana; induced innovation; innovation systems

JEL code: Q12, Q16

1. Introduction

Innovation is essential for agricultural and economic development (Hayami and Ruttan, 1985; World Bank, 2011). The need to overcome challenges and harness opportunities has induced the development of several innovations in agriculture (Hayami and Ruttan, 1985; Goldman, 1993). However, the focus of research and development has mainly been on externally-driven innovations which are generated by universities and research institutions. There is a mounting body of evidence on the positive impacts of these innovations. However, externally-driven innovations are often promoted in Africa using the transfer-of-technology (ToT) model, which considers farmers as recipients of knowledge only. This has led to the development of technologies that are inappropriate for farmers' conditions (Röling, 2009a; Reij and Waters-Bayer, 2001; Letty *et al*., 2011). Hampered by a number of constraints, smallholders often cannot benefit from these technologies which are may be unavailable, expensive for resource-poor farmers or require complementary inputs (e.g. fertilizer) which can increase environmental problems (Chambers *et al*., 1989; Tambo and Abdoulaye, 2012).

Over the years, farmers have also been recognised as innovators (i.e., generators of new practices) and experimenters, rather than mere adopters of introduced technologies. In fact, farmers have been innovating long before the emergence of formal research and development (Biggs, 1981), and there are even claims that some of the technologies developed by scientists were actually based on ideas and practices of local farmers (Rhoades, 1989; Röling, 2009b). In the face of increasing global challenges, rural farmers are becoming more innovative (Sanginga *et al*., 2009). They engage in informal experimentation, develop new technologies and modify or adapt external innovations to suit their local environments (Reij and Waters-Bayer, 2001). Farmer innovation processes are claimed to be relatively inexpensive, easily accessible, locally appropriate and highly disseminated (Waters-Bayer and Bayer, 2009). Thus, farmer innovation could complement the highly promoted external innovations in addressing increasing challenges in agriculture, and also contribute to sustainable intensification efforts.

There has been some attention on promoting farmer innovations in recent years. For instance, the establishment of Prolinnova – a global learning network seeking to promote local innovation in ecologically-oriented agriculture and natural resource management – in 1999 has facilitated the identification and promotion of farmer innovations in several developing countries. While there is increased interest in promoting farmer innovations, little attention has been paid to what determines the innovation capacity of farmers. The plethora of studies on innovative behaviour of farmers has focussed on adoption with little consideration for innovation generation. The few studies on the determinants of farmer innovativeness (e.g. Reij and Waters-Bayer, 2001; Nielsen, 2001; Kummer, 2010) are qualitative if not anecdotal. In this paper, we attempt to address this gap in the innovation literature using econometric techniques. Thus, the main objective of this paper is to assess the determinants of innovation-generating behaviour of farm households. This is essential for policy efforts aiming at promoting farmer innovation, strengthening innovation capacity of farm households, and sustainable intensification.

In examining the determinants of innovation generation[1], we rely on elements of the induced innovation theory and the innovation systems perspective. The theory of induced innovation considers challenges and opportunities as key drivers of innovation, whereas the innovation systems approach argues that innovations emerge through networks of actors and organisations. We particularly focus on farm households' participation in Farmer Field Fora (FFF), a participatory platform for enhancing innovation capacities, as a measure of the innovation system approach. To account for the possible selection bias from the non-random nature of the FFF participation, endogenous treatment-regression and recursive bivariate probit models are used in estimating the determinants of farmers' innovative behaviour. We also analyse spillover effects of FFF participation on innovation generation. The analyses are based on farm household data obtained from rural northern Ghana, which is an interesting case study. On the one hand, northern Ghana is characterised by resource-poor farmers who face challenges of climate change, soil infertility, land degradation, pest and diseases, population pressure and food insecurity (Runge-Metzger and Diehl, 1993), and thus serves as an appropriate example for analysing the induced innovation hypothesis. On the other hand, there are FFF programmes in the region which can be used in studying the effects of innovation systems in building farmers' innovation capacity.

The contribution of this paper to the extant literature is twofold. First, we focus on the drivers of smallholder innovation generation instead of innovation adoption which has been studied extensively. Secondly, there are many studies looking at the impact of farmer field schools (FFS) on outcome variables such as empowerment, technology adoption, household income

[1] Innovation generation, innovation capacity, innovation behaviour and farmer innovation are used interchangeably in this paper.

and food security but with inconclusive findings (for a review, see Davis *et al*., 2012, Table 1). Within this vast literature, however, there is little, if any, on the innovation-generating effects of FFS. This study provides empirical evidence on the potential of FFF, a variant of FFS, in stimulating innovation-generating behaviour among farm households.

The remainder of this paper is structured as follows. Section 2 presents the theories and relevant concepts of the study. In section 3, we explain the methods including details of the estimation approaches, data, and some descriptive statistics. The regression results are presented and discussed in section 4, and section 5 concludes the paper.

2. Theories and concepts

2.1 Induced innovation and innovation systems

As mentioned, we rely on elements of the induced innovation theory and the innovation systems perspective in explaining the determinants of farmer innovativeness. The induced innovation theory considers challenges and opportunities as key drivers of innovation. The original idea of the theory was price-induced innovation (Hicks, 1932), and there have since been many variants. Hayami and Ruttan (1985) extended the theory to include pressures due to resource endowments and economic change. There is also the induced innovation concept of Boserup (1965), which suggests that an increase in population density can stimulate technological innovations that increase land use intensity. In recent years climate-induced innovation has emerged as a basis for understanding the potential role of climate change in stimulating innovation (Easterling, 1996; Sunding and Zilberman, 2001). The induced innovation hypothesis can also be used in explaining the generation of new innovations to address production constraints such as the random emergence of pests and diseases (Sunding and Zilberman, 2001). Other authors argue that innovation in a region is not only determined by factor scarcities, but also economic and market-related opportunities, agro-ecological conditions, and government policies (Goldman, 1993). This study takes inspiration from the variants of the induced innovation hypothesis to examine if constraints to production such as climatic stress, pest and diseases, labour shocks, and opportunities such as increased market access induce innovativeness in farm households.

The innovation systems approach emerged as a result of the increasing recognition that the ToT model which views innovation as a linear process driven by the supply of research and development has not fulfilled expectations in terms of developing locally adapted innovative practices (Röling, 2009a; World Bank, 2011). The innovation systems approach acknowledges the role of education, research, and extension in supplying new knowledge and technology to the farmer, but in addition, recognises the farmer as part of a complex network of heterogeneous agents engaged in innovation processes, and also looks at the actions and interactions that link these agents to each other, along with the formal and informal institutions and policy environments that influence these processes (Spielman, 2005). Hence, the approach argues for strengthening the interactions between actors of the innovation process. It emphasizes highly on building innovative capacity and acknowledges the important role of an enabling environment for innovation generation (Rajalahti, 2009).

2.2 Farmer Field Fora

Our empirical analysis of the potential of the innovation systems perspective in explaining farmer innovativeness is based on the FFF of the Root and Tuber Improvement and Marketing Programme (RTIMP) in Ghana. The RTIMP used the FFF as a platform for mutual learning among stakeholders in the root and tuber value chain, particularly farmers, extension agents and researchers. The aim of FFF is to "build the capacities of farmers to become experts in the development of technologies and managerial practices to solve specific problems within the agro-ecological context of farming" (Gbadugui and Coulibaly, 2010). It is a variant of the well-known Farmer Field School (FFS), a participatory extension model. Unlike FFS which gives little or no attention to farmer-developed innovations (Reij and Waters-Bayer 2001), FFF provides an opportunity for farmers to experiment with their own innovations, thereby strengthening their decision-making and innovation capacities.

The RTIMP-FFF in Ghana, which started in 2006, aims at improving farmer innovation and productivity of root and tuber crops in major production districts of the country. In each participation district, the FFF was developed for the most important root or tuber crop. This study is based on the sweet potato FFF in 10 communities in three northern districts of Ghana. The main actors include researchers, extension agents, business advisors, farmers and processors, and they are all placed on an equal footing. During a participatory rural appraisal, the farmers determine the theme of the FFF, thereby ensuring that their priorities are addressed. The thematic areas normally selected by the farmers include improved crop varieties, integrated pests management (IPM), improved cultivation practices and integrated soil fertility management. There are also discussion sessions on non-farm topics. Each forum consists of a group of 30 to 40 farmers together with other key actors who meet regularly (usually weekly) in the field during a growing season. They engage in comparative experimentations using three plots: farmers practice (FP), integrated crop management (ICM) and participatory action research (PAR), with the assistance of a facilitator who stimulates critical thinking and discussions, and ensures active participation. The participating farmers experiment with their own innovations or test new ideas on the PAR plots. Conventional practices and improved innovations are implemented on the FP and ICM plots, respectively.

It should be noted that the RTIMP-FFF does not include all relevant stakeholders as required by the innovation systems model. Nevertheless, it is has some elements of the model, hence, could be considered as a “partial innovation systems” framework. This is typical of most studies adopting the innovation systems framework (Sanginga *et al*., 2009).

2.3 Farmer innovation

There are several definitions and classifications of innovation (for an overview, see Garcia and Calantone, 2002), and this is partly because research on innovation spans many disciplines. Nonetheless, innovation generally entails the implementation of new or significantly improved products, processes or methods (OECD, 2005). In agriculture, it is well acknowledged that innovations could emerge from many sources including farmers, and these are normally referred to as farmer innovations (Biggs, 1981; Röling, 2009b). Farmer innovations are sometimes termed farmer-driven or farmer-led innovations, grassroot innovations, local innovations, folk or farmer experiments, etc. (Saad, 2002). Similar to innovation, there is no generally agreed definition for a farmer innovation or a farmer innovator. It is, however, different from the concept in the literature on adoption and diffusion of innovations in which adopters or the first group of adopters of introduced technologies are referred to as innovators (Rogers, 1962). Following Saad (2002) and Waters-Bayer *et al*. (2009), we define a farmer innovation to be a new or modified practice, technique or product that was developed by an individual farmer or a group of farmers without direct support from external agents or formal research. In our study, the term innovative behaviour goes beyond the final outcome and encompasses activities of the innovation process such as experimentation. Innovation processes or activities may be new to farmers in one community, but not necessarily new to farmers in other communities (Saad, 2002; Waters-Bayer and Bayer, 2009).

In this study, we focus on four categories of innovation-generating activities of farm households. These are: (i) developing new techniques or practices (hereafter, invention), (ii) adding value or modifying indigenous or traditional practices, (iii) modifying or adapting external techniques or practices to local conditions or farming systems, and (iv) informal experimentation. Thus, innovators are farm households who have implemented any of these four categories of innovation-generating activities during the 12 months prior to the survey. In our framework, there are several factors that can trigger the implementation of these innovation-generating activities. These include shocks, scarcity of factors of production, opportunities, stakeholder interactions, or socio-economic factors.

3. Methodology

3.1 Empirical strategy

We are interested in estimating the determinants of innovation-generating behaviour of farm households. This can be specified as:

$$FI_i = \beta_0 + \beta_1 X_i + \beta_2 \mathrm{II}_i + \beta_3 FFF_i + \beta_4 R_i + \beta_5 V_i + \varepsilon_i \quad (1)$$

where the dependent variable *FI* (farmer innovation) indicates innovation-generating behaviour of household *i*. We use four different measures of the dependent variable to check if the results are sensitive to the indicator employed. The first (*innovation_binary*) is a binary variable which is equal to one if the household has implemented any of the four categories of farmer innovation (see section 2.3) in the past 12 months; and 0 otherwise. The second (*innovation_count*) is a count variable that indicates the number of different innovation-generating activities implemented by a household in the past 12 months. In the third and fourth measure of *FI*, we consider the varied importance of each of the four categories of farmer innovation and constructed an innovation index using weights. In the third measure of *FI* (*innovation index 1*), we followed Filmer and Pritchett (2001) and used principal component analysis (PCA) to assign weights to each of the four innovation categories, and constructed a household innovation index. The final indicator (*innovation index 2*) also involves the construction of a household innovation index but relies on weights obtained through expert judgements. A stakeholder workshop was organised and 12 agricultural experts in the study region assigned weights to the four innovation categories based on their relative importance. They assigned weights of 0.4, 0.2, 0.3 and 0.1 for invention, adaptation of exogenous ideas, modification of traditional practices and experimentation, respectively.

Variable *Xi* is a vector of household socio-demographic and economic variables that are commonly found in the agricultural innovation adoption literature (e.g. age, gender and education of the household head; household size and dependency ratio; access to services and the wealth position of the household). It also includes variables capturing land rights and soil fertility status of plots. The vector *II* contains variables motivated by the induced innovation hypothesis. It includes idiosyncratic shocks experienced by the household during the past 5 years (e.g., climatic stress, pests and diseases, and labour shocks), change in household size, and access to market opportunities. The variable FFF is equal to one if a household member participated in a FFF and zero otherwise, and we use it as a proxy for the innovation systems perspective.

Variable *R* represents household risk behaviour. Following the seminal study by Binswanger (1980), we conducted a simple experiment using the ordered lottery selection design with actual payments to elicit households' risk preferences. In the design, each respondent was presented with a choice of six lotteries (A-F), and was asked to select one. Once chosen, a coin was tossed to decide the payoff. A higher payoff could only be obtained at the cost of a higher variance. Table A1 in the appendix shows the structure of the experiment, but it was actually presented to respondents in the form of photographs of money. This design is most suitable and generates accurate result when the respondents are mostly illiterate or less skilled in mathematics, as in our case (Harrison and Rutström, 2008). We also include village fixed effects (*V*) to control for unobserved heterogeneity in the sample villages. Finally, ε is the random error term.

A usual problem of estimating equation 1 is the potential endogeneity of the FFF participation variable; hence, applying binary and count data regression models or ordinary least squares might yield biased estimates. There are two potential sources of endogeneity. First, there is placement endogeneity stemming from the non-random selection of FFF participating communities. Thus, if communities with more innovative farmers were selected to participate in the FFF, then the impact will be overestimated. Secondly, within the FFF communities farmer participation is voluntary, i.e. farmers self-select to participate. Thus, participating farmers may differ systematically from non-participants in unobserved characteristics such as entrepreneurship and risk behaviour which might lead to biased estimates of the effect of FFF on innovation. Due to the endogeneity issues, participants and non-participants are, therefore, not directly comparable.

To deal with these problems, we exploited our sampling frame and also used instrumental variables approach. First, in our sampling strategy, the non-participants sample was drawn from both FFF participating and non-participating villages, and this helps in reducing the problem of placement endogeneity. Though non-participants in FFF villages might potentially be affected by spillovers, we believe that participation enhances innovative generation capacity and exposure alone does not confer this skill, and this is later proven to be true when we look at the spillover effects of FFF participation. The non-participation villages were also drawn from the same agro-ecological zone and districts as the participation villages and are likely to be the next group of FFF villages in any future scaling up. Secondly, we use village fixed effects to account for unobservable heterogeneity between villages. Furthermore, we control for risk attitude of farmers which is one of the key characteristics of innovative behaviour which, however, is often not captured in agricultural innovation studies (Feder *et al*., 1985). Finally, we employ two instruments and estimate equation 1 using recursive bivariate probit (RBP) and endogenous treatment-regression (ETR) models to further remedy the endogeneity problems. In the RBP and ETR models, we first estimate a selection model, expressed as:

$$FFF_i = \delta_0 + \delta_1 X_i + \delta_2 R_i + \delta_3 V_i + \delta_4 Z_i + \mu_i$$

(2)

where *FFF, X, R* and *V* are defined as in equation 1. The vector *Z* consists of the two instruments: initial sweet potato cultivation and membership of farmer group[2]. We argue that these two variables affect FFF participation but do not directly affect innovation-generating behaviour. In the study region, sweet potato is a minor crop which is cultivated by almost every household, albeit irregularly and on a very small scale. Since participation in FFF is

[2] 'Initial' implies before the start of FFF in the participating villages and recent situation in non-participating villages. They are based on recall data.

voluntary, every farmer could volunteer to join but we expect farmers who cultivate sweet potato at least two continuous cropping seasons prior to the FFF to show more interest in participating. Similarly, villages with regular sweet potato producers were more likely to be selected. Discussions with the FFF facilitators also indicated that, although not encouraged, extension officers responsible for registering interested participants appear to have given preferences to farmer group members because they believed they were more likely to be committed to participate actively in the programme.

One could argue that these instruments may be endogenous to innovation-generating behaviour. To address this challenge, we use lagged variables to capture sweet potato cultivation and farmer group membership. That is, whether a farmer – before the start of FFF – (i) cultivated sweet potatoes on a regular basis, and (ii) was member of a farmer group. These are likely to be exogenous to recent innovation-generating decisions. Moreover, discussions with farmers indicate that the motivation for cultivating sweet potato regularly and joining farmer groups has nothing to do with innovation generation. Prior to FFF, the farmer groups were not active or engaging in any collective action that could induce innovation generation. Also, regular cultivation of sweet potato seems unrelated to innovation as almost all the innovation-generating activities observed are not connected to sweet potato production. Following Di Falco et al. (2011) and Fischer and Qaim (2012), we also estimated a placebo regression to test the exogeneity of our instruments. Using data from only non-participating villages, we examined the effect of the two instruments and other covariates on the innovation-generating decision of households not exposed to FFF. We expect significant effects of the two instruments if they are endogenous to the innovation-generating decision of households. The result (see Table A2 in the appendix) indicates that there is no direct effect of the two instruments on the outcome variable; hence, both variables are valid instruments. We will show in the results section that the two instruments also significantly affect FFF participation.

As already indicated, we use four different measures of the dependent variable to check if the results are robust to different specifications of innovation generation. We therefore require estimation techniques that account for the different measures of the dependent variable and the endogeneity of the FFF participation variable. Consequently, we use three different econometric techniques. In the first model, (*innovation binary)*, we estimate a maximum likelihood RBP with instruments because both the outcome and endogenous FFF participation variables are binary. In the second model (*innovation count)*, the outcome is a count variable so we employ a Poisson regression with endogenous treatment effects (PRETE). Finally, linear regression with endogenous treatment effects (LRETE)[3] was used in estimating model 3 (*innovation index 1)* and model 4 (*innovation index 2)*. For robustness checks, we also compute naïve models of equation 1 without accounting for the potential endogeneity of FFF participation.

3.2 Data and descriptive statistics

The empirical analysis is based on data for the 2011-2012 agricultural season obtained from a household survey in the districts of Bongo, Kassena Nankana East and Kassena Nankana West in the Upper East Region, one of the poorest administrative regions of Ghana. The districts fall within the Sudan savanna agro-ecological zone which is characterised by systems of permanent cultivation on rain-fed land with high population density, small land holdings, soil degradation, low labour productivity, predominance of annual and biannual crops and increasing cash crop production (Ruthenberg, 1971; Runge-Metzger and Diehl, 1993). Agriculture is the main income source and a cereal-legume cropping system is predominant in the study region. The major crops are millet, sorghum, maize, cowpea, rice and groundnut. Most households also rear livestock. The area is characterised by a prolonged dry season and erratic rainfall; hence, many of the inhabitants migrate to southern Ghana to seek employment opportunities or engage in irrigated vegetable farming during the dry season.

The sample included FFF participants, non-participants from FFF communities (hereafter, exposed farmers) and non-participants from control communities (hereafter, control farmers). We interviewed 409 households from 17 villages using a stratified random sampling. We first obtained from the district RTIMP project officers, a list of all the 24 villages in the three districts where FFF has been implemented between 2008 and 2011. Then we randomly selected 10 participating villages across the three districts. We interviewed about 16 to 21 participants from each of these villages, resulting in a total of 185 FFF participants. We also obtained a list of all households in each participating village and randomly sampled and

[3] Models fit by PRETE and LRETE are referred to as ETR models (StataCorp, 2013).

interviewed 99 exposed farmers across the 10 villages. Since these exposed farmers are located in the same FFF villages, they may be potentially exposed to some of the effects of FFF. To obtain a group of control farmers devoid of potential spillovers, we randomly selected seven villages (from the same three districts) that have similar infrastructural services and socio-economic conditions but not in close proximities to the FFF communities. Out of these, we randomly selected 125 farm households from a household list obtained from the District Agricultural Offices. Thus, our final sample consists of 185 FFF participants and 224 non-participants (99 exposed and 125 control farmers), making a total of 409 sample farmers.

Data collection was conducted by experienced enumerators who were highly trained for this research. Interviews were conducted with the aid of pre-tested questionnaires and were supervised by the first author. The questionnaire captured data on household and plot characteristics, crop and livestock production, off-farm income earning activities, innovation-generation activities and access to infrastructural services, information and social interventions. The respondents were mainly FFF participants or household heads in the presence of other available household members.

[TABLE 1]

Table 1 outlines the description of the variables used in the regression and their mean values. The table shows that about 42 percent of the sample households conducted at least one innovation-generating activity in the past 12 months. The explanatory variables consist of household and farm characteristics, FFF participation, variables motivated by the induced innovation theory and risk preference. The explanatory variables also include village dummies to control for village fixed effects and the two instrumental variables, initial regular sweet potato cultivation and initial membership of farmer group.

[FIGURE 1]

Figure 1 presents the share of households that implemented innovation-generating activities and compares the results between participants and non-participants. Informal experimentation, which was implemented by 25 percent of the sampled households, constitutes the most practiced activity. A similar trend is observed when we compare the innovation activities of FFF participants and non-participants. This is expected as experimentation is the first stage of most innovation processes. The figure also shows that relative to non-participants, FFF participants implemented more innovation-generating activities in each of the the four categories which seems to suggest that FFF participation enhances innovation capacity. In the next section, we analyse this relationship using econometric techniques. Land preparation, method of planting, cropping pattern, soil fertility, new crops and varieties, soil and water conservartion and animal husbandry are the major domains of the farmers' innovations. Examples of the farmer innovations include: informal trials or introduction of new crops or varieties in a community; testing and modification of planting distance and cropping pattern; using plant extracts as insecticide; new formulations of animal feed and new herbal remedies in the treatment of livestock diseases (ethnoveterinary practices); developing and using new farming tools; storage of farm products using local grasses; and new methods of compost preparation.

4. Results and Discussion

In this section, we look at the econometric results on the determinants of innovation generation. We check for robustness using alternative specifications and also analyse spillover effects of FFF participation.

4.1 Determinants of farmers' innovation-generating behaviour

As already indicated, different econometric models (RBP and ETR) are used to deal with the endogeneity problems and also account for the nature of the four dependent variables. We instrumented for the FFF participation in the first stage regression on the determinants of FFF participation, and the results are reported in Table A3 in the appendix. The two excluded instruments (initial farmer group membership and initial sweet potato cultivation) are highly significant in all models, which suggests the relevance of the instruments. The results of the estimated models on the determinants of innovation generation are presented in Table 2. The Wald tests of independent equations indicate that there is a significant correlation between the error terms in equations 1 and 2, suggesting that there is a potential selectivity bias; hence, the use of treatment effect models is justified.

[TABLE 2]

The results indicate that the robust determinants of innovation capacity, irrespective of the type of indicator employed, are FFF participation, level of education of household head, size of land holding, household experience of climate shock, change in household size and risk preferences. A key variable of interest, FFF participation, which is used to capture the innovation systems perspective, is highly significant in all the four models. Participation in FFF is found to increase the probability of generating innovations by 22.3 percentage points, and FFF participants are also likely to implement 0.41 more innovation-generating activities than non-participants. There are three possible pathways through which FFF participation may influence innovation capacity. First, FFF provides opportunity for farmers to test their innovations in the presence of other stakeholders, and this builds their self-esteem and empowers them to innovate due to the recognition and appreciation of their ideas by others. Second, FFF may enhance the analytical and problem-solving skills of participants which are essential for innovation. Finally, the FFF graduates form vibrant farmer groups for continuous group discussion and learning which may facilitate further innovative activities. This result suggests that the concept of innovation systems which facilitates active interactions among key stakeholders has a potential for strengthening farmers' innovation capacity. This result also adds to evidence of the positive effects of FFS participation on adoption of agricultural innovations (e.g. Erbaugh *et al*., 2010; Friis-Hansen and Duveskog, 2012).

Education is another important determinant of innovation capacity as shown by its significant positive effect in all the four models. An additional year of education of the household head increases household innovation practices by 2.6 percent. The significant and positive effects of both FFF participation and education confirm the important role of human capital formation in innovation processes.

Two of the variables motivated by the induced innovation theory – change in household size and climate shocks – are statistically significant, albeit the latter with a sign contrary to our expectations. While arguments of the induced innovation hypothesis would predict households that are affected by climate-related shocks to be innovative and to overcome the adverse effects of the shock, our results suggest otherwise. This is, however, plausible as affected households may have lost their economic capabilities to implementing innovations. Also, coping with such shocks may involve reallocating household resources (e.g. to non-farm employment) resulting in decreased agricultural production, hence, the less likelihood of generating innovations.

Among the four wealth-related factors included in the models, only size of land holding is a significant determinant of innovation generation. Most large land holders have several plots, hence, have the leverage to carry out experiments on some of them. There is no active land market in the study region so it is possible that the significance of land holding may be related to the opportunity for experimentation, rather than wealth. Finally, the results show that compared to risk averse farmers, risk neutral and risk preferring farmers are more likely to be innovative. This is expected since innovations generally involve risk (Feder *et al*., 1985).

As a robustness check, we also estimate three naïve models of the determinants of innovation-generating capacity using the *innovation_binary* indicator as the dependent variable[4] and compare the results (see Table 3) with the RBP result in Table 2. First, we estimate a probit model (Model 1) which ignores self-selection and placement bias. This is the preferred model assuming FFF participation is exogenous, hence, it allows us to examine if the two-stage approaches used above significantly changes the result of other exogenous variables of interest. The result shows that FFF participation increases innovation generation by 12.7 percentage points, thus indicating a downward bias if FFF participation is treated as exogenous. The direction and significance level of the other covariates, however, do not differ largely from those in Table 2.

[TABLE 3]

In Model 2, we control for placement bias but assume no self-selection into FFF. Here again, we find that the innovation-generating effect of FFF (13.2 percentage points) seems to be underestimated. Finally in Model 3, we assume random village placement of FFF but account for potential self-selection into FFF. The result shows that FFF participants are 23 percentage points more likely to implement innovation-generating activities relative to non-participants, which suggests a slight upward bias. The results from these three models suggest that the

[4] We also performed robustness checks using the other three specifications of the dependent variable. We obtained results very similar to Table 3.

positive and significant effect of FFF on innovation-generating behaviour is consistent and robust, but without controlling for self-selection and placement bias, the effect appears to be over-or underestimated.

4.2 Spillover effect of FFF participation

In this section, we test whether FFF participation has spillover effects by comparing the innovation capacity of participants with that of the exposed group (Table 4, Model A) and the innovation capacity of the exposed group with the control group (Table 4, Model B). FFF do not reach all farmers, but promoters believe that knowledge gained will be transmitted from participants to other farmers. It is expected that if there is a strong spillover effect, there will be no significant effect of FFF participation on innovation capacity in Model A. Similarly, in Model B, we expect the exposed group to carry out significantly more innovative activities than the control group if there is a spillover effect. In both models, the dependent variable is the number of innovation activities implemented by households so we employ a Poisson regression. However, we take the potential endogeneity of FFF participation in Model A into consideration by estimating a PRETE model. The main variable of interest, Treatment, takes values of 1 and 0 if the household is a FFF participant or belongs to the exposed group, respectively (Model A); and 1 and 0 if the household belongs to the exposed or control group, respectively (Model B).

[TABLE 4]

The highly statistical significance of the Treatment variable in Model A indicates that relative to the exposed group, participating households are more likely to implement innovation-generating activities, implying that there is no strong spillover effect of FFF on innovation capacity. Similarly, the result in Model B shows that exposed farmers are not significantly more innovative than control farmers which further suggests that there is no spillover effect. Similar results were obtained in IPM-FFS studies by Rola et al. (2002), Feder et al. (2004a) and Tripp et al. (2005) in Philippines, Indonesia and Sri Lanka, respectively. This finding is plausible because FFF strengthens the analytical and problem-solving skills of participants, and the mere location of non-participating households in FFF villages or interactions with other FFF graduates does not confer these skills. Another possible explanation is the low level of intensity of the program. Only one FFF with 30 to 40 participants (out of about 200 potential participants) was implemented in each participating village. This low intensity is argued to be an important determinant of successful applications and dissemination of FFS principles (Feder *et al*., 2004b).

This result also validates the inclusion of the exposed group into the group of non-participants in our initial analyses as part of our attempt to minimise the endogeneity problems. It is possible that FFF may have spillover effects on other outcome objectives of the programme such as innovation adoption and farm productivity, but this is not the focus of this paper. It should also be stressed that the innovation effect of FFF appears to be independent of the crop it focuses on since most of the innovations reported by the farmers were unrelated to sweet potato production.

5. Conclusion

Innovation is essential for agricultural and economic development and global change further increases its importance. While there is increased interest in promoting farmer innovations as a complement to externally-driven technologies, little attention has been paid to what determines the innovation capacity of farmers. Using cross-sectional data from 409 farm households and econometric techniques, this study analyses the innovation-generating activities among rural farmers in northern Ghana. We specifically look at the determinants of innovation capacity in farm households using inspiration from two innovation theories: induced innovation and innovation systems.

This study has shown that resource-poor farmers are capable of implementing innovation-generating activities. The innovations range from experimenting with new ideas, modifying or adding value to existing or external practices to complete discovery of better farming practices. Controlling for selection bias, we found that participation in FFF, a participatory extension approach with elements of the innovation systems concept, is a key determinant of innovation capacity in farm households. This is possible because participants are likely to be empowered and also gain problem-solving and analytical skills which are essential for innovation. This result is robust to alternative specifications and estimation techniques. Innovation capacity also increases significantly with general education levels, another human capital related determinant.

In contrast to the innovation adoption literature where poor farmers are often found to be significantly constrained in adopting new technologies, our findings seem to suggest that wealth does not play a key role in innovation-generating decisions of farmers. We also found little evidence that shocks induce innovativeness. Climate shocks rather appear to reduce the probability of generating innovations. This study also attempted controlling for farmers' risk attitudes and found that it is a very important determinant of innovation capacity in farm households. There appears to be no spillover effect of FFF on innovation generation, and this has implications for the cost-effectiveness of the programme. Farmers have, however, extended the knowledge acquired from participating in FFF to other farming activities and there is a possibility of spillovers on other outcome indicators such as farm productivity. Therefore, further studies will be needed before a concrete conclusion on the cost-effectiveness of the FFF programme can be drawn.

Policy efforts aiming at strengthening farmers' innovation capacity should provide platforms for active interaction between stakeholders as argued by the innovation systems theory. The innovation platform (IP) of the Forum for Agricultural Research in Africa (FARA) is a good example. An IP facilitates interactions between actors who have a common interest in innovation generation (Nederlof *et al*., 2011). This does not imply that promoting FFF or its variants will definitely induce innovation-generating behaviour in farmers. There are reports that some FFSs have rather been used as means to facilitate the transfer of technologies to farmers (Röling, 2009a). The innovation potential of FFF, therefore, likely hinges on how it is implemented in the field.

Farmer innovation is a continuous process, but this study is based on cross-sectional data which does not allow the analyses of these dynamics and is further challenged by endogeneity problems. While we have tried to address these issues by using robust estimation techniques, a more rigorous analysis will require the use of panel data; hence, future research in this direction will be useful in corroborating the findings of this study. There are increasing attempts to promote farmer innovations and this study has illustrated some useful pathways. To further strengthen arguments in support of farmer innovations, studies on the livelihood impacts of these innovations are also needed.

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FIGURES

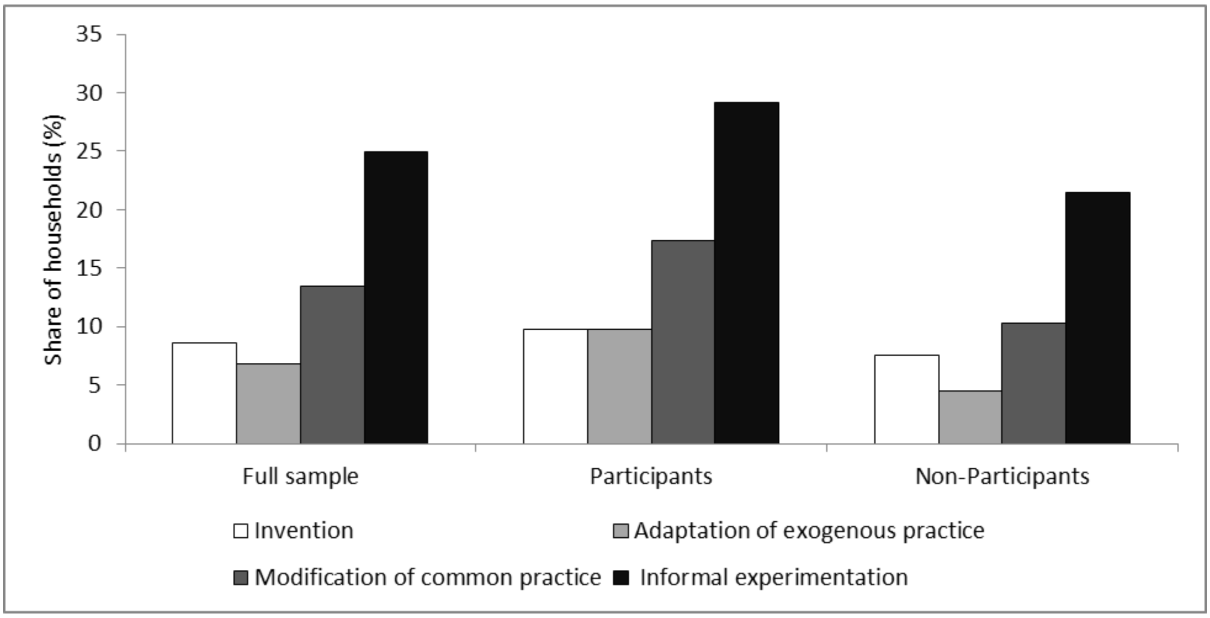

Figure 1: Share of households that implemented innovation-generating activities

TABLES

Table 1: Description and descriptive statistics of variables

Variable	Description	Mean	SD
Dependent variable (farmer innovation)			
Innovation_binary	Household has conducted innovation-generating activities (Binary)	0.42	0.41
Innovation _count	Number of innovation activities conducted by household (Count)	0.59	0.79
Innovation index 1	Household innovation index based on weights obtained through PCA	0.00	1.00
Innovation index 2	Household innovation index based on weights assigned by experts	0.13	0.21
Household and farm characteristics			
Age	Age of household head	49.42	14.88
Gender	Gender of household head (dummy, 1=male)	0.86	0.35
Household size	Number of household members	6.64	2.59
Dependency ratio	Ratio of members aged below 15 and above 64 to those aged 15-64	0.89	0.79
Education	Education of household head (years)	1.67	1.10
Land holding	Total land owned by household in acres	4.56	4.15
Livestock holding	Total livestock holding of household in Tropical Livestock Units (TLU)	2.92	3.41
Assets	Total value of non-land productive assets in 100 GH¢*	4.54	6.92
Off-farm activities	Household has access to off-farm income earning activities	0.76	0.43
Credit	Household has access to credit	0.26	0.43
Road distance	Distance to nearest all-weather road in km	0.54	0.84
Social group	Household member belongs to a non-farm group	0.40	0.49
Land right	Proportion of plots in which household has full user rights	0.86	0.25
Soil fertility	Proportion of plots with infertile soil	0.37	0.44
Innovation systems			
FFF participation	Household member participated in FFF	0.45	0.50
Induced innovation			
Climate shock	Household suffered from droughts or floods in the past 5 years	0.91	0.29
Pest and disease shock	Household farm affected by pests or diseases in the past 5 years	0.82	0.39
Labour shock	Death or illness of a household member in a year prior to survey	0.60	0.49
Household size change	Change in household size (between 2008 and 2012)	-0.35	2.13
Market opportunities	Household has improved access to markets in the past 5 years	0.50	0.50
Risk aversion category			
Extreme	Household is extremely risk averse	0.40	0.49
Severe	Household is severely risk averse	0.22	0.42
Intermediate	Household is intermediate risk averse	0.14	0.34
Moderate	Household is moderately risk averse	0.04	0.20
Slight to neutral	Household is slightly risk averse to risk neutral	0.11	0.32
Neutral to preferring	Household is risk neutral to risk preferring	0.09	0.30
Instruments			
Sweet potato	Household cultivates sweet potato regularly prior to FFF	0.69	0.38
Farmer group	Household member belongs to farmer group prior to FFF	0.33	0.43

* The exchange rate at the time of the survey was US $1 = GH¢ 1.90

Table 2: Determinants of innovation-generating behaviour

	Innovation (binary)	Innovation (count)	Innovation index 1	Innovation index 2
	RBP[a]	PRETE[b]	LRETE[c]	LRETE[c]
FFF Participation	0.223 (0.107)**	0.409 (0.168)**	0.655 (0.201)***	0.134 (0.039)***
Age	-0.003 (0.002)	-0.003 (0.003)	-0.004 (0.003)	0.000(0.001)
Gender	-0.084 (0.069	-0.143 (0.133)	-0.187 (0.140)	-0.013 (0.029)
Household size	-0.004 (0.011)	0.005 (0.020)	-0.000 (0.022)	-0.001 (0.005)
Dependency ratio	-0.010 (0.030)	-0.040 (0.058)	-0.055 (0.061)	-0.018 (0.013)
Education	0.013 (0.006)**	0.026 (0.011)**	0.035 (0.013)***	0.008 (0.003)***
Land holding	0.019 (0.007)***	0.017 (0.010)*	0.026 (0.013)**	0.005 (0.003)*
Livestock holding	-0.010 (0.008)	-0.016 (0.015)	-0.015 (0.017)	-0.006 (0.004)
Assets	0.002 (0.004)	0.006 (0.006)	0.000 (0.000)	0.000 (0.000)
Off-farm activities	0.041 (0.057)	0.140 (0.112)	0.160 (0.116)	0.041 (0.024)*
Credit access	0.057 (0.055)	0.087 (0.095)	0.149 (0.113)	0.016 (0.024)
Road distance	0.025 (0.030)	0.011 (0.056)	0.042 (0.062)	-0.001 (0.013)
Social group	0.004 (0.050)	-0.017 (0.091)	-0.083 (0.101)	-0.014 (0.021)
Land right	-0.054 (0.099)	0.057 (0.182)	0.081 (0.197)	0.038 (0.0415)
Soil fertility	-0.004 (0.059)	-0.009 (0.111)	-0.022 (0.118)	-0.022 (0.025)
Climate shock	-0.174 (0.085)**	-0.265 (0.144)*	-0.469 (0.173)***	-0.086 (0.037)**
Pest and disease shock	0.116 (0.065)*	0.165 (0.124)	0.192 (0.128)	0.020 (0.027)
Labour shock	-0.081 (0.050)	-0.085 (0.091)	-0.041 (0.099)	-0.011 (0.021)
Household size change	-0.019 (0.011)*	-0.037 (0.020)*	-0.061 (0.023)***	-0.008 (0.005)
Market opportunities	-0.012 (0.030)	-0.033 (0.054)	-0.030 (0.060)	-0.033 (0.013)
Severely risk averse (RA)	0.060 (0.062)	0.150 (0.118)	0.126 (0.122)	0.021 (0.026)
Intermediate RA	-0.008 (0.075)	-0.014 (0.149)	-0.008 (0.147)	-0.001 (0.031)
Moderately RA	0.217 (0.119)*	0.301 (0.193)	0.344 (0.244)	0.082 (0.051)
Slightly to neutral RA	0.084 (0.077)	0.225 (0.139)	0.339 (0.159)**	0.088 (0.033)***
Neutral to risk preferring	0.190 (0.082)**	0.314 (0.136)**	0.463 (0.167)***	0.105 (0.035)***
Village fixed effects	Yes	Yes	Yes	Yes
Constant	0.309 (0.698)	-0.607 (0.735)	0.130 (0.457)	0.094 (0.096)
No. of observations	409	409	409	409
Wald (Chi^2)	0.863	-	5.28**	6.22**

***, **, * represent 1%, 5%, and 10% significance level, respectively. Values in parentheses are standard errors.
[a] We report the average marginal effects which were obtained using the stata command, margins with the option predict (pmarg1) force.
[b] The PRETE model was estimated using *etpoisson* command in stata 13. Average treatment effects (ATE) are reported.
[c] The LRETE models were estimated using *etregress* command in stata 13. The values are ATE.

Table 3: Determinants of innovation generation, naïve estimates[a]

	Model 1		Model 2		Model 3	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
FFF Participation	0.127***	0.048	0.132**	0.059	0.230***	0.078
Age	-0.003*	0.002	-0.003*	0.002	-0.002	0.002
Gender	-0.065	0.069	-0.09	0.069	-0.063	0.067
Household size	0.001	0.011	-0.002	0.011	-0.002	0.01
Dependency ratio	-0.004	0.031	-0.006	0.031	-0.01	0.03
Education	0.012*	0.006	0.013**	0.007	0.012*	0.006
Land holding	0.019***	0.007	0.020***	0.007	0.018***	0.007
Livestock holding	-0.008	0.008	-0.01	0.008	-0.008	0.008
Assets	0.001	0.004	0.002	0.004	0.002	0.003
Off-farm activities	0.038	0.057	0.037	0.057	0.041	0.055
Credit access	0.032	0.055	0.066	0.055	0.017	0.054
Road distance	0.032	0.027	0.024	0.03	0.04	0.027
Social group	0.000	0.048	0.01	0.05	-0.009	0.047
Land right	-0.039	0.098	-0.061	0.101	-0.035	0.094
Soil fertility	0.001	0.059	-0.012	0.06	0.005	0.057
Climate shock	-0.140*	0.084	-0.175**	0.087	-0.136*	0.081
Pest and disease shock	0.065	0.065	0.113*	0.066	0.067	0.063
Labour shock	-0.063	0.05	-0.089*	0.051	-0.057	0.048
Household size change	-0.022*	0.012	-0.020*	0.012	-0.020*	0.011
Market opportunities	0.004	0.031	-0.011	0.031	0.001	0.03
Severely Risk Averse (RA)	0.054	0.062	0.061	0.062	0.05	0.06
Intermediate RA	0.004	0.075	-0.016	0.076	0.002	0.073
Moderately RA	0.221*	0.12	0.223*	0.122	0.206*	0.116
Slightly to neutral RA	0.079	0.077	0.079	0.078	0.074	0.075
Neutral to risk preferring	0.199**	0.083	0.193**	0.084	0.183**	0.082
Village fixed effects	No		Yes		No	
Constant	-0.031	0.562	0.335	0.701	-0.198	0.566
No. of observations	409		409		409	

***, **, * represent 1%, 5%, and 10% significance level, respectively

[a] Average marginal effects are reported

Table 4: Spillover effect of FFF participation on innovation generation[a]

	Model A		Model B	
	Coefficient	SE	Coefficient	SE
Treatment	0.781***	0.263	0.508	0.535
Village fixed effects	Yes		Yes	
No. of observations	284		224	

***, **, * represent 1%, 5%, and 10% significance level, respectively

[a] The full estimation results are presented in Table A4 in the appendix.

Appendix

Table A1: Risk preference elicitation set-up

Choice	High pay-off	Low pay-off	Risk aversion class
A	3	3	Extreme
B	4	2.5	Severe
C	5	2	Intermediate
D	6	1.5	Moderate
E	7	1	Slight to Neutral
F	8	0	Neutral to Preferring

Table A2: Estimation results of the placebo regression

	Probit Model	
	Coefficient	SE
Sweet potato	-0.122	0.340
Farmer group	0.204	0.479
Age	-0.021*	0.012
Gender	-0.300	0.435
Household size	0.165**	0.079
Dependency ratio	-1.149***	0.351
Education	0.062	0.043
Land holding	0.076*	0.044
Livestock holding	0.712*	0.407
Assets	-0.105	0.065
Off-farm activities	0.000	0.000
Credit access	-0.093	0.419
Road distance	-0.394	0.429
Social group	0.137	0.167
Land right	0.510	0.654
Soil fertility	-0.377	0.504
Climate shock	-1.408	1.262
Pest and disease shock	0.753	0.563
Labour shock	-0.084	0.356
Household size change	-0.111	0.091
Market opportunities	-0.161	0.231
Severe risk averse (RA)	0.197	0.391
Intermediate RA	-0.869	0.645
Moderate RA	1.613**	0.810
Slight to neutral RA	0.051	0.614
Neutral to risk preferring	-0.125	0.677
Village fixed effect	Yes	
Constant	0.780	2.107
No. of observations	125	

***, **, * represent 1%, 5%, and 10% significance level, respectively

Table A3: Estimation results of the first stage regression[a]

	Innovation (binary)		Innovation index 1		Innovation index 2	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
Sweet potato	1.321***	0.26	1.339***	0.254	1.373***	0.256
Farmer group	1.248***	0.237	1.285***	0.234	1.268***	0.236
Age	-0.004	0.007	-0.004	0.007	-0.003	0.007
Gender	-0.138	0.288	-0.165	0.282	-0.151	0.284
Household size	0.080*	0.045	0.079*	0.045	0.086*	0.045
Dependency ratio	0.194	0.126	0.205	0.122	0.207*	0.124
Education	-0.005	0.029	-0.004	0.029	-0.003	0.029
Land holding	-0.024	0.039	-0.024	0.038	-0.028	0.038
Livestock holding	0.036	0.041	0.042	0.042	0.042	0.042
Assets	-0.004	0.017	-0.004	0.017	-0.007	0.017
Off-farm activities	-0.498**	0.241	-0.481**	0.237	-0.505**	0.241
Credit access	0.139	0.225	0.071	0.223	0.098	0.223
Road distance	0.115	0.159	0.084	0.165	0.102	0.166
Social group	0.935***	0.229	0.934***	0.225	0.963***	0.228
Severe risk averse (RA)	0.071	0.264	0.097	0.263	0.088	0.264
Intermediately RA	-0.089	0.282	-0.064	0.282	-0.082	0.284
Moderately RA	-0.303	0.545	-0.259	0.528	-0.236	0.535
Slightly to neutral	-0.047	0.325	-0.06	0.321	-0.053	0.319
Neutral to risk preferring	0.060	0.360	0.033	0.343	0.029	0.347
Village fixed effects	Yes		Yes		Yes	
Constant	-8.537	1645	-8.478	3329	-8.602	1980

***, **, * represent 1%, 5%, and 10% significance level, respectively

[a] We do not report the first stage regression for the PRETE model because it failed to fully converge.

Table A4: Full estimation results of the spillover effects of FFF participation

	Model A		Model B	
	Coefficient	SE	Coefficient	SE
Treatment	0.781***	0.263	0.508	0.535
Age	-0.007	0.007	-0.010	0.008
Gender	-0.376	0.271	-0.234	0.294
Household size	-0.021	0.041	0.073	0.050
Dependency ratio	0.063	0.103	-0.294*	0.174
Education	0.046**	0.023	0.037	0.029
Land holding	0.040	0.032	0.024	0.019
Livestock holding	-0.003	0.031	-0.015	0.036
Productive assets	0.001	0.014	0.007	0.012
Off-farm activities	0.164	0.211	0.660**	0.321
Credit access	0.073	0.188	0.120	0.276
Road distance	0.096	0.121	-0.057	0.139
Social group	-0.106	0.188	0.025	0.248
Land right	-0.116	0.372	-0.107	0.441
Soil fertility	0.000	0.212	0.128	0.318
Climate shock	-0.550**	0.251	0.193	0.498
Pest and disease shock	0.344	0.235	0.209	0.329
Labour shock	-0.189	0.177	0.087	0.252
Household size change	-0.055	0.038	-0.119**	0.057
Market opportunities	-0.027	0.110	-0.282*	0.147
Severely Risk Averse (RA)	0.284	0.243	0.223	0.287
Intermediate RA	0.057	0.274	-0.280	0.387
Moderately RA	0.349	0.396	0.238	0.593
Slightly to neutral RA	0.256	0.276	0.389	0.337
Neutral to risk preferring	0.491*	0.257	0.117	0.409
Village fixed effects	Yes		Yes	
Constant	-0.44	0.796	-1.074	1.182
No. of observations	284		224	

***, **, * represent 1%, 5%, and 10% significance level, respectively