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Research Article

Do farmer-actor interactions in the agricultural innovation system drive technological innovation adoption in Ghana?

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The low level of technological innovation adoption among farmers has been a development concern. However, not much attention has been paid to how agricultural innovation system actors contribute to the adoption of technological innovations among farmers. This paper, therefore, analyzed the factors that drive the adoption of technological innovations using the agricultural innovation system concept. The study adopted a mixed method approach where qualitative data from focus group discussions were used to triangulate findings obtained from the quantitative data analyzed. A two-period panel data of 3486 observations of randomly sampled agricultural households across Ghana was analyzed using descriptive statistics and the multinomial logit regression model. Findings showed that farmers with strong ties in the innovation system had a higher probability of adopting multiple sets of innovations, compared to those with weaker linkages. Platforms that encourage actor interactions such as innovation platforms should be strengthened to increase the innovative performance of smallholder farmers. This study is one of the few that have quantified the effect the agricultural innovation system has on the adoption of innovations and hence makes a positive contribution to the budding literature regarding the importance of unpacking actor interactions whilst considering a holistic inquiry of the agricultural innovation system.

Keywords: agricultural innovation system, multiple innovations, adoption

Introduction

Background

Agricultural innovation has become a necessity for global agriculture, with a particular emphasis on farmers operating in developing economies with vulnerable smallholder agricultural systems such as Ghana. Climate change and its associated shocks and stressors have increased the susceptibility of agriculture to failure (Asare-Nuamah 2022; IPCC 2014, 2018). Studies show that complex problems such as rising temperature, erratic rainfall, floods and droughts as well the spread of pests and diseases have intensified the quest for agricultural innovation (Turner et al. 2017). This stems from the fact that climate change and extremes have significantly reduced crop productivity and yields, globally (FAO et al. 2017). The reduction in agricultural yield has resulted in rising poverty, hunger, and food insecurity, which threaten efforts towards achieving sustainable development, particularly in the developing economies (AGRA 2021; FAO et al. 2017).

Consequently, efforts and initiatives at the global level, such as the Sustainable Development Goals (SDGs) and the United Nations Framework Convention on Climate Change (UNFCCC), emphasize agricultural innovations and recommend parties including governments and development organizations to promote the adoption and scale-up of innovation. In Africa, the Malabo Declaration and Agenda 2063 prioritize agricultural innovation as a critical ingredient for the socioeconomic development of the continent (AGRA 2018; African Union 2014). This is largely due to the centrality of agriculture to the development of African economies – a source of employment, foreign income, and food security. Agriculture equally plays an important role in achieving SDG 1, which focuses on poverty eradication, which is urgently needed in Africa (AGRA 2021). According to Gurib-Fakim (2015), agricultural mechanization and the scale up of innovations can significantly leapfrog Africa's development.

However, agricultural innovation, which constitutes the use of new knowledge, skills, practices, and products within the agriculture sector (Muilerman, Wigboldus, and Leeuwis 2018; Turner et al. 2017), is sparingly adopted in many vulnerable agriculture systems in Ghana and other African countries alike. While studies have associated the low adoption of agricultural innovations to the low adaptive capacity of farmers, there are equally enough evidence of poor coordination among policymakers, actors and funding institutions within the agricultural systems in Africa (Forum for Agricultural Research in Africa 2022), which affect the uptake of innovation. To address the prevailing problem, Adger et al. (2004) and Gurib-Fakim (2015) call on policy makers and other actors to make intentional efforts towards the scale up of innovation, as actors are critical players which concurs with the position of the innovation system theory (Joseph 2009).

The agricultural innovation system (AIS) argues that actors' interaction within an agriculture system centres on knowledge generation and exchange as well as the development, scale up, and use of innovations (Aerni et al. 2015). Pound and Conroy (2017) posits that interactions occur among multiple actors including agents and institutions (social and economic institutions), coupled with the prevailing opportunities offered by institutions and technology. Rajalahti (2012) also emphasizes a wide array of formal and informal actors – agricultural research and extension institutions, private sector and agro-industrial players, and regulatory institutions as well as civil society and farmer-based organizations, and financial institutions, that influence and play key roles in the development and application of innovations. It is noteworthy that actors' interactions also deal with leveraging on their individual and collective strengths and exploiting opportunities (Candel 2014), which are necessary for the development of innovations and advancement of agricultural systems. As indicated in Yongabo (2022), it is important to build synergies and complementarities among actors through interactive learning and the AIS can be leveraged to harness both scientific and indigenous knowledge for increased innovative performance.

The Ghanaian agricultural system constitutes fisheries, crops, and livestock subsectors and involves multiple actors with different and overlapping roles along the value chain (Onumah, Asante, and Osei 2021). Understanding how actors' interactions contribute to the uptake of agricultural innovations within Ghana's agricultural systems is very important, even though to the best of the knowledge of the authors, there is a dearth of literature on this key issue. This is problematic since agricultural innovations are needed in vulnerable agriculture systems, including those in Ghana, to bridge the yield gap, improve household food security and income from agriculture, as well as address poverty (Tomich et al. 2019). This study used the maize and cocoa subsectors as cases for the agricultural sector in Ghana, given their important role in providing food and income security for the country. These sectors have seen key investments by the government in terms of research and development support but there is still a low level of technology adoption among producers. This creates interest for scholars to unearth what drives farmers' adoption decisions and provide recommendations.

Literature, theoretical and conceptual framework

The innovation system theory

The innovation system perspective (ISP) is an evolving theory that has been in existence for over three decades and has been applied to various sectors and value chains (Anandajayasekeram and Gebremedhin 2009; Joseph 2009; Lundvall 2007). The framework seeks to provide an opportunity to understand how innovation activities could be coordinated at the national level through policies, governance and institutional strengthening (Rajalahti, 2012). To narrow the concept and make it applicable to specific units within the national context, the sectoral innovation system (SIS) was developed to provide an integrated and multidimensional view of the various sectors in an economy (Joseph 2009; Malerba 2002; Malerba and Mani 2009). An SIS is composed of a set of agents who create, produce and distribute products by carrying out both market and non-market interactions; products; knowledge learning and transmission process; networks; institutions; technologies/inputs; platforms for interactions; and a process of competition and selections (Joseph 2009; Malerba and Mani 2009).

Technological opportunities differ across sectors and hence it is important to analyze the structures and frameworks of different sectoral systems to find a point of convergence through interactions, if any. Every sector has a dynamic learning process and the point of complementarities is also one key component of the SIS (Malerba 2002) since it defines the boundaries of each sectoral system. Individual SIS differ in the set of agents, technologies/inputs and platforms of interaction. These differences affect the nature and structure of the sectors. A range of technologies could be used in a sector to produce a single product and, at the same time, produce different products in other sectors; and that dynamism is what defines the SIS (Malerba and Mani 2009). However different these agents are, they are linked through what is called a network, which holds the system together and keeps the system dynamic and evolving. Applying the innovation system concept to development challenges then requires a sector specific analysis as the SIS posits and one of such sectors is the agricultural sector. The agricultural sector is an important sector in developing economies as it has the potential of contributing to poverty reduction through the creation of value-added products and employment through innovations along the value chain (Cervantes-Godoy and Dewbre 2010; Christiaensen, Demery, and Kuhl 2011; Dorosh and Mellor 2013; Esmaeeli and Sadighi 2017). The AIS is then a framework that takes into cognizance the different and multiple collaborative arrangements of several actors who work towards institutional, managerial and technological changes in agriculture, including traditional innovation agents (Aerni et al. 2015; Anandajayasekeram and Gebremedhin 2009; Spielman et al. 2011; Suchiradipta and Raj 2015).

Brief literature on related adoption studies

The literature indicates that farm(er) and other institutional characteristics are some of the key drivers that influence the adoption of innovations. Each of these factors has a different effect on adoption decisions, depending on the context and scope of what is being analyzed. Weyori et al. (2018) for instance, observed that plantain farmers in Ghana with relatively larger farm sizes were likely to adopt innovations compared to those with smaller farm sizes. Tambo and Wünscher (2017) found that farmers with larger land holdings significantly adopted innovations and had household incomes significantly higher than non-innovators. Similarly, Asfaw et al. (2012) also observed a significant positive effect of farm size and adoption of improved technologies of pigeon peas in Tanzania. The influence of farm size is indirectly linked to farmers' capacity (income) as those receiving high/good income from agriculture are likely to increase their farms, and adopt and apply innovations as a means to improve further agricultural productivity and income.

Adoption of agricultural innovations and certain sustainable practices to a large extent also depends on the tenure security of the farmer. Farmers with high tenure security are likely to adopt certain innovations, especially when they are long term compared to farmers with no tenure security. For instance, in Cameroon, Kazianga and Masters (2006) reported that long-term to permanent land tenured cocoa farmers adopted innovations compared to their counterparts with short-term tenure (Insaidoo, Ros-Tonen, and Acheampong 2013). The case of tenure also influenced the uptake of afforestation innovation among farmers in Ghana's forest zones. Another factor influencing the adoption of innovation is a farmer's household size or dependency ratio, which depicts the extent of dependency/burden on farmer household heads. Existing studies show that farmers with larger household sizes or higher dependency ratios have a higher likelihood of adopting innovations (Asfaw et al. 2012; Bezu et al. 2014; Shiferaw et al. 2014). Conversely, though, some studies such as Weyori et al. (2018) have reported a negative relationship between household size and adoption.

The critical role of agricultural extension has been highlighted in the literature as it aids in the spread of emerging knowledge and practices and builds the adaptive capacity of farmers (Asare-Nuamah, Botchway, and Onumah 2019). Studies show that farmers' access to extension services increases their likelihood of adopting research-led improved technologies and farmer-led innovations (Mabe 2018). Weyori et al. (2018) also observed that extension, FBO, NGO, and research indices, representing the networks farmers have created with these institutions, have a significant positive effect on technological adoption within the plantain value chain in Ghana.

It is evident from the preceding discussion that studies examining the uptake of innovation have excessively focused on socioconomic and demographic characteristics of farmers and less on examining the innovation system holistically. Undoubtedly, the generation and utilization of innovations usually involve a myriad of actors and their interactions. However, the effect of these collective interactions has often been overlooked by scholars, which justifies the need for this study. Farmers also do not adopt innovations in isolation and so this study sought to bridge the literature gap by understanding the multiple innovations adoption behaviour of farmers and the effects of innovation system interactions. Also, most of the studies reviewed adopted only a quantitative approach to understanding the adoption behaviour of farmers, with not much emphasis on qualitative enquiry, which necessitates the use of mixed methods in this study. The objectives of this study were therefore to: 1. Examine the pattern of multiple innovation adoption by farmers, and 2. Analyze how actor interactions in the AIS among other variables drive adoption decision.

Conceptualization

Innovations in agriculture usually occurs within an interactive network of actors in both formal and informal settings. These interactions are open, which is a prerequisite for the innovative activity to take place, relying on all sources of knowledge and competencies (Rajalahti, 2012). It is said that the innovative ability of the sector, like any other sector, depends on a kind of collective action among the various actors in the value chain, as well as the opportunities that make the utilizations of these innovation possible (Lynam 2012). The actors in the AIS influence the innovation development and utilization process and include formal and traditional agents such as agricultural research institutes of national or international origin; private sector agents, who could equally be national or multinational; public institutions such as policy and extension; agro-industrial players; formal and informal institutions that perform regulatory functions; civil society and farmer groups. The concept also takes into account multiple innovations along the value chain which has not received much attention in the literature. Considering multiple innovations in analyzing impact on welfare is however evolving as evidenced by recent work by Tesfaye and Tirivayi (2018) and Khonje et al. (2018).

This implies that innovations do not occur in isolation, and it is better to analyze them in the context of the systems within which they occur. The AIS then provides such a framework for the analysis of agricultural innovations. The study conceptualizes in Figure 1 that the interactions among the various actors such as R&D institutions, policy, extension, finance, markets, farmer-based organizations (FBOs), among others in the AIS to improve the innovative performance results in the production of innovations such as improved seeds, post-harvest technologies and informational innovations.

The adoption of these innovations however is driven by household and farmer characteristics as well as network interactions between farmers and extension service providers, FBOs, policy, markets, finance, non-governmental organizations (NGOs), and the intensity of interactions a farmer has with actors in the AIS as conceptualized in this study. The farmer and household characteristics in this study included household size, age of farmer, gender of farmer, land tenurial arrangement, and educational level of the farmer. It is therefore hypothesized in this study that stronger interactions with actors in the AIS will positively influence the adoption of innovations by farmers. The study makes a significant contribution to the strengthening of existing practices and policies for the uptake of agricultural innovations by providing relevant information on the interactions of multiple actors and their influence on farmers' adoption of innovations. It also contributes to the AIS literature by providing alternative ways of applying the innovation system concept through a quantitative measure. The remaining sections of the paper are as follows. The second section presents the methodology adopted for the study and the results and discussions with conclusions presented in the third section.

Methodology

Data and data collection approaches

Both qualitative (primary data) and quantitative (secondary) data were used to analyze the objectives of this study.

Primary data description

For the primary data used in triangulating the findings of this study, two regions, the Ashanti and Eastern regions were selected. These regions were selected based on their proximity to key research institutions in the cocoa and maize sectors: the Cocoa Research

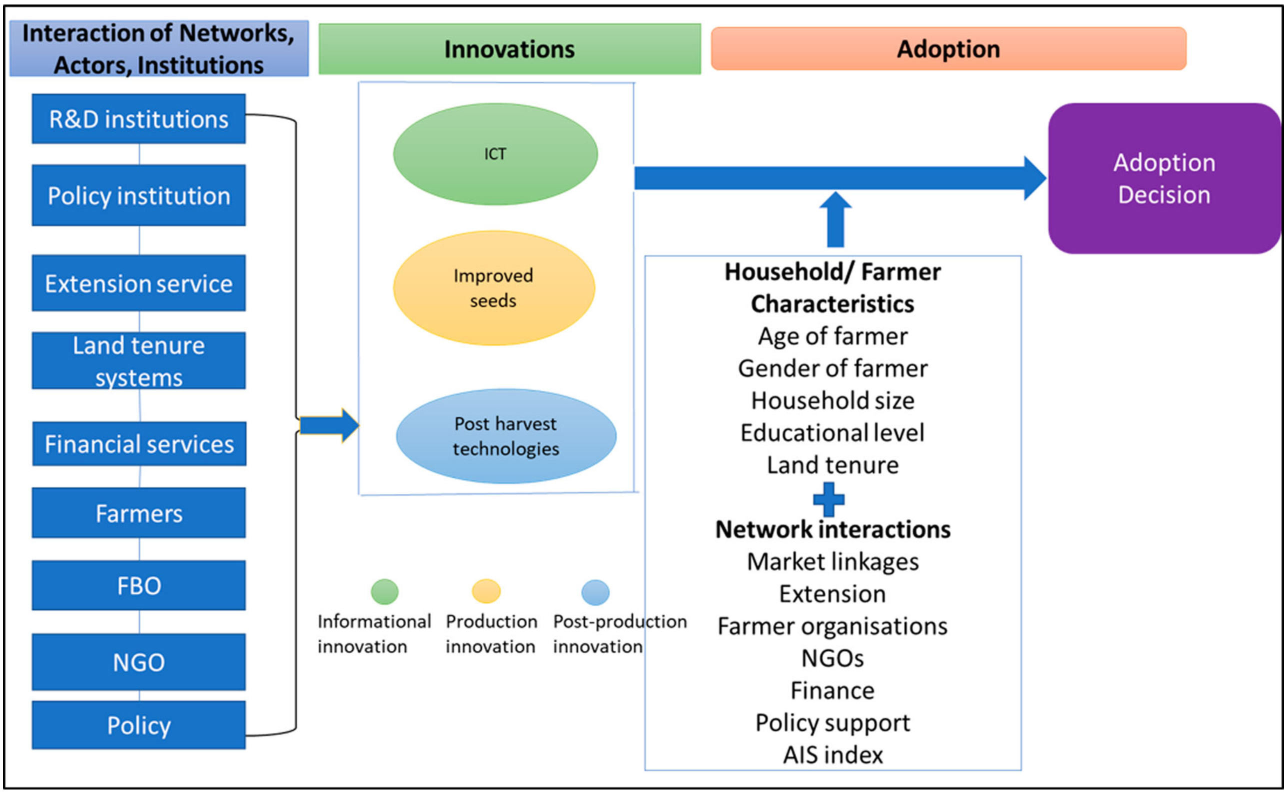

Figure 1: Conceptual framework of the study.
Source: Authors' construct (2020)

Institute and the Crop Research Institute, respectively. One municipal assembly and a district in the two regions were further selected for the cases. The Suhum Municipal in the Eastern region and the Sekyere Central District in the Ashanti region were selected. The Sekyere Central District is also one of the highest cocoa producing areas and Nsuta, its capital, is known for producing maize as its priority food crop (MOFA 2019a). The Suhum Municipal is also known for its high crop production with cocoa and maize as the major crops grown (MOFA 2019b). The data from these areas only sought to provide additional insights into the findings obtained in the quantitative data, for triangulation purposes and not for generalization. Four focus group discussions (FGDs) were held to obtain the qualitative data. The first criterion for selecting farmers for participation in focus groups was that the farmer did not produce cocoa and maize concurrently. The second criterion that farmers had to have been farming since 2008 since the first wave of the secondary data was collected in 2009/2010. To ensure gender representation, each group had to have at least 2 women farmers. Each group was made up of 10 participants bringing the total number of participants to 40 since 4 focus groups discussions were held: 2 in each district for maize and cocoa, respectively.

Secondary data description

The secondary data used were the first two waves of the Ghana Socioeconomic Panel Survey (GSPS). This survey was conducted in 2009/2010 and 2013/2014 using a well-structured questionnaire. The survey adopted a two-stage stratified sampling approach based on the previous 10 regions of Ghana. In the first stage, the 2000 Ghana Population and Housing Census (GPHC) master sampling frame was used to select geographical clusters. This further resulted in the selection of 334 Enumeration Areas (EAs) from the regional clusters based on the GPHC. Random selection of clusters from the EA list was done and a complete household listing was conducted to provide a frame for the next stage of sampling. In the second stage of the sampling procedure, a simple random sampling of 15 households in each EA cluster was done. The downsizing of the household list per EA was to reduce interviewer workload and to ensure that intra-class correlation within a sample area on the variance of the survey estimates was reduced (Aryeetey et al. 2011). The data provides a regionally representative sample of 2800 agricultural households in the first wave and 2463 in the second wave. The reduction in the number of households between the periods was a result of the non-traceability of some households. This current study focused on two agricultural commodity cases, maize and cocoa, since they are the major food and cash crops in Ghana, respectively. Further data cleaning generated 891 observations for the cocoa sub-sample and 2595 observations for the maize sub-sample. Therefore, a total of 3486 panel observations were used for this study.

Analytical framework

Content analysis was used to analyze the findings from the focus group discussions. The discussions were recorded using field notes and a recorder with the consent of participants. The recordings were then transcribed to add more details to the field notes taken. The content was then analyzed to provide new perspectives and triangulation to the study findings. For the secondary data, both descriptive and inferential statistics such as regression were used to analyze the objectives of the study. Descriptive statistics were used to analyze the adoption rates of the various innovations and inferential statistics, specifically the multinomial logit model, was used to analyze the drivers of adoption.

The multinomial logit model

The decision to adopt innovation by a farmer is said to posit from either a profit or utility-maximizing behaviour of the adopting unit (farmer). The utility or profit maximization behaviour is subject to a certain set of production, income, and time constraint. The assumption behind the utility theory suggests that farmers will adopt an innovation if the utility from adoption outweighs the various constraints faced by them in the process of adoption and practice. All things being equal, a farmer will choose multiple innovations at various stages of the value chain to maximize outcomes. It is hardly the case that a farmer will practise only a single type of innovation due to the heterogeneity of activities along the agricultural value chain. Therefore, we posit in this study that farmers will adopt multiple sets of innovations given a bundle of choices available to them. Following and adapting agricultural innovation classification from Tambo and Wünscher (2017), the various sets of innovation were classified:

Informational innovation:

In this study, access to and use of mobile phones were used as a proxy for informational innovation. Some farmers use their mobile phones to access production, weather, and marketing information using the services of mobile applications and telecommunication companies.

Post-production innovation:

These were the innovations used in post-harvest handling such as improved storage facilities, which were mainly new and improved structures built to store produce.

Production innovations:

These are innovations used in the production processes of the various crops under investigation and included tractors, ploughs, harvesters, improved seeds, and other agronomic innovations. However, in this study, improved seeds was used as a proxy for the production innovation. Seeds were chosen as a proxy because the proportion of farmers using ploughs and other implements was small.

Following previous related works (Kassie et al. 2018; Khonje et al. 2018), the utility function is given as a latent function U_{ij}* of the *ith* farmer, with *jth* innovation combinations, expressed as:

$$U_{ij}^{*} = \alpha_{ij} X_{ij} + \varepsilon_{ij} \tag{1}$$

where X_{ijt} is the list of factors influencing the adoption behaviour of farmer, *i* regarding innovation regime, *j*.

Hence the utility function of an adoption of *j* relative to *m*, where *m* is any of the combinations, is given in Equation (2) as:

$$\left\{ \begin{array}{c} 1 \quad if \ U_{ij}^{*} > \max(U_{im}^{*}) \ or \ \emptyset_{ij} < 0 \\ \vdots \\ j \ if \ U_{ij}^{*} > \max(U_{im}^{*}) or \ \emptyset_{ij} < 0 \end{array} \right\} m \neq j; j = 1 \ldots .8 \tag{2}$$

The adoption decision is then given by the multinomial logit expression in Equation (3):

$$P_{ij} = Pr(\ \emptyset_{ij} < 0 | X_{ij}) = \frac{exp(\alpha_j X_{ij})}{\sum_{m=1}^{j} \exp(\alpha_m X_m)} \tag{3}$$

The empirical multinomial model estimated is specified in Equation (4):

$$y_{ij} = \beta_o + \beta_{ij} \sum_{i=1}^{9} X_i + \gamma_{ij} \sum_{i=1}^{6} A_{ij} + \delta N_j \tag{4}$$

where $y_i = 0, 1$ with 1 indicating adoption of the *jth* regime and 0, otherwise; $i = 1 \ldots 8$

The adoption regimes, where subscripts 1 and 0, representing adoption and non-adoption, respectively, are represented below:

$\mathbf{Y_1}$ = **Regime 1**: Adopters of Informational innovation (I) only with choice combinations of $I_1P_0S_0$

$\mathbf{Y_2}$ = **Regime 2**: Adopters of Post-harvest innovation (P) only with choice combinations of $I_0P_1S_0$

$\mathbf{Y_3}$ = **Regime 3**: Adopters of Improved seeds (S) only with choice combinations of $I_0P_0S_1$

$\mathbf{Y_4}$ = **Regime 4**: Adopters of I and P with choice combinations of $I_1P_1S_0$

$\mathbf{Y_5}$ = **Regime 5**: Adopters of I and S with choice combinations of $I_1P_0S_1$

$\mathbf{Y_6}$ = **Regime 6**: Adopters of P and S with choice combinations of $I_0P_1S_1$

$\mathbf{Y_7}$ = **Regime 7**: Adopters of I, P and S with choice combinations $I_1P_1S_1$

$\mathbf{Y_8}$ = **Regime 8**: Non-adopters with choice combinations of $I_0P_0S_0$

Regime 8, Y_8, which is non-adoption, was used as base.

β_i is the coefficient measuring the *ith* exogenous variable of the *jth* adoption regime;

δ is the coefficient measuring the effect of the innovation system index which is the intensity of interaction a farmer has with the actors; and

γ measures the coefficient of the individual actor interaction with farmers.

The explanatory variables X_{is}, A_{is} and N_j are described and presented in Table 1.

The proxy index measuring AIS in the model was the intensity of interactions a farmer has with other actors (A_i)

Table 1: Variable description for the adoption model.

Variable	Description	Measurement
Household size (X_1)	The size of the household	Number
Education (X_2)	The level of education of the household head	Levels: 0 = none (reference); 1 = basic; 2 = secondary; 3 = tertiary
Age (X_3)	Age of farmer in years	Levels: 0 = below 30 years (reference); 1 = 31-45 years; 2 = 46-60 years; 3 = above 60 years
Sex (X_4)	Sex of the farmer	Dummy (0 = female; 1 = male)
Time (X_5)	Period data was taken	Dummy (0 = 2010; 1 = 2014)
Cocoa farmer (X_6)	Whether the farmer grows cocoa or maize	Dummy (0 = Maize; 1 = Cocoa)
Land tenure (X_7)	Whether farmer farms on own land or otherwise, including hired, share cropping, etc.	Dummy (1 = own land; 0 = otherwise)
Financial service (A_1)	Farmer's interaction with financial service providers	Dummy (Yes = 1; No = 0)
Extension services (A_2)	Farmer's interactions with extension agents	Dummy (Yes = 1; No = 0)
Policy support (A_3)	Farmer's access to government's fertilizer subsidy programme	Dummy (Yes = 1; No = 0)
Farmer-based organization (FBO) (A_4)	Membership of farmer to an FBO	Dummy (Yes = 1; No = 0)
Non-governmental organization (NGOs) (A_5)	Farmer's interaction with NGOs	Dummy (Yes = 1; No = 0)
Market (A_6)	Farmer's linkage to market actors	Dummy (Yes = 1; No = 0)
AIS (N)	Intensity of interaction with actors in the AIS	Scores (0 = none (lowest); 1 = one actor (lower); 2 = two actors (low); 3(medium)= three actors; 4 = four actors (high); 5 = five actors (higher); 6 = all six actors (highest)

which generated a score ranging from 0 to 6.

$$N_i = \sum_{i=0}^{6} A_i \tag{5}$$

The higher the number, the higher the intensity of a farmer's interaction in the innovation system. As a result, two models were estimated for each of the adoption regimes. Model 1 was the model with individual actor interaction and Model 2 was the model that controlled for the intensity of interactions of actors with the AIS index. Placing the AIS index in the same model as the individual interactions was not feasible due to the high multicollinearity between them.

Results and discussion

Innovation adoption regimes

Table 2 presents the percentage distributions of adopting farmers for the various innovations over the two periods. Complete adoption ($I_1P_1S_1$) was driven by informational innovation, in this case ICT in the form of mobile phones or other digital platforms that served as a source of agricultural information for farmers. It can be observed from Table 2 that the adoption rate of the single innovation cases decreased for improved variety ($I_0P_0S_1$) and post-harvest ($I_0P_1S_0$) but increased by 23% with informational innovation ($I_1P_0S_0$).

This could be good or bad depending on the rate of adoption of their combinations with other innovations. Hence, a decline in adopting only improved variety or post-harvest innovation could either imply farmers dis-adopted or they combined with other innovations. This is evident in the increased adoption rate of the combination of improved variety and informational innovation ($I_1P_0S_1$); and post-harvest and informational innovation ($I_1P_1S_0$). Since there was a decline in the adoption of both improved seed variety and post-harvest innovation, their combination also recorded a decline in their adoption rates.

On the other hand, non-adoption ($I_0P_0S_0$) of any of the innovations, decreased by 69% between the two periods. With this rate of decline, one would have expected a larger increase in adoption of all the innovations, but this

Table 2: Adoption regimes over time.

Choices	Combination	Maize		cocoa		Pooled		Adoption growth rate (pooled data) (T1-T0)/T0 (%)
		T = 0	T = 1	T = 0	T = 1	T = 0	T = 1	
1	$I_0P_0S_0$	6.1	3.3	28.7	4.7	11.9	3.7	−69.0
2	$I_1P_0S_0$	5.5	7.9	20.7	22.0	9.4	11.5	23.0
3	$I_0P_1S_0$	19.5	9.1	1.1	0.5	14.8	6.9	−53.0
4	$I_0P_0S_1$	4.3	2.8	8.6	10.5	5.4	4.8	−11.0
5	$I_1P_1S_0$	19.8	34.2	2.2	3.0	15.3	26.2	71.0
6	$I_1P_0S_1$	10.6	13.0	29.8	47.4	15.5	21.9	41.0
7	$I_0P_1S_1$	11.3	6.5	1.5	1.4	8.8	5.2	−.41.0
8	$I_1P_1S_1$	22.9	23.0	7.3	10.5	18.9	19.8	5.0
	N	1,358	1,237	463	428	1,821	1,665	

Source: Authors' computation based on the 2009/2010 and 2013/2014 GSPS data (2020) was not so. Further observation from Table 1 reveals that the reduction in the rate of non-adoption could have been absorbed by the increased adoption of informational innovation and its paired combination with the other innovations. The inherent information asymmetry prevalent in agricultural value chains as indicated by Chikuni and Kilima (2019) could be solved by the increased adoption of informational innovation observed in both cocoa and maize farmers. The adoption of $I_1P_0S_1$ observed a 41% increase over the period which appeared to be also driven by the increase in adoption of informational innovation since improved variety adoption decreased over the period. There was also a marginal increase in the adoption of the full innovation set of about 5%. It can therefore be inferred that overall technological progress has been slow. Though efforts are being made in Ghana's agriculture, technological progress as indicated in Nowak, Kijek, and Domańska (2015) is important for agricultural modernization and hence actions to speed up the process will be necessary.

Reasons for low adoption of innovations

In attempting to explain the low adoption of improved seeds and post-harvest innovations as observed in Table 1, views were sought through focus group discussions with some farmers. The reasons given had both institutional and personal dimensions. The institutional dimension included seed unavailability and inadequate financial support to purchase these innovations. The personal factors were centred on farmers' local knowledge and beliefs toward new agricultural practices.

Farmers highlighted the unavailability of improved seeds in some areas, which made it difficult for them to access, especially in areas with low extension contacts. Non-proximity of input dealer shops also served as a disincentive to adopting improved seeds, in cases where dealer shops were not present in the communities as pointed out by a farmer:

> *We don't get them, extension officers are not frequent here and the input shops are not in our farming communities.* (Farmer, Maize FGD, Eastern region)

Farmers then relied on their local seeds for production and this could have accounted for the low adoption rate of improved seeds. It was also highlighted that the case was not that farmers did not know the advantages of these innovations but they were bedevilled with the challenges mentioned, which hindered their adoption, as opined by a farmer in the Ashanti region:

> *The improved Tetteh Quarshie cocoa is high yielding compared to some others but they are not readily available.* (Farmer, Maize FGD, Ashanti region)

Aside from the institutional challenges to adopting improved varieties, some farmers were also of the view that their own beliefs also contributed to the low adoption process:

> *We are so used to our way of doing things and so sometimes it is difficult for us to easily accept something new.* (Farmer, Maize FGD, Ashanti region)
> *Sometimes we reject some new technologies because of the knowledge handed down to us by our forefathers.* (Farmer, Cocoa FGD, Ashanti region)

Additionally, the farmers revealed that they had their own innovative ways of determining a high-yielding seed from the local seeds they grow. The cocoa farmers, for instance, revealed that when they plant their local seeds and the pods on the tree spread to the knee level of the farmer, it is an indication that the next generation of that seed will be as productive as the hybrid seeds. They, therefore, look out for these signs and select these seeds for the next season's planting:

> *When the tree fruits to 1–2 feet, the fruits below are exactly like the agric ones so you take those seeds and nurse them for production. When they are transplanted, it yields the same output as the agric one.* (Farmer, Cocoa FGD, Eastern region)

> *The cocoa pods on the down part of the high yielding Tetteh Quarshie tree, when it is harvested and nursed and planted, it bears fruit early and they are big.* (Farmer, Cocoa FGD, Ashanti region)

In the case of post-harvest innovations, farmers also cited finance as the main challenge to adopting them. Finance to access or build improved storage facilities and meeting household needs were the categories of financial challenges impeding their adoption of improved post-harvest structures. It appeared farmers were characterized by the subsistence culture of agriculture in Ghana, working hard to meet the basic needs of their households. Therefore, investing in post-harvest innovations was not a popular option for them as intimated by this farmer's response:

> *It is the money oo, we need the money to meet family needs. If you store and you don't sell, you will not get money to cater for the education of the children.* (Farmer, Maize FGD, Eastern region)

Some were also of the opinion that storage facilities did not require only structures but also chemicals to treat the produce. This they indicated was an extra expenditure that they did not have the means to incur. Given that post-harvest loss is one of the challenges farmers face, it will be necessary for farmers to be educated on the importance of adopting technologies that will reduce the menace. Innovation system actors and other stakeholders can support farmers in this regard. Warehousing systems and the Buffer Stock company can also be expanded to cushion farmers who cannot build their personal structures against post-harvest losses.

Factors influencing adoption of agricultural innovations

Household/farmer characteristics

Table 3 presents findings on how household and farmer characteristics drive farmers' adoption decisions. The results generally show that farmers with larger household sizes were more likely to adopt any of the innovations and/or their combinations compared to farmers with smaller household sizes. This was however not observed for the adoption of improved seed. One would have expected that farmers with larger household sizes would be likely to adopt improved varieties knowing the potential that this innovation could have on increasing productivity (Kassie et al. (2018). Household size significantly influenced the probability of a farmer

Table 3: Household and farmer characteristics as drivers of adoption.

	$I_1P_0S_0$		$I_0P_1S_0$		$I_0P_0S_1$		$I_1P_1S_0$	
Variables	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Household size	0.122**	0.122**	0.229***	0.244***	−0.0158	−0.0183	0.224***	0.251***
	(3.08)	(3.12)	(5.97)	(6.56)	(−0.33)	(−0.39)	(5.54)	(6.81)
Basic education	0.875***	0.970***	−1.003***	−1.102***	−0.177	−0.13	0.09	0.351
	(4.50)	(5.06)	(−3.91)	(−4.36)	(−0.75)	(−0.55)	(0.42)	(1.78)
Secondary education	1.429***	1.458***	−0.433	−0.589	−1.079	−1.108	0.701	0.847*
	(3.50)	(3.64)	(−0.84)	(−1.16)	(−1.36)	(−1.40)	(1.54)	(1.98)
Tertiary education	1.305*	1.565*	−0.854	−0.981	−1.14	−0.934	−0.115	0.416
	(1.96)	(2.37)	(−0.90)	(−1.05)	(−0.98)	(−0.80)	(−0.16)	(0.61)
31–45 years	0.315	0.349	0.286	0.274	0.372	0.413	−0.004	−0.008
	(0.99)	(1.1)	(0.87)	(0.85)	(0.95)	(1.06)	(−0.01)	(−0.03)
46–60 years	0.0614	0.0738	−0.0433	−0.0772	0.28	0.307	−0.337	−0.303
	(0.19)	(0.23)	(−0.13)	(−0.24)	(0.73)	(0.8)	(−1.02)	(−0.99)
>60 years	−0.161	−0.153	0.00186	−0.072	−0.134	−0.115	−0.653	−0.449
	(−0.50)	(−0.48)	(0.01)	(−0.22)	(−0.34)	(−0.30)	(−1.95)	(−1.45)
Male Farmer	−0.602**	−0.640**	0.0889	0.191	−0.29	−0.329	−0.0945	−0.0437
	(−2.84)	(−3.05)	(0.38)	(0.83)	(−1.23)	(−1.40)	(−0.40)	(−0.21)
	$I_1P_0S_1$		**$I_0P_1S_1$**		**$I_1P_1S_1$**			
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**		
Household size	0.0836*	0.103**	0.139**	0.152***	0.213***	0.236***		
	(2.08)	(2.77)	(3.01)	(3.600)	(5.331)	(6.460)		
Basic education	0.486*	0.760***	−1.088***	−0.962***	0.177	0.570**		
	(2.49)	(4.22)	(−3.64)	(−3.39)	−0.86	(3.00)		
Secondary education	0.916*	1.089**	−0.926	−0.978	0.944*	1.226**		
	(2.13)	(2.70)	(−1.31)	(−1.41)	−2.15	(3.00)		
Tertiary education	0.653	1.141	−1.435	−1.27	0.637	1.394*		
	(0.97)	(1.77)	(−1.20)	(−1.08)	(0.93)	(2.16)		
31–45 years	−0.206	−0.173	−0.103	−0.060	−0.202	−0.148		
	(−0.68)	(−0.61)	(−0.28)	(−0.18)	(−0.64)	(−0.51)		
46–60 years	−0.537	−0.515	−0.416	−0.389	−0.583	−0.491		
	(−1.79)	(−1.84)	(−1.13)	(−1.12)	(−1.86)	(−1.68)		
>60 years	−1.212***	−1.148***	−0.754*	−0.773*	−1.168***	−0.948**		
	(−3.90)	(−3.98)	(−2.01)	(−2.20)	(−3.61)	(−3.18)		
Male Farmer	−0.599**	−0.669***	−0.0685	−0.0266	−0.088	−0.0955		
	(−2.79)	(−3.47)	(−0.25)	(−0.11)	(−0.38)	(−0.46)		

***Source*:** Author's computation based on the 2009/2010 and 2013/2014 GSPS data (2020)

Notes: t statistics in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; Model 1: LR(χ^2) = 2070.67; $P > \chi^2 = 0.000$; Model 2: LR(χ^2) = 1775.02; $P > \chi^2 = 0.000$. Age (Ref: 18–30 years); Education (Ref: No education). Model 1 = model with individual farmer-actor interactions; Model 2 = model with the intensity of actor interactions as the sum of the individual interactions.

adopting all the three combinations of innovations ($I_1P_1S_1$) positively. This indicates that given a bundle of choices, these farmers make decisions in selecting what will best suit their household needs and a single choice may not be ideal. They may understand that the combination of a set of innovations will in the long run benefit the household and so decide not to use a single innovation.

Another important driver of adoption was the level of education, the human capital of the adopting unit, as pointed out by Khumairoh et al. (2019). This study found that a minimum of basic education was needed for farmers to adopt informational innovation, but a combination of informational innovation and improved seeds adoption required both basic and secondary levels of education. All levels of education had a negative effect on the adoption of improved variety ($I_0P_0S_1$), post-harvest innovations ($I_0P_1S_0$) and their combinations ($I_0P_1S_1$). Though the levels of education influenced adoption differently across the innovation regimes, the influence on the complete set of innovations ($I_1P_1S_1$) showed consistent results. For all the levels of education, adoption of the full set of innovation ($I_1P_1S_1$) was significantly positive compared to no education. This supports the assertion by Khumairoh et al. (2019) that education is key in driving adoption decisions and could have a subsequent effect on the outcome of their choices.

The various age categories of farmers did not significantly influence the probability of adopting an innovation except for those in the above 60 age group. The analysis indicated the likelihood of adopting informational and post-harvest innovations ($I_1P_1S_0$), post-harvest and improved variety ($I_0P_1S_1$), and the combination of all innovation regimes ($I_1P_1S_1$) reduced with farmers above age 60 compared to younger farmers (<30 years). This suggests that relatively younger farmers were more likely to adopt the combination of innovations compared to the older ones. This is a good indicator of the sustainability of the agricultural sector. However, the average age of farmers in Ghana obtained from this study was approximately 50 years, which makes the sector not a youthful one and threatens its sustainability. Therefore, if youth are encouraged to venture into agriculture, the sector could have a sustainable outlook. There are a number of government initiatives, such as the Youth in Agriculture Programme, to encourage the youth to go into agriculture (Avura and Ulzen-Appiah 2016; Gough and Birch-Thomsen 2016) which is laudable and will encourage youth participation.

On the gender dimension, being a female farmer significantly influenced the decision to adopt informational innovation ($I_1P_0S_0$) and a combination of informational and post-harvest innovations ($I_1P_1S_0$). This finding may be highlighting the information constraint that female farmers face, explaining why they were likely to adopt an innovation that would improve their access to information. More so, women are usually found at the post-harvest or processing stage of the agricultural value chain (Twin, 2013) and hence it is not surprising that being a female farmer significantly influenced the likelihood of adopting a combination of informational and post-harvest innovations. Therefore, empowering women farmers with access to agricultural information and providing opportunities where they can link to markets in their active post-harvest roles could strengthen the agricultural value chains in Ghana.

Temporal, structural, and innovation system drivers of adoption

These factors include time period, cropping system, land tenure security, and the interactions of actors in the innovation system, as shown in Table 4. Generally, the adoption of innovations increased significantly over the period (2010–2014). This implies that notwithstanding the slow technological progress observed in Table 1, the difference between periods was significant.

Being a maize farmer significantly influenced the adoption of all the streams of innovations positively compared to being a cocoa farmer. This is quite surprising given that both the maize and cocoa innovation systems have strong research institutions driving the process of innovation development and diffusion. There could be a problem of system weakness on the part of the cocoa innovation system as there is no dedicated innovation platform to promote actor interactions (Onumah, Asante, and Osei 2021), as is the case in the maize innovation system. The difference could also be because cocoa farmers do not necessarily need post-harvest innovations since the various license buying companies (LBCs) provide them a ready market for their produce. Post-harvest innovations such as improved storage and processing are more likely to be adopted by maize farmers since there is a higher chance of moving from primary processing (e.g., dehusking) to a higher form of processing (e.g., flour production). This could explain why cocoa farmers are less likely to adopt post-harvest innovations or any combinations of it. Nonetheless, it would have been expected that the adoption of improved seeds by cocoa and maize farmers would not have been significantly different from each other, given that both are strongly supported by research institutions.

Interactions with financial service providers for accessing loans/credit significantly increased the probability of adoption in all the innovation regimes except for post-harvest innovations. This could indicate that farmers who solely adopted post-harvest innovations were able to store/preserve their produce and received higher revenues from favourable market prices. Hence, accessing financial support might not be necessary for them. Financial constraint has been one major challenge to adopting innovations (Duy et al. (2018). It is therefore not surprising that the findings of the study reflect in that direction, where farmers who interacted with financial institutions to access support were likely to adopt the set of innovations compared to those who did not. Ferreira Gonzaga, Vilpoux, and Gomes Pereira (2019), using a number of proxies for credit support, also found that farmers with credit access had a higher probability of adopting innovative practices compared to those without credit support.

Farmers' interactions with extension service providers was found to significantly drive the adoption behaviour of

Table 4: Time, structural, and innovation system drivers of adoption.

Variables	$I_1P_0S_0$ Model 1	$I_1P_0S_0$ Model 2	$I_0P_1S_0$ Model 1	$I_0P_1S_0$ Model 2	$I_0P_0S_1$ Model 1	$I_0P_0S_1$ Model 2	$I_1P_1S_0$ Model 1	$I_1P_1S_0$ Model 2
Period	2.810***	2.550***	1.668***	0.803*	2.026***	1.546***	3.685***	3.066***
	(6.70)	(7.9)	(4.02)	(2.4)	(4.05)	(4.11)	(8.3)	(9.75)
Cocoa farmer	−0.563**	−0.357*	−3.960***	−4.019***	−0.630**	−0.545**	−4.853***	−4.123***
	(−3.03)	(−2.05)	(−9.64)	(−9.90)	(−2.96)	(−2.69)	(−14.99)	(−14.82)
Land tenure	−0.0918	−0.125	0.348	0.271	0.241	0.211	0.813***	0.776***
	(−0.53)	(−0.72)	(1.92)	(1.53)	(1.18)	(1.05)	(4.343)	(4.583)
Finance	0.785***		−0.390*		0.699**		0.842***	
	(3.45)		(−1.99)		(2.77)		(3.82)	
Extension	0.689*		0.972**		0.36		1.081**	
	(2.00)		(2.97)		(0.85)		(3.15)	
Policy support	0.00714		−0.826*		−1.075**		0.810**	
	(0.03)		(−2.31)		(−2.60)		(2.77)	
FBO	0.462		0.137		0.482		−0.154	
	(1.20)		(0.36)		(1.03)		(−0.36)	
NGO	1.172**		1.245**		0.634		1.838***	
	(2.98)		(2.97)		(1.4)		(3.800)	
Market linkage	0.720***		0.413*		0.263		0.846***	
	(3.66)		(2.17)		(1.22)		(4.172)	
AIS		0.320***		0.0505		0.113		0.385***
		(4.00)		(0.60)		(1.20)		(4.87)
Constant	−3.141***	−2.240***	−1.577**	−0.559	−2.082**	−1.029	−2.674***	−2.269***
	(−5.59)	(−4.18)	(−2.87)	(−1.01)	(−3.15)	(−1.64)	(−4.80)	(−4.35)

Variables	**$I_1P_0S_1$ Model 1**	**$I_1P_0S_1$ Model 2**	**$I_0P_1S_1$ Model 1**	**$I_0P_1S_1$ Model 2**	**$I_1P_1S_1$ Model 1**	**$I_1P_1S_1$ Model 2**
Period	3.598***	2.651***	2.096***	1.435***	3.174***	2.567***
	(7.83)	(8.65)	(4.06)	(3.93)	(7.29)	(8.25)
Crop system	−1.061***	−0.491**	−3.932***	−3.158***	−3.455***	−2.605***
	(−5.18)	(−2.95)	(−10.27)	(−9.83)	(−14.44)	(−13.49)
Land tenure	0.364*	0.282	0.526*	0.456*	0.738***	0.624***
	(2.052)	(1.741)	(2.410)	(2.301)	(4.011)	(3.742)
Finance	1.351***		0.508*		1.726***	
	(5.62)		(2.08)		(7.24)	
Extension	0.413		0.987**		1.422***	
	(1.17)		(2.66)		(4.26)	
Policy support	0.149		0.252		0.634*	
	(0.61)		(0.702)		(2.340)	
FBO	0.463		0.056		−0.407	
	(−1.09)		(−0.12)		(−0.99)	

(*Continued*)

Table 4: Continued.

Variables	$I_1P_0S_0$ Model 1	$I_1P_0S_0$ Model 2	$I_0P_1S_0$ Model 1	$I_0P_1S_0$ Model 2	$I_0P_0S_1$ Model 1	$I_0P_0S_1$ Model 2	$I_1P_1S_0$ Model 1	$I_1P_1S_0$ Model 2
NGO	1.475**		1.384*			1.969***		
	(3.07)		(2.475)			(4.01)		
Market linkage	0.545**		1.028***			0.620**		
	(2.783)		(4.411)			(3.114)		
AIS		0.281***		0.199*				0.367***
		(3.73)		(2.12)				(4.71)
Constant	−2.300***	−0.87	−1.897**	−0.836		−2.815***		−1.754***
	(−4.11)	(−1.77)	(−2.93)	(−1.39)		(−5.14)		(−3.45)

Source: Author's computation based on the 2009/2010 and 2013/2014 GSPS data (2020)
Notes: t statistics in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; Model 1: $LR(\chi^2) = 2070.67$; $P > \chi^2 = 0.000$; Model 2: $LR(\chi^2) = 1775.02$; $P > \chi^2 = 0.000$. Model 1 = model with individual farmer-actor interactions; Model 2 = model with the intensity of farmer-actor interactions as sum of the individual interaction.

farmers positively which confirms findings of Van Ho, Nanseki, and Chomei (2019). This implies that with improved extension service delivery and access, farmers will be well informed about the innovations driving agricultural productivity which will potentially influence their choice of adoption positively. Additionally, with increased extension interaction, local innovation development by farmers could be fine-tuned to suit their needs for increased innovative performance as observed by Weyori et al. (2018).

For farmers who adopted any of the single sets of innovation, having tenure security or otherwise did not significantly influence their adoption decision positively. On the other hand, tenure security played a significant role in adopting the combination of any of the innovations. This implies that farmers with tenure security are advantaged in making adoption decisions on multiple innovation choices. Insaidoo, Ros-Tonen, and Acheampong (2013) and Kazianga and Masters (2006) obtained similar findings in their work and this has implications for sustainable agriculture since long-term innovative decisions could be made on land use with improved tenure security.

The fertilizer subsidy and cocoa mass spraying programmes are some of the key policy support programmes in the maize and cocoa sub-sectors. The programme gives farmers access to fertilizers and agrochemicals at a subsidized price. In the case of cocoa, the total cost of the mass spraying programme is absorbed by government whilst maize farmers are given a 50% subsidy of the cost of fertilizers (MOFA, 2017). The findings revealed that policy support acted as both an incentive and disincentive for adopting some types of innovations. Information access is also key to a farmer accessing this policy support and hence it can be observed that policy support significantly influenced the adoption of informational innovation in its singular form and its combination with post-harvest innovations, positively. Complete adoption regime ($I_1P_1S_1$) was also significantly driven by policy support. The findings of Zakaria et al. (2021) and Koppmair, Kassie, and Qaim (2017) also corroborate this current finding on how input subsidies incentivize adoption of improved technologies. This could mean that if the structure of the policy support programme is strengthened and all bottlenecks removed, favourable government policy programmes on agriculture will influence adoption of innovative practices.

Being a member of an FBO did not show any significant effect on adoption of any of the innovations. This is quite unexpected given that FBOs could be a strong force in driving adoption decisions. As observed by Fisher et al. (2018), the role of lead farmers in FBOs are important in adoption decisions, and so having lead farmers could change this finding. Farmer interaction with NGOs was found to significantly drive adoption decision positively for most of the innovation regimes. It was revealed during the field interviews that NGOs have over the years facilitated best agricultural practices among farmers in Ghana. This revelation therefore support the strong influence they have on the adoption decision of farmers. Given the right environment, NGOs have the potential to transform the agricultural landscape in Ghana through their activities as highlighted by Azumah, Donkoh, and Awuni (2018).

The decision of a farmer to adopt an innovation with the expectation of a productivity increase could also hinge on the certainty of an available market where outputs would be sold to earn the required income. An appropriate market linkage was found to significantly influence the adoption of all innovations positively. Providing market linkages and access is hence important and will serve as an incentive to innovation development and adoption. Such a reduction in market uncertainty, with the various market linkage options that would be available, could also act as an incentive for people to engage in agriculture.

The foregoing discussion has highlighted how individual actors within the AIS generally contribute to the adoption of innovations, with some actors significantly driving the adoption process whilst others do not. Weyori et al. (2018) reported similar findings but also cautioned against existing weakness in some of the actor ties in the innovation system which could tend to hamper the collective impact of the network as has been observed in this study. The findings further reveal that farmers with stronger ties in the AIS had a higher likelihood of adopting any of the set of innovations and were consistently significant with the multiple sets. Except for informational innovation, the sole adoption of improved seeds ($I_0P_0S_1$) and post-harvest innovations ($I_0P_1S_0$) was not significantly influenced by the interactions in the innovation system, but the adoption of all multiple choices was. This suggests that increased intensity of interactions between farmers and other actors within the AIS play an important role in positively influencing the adoption of multiple innovations as opposed to a single regime. The importance of having complementary suites of technological innovations as against a single one and how farmers' welfare are impacted have been highlighted in Khonje et al. (2018). It is encouraging therefore to note that the AIS potentially provides an opportunity for farmers to adopt multiple innovations to increase their innovative performance.

Other drivers of adoption

Focus group discussions with the selected farmers additionally revealed other drivers of adoption as shown in Figure 2. These included the innovation cost, expected benefits, innovation attributes, climatic factors and soil type.

Farmers, like any economic agents, were found to be rational in their choice of adoption and hence only adopted an innovation when the perceived benefits outweighed the cost, as indicated by this quote:

> *The farming business is such that when you do, you have to get profits. If you don't get profit, then it is a big problem. So you have to do what you have to do to get more profits and so we think about the profiting opportunity of any innovation before adopting it.* (Farmer, Maize FGD, Eastern region)

They also revealed that some innovations after adoption accrued less profit because the cost could not be defrayed by the revenue generated due to poor pricing and market conditions. The type of soil was also one factor that influenced the adoption of an innovation. Farmers attested that the fertility of soils in their production areas was generally low and hence any innovation that was aimed at boosting soil fertility was easily adopted. Some of the improved varieties (hybrid) were reported to perform poorly on some soils. In such cases, farmers indicated they were inclined to plant their local varieties rather than adopting any improved variety:

> *Because the soil is harsh it sometimes does not support the hybrid maize so we don't adopt at all.* (Farmer, Maize FGD, Ashanti region)
> *The soil in this area is not good so if we get new approaches that will improve the soil, you see all of us rushing to do it.* (Farmer 3, Cocoa FGD, Ashanti region)

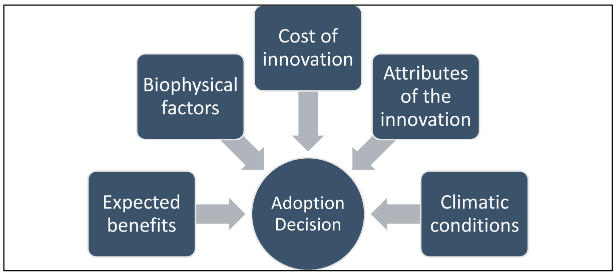

Figure 2: Other drivers of adoption.
Source: Field interviews (2020)

The attributes of a particular innovation also drove its adoption. For example, farmers indicated that because some of the improved seeds are early maturing, they usually opt for those to reap benefits early as intimated by a participant:

> *The agric one doesn't take long in maturing and hence every farmer likes that.* (Farmer, FGD Cocoa, Eastern region)

There was also a lot of discussion on the adaptability of improved seeds to the different seasons. Maize farmers, for instance, switched the type of variety to plant between seasons. Cocoa farmers expressed similar sentiments except they did not have much choice to switch in between seasons since it is a long-term crop. The reason for the switch was that the local varieties perform well in all seasons, but the improved varieties perform exceptionally well only during the major rain season. The findings of Senyolo et al. (2018) support how these characteristics indicated by farmers potentially influence the adoption of a particular innovation.

Conclusion, theoretical, and policy implications

Using descriptive statistics and multinomial logit regression, supported by qualitative analysis, the study concludes that there is low adoption of innovations among farmers. However, despite the decline in the adoption of some innovation bundles, the complete bundle (informational, improved seeds, and post-harvest innovations) realized a 5% increase in adoption rate, hinting on the possibility of slow technological progress. However, younger farmers, female farmers and farmers with higher level of education, are more likely to adopt multiple innovations compared to older farmers, male farmers, and farmers with lower levels of education. Increased interactions with actors such as financial service providers, market actors, extension service providers, and NGOs positively influence farmers' adoption decisions. Additionally, the collective effect of the AIS with higher intensity of actor interactions equally serves as a significant enabler in influencing adoption of innovations by farmers, which can increase their innovative performance. These suggest that farmer interactions with actors in the innovation system should be stimulated using different platforms that encourage interactions such as innovation platforms. The roles of agricultural extension agents need to be reoriented with adequate attention paid to their logistical needs to increase contacts with farmers so they can deliver on their role in the AIS. Farmers should also position themselves to form networks with these actors to access support for their activities. The study has made contribution to the literature by quantifying the effect AIS has on the adoption of innovations which is a budding area in AIS research as most previous studies have focused on the linear technology transfer model. By showing that increased collective interactions in the innovation system influence adoption of multiple innovations whilst some individual interactions by themselves did not, the importance of collective actions in fostering innovative performance has been highlighted in this study but also hints at the importance of strengthening individual actors in the AIS. Therefore, theoretically, it is important for innovation system scholars to unpack individual actor interactions to see where weaknesses exist for actions of strengthening to be targeted, even as they consider the system holistically. In terms of policy, the Youth in Agriculture Programme of the government of Ghana should be expanded to encourage more youth participation in agriculture since they are more likely than the older generation of farmers to adopt innovations to boost agricultural productivity. The activities of the Women in Agricultural Development (WIAD) directorate should also be supported to encourage more women in agriculture due to their positive adoption behaviour of innovations. Finally, platforms to support and encourage actor interactions should be established with support from both government and non-government actors in order to promote innovative performance through learning and interaction. Interventions by governments to promote innovation should also focus on appropriate ways of incorporating innovation systems through policy and practice for its full benefits to be realized as highlighted in Mgumia, Mattee, and Kundi (2015).

Disclosure statement

No potential conflict of interest was reported by the authors.

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