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ORIGINAL ARTICLE

Enhancing resilience to climate shocks through farmer innovation: evidence from northern Ghana

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Abstract In this paper, we contribute to recent attempts to operationalize the measurement of climate resilience by measuring household resilience to climate shocks and by assessing the role of farmer innovations in enhancing climate resilience. Adapting the Food and Agriculture Organization's resilience tool, we develop a household resilience index using survey data from rural farm households in northern Ghana. The index consists of six components and 23 indicators and was constructed using two indicator-weighting approaches. The proposed resilience index is a simple tool that can be used to quantitatively assess the resilience of households to the incidence of climate shocks and to monitor interventions aimed at building rural household resilience to unpredictable shocks. The results indicate that farm households in the study region are weakly resilient to climate shocks. We also show that farmers go beyond adoption of externally driven technologies to develop their very own innovations, and these innovations contribute significantly to enhancing household resilience to climate shocks. Using propensity score matching method, we found that farmer innovators are about 6% more resilient to climate shocks than non-innovators. This result is robust to alternative weighting approaches and matching algorithms, and also to hidden bias. The paper concludes that policy efforts aiming at enhancing farm households' resilience to climate shocks should consider providing support for farmers' innovations.

Keywords Climate shocks · Resilience · Farmer innovation · Index · Propensity score matching · Northern Ghana

Introduction

In recent decades, the world has been hit by a series of shocks, including climate-related shocks, natural disasters, food price volatility, financial crises, health crises and political unrests; many of these shocks are becoming more frequent and intense (Barrett and Constas 2014; Zseleczky and Yosef 2014). Climate change, in particular, poses serious threats to agricultural production and has major implications for rural poverty and food security (World Bank 2009; Thornton et al. 2011; Wheeler and von Braun 2013). According to the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC), many countries are experiencing an increase in extreme weather and climate events such as cyclones, heat waves, droughts and floods (IPCC 2014). These climate-related events may have negative effects on water availability and supply, agricultural incomes and food security, and the poor and vulnerable people (such as smallholder African farmers) will be particularly hard hit (IPCC 2014).

Farm households have always faced extreme and unexpected events and coped, but their ability to respond effectively to the increasing incidence of shocks needs to be strengthened (Darnhofer 2014). Resilience building is, therefore, necessary for smallholder farm households to be able to withstand future climate shocks. Resilient households are more likely to anticipate, resist, cope with and

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recover from shocks (Fan et al. 2014). While the concept of resilience is gaining much attention in the literature, there have been few attempts to measure resilience, and there is little evidence on how resilience can be enhanced. This study attempts to contribute to filling this gap in the climate resilience literature. To this end, we modified a food insecurity resilience tool developed by the Food and Agriculture Organization (FAO) to address climate resilience.

Innovation is considered to be important for building resilience of rural poor against shocks (Fan et al. 2014). Agricultural innovation may contribute to resilience through increase in production and income, and knowledge development. Agricultural innovations may stem from many sources, including farmers (Biggs and Clay 1981), but most of the innovations are developed by universities and research institutes and then disseminated to farmers. With the rapidly changing economic environment, however, rural farmers do not only adopt, but also generate innovations (Sanginga et al. 2009; Conway and Wilson 2012). They engage in informal experimentation, develop new technologies and modify or adapt external innovations to suit their local environments (Reij and Waters-Bayer 2001). Such practices, which are commonly referred to as farmer innovations, are claimed to play an important role in building farmers' resilience to changing environments (Kummer et al. 2012). Farmers may innovate in order to improve farm productivity and achieve food security (Tambo and Wünsher 2014), but these innovations may indirectly contribute to enhancing their resilience to shocks. However, within the emerging literature on the importance of farmer innovation, its role in building resilience has not been studied.

Thus, the objectives of this study are (1) to develop a method for assessing farm households' resilience to climate shocks by modifying a previously established resilience index (and examine both equally and unequally weighted-indicator approaches) and (2) to test this modified index and assess the role of farmer innovation in building climate resilience, using household survey data from northern Ghana, which is an ideal case study. The region is characterized by recurrent climate shocks (droughts and floods), which will probably intensify under climate change. Building farmers' resilience is essential for addressing the vulnerabilities faced by the farmers as a result of the changing climate. Moreover, farmers in the region have been continuously developing innovations to address the numerous challenges they face (Millar 1994; Tambo and Wünscher 2015).

Farmer innovation

Agriculture is rapidly undergoing economic changes, with new challenges and opportunities. This calls for agricultural innovation, which is essential in meeting food demands and the challenges facing agriculture. Farmers have been recognized as an important source of agricultural innovations (Biggs and Clay 1981; Reij and Waters-Bayer 2001). However, investment in the development of agricultural innovations has focused largely on scientific research by private and public research institutions, with neglect or under-valuation of innovative practices of farmers (Reij and Waters-Bayer 2001; Macmillan and Benton 2014). These research institutions have developed numerous one-size-fits-all technologies that have had some great successes, but also with limited scopes (Macmillan and Benton 2014). The diversity of farming systems requires context-specific innovations, and this is an enormous challenge for research institutions (Röling 2009). Farmers are, however, able to develop innovations that are suitable for their local conditions, and reorient existing technologies and practices to new situations.

Farmer innovation is essential for the development of local farming systems (Sumberg and Okali 1997). It is the process through which farmers adapt numerous technologies and practices to different conditions. The importance of farmer innovation for agricultural and rural development and the growing recognition of the need for increased participation of farmers in agricultural research have stimulated interest in the subject in recent decades [see Tambo and Wünscher (2015) for some of the initiatives aimed at promoting farmer innovation]. In this paper, farmer innovation is defined as 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. A key aspect of the farmer innovation process is experimentation, which is usually informal, and involves the process of trying, testing, generating or evaluating a technique or practice by an innovator (Saad 2002; Sumberg and Okali 1997). Hence, in the innovation literature, farmer innovation is sometimes referred to as farmer experiments (Sumberg and Okali 1997), folk experiments (Bentley 2006) or lay experimentation (Saad 2002).

Farmers innovate in several domains to suit the complex and diverse farming systems; hence, these innovations can be considered as farming system innovations. Most of the farmer innovations identified by previous studies are technical in nature with very few institutional innovations. Commonly observed topics of farmer innovations include new crops and varieties, soil fertility, soil conservation, time of planting, planting methods, crop spacing and density, land preparation, intercropping, weed and pest management, animal husbandry and farm tools (Sumberg and Okali 1997; Leitgeb et al. 2014).

The innovation literature suggests several factors as potential motives for farmers' decisions to innovate. A farmer may innovate out of curiosity, coincidence or interest in increasing production or solving problems (Millar 1994; Leitgeb et al. 2014). The outcomes of farmer innovations include increased knowledge, improved productivity, better income and food security, and labour and capital saving (Bentley 2006; Kummer 2011; Leitgeb et al. 2014). Using data from rural Ghana, this paper aims to add new empirical insights into the impact of farmer innovation by focusing on resilience to climate shocks.

Resilience

The IPCC defines resilience as 'the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner' (IPCC 2012, pp. 563). Resilience has gained prominence in the development and climate change discourses in the past few years. The 2014 Human Development Report, for example, focuses on addressing vulnerabilities and building resilience (UNDP 2014). The heightened interest in resilience is partly due to the increasing incidences of unpredictable stresses and shocks in the world, hence the need for resilience building. Moreover, the concept of resilience spans many fields, such as ecology, engineering and social sciences. The wide use of the resilience concept has also resulted in varied definitions and dimensions, such as ecological resilience, socio-ecological resilience, social resilience, human resilience and spatial resilience [see Speranza et al. (2014) for an overview of some dimensions and definitions of resilience]. Furthermore, resilience can be observed or studied at different levels, ranging from individual, household, group, village, nation to system levels. Though resilience is applied in different fields with varied definitions, there are some commonalities among the myriad of definitions. It generally refers to the ability to respond to disturbances or change. In this paper, we consider resilience to be the ability of farm households to absorb and recover from climate-induced shocks and stresses. Thus, the extent to which climate shocks may affect farm households hinges on their ability to adjust to and recover from these shocks.

Despite the increasing interest in the resilience concept, very limited attention has been directed towards the aspect of measurement. This is because resilience is a complex concept and a latent variable (i.e. not directly observable), hence difficult to measure. Nevertheless, there have been some recent attempts to operationalize and measure resilience. For instance, Barrett and Constas (2014) propose the concept of development resilience and conceptualize it in terms of avoiding poverty in the presence of stressors and shocks. Building on earlier studies, Darnhofer (2014) suggests the concept of farm resilience, which encompasses buffer capability, adaptive capability and transformative capability. Thus, integrating these three capabilities will contribute to building farm resilience. Speranza et al. (2014) also offer a related concept, livelihood resilience, which also consists of the following three attributes or dimensions: buffer capacity, self-organization and capacity for learning. They go beyond conceptualization to propose several indicators for measuring each of the dimensions of resilience. Finally, FAO (2010) provides a framework for measuring households' resilience to food security shocks. The framework consists of six components (i.e. income and food access, access to basic services, safety nets, assets, adaptive capacity and stability) with their specific set of indicators. This resilience framework has been empirically validated in Palestine (Alinovi et al. 2008), Kenya (Alinovi et al. 2010) and Nicaragua (Ciani and Romano 2014). We adapt this framework to measure household resilience to climate shocks.

Methods

Computing the household resilience index

As indicated above, in measuring resilience to climate shocks, we adapted the resilience tool proposed by FAO (2010). This tool was originally designed to measure resilience to food insecurity, but it is a flexible framework that can be used in analysing households' capacity to absorb unpredictable shocks and stresses, such as climate shocks. One advantage of the tool is that it considers both short-term actions that help households to cope in case of shocks and long-term actions that contribute to resilience building over time (FAO 2010). The resilience tool consists of six components (previous section and Table 1). Thus, a household is considered to be more resilient if it is averagely better in terms of these six components. Each of the six components has a specific set of indicators that can confer resilience. Overall, our resilience framework consists of 23 indicators (Table 1). For example, income is an indicator for the component 'income and food access'. High-income households are therefore more likely to be resilient to shocks. Household-level data on the indicators were obtained from a field survey. Our resilience framework draws on some of the indicators of the FAO resilience tool, but we also included additional indicators, which we believe can enhance households' resilience to climate shocks. For instance, we added indicators such as 'knowledge of climate change' and access to 'early warning system' to the adaptive capacity components, since these are relevant for building resilience to climate shocks.

The indicators of each component of resilience are measured on different scales; hence, normalization or standardization is required to scale all the indicators in the

Table 1 Indicators of the household resilience index

Component	Indicators	Description	Units
Income and food access	Per capita income	Annual per capita household income	Ghana Cedis
	HFIAS	Household Food Insecurity Access Score (HFIAS). Household response to nine food insecurity perception questions (Coates et al. 2007)	Index, 0–27
	Dietary diversity	Household Dietary Diversity Score (HDDS). Household daily consumption of 12 food groups (Swindale and Bilinsky 2006)	Index, 0–12
Access to basic services	Distance to source of water	Distance to nearest source of water	km
	Distance to health service	Distance to nearest healthcare services	km
	Distance to all-weather road	Distance to nearest all-weather road	km
	Access to electricity	Household has access to electricity	Dummy
	Access to telecommunication	Household has access to a telephone	Dummy
	Access to credit	A household member receives credit (in cash or in kind) from any source	Dummy
Safety net	Social safety nets	Number of social safety net programmes household participates in	Count
	Group membership	A household member belongs to a group or an association	Dummy
Assets	Productive assets	Total value of household's non-land productive assets	Ghana Cedis
	Livestock holding	Total livestock holding of household in Tropical Livestock Units (TLU)	TLU
	Land holding	Total amount of land owned by household	Acres
Adaptive capacity	Diversity of income sources	Number of household income sources	Count
	Dependency ratio	Ratio of members aged below 15 and above 64 to those aged 15–64	Ratio
	Adaptation strategies	Number of available climate change adaptation strategies	Count
	Early warning system	Household receives early warning system notices	Dummy
	Knowledge of climate change	Household members are aware of climate change and its impacts	Dummy
	Savings	Household has savings with a bank or saving group	Dummy
Stability	Job lost	Number of household members that have lost their jobs	Count
	Income change	Change in household income over the past year (worse off, same, better off)	Ordinal
	Future stability	Perception of capacity to maintain stability in the future (unlikely, somewhat likely, likely, very likely)	Ordinal

range [0, 1]. We followed the method used in the Human Development Index (UNDP 2006) to normalize the values of the indicators. For the normalization, we took into account the fact that the values of some of the indicators increase, while others decrease with resilience. That is, we considered the functional relationship between resilience and the indicators. We therefore employed two methods of normalization so that resilience increases with an increase in the value of each indicator. For indicators in which higher values imply better resilience (e.g. per capita income, value of assets and diversity of income sources), we normalized by:

$$\tau_{\text{norm}} = \frac{\tau_{ij} - \tau_{\min}}{\tau_{\max} - \tau_{\min}} \quad (1)$$

While indicators for which higher values imply lower resilience [e.g. Household Food Insecurity Access Score (HFIAS), distance to basic services and job lost] were normalized using:

$$\tau_{\text{norm}} = \frac{\tau_{\max} - \tau_{ij}}{\tau_{\max} - \tau_{\min}} \quad (2)$$

where τ_{ij} is the value of the indicator j for household i, norm, min and max are the normalized, minimum and maximum values of the indicator τ, respectively.

After normalization, we need to assign weights to each indicator. Commonly used methods for assigning weights include arbitrary choice of equal weights, expert judgement and statistical methods (Gbetibouo et al. 2010). For a robustness check, we used two weighting approaches: equal and unequal weights. In the equal weighting approach, each indicator is assumed to contribute equally to the resilience score; hence, the method involves a simple average of the normalized scores. Thus, the values of the different indicators under each component were averaged to derive a score for each of the six components. The component scores were then averaged to obtain the overall household resilience score.

In the unequal weighting approach, we used principal component analysis (PCA), which is a statistical method. Following Filmer and Pritchett (2001) and Gbetibouo et al. (2010), the scores on the first principal component were used to assign weights to the indicators. The assigned weights were then used to construct the household resilience index, using the formula:

$$r_j = \sum_{i=1}^{k} [b_i(a_{ji} - x_i)]/s_i \quad (3)$$

where r is the resilience index for household j; b represents the weights (scores) assigned to the indicators on the first principal component; a is the indicator value for household j; x is the mean value of each indicator; and s is the standard deviation of the indicators.

Estimating the contribution of farmer innovation to resilience

After computing the household resilience index, our second objective is to assess the contribution of farmer innovation to household resilience to climate shock. We expect farmer innovation to contribute to household resilience mainly through the income and food access, assets, adaptive capacity and stability components. Thus, we are interested in examining whether farmer innovators are more resilient to climate shocks than non-innovators. In this study, we focus on four categories of farmer innovation, which include: (1) developing new techniques or practices, (2) adding value to indigenous or traditional practices, (3) modifying or adapting external techniques or practices to local conditions or farming systems and (4) conducting own experiments. Thus, farmer innovators are households who have implemented any of these four categories of innovation-generating activities during the 12 months prior to the survey. Farmer innovators may, however, differ systematically from non-innovators in observed characteristics such as education, age and wealth, and unobserved characteristics such as entrepreneurship, risk behaviour or motivation, which might lead to biased estimates of the effect of farmer innovation on resilience. Thus, there is a potential problem of selection bias. Due to this bias, innovators and non-innovators are not directly comparable. To minimize this problem, we use propensity score matching (PSM), a nonparametric technique suggested by Rosenbaum and Rubin (1983). It involves matching farmer innovators with non-innovators that are similar in terms of observable characteristics (Caliendo and Kopeinig 2008). Since the PSM method accounts for only observables, we use the bounding approach of Rosenbaum (2002) to examine the sensitivity of our results to unobserved characteristics or hidden bias.

In the PSM, we first estimated a logit regression to obtain households' propensity to innovate (see Table S1, electronic supplementary material). The covariates in the logit regression are comprised of important household socio-demographic and economic variables that could influence both innovation decision and household resilience index (e.g. age, gender and education of the household head, household size and household's risk preference and experience with shocks). Thus, we excluded variables that were used in computing the household resilience index. We then use the propensity scores obtained in the first stage to match farmer innovators and non-innovators. The matching algorithm used is kernel matching with a bandwidth of 0.3, but for robustness check, radius matching with a calliper of 0.008 and nearest neighbour matching are also employed.[1] We conducted a matching quality test (Rosenbaum and Rubin 1983) to check whether the balancing property is satisfied. Based on the kernel matching, the test result (Table S2, electronic supplementary material) shows that in contrast to the unmatched sample, there are no statistically significant differences in covariates between innovators and non-innovators after matching.[2] Thus, the balancing requirement is satisfied. Using the PSM, we computed the average difference in the resilience index between farmer innovators and non-innovators, synonymous to the average treatment effect on the treated (ATT). This can be specified as:

$$\text{ATT}^{\text{PSM}} = E[R_1|I_f = 1, P(K)] - E[R_0|I_f = 0, P(K)] \quad (4)$$

where R_1 *and* R_0 refer to resilience scores for innovators and non-innovators, respectively; I_f and K refer to farmer innovation and the covariates indicated above, respectively; and $P(K)$ indicates the probability of a household innovating given characteristics K, which is obtained from the logit regression. The ATT measures the contribution of

[1] For a review of the different matching techniques, see Caliendo and Kopeinig (2008).

[2] The other two matching estimators also yield similar results of matching quality, but are not reported for brevity.

farmer innovation to the resilience of farm households who innovate.

Study area

The study was conducted in the Upper East region of northern Ghana. The region has a high population density, and majority of the households (76.4%) live in rural areas (GSS 2012). Agriculture is the predominant economic activity in the area. Relative to other regions in the country, Upper East has the highest rate of households (83.7%) involved in agriculture (GSS 2012). The region is located in the Sudan savannah agro-ecological zone. The cropping systems involve monocropping, permanent intercropping and mixed farming, which are mainly characterized by rain-fed cultivation, small land holdings, soil degradation, low use of external inputs, low yields and low labour productivity (Callo-Concha et al. 2013). Rainfall is erratic, unpredictable and unimodal, with about 600–900 mm rainfall per year and 90–140 growing days (Ker 1995). Cereal–legume intercropping system is commonly practiced in the region. The major crops include cowpea, maize, millet, rice and sorghum. Tomato and pepper are also cultivated in the dry season under irrigated farming. Most farm households also own livestock, mainly cattle, sheep, goats, chickens and guinea fowls. Many households engage in non-farm income-earning activities such as artisanry, processing of shea butter and brewing of local beer. Seasonal labour migration from the region to southern Ghana is also common.

The data for this study were obtained through household surveys. The surveys were conducted between December 2012 and May 2013 in Bongo, Kassena Nankana East and Kassena Nankana West districts in the Upper East region. Part of this research aimed at examining the effect of a participatory extension approach, the Farmer Field Fora (FFF), on farmers' innovativeness (Tambo 2015); hence, this influenced the choice of the three districts and sampling strategy used in this study. The three selected districts are among the four districts in the Upper East region where the FFF programmes have been implemented. By stratifying the sample according to FFF participation, we randomly selected farm households from 17 communities across the three districts. About 15–30 households were selected from each community. Overall, our sample consists of 409 farm households (101, 156 and 152 from Bongo, Kassena Nankana East and Kassena Nankana West districts, respectively).

The household survey was implemented in two phases. Interviews were conducted with the aid of pre-tested questionnaires and were supervised by the first author. Most of the interviews were conducted in the local languages, namely *Gurini, Kasem* and *Nankane*. The respondents were mainly head of households in the presence of other available household members. The first phase of the survey was conducted between December 2012 and March 2013. The questionnaire used in this phase captured data on household and plot characteristics, crop and livestock production, off-farm income-earning activities, innovation-generating activities, access to infrastructural services, information and social interventions, household experiences with shocks, climate change adaptation strategies and risk preferences. In the second phase, implemented just after the end of the first phase, the same households were revisited and interviewed to obtain data on various food security indicators. In this phase, the survey was conducted simultaneously in the three districts so that the households' subjective responses to food insecurity are not influenced by differences in survey periods.

Results and discussion

Household resilience index

As already mentioned, we used two different weighting approaches in constructing the household resilience index. Table S3 in the electronic supplementary material shows the summary statistics for the approach with equal weighting of indicators and components. The table shows that the non-innovators appear to have lower scores in most of the indicators and in all but one component. Table S4 in the electronic supplementary material shows the factor scores from the principal component analysis. The scores were used as weights in computing the resilience index, i.e. applying the unequal weighting approach. Among the indicators with the highest weights (i.e. above 0.1) are per capita income, dietary diversity, HFIAS, livestock holding, productive assets, land holding, early warning system and future stability. Thus, the indicators of the two components 'income and food access' and 'assets' have the highest weights.

The results of the major components of the resilience framework—using equal and unequal weighting approaches and disaggregated by innovation status—are presented in Fig. 1. The figure suggests that there are large differences between the component scores for innovators and non-innovators depending on the weighting method employed. In the equal weighting approach, farmer innovators and non-innovators have identical scores in terms of access to basic services and stability, but differ marginally with respect to safety nets and adaptive capacity. In the unequal weighting approach, however, the innovators have better component scores for all the indicators. In particular, there are large differences between innovators and non-innovators in terms of income and food access, assets and

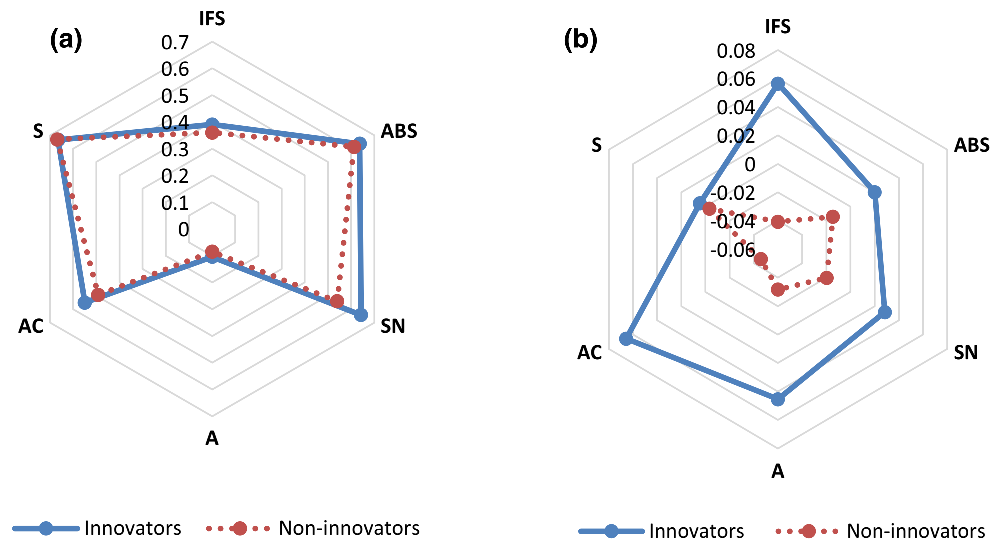

Fig. 1 Resilience components by innovation status: **a** equal weights, **b** unequal weights. *IFS* income and food access, *ABS* access to basic services, *SN* safety net, *A* assets, *AC* adaptive capacity, *S* stability

adaptive capacity. This is not surprising as the farmers' innovations are likely to contribute to increased income and food security, increased asset holdings and higher adaptive capacity. Overall, the results suggest that relative to non-innovators, farmer innovators are better off in most of the resilient components.

The results for the resilience indices are presented in Fig. 2. Similar to the component scores above, the figure shows that there is a large difference between the resilience indices computed using equal weighting and unequal weighting. While the equal weighting method suggests that farm households in the study region are moderately resilient, the unequal weighting method indicates that they are weakly or not resilient to climate shocks.

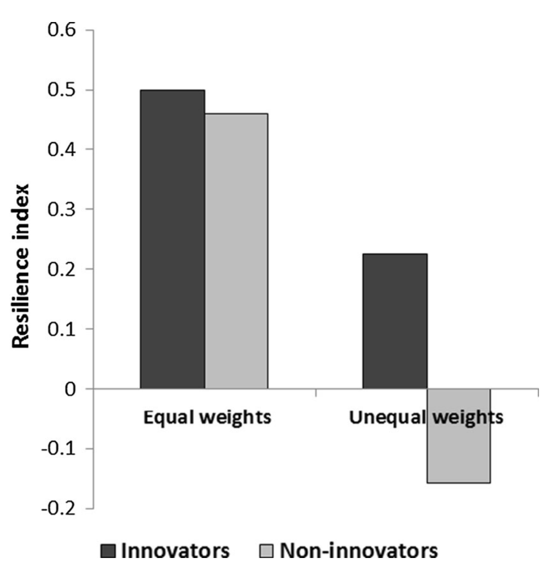

Fig. 2 Resilience index by innovation status

This finding suggests that the weighting method used in constructing the resilience index matters. Furthermore, the result indicates that farmer innovators are more resilient to climate shocks than non-innovators irrespective of the weighting method, but the difference is more discernible in the unequal weighting approach. In the equal weighting approach, the resilience index scores are 0.499 and 0.460 for innovators and non-innovators, respectively, whereas the scores are 0.225 and −0.158 for innovators and non-innovators, respectively, in the unequal weighting approach. The differences between the scores for the innovators and non-innovators are statistically significant ($t = 4.703$ and $t = 3.866$ for equal weighting and unequal weighting approaches, respectively).

Contribution of farmer innovation to household resilience

In the previous section, we showed that farmer innovators are more resilient to climate shocks than non-innovators. In this section, we look at the extent to which farmer innovation can contribute to enhancing household resilience to climate shocks. We first present the results of the innovation practices of farm households in the study region.

We found that about 9, 7, 13 and 25% of households have developed new techniques or practices, added value to indigenous or traditional practices, modified or adapted external techniques or practices to local conditions or farming systems, and conducted their own experiments, respectively. Overall, about 41% of the sampled households have implemented at least one innovation, and this is our innovator category. We also found that the FFF

Table 2 Effect of farmer innovation on resilience to climate shocks

Matching algorithm	Outcome[a]	Innovation decision		ATT[b]	Critical level of hidden bias (Γ)
		Innovate	Not innovative		
Kernel matching	Resilience_1	0.496	0.468	0.028 (0.008)***	1.90–1.95
	Resilience_2	0.179	−0.052	0.231 (0.098)**	1.35–1.40
Radius matching	Resilience_1	0.495	0.470	0.025 (0.009)***	1.70–1.75
	Resilience_2	0.168	−0.044	0.212 (0.107)**	1.20–1.25
Nearest neighbour	Resilience_1	0.496	0.470	0.026 (0.010)**	1.55–1.60
	Resilience_2	0.179	−0.074	0.253 (0.121)**	1.35–1.40

***, **, * represent 1, 5 and 10% significance level, respectively. Values in parentheses are standard errors

[a] Resilience_1 and Resilience_2 refer to household resilience indices obtained using equal and unequal weighting approaches, respectively

[b] The ATT estimates were obtained by implementing ‘psmatch2’ command in Stata

participants are more likely to innovate than non-participants, and the heads of innovative households are significantly younger, more educated and less risk averse than non-innovators. Majority of the innovations are related to agronomic practices, including adaptation of new crops or crop varieties into a community; carrying out informal experiments to select the crop cultivars that suit the farming system; modification of land preparation, planting methods and cropping patterns (e.g. new methods of intercropping or planting with reduced seed rate); soil fertility measures such as new methods of compost preparation or methods to prevent soil nutrient loss; and weed, pest and disease control methods such as the use of biopesticides. Some of the innovations are related to livestock production, and they include new formulations of animal feed and applying herbal remedies in the treatment of livestock diseases (i.e. ethnoveterinary practices). Other minor domains of the farmers’ innovations are related to storage, farm tool, agroforestry, and soil and water conservation. Similar domains of farmers’ innovations were obtained by other studies, such as Sumberg and Okali (1997) and Leitgeb et al. (2014).

We now present the results of the contribution of the farmers’ innovations to building households’ resilience to climate shocks. As mentioned earlier, we used PSM technique to achieve this objective. The results of the first step of the PSM estimation process, which shows the factors influencing households’ propensity to innovate, are presented in Table S1 in the electronic supplementary material. The results suggest that participants in the FFF programme are more likely to innovate, and this is expected since FFF empowers farmers and improve their problem-solving skills (Gbadugui and Coulibaly 2013). The results also indicate that risk-preferring households as well as household heads that have a higher level of educational attainment have significantly higher propensity to innovate.

The ATT results in Table 2 show that farmer innovation is positively and significantly associated with households’ resilience to climate shocks. Using equal weighting of resilience indicators and kernel matching methods, we find that farmer innovation significantly improves innovative households’ resilience to climate shocks by 0.028 index points or about 6%. Similarly, the result of the ATT using unequal weighting approach implies that farmer innovators are about 0.231 index points more resilient to climate shocks than they would have been if they were not to innovate.[3] Once again, we observe a large difference between the results from the two weighting approaches. Overall, the ATT results suggest that the positive contribution of farmer innovations to building household resilience to climate shocks is consistent, irrespective of the matching algorithm or weighting approach employed. Our results also corroborate the qualitative study by Kummer et al. (2012), who found that farmers’ experiments can contribute to building farm resilience.

The results of the sensitivity analysis on hidden bias are presented in the last column of Table 2. The results suggest that the positive and significant effect of farmer innovation on household resilience to climate shocks is not too sensitive to unobservables or hidden bias. For instance, the critical value of gamma, $\Gamma = 1.90–1.95$, for kernel matching implies that the ATT of 0.028 would be questionable only if matched pairs differ in their odds of innovation by a factor of 90–95 per cent.

[3] The resilience indices based on the unequal weighting approach, which were constructed using PCA, have a sample mean value of zero. Thus, percentage interpretations relative to the sample mean are not possible (Kabunga et al. 2014). However, the ATT values suggest that innovators are significantly more resilient to climate shocks than non-innovators.

Conclusion

The objectives of this paper were to measure household resilience to climate shocks and to assess the role of farmers' innovation in enhancing climate resilience. Thus, we contribute to recent attempts to operationalize, measure and build climate resilience. Adapting the resilience tool by the FAO (2010), we constructed household resilience index using cross-sectional data from rural farm households in northern Ghana. The index consists of six components (income and food access, access to basic services, safety net, assets, adaptive capacity and stability) and 23 indicators. Our resilience index is a simple tool that can be used in monitoring programmes or interventions aimed at building rural households' resilience to unpredictable shocks, such as droughts and floods. It can also be used to quantitatively assess the resilience of households after the incidence of shocks.

In calculating the resilience index, we employed two different approaches in assigning weights to the indicators, that is, arbitrary choice of equal weight and unequal weights based on factor scores from principal component analysis (PCA). Most previous vulnerability and resilience assessment studies have often used either the equal weighting (e.g. Hahn et al. 2009) or statistical methods, such as PCA or factors analysis (Gbetibouo et al. 2010; Alinovi et al. 2010; Ciani and Romano 2014). In using both approaches in this study, we obtained consistent results in terms of which group of farmers are more resilient to climate shocks, but varied results in terms of the magnitude of the resilience components or the overall resilience index, depending on the weighting approach employed. Future indicator-based resilience assessment should, therefore, consider using different weighting approaches to assess the robustness of the indices. In our case, employing other weighting approaches such as expert judgement or the two-step factor analysis proposed by Alinovi et al. (2010) may be helpful in confirming the findings of this study.

Our analysis shows that farm households in the study region go beyond adoption of externally driven technologies to generate innovations, and these innovations contribute significantly and positively to enhancing households' resilience to climate shocks. Using propensity score matching method, we found that farmer innovators are about 0.028 index points (or about 6%) more resilient to climate shocks than non-innovators. Our results are robust to alternative weighting approaches and matching algorithms, and also to hidden bias. Thus, policy efforts aiming at enhancing farm households' resilience to climate shocks through improvement in income, food access, assets and adaptive capacity should consider supporting farmers' innovation-generating practices. Our findings also strengthen arguments for better support for farmer innovation as a complement to externally promoted technologies.

Similar to other indicator-based indices, our resilience index is not devoid of limitations. The choice of the resilience components and the various indicators for each component can be argued to be subjective. Some of the indicators can be placed into two different resilience components, and this is also a challenge. Furthermore, resilience is a dynamic concept, but most of our indicators do not vary over time since our study is based on cross-sectional data. To measure and monitor the dynamics of households' resilience, higher-frequency household-level panel data are necessary. This would allow the assessment of variations in level of household resilience due to changes in the indicators or shocks over time. Similarly, innovation is generally a dynamic process; hence, further research involving panel data would be needed to study whether the contribution of farmer innovation to household resilience to climate shocks can be maintained over the long term. Such panel data would also permit robust estimation of the causal effect of farmer innovation on household resilience to climate shocks.

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