Do agricultural interventions influence network formation?

Insights from a randomized experiment in Kenya

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Abstract

Farmer groups are important target units for agricultural development interventions; however, little is known on how these groups communicate and if interventions, such as agricultural extension, affect networks. Using a clustered randomized controlled trial in combination with a panel set of detailed network data, we investigate the impact of a group-based agricultural intervention on communication networks of farmers in rural Kenya. Our analysis is based on group level as well as dyadic regressions to detect network changes. We find evidence that the intervention has a positive effect on communication networks within farmer groups, i.e., it fosters the creation of agricultural communication links. Furthermore, the increase in network activity is predominantly driven by the creation of new communication links. Finally, (joint) attendance of agricultural training sessions more than doubles the likelihood of new link formation. By fostering positive network activity, group-based extension can thus be a promising approach for technology delivery.

Keywords: Network changes, communication networks, RCT, group-based extension

JEL Codes: O13; O33; Q16

1. Introduction

Farmer groups are important target units for agricultural development interventions (Feder et al. 2010). Group-based interventions are participatory and considered efficient in spreading information and hence promoting new technologies (Fischer & Qaim 2012). However, little is known on how information networks evolve within these groups and to what extent they are modified by interventions, such as agricultural extension. Given that the main purpose of agricultural extension is the diffusion of knowledge, a change in network activity may at first sight be considered as a byproduct and not as a direct economic outcome. However, creating a network link between two persons is associated with costs, and hence maintaining or expanding networks can be seen as an investment in future cooperation (Fafchamps & Gubert 2007a; 2007b; Santos & Barrett 2010; Hayami 2009). Furthermore, the formation of new links is efficient from a network perspective, since sticking to people that are like oneself and that one usually talks to can limit exposure to new information and perceptions (McPherson et al. 2001). If group-based agricultural interventions change the information networks of farmer groups positively – for instance through the creation of new information links – this would provide an economic argument in favor of advocating for training groups instead of individuals only.

Understanding the potential positive social dimensions of group approaches becomes important in the context of recent trends in agricultural extension systems, which focus increasingly on individuals. Especially in Africa, model or lead farmer approaches have become popular whereby individual farmers are trained, who then in a second step are supposed to diffuse the new information to their peers. An increasing body of literature has analyzed the effect of the lead or model farmer approach, with mixed results. Kondylis et al. (2017) for instance found that even if lead farmers adopt a technology, their adoption decision has little impact on the adoption decision of other farmers. Maertens (2017) argues that farmers mostly learn from a few progressive farmers. Training exclusively these progressive and powerful farmers consequently bears the risk of project failure in case they eventually decide not to commit to the project. Beaman & Dillon (2018) conducted a network targeting experiment in Mali. They found that targeting influential persons may prevent that new information and knowledge reaches farmers who are not close to these influential persons.

Strikingly little is known on how informal information networks, e.g. within farmer groups, change over time and respond to interventions (Maertens & Barrett 2012). One explanation is that so far, according to Comola & Prina (2017), studies using detailed network data are mostly cross-sectional and thereby assume that networks are static. There are exceptions such as the recent work of Banerjee et al. (2018) who study how networks respond to the introduction of microfinance in India. The authors collected two waves of panel data in 2006 and 2012 and found that the probability of advice, borrowing and lending relationships decreased in villages exposed to microfinance. However, program placement by the bank was non-random, which might be associated with selection bias as discussed by the authors.

In the present study, we analyze the impact of a group-based agricultural extension intervention on communication networks within farmer groups. More specifically, we investigate whether agricultural information exchange increases (or decreases) at the group level in response to the intervention, and what mechanisms explain the observed changes in communication networks. For this purpose, we combine detailed panel network data on communication networks with a randomized controlled trial (RCT). The RCT introduces various combinations of group-based training sessions to promote pro-nutrition technologies, including iron-rich beans and high-yielding chicken, in rural Kenya. Survey data from 48 farmer groups and 824 households was collected before and after the intervention and analyzed using group level and dyadic regressions.

2. Conceptual framework

In rural areas of developing countries extension systems commonly target farmer groups to spread information about new agricultural technologies or agronomic practices (Cuellar et al. 2006). Farmer groups are seen as cost-effective entry points for interventions. Working with groups of farmers reduces transaction costs compared to visiting a large number of dispersed individual farmers. Furthermore, farmer groups can provide important informal networks for the rural population. In particular in remote, rural areas with lacking formal infrastructure, informal networks can play an important role for the diffusion of information and consequently for the adoption of new technologies (Foster & Rosenzweig 1995; Bandiera & Rasul 2006; Munshi 2007; Conley & Udry 2010; Maertens & Barrett 2012; overview by De Janvry et al. 2017).

To study the diffusion of agricultural information in farmer groups, it is relevant to observe whether a communication link exists between two farmers, i.e., whether information on the agricultural technology is actually exchanged. Each communication link between two farmers can be understood as an investment. The farmer will invest in creating and/or maintaining a link if the benefits of the link outperform the costs of creating and/or maintaining the link (e.g. Fafchamps & Gubert 2007a; 2007b; Santos & Barrett 2010):

$$l_{ijg} = \begin{cases} 1 \; if \; B(d_{ijg}) - C(d_{ijg}) \geq 0 \\ 0 \; otherwise \end{cases} \qquad (1)$$

$B(d_{ijg})$ represents the benefits and $C(d_{ijg})$ the costs of the link l_{ijg} between actors i and j that are embedded in farmer group g. The costs and benefits of each link depend on the distance d_{ij}

between *i* and *j* which can be interpreted as geographic distance or as social distance, such as kinship or same gender. Farmers may reconsider the costs and benefits associated with a particular link over time. Benefits and costs of a link can change from t_0 to t_1, implying that new links may be created and links existing at t_0 may be either maintained or discontinued.

Furthermore, benefits *B* and costs *C* are likely to be influenced by the intervention and therefore introduce a vector of treatment variables as additional distance indicators. The *treatment distance* can either refer to treatment assignment (i.e., farmer *i* and *j* were both assigned to treatment) or to treatment attendance (i.e., farmer *i* and *j* attended training sessions (jointly)). We hypothesize that the treatment – in our case the agricultural extension intervention – has a positive effect on link formation at t_1. The treatment will likely reduce the costs of link formation, since the extension meetings decrease individual transaction costs related to setting up a time and date to meet. In addition, the treatment should also increase the benefits of link formation (since new information is available) and/or make those benefits more evident to farmers.

3. Study context and intervention

The study was implemented in rural Kenya in the two Counties Kisii and Nyamira. In these densely populated Counties, more than half of the population depends on the agricultural sector. Most farmers have a diversified farming system including e.g. maize, beans, bananas, sugar cane, tea, and horticultural crops. Land sizes are usually small and almost all of the land is under cultivation (Mbuvi et al. 2013). The majority of the farmers are poor in terms of income poverty, meaning that they have less than 1.90 US dollars per capita and day in PPP terms (Ogutu & Qaim 2019). Regarding the nutritional status of the population, one-quarter of the children in Kisii and Nyamira are stunted, which means that they are too short for their age. At the same time, a third of the women of reproductive age are overweight or obese (KNBS 2015; Fongar et al. 2018).

These circumstances, which can similarly be found in many African rural areas, suggest that the promotion of pro-nutrition technologies could contribute to an improvement of the farmers' livelihoods.

In Kisii and Nyamira, as in most rural areas of Kenya, farmer groups play an important role for the access to agricultural information. Farmer groups are considered effective entry points to reach the rural population and are hence frequently targeted by extension and development programs in Kenya. For instance, the Kenyan government with support of the World Bank implemented the "Kenya Agricultural Productivity Program (KAPAP)" that builds on farmer groups (Cuellar et al. 2006). More recently, the lead farmer approach has also gained popularity among extension providers in Kenya, since it allows covering a large area with relatively few extension agents (Kiptot & Franzel 2015).

Against this background, an agricultural extension intervention targeting farmer groups was designed to promote pro-nutrition technologies[1]. The promoted technologies include the black been variety KK15 and Kuroiler chicken. KK15 is rich in iron and zinc and was bread conventionally at the Kenyan Agriculture and Livestock Research Organization (KALRO). Besides its nutritional benefits, KK15 is high-yielding and root-rot resistant. Kuroiler chicken is an improved, high-yielding and hardy dual-purpose breed. It was initially bred in India, where it proofed to be especially suited for the rural poor. Compared to indigenous breeds, it lays more eggs and grows faster. It has been extensively promoted in Uganda, but in Kenya it is not yet widely spread (Ahuja et al. 2008; Fotsa & Ngeno 2011).

[1] The extension intervention was implemented by the partnering NGO Africa Harvest Biotechnology Foundation International.

The intervention consists of three different extension treatments that are all targeting farmer groups, but vary in terms of their intensity. Seven agronomic training sessions imparting agricultural information on the pro-nutrition technologies represent the core of the intervention, and were identically implemented across the three treatments. On top of these seven agricultural sessions, farmer groups assigned to the second treatment received three training sessions on nutrition. Finally, farmer groups assigned to the third treatment received three training sessions on marketing in addition to the agricultural sessions and the nutrition sessions. Ogutu et al. (2018) demonstrate that all three treatments effectively increase the adoption of pro-nutrition technologies among farmers. Given that as a core element, all treatments deliver agricultural information, we summarize the three treatments into one for our analysis of agricultural communication networks.[2]

4. Study design and data

The agricultural extension intervention was implemented as a randomized controlled trial (RCT) with three treatment arms and one control. To accommodate the group-based extension intervention, randomization was done at the group level, facilitating not only implementation, but also minimizing potential spillovers between treatments and control (Duflo et al. 2007). Survey data, including detailed network interactions between group members, was collected before and after the intervention. Figure 1 depicts the timeline of the study.

[2] We estimated intent-to-treat regressions to test whether treatment 2 and treatment 3 have additional effects on link formation (see Appendix, Table A1). We did not find significant differences between the treatments, which justifies the choice of treating the three arms as one.

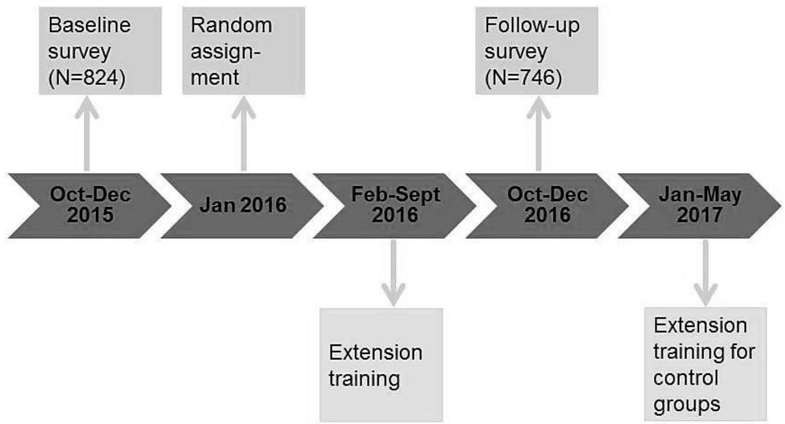


Figure 1: Timeline of the study

Sampling strategy

We build on existing group structures in the research area to construct the sampling frame for the study. From the list of all existing farmer groups in Kisii and Nyamira, we excluded those groups that had received extension during the previous two years, resulting in a list of 107 active farmer groups. All groups were initially formed for extension purposes, and had received training in the past. In addition, groups engage in a diverse range of self-help activities including table banking, joint produce marketing, as well as social and church-related activities. From the list of active farmer groups, we randomly selected 48 farmer groups proportionate to the number of groups per county (i.e., 16 in Nyamira and 32 in Kisii). For the selected farmer groups, member lists were carefully checked and cleaned with the help of the group leaders. Group sizes range between 20 and 40 active members.

Randomization and treatment implementation

The 48 selected farmer groups were randomly assigned to the three treatment arms and the control, i.e. 12 farmer groups each. Random assignment was stratified by county, share of female group members, and group size to reduce heterogeneity across treatment arms and control. The extension sessions were implemented between February and September 2016. To ensure harmonization, standardized protocols were developed for each session and extension assistants were trained on the delivery of standardized messages. Similarly, mobilization of farmers followed a standardized protocol. At the end of each session, a date and time for the next session was agreed upon. In addition, group members were contacted and reminded three days before the session. We used standardized participation lists in which farmers entered their name, age, and signature each time they attended a session. Training attendance was not incentivized and entirely voluntary. The implementation of the extension intervention was closely accompanied by the researchers. Out of ethical considerations, we employed a phase-in design; i.e., the control group received extension training after the follow-up survey was completed.

Household survey

Household data was collected in two survey rounds. The baseline survey was implemented between October and December 2015, the follow-up survey one year later. For the baseline survey we randomly selected 20 members in each of the selected farmer groups. If households were unavailable for the interview, we strived to replace them with the next household on the list. Overall, we were able to interview a total number of 824 group members in the baseline survey, of which 815 completed the network module. In the follow-up survey, we re-visited the same households and – due to general attrition – obtained complete network data from 719 group members. The main reasons for attrition were related to travels, e.g. attending funerals or visiting family. Our attrition rate of 12% (Table A2 in the Appendix) is relatively low compared to other RCTs (Ashraf et al. 2014).

Data was collected through face-to-face interviews in the homestead of the respondents. The questionnaires were administered by trained enumerators, familiar with local living conditions and language. We gathered information on demographics, agricultural and non-agricultural income activities, group membership and other social activities. In addition, we elicited comprehensive network data on agricultural information exchange within the groups.

Network data

Our network dataset consists of 48 block-diagonal matrices, since we elicited data on information flows within farmer groups, but not across them. Within farmer groups, each respondent can engage in conversation with n_g-1 members since self-links are excluded, where n_g is the number of members of farmer group g. We were able to collect full network information from four of the selected farmer groups and close to full information from two thirds of the groups. In total, around 80% of all group members were interviewed, providing us with close to full census network data for the farmer groups in our sample. The advantage of such dataset is that it allows us to draw inference on the structure of networks, and consequently, on how the structure of networks changes over time (Hanneman & Riddle 2005).

For each group member *j*, respondent *i* was asked to indicate the type of information exchanged and details of their proximity (relationship, whether they share the same plot border and/or inputs). To assess the exchange of agricultural information the following question was posed: *During the last 12 months, did you share information on agriculture with j?* Given that we obtain information on *i*'s perception of information exchange with *j* as well as *j*'s perception of information exchange with *i*, and these perceptions do not necessarily coincide in all cases, we are dealing with directed network data in the analysis. Reciprocity is assumed only in the case of attritors to avoid the loss of follow-up network data. As described above, we observe an attrition rate of 12 percent between the baseline and the follow-up survey. Our research design allows us to replace missing network data as follows: let us assume to have information from *i* about *j*, but *j* is an attritor: *i* indicates to exchange agricultural information with *j*, but we miss information on whether *j* also indicates to exchange information with *i*. We then replace the missing data of *j* with the information given by *i*. As a result, our network dataset consists of 815 group members, and 13,318 dyads or 6,659 pairs of dyads observed over two time periods.

Sample characteristics and balance

The majority of the farmer group members in our sample are female (62%). They are on the average 46 years old and farm two acres of land. Every fifth person is widowed. The average number of group memberships is 1.3, although up to five memberships were reported by respondents. Besides farmer groups, farmers have other networks such as family or church that can represent important sources of agricultural information. An overview of sample characteristics is provided in Table A3 in the Appendix.

Compared to regional and national averages, the farmers in our sample are slightly older (KNBS & SID 2013). Yet, comparing our sample statistics with the statistics of previous extension programs, we find that regarding farmer group characteristics our sample is quite representative for the area. For instance, the "National Livestock and Extension Program (NALEP)" reports that 70 percent of the members of Kenyan farmer groups focusing on food crops and small livestock production are female. It is further emphasized that widows and female-headed households play a powerful role for the functioning of farmer groups and therefore tend to be actively incorporated as group members. Cuellar et al. (2006) mention Kisii in particular as a hub for female group activities, with the overall majority of group members in Kisii being women.

We use baseline data to test for balance between control and treatment group. While the group level characteristics are balanced (Table A4 in the Appendix), some differences in individual and dyadic characteristics can be observed between control and treatment group (Tables A5 and A6 in the Appendix). Farmers assigned to treatment are on the average less educated, older, more often widowed and more often female household heads, compared to the control group. Whenever applicable, we therefore include baseline controls in the regressions. All network measures at group and dyadic level, which represent our outcome variables and are introduced in the next section, are balanced at baseline between control and treatment (see Tables 1 and 3 below).

5. Empirical strategy

Network changes at group level

To test whether the extension intervention has an impact on information exchange networks at group level, we estimate intent-to-treat (*ITT*) effects on network activity within groups. For this purpose we define two measures of aggregate network activity. First, network density, an indicator of the group's connectedness (Hanneman & Riddle 2005), is calculated by dividing actual communication by potential communication:

$$Density_g = \frac{L_g}{n_g(n_g-1)} \quad , \tag{1}$$

where n_g refers to the number of group members in farmer group g. A link is defined as a binary variable that equals one if an agricultural information link exists between farmer *i* and *j*. L_g is the sum of actual links within farmer group *g*.

Second, we calculate the average degree centrality of a farmer group, as an indicator of communication activity (Wasserman & Faust 1994). Degree centrality d_{ij} refers to the number of persons *j*, with whom farmer *i* has an information link. To obtain the mean degree centrality at group level, $Degree_g$, we sum up the degrees d_{ij} of all members *i* of group *g*, and divide it by the number of group members n_g:

$$Degree_g = \frac{\sum_g d_{ij}}{n_g} \quad . \tag{2}$$

Intent-to-treat (*ITT*) effects on group-level network activity are then obtained using difference-in-difference estimations:

$$NETWORK_{gt} = \alpha_0 + \alpha_1 Post_t + \alpha_2 ET_g + \alpha_3 \, Post_t \times ET_g + \varepsilon_{g.} \tag{3}$$

$NETWORK_{gt}$ refers to the group-level network measures $Density_g$ and $Degree_g$, as introduced above. $Post_t$ is a year dummy that equals one for the follow-up data (t_1). ET_g is a dummy that equals one, if the farmer group was assigned to the extension treatment, and zero if the farmer group was assigned to the control. Our main coefficient of interest is α_3, which represents the effect of treatment assignment on network activity. First differencing allows us to control for time-invariant unobservable heterogeneity between groups.

Link formation between group members

Network changes observed at group level can result from different patterns of link formation at the dyadic level, i.e. between pairs of farmers. Changes in network activity can for example be driven by accelerated or decelerated creation of new links or discontinuation of existing links. To investigate the role of these underlying mechanisms for network change, we estimate *intent-to-treat* effects of the intervention on link formation in a dyadic regression framework (Fafchamps & Gubert 2007b) using difference-in-difference:

$$l_{ijgt} = \beta_0 + \beta_1 \, Post_t + \beta_2 ET_g + \beta_3 \, Post_t \times ET_g + \beta_4 X_{ijg} + \varepsilon_{ijg}. \quad (4)$$

We estimate two separate specifications, where l_{ijgt} is a binary variable that indicates (1) the creation of a *new link* between *i* and *j* at follow-up and (2) the discontinuation of an existing link between *i* and *j* at follow-up, respectively. Our main coefficient of interest is β_3, which represents the effect of treatment assignment on the likelihood of link formation (creation and discontinuation, respectively) at follow-up. Standard errors ε_{ijg} are clustered at group level. To enhance the accuracy of the estimates (Carter et al. 2013), vector X_{ijg} includes those covariates that showed significant differences between control and treatment group at baseline (see Table A3).

The role of attendance for link formation

Intent-to-treat effects measure the impact of treatment assignment on link formation. In practice, farmers assigned to treatment can choose to what extent they comply with their treatment status and attend the offered extension sessions. From a conceptual point of view, joint attendance of extension sessions is an important mechanism through which the intervention can reduce costs and increase the (visibility of) benefits of link formation. We therefore analyze to what extent (joint) attendance of training sessions drives the observed link formation patterns.

The treatment-on-the-treated (*TOT*) effect is obtained by estimating the following specification:

$$l_{ijg}(t_1) = \delta_0 + \delta_1 \widehat{ATTEND}_g + \delta_2 X_{ijg} + \varepsilon_{ijg} \quad (5)$$

where $l_{ijg}(t_1)$ is a binary outcome variable measuring link formation at follow-up, for instance the creation of a *new link*, and δ_1 is the treatment-on-the-treated effect. *ATTEND* refers to the attendance measure of interest, in particular training attendance (*i* and *j* each attended at least one session) and joint training attendance (*i* and *j* attended at least one training session jointly) [3].

Training attendance is a choice variable and subject to self-selection. More open and communicative individuals, who enjoy talking to other people, may be more likely to attend extension sessions, and at the same time would be more likely to form a link with other group members. To reduce potential bias from self-selection, we estimate the *TOT* effects in equation (5) using an instrumental variable approach. As an instrument for training attendance we use the random assignment to treatment (Angrist & Imbens 1996; Duflo et al. 2007).[4] Random assignment is defined as a dummy variable (0 = control, 1 = treatment). In specification (5), $\widehat{ATTEND}_g$ refers to the fitted values obtained from the first stage regression.

6. Empirical results

6.1. Changes in network activity at group level

At baseline, we can observe that the groups in our sample are quite active in terms of agricultural information exchange (Table 1). The network measure $Density_g$ indicates that on the average 50 percent of the potential links share agricultural information. This high level of network activity is likely due to the fact that we are dealing with small, village-level groups whose members interact

[3] All attendance variables are based on the attendance records kept by the extension agents to avoid recall biases.
[4] First stage regressions in Table A8 and A9 indicate that the random assignment is strongly correlated with the training attendance variables.

frequently (90 percent of the potential links share general information) and for whom agriculture is a central livelihood component (86 percent of the respondents indicated that farming is their main occupation). Similarly, our second network measure, $Degree_g$, confirms relatively high levels of communication activity, with an average degree centrality of 7.97. Both group-level network measures are balanced at baseline across treatment and control, as can be seen in column (4) of Table 1.

Table 1: Group-level network measures at baseline

	(1) Full sample Mean (s.d.)	(2) Control Mean (s.d.)	(3) Treatment Mean (s.d.)	(4) Control-Treatment Diff. (t-stat.)
$Density_g$	0.50	0.50	0.50	0.00329
	(0.13)	(0.12)	(0.14)	(0.07)
$Degree_g$	7.97	8.15	7.92	0.233
	(2.44)	(2.41)	(2.48)	(-0.28)
N_{Group}		12	36	48

Note: We also performed two-sample Wilcoxon rank-sum (Mann-Whitney) tests correcting for small sample size. Results are similar and can be provided upon request.

Intent-to-treat effects indicate that assignment to the intervention is associated with a significant increase in group-level network activity (Table 2). On the average, the intervention increases the density of the communication network within the assigned farmer groups by nine percentage points, compared to the control group. Similarly, the effect on degree centrality is significant indicating that in the assigned farmer groups members reported 1.7 more information links on the average after the intervention, compared to the control group. The negative coefficient of the time dummy *Post* reveals that overall communication decreased by around 18 percentage points between the two time periods.

Table 2: Intent-to-treat effects at group level (difference-in-difference)

	(1) $Density_g$	(2) $Degree_g$
Post*ET	0.0931*	1.701*
	(0.0541)	(0.889)
Post (Dummy)	-0.184***	-3.103***
	(0.0497)	(0.819)
ET (Dummy)	-0.00329	-0.233
	(0.0417)	(0.802)
Constant	0.500***	8.149***
	(0.0349)	(0.683)
Mean dependent variable at *t1*	0.38	6.15
N_{Group}	96	96
R-squared	0.190	0.154

Note: ET is a dummy turning one if the farmer group was assigned to treatment. Asterisks *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

These findings are visualized in Figure 2, which compares information networks before and after the intervention of four selected farmer groups (two treatment and two control farmer groups). The lines represent agricultural communication links and the dots individual farmers. A general comparison of network graphs between baseline and follow-up exemplifies a distinct drop in overall communication levels. Furthermore, the drop in communication is much less pronounced in the selected treatment farmer groups than in the control farmer groups, reflecting the relative increase in communication induced by the intervention. In the following sections we investigate in more detail the underlying mechanisms driving the observed network changes.

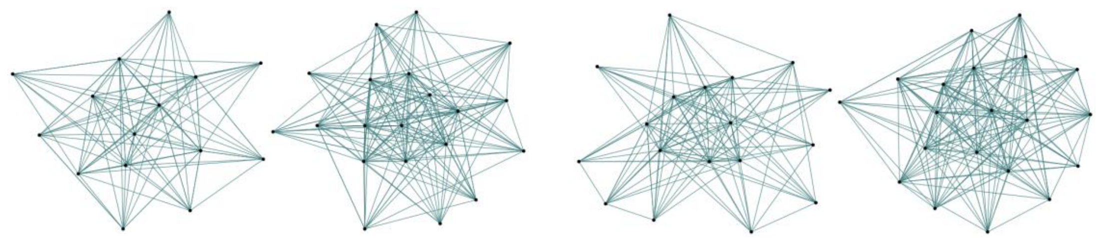
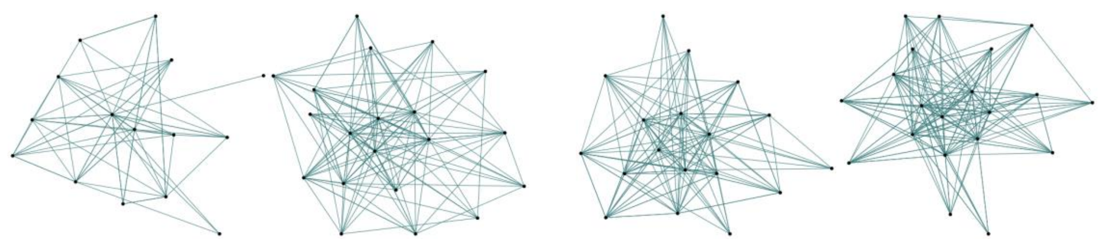
	Control		Treatment	
Group ID	11	44	5	26
Group size	15	20	18	20
Baseline				
$Density_{gt0}$	0.54	0.52	0.45	0.50
$Degree_{gt0}$	7.60	9.95	7.61	9.50
Follow-up				
$Density_{gt1}$	0.31	0.39	0.48	0.50
$Degree_{gt1}$	4.40	7.40	8.16	9.55

Figure 2: Network activity in four selected farmer groups

6.2. Impact on link formation

In order to investigate the underlying mechanisms that drive the observed network changes at group level, we investigate link formation at the dyadic level, i.e. between pairs of farmers. In general, increases in information exchange at the group level can result from two underlying patterns; we may observe either an increase in the number of new links being formed, or a decrease in the number of links given up between the two time periods. Table 3 provides an overview of dyadic link formation at baseline and follow-up. In accordance with the group-level network measures, we observe no significant difference in links between treatment and control at baseline. In the follow-up, overall communication activity decreased, but to a lesser extent in the treatment group – mirroring the group-level results. The descriptive statistics in Table 3 further show that 16 percent of the potential links are newly formed at follow-up and 27 percent of the potential links are discontinued at follow-up. New links are more often created in the treatment group (18 percent of the potential links) compared to the control group (11 percent of the potential links), and existing links less often discontinued (26 percent in treatment versus 30 percent in control group).

Table 3: Descriptive statistics of dyadic network variables

	(1)	(2)	(3)	(4)	(5)
Dyadic network variables	Total number of *links*	Full sample	Control	Treatment	Treatment-Control
		Mean (s.d.)	Mean (s.d.)	Mean (s.d.)	Mean difference (t-value)
Link (t_0)	6,656	0.50	0.50	0.50	-0.004
		(0.50)	(0.50)	(0.50)	(-0.43)
Link (t_1)	5,137	0.39	0.31	0.41	0.106***
		(0.49)	(0.46)	(0.49)	(11.03)
New link in t_1	2,104	0.16	0.11	0.18	0.070***
		(0.36)	(0.31)	(0.38)	(9.71)
Discontinued link in t_1	3,623	0.27	0.30	0.26	-0.040***
		(0.45)	(0.46)	(0.44)	(-4.57)
N_{Dyads}	13,318	13318	3410	9908	13318

Note: Link (t_0) refers to agricultural links at baseline (t_0) and *link* (t_1) refer to agricultural links at follow-up (t_1) respectively; *New link* refers to newly created agricultural links if *Link*$(t_0)=0$ & *Link*$(t_1)=1$; *Discontinued link* refers to dropped agricultural links if *Link*$(t_0)=1$ & *Link*$(t_1)=0$. Asterisks *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Intent-to-treat effects confirm that the assignment to the intervention has a positive and significant effect on the formation of new links (Table 4). The intervention increases the likelihood of forming a new information link by seven percentage points on the average. Although the likelihood of abandoning existing links is slightly lower in the treatment group than in the control group, this effect is not statistically significant. We therefore conclude that the observed changes in network activity at group level are mostly driven by an increase in the incidence of new link creation among members of farmer groups assigned to treatment.

Table 4: Intent-to-treat effects on the creation of new links and the discontinuation of existing links (difference-in-difference)

	(1) *New link*	(2) *Discontinued link*
Post**ET*	0.0701***	-0.0403
	(0.0216)	(0.0368)
Post (Dummy)	0.106***	0.302***
	(0.0173)	(0.0347)
ET (Dummy)	0.00101	-0.00126
	(0.00223)	(0.00310)
Constant	-0.0212	-0.0329
	(0.0342)	(0.0359)
Mean dependent variable at *t1*	0.16	0.27
Baseline controls	Yes	Yes
N_{Dyads}	26,636	26,636
R-squared	0.094	0.161

Note: Dependent variable *New link* in (1) is a dummy, turning one at t_1 if sharing of agricultural information took place during follow-up, but did not take place during baseline. Dependent variable *Discontinued link* in (2) is a dummy, turning one at t_1 if sharing of agricultural information took place at baseline and stopped taking place at follow-up. Values at baseline are set to zero. *ET* is a dummy turning one if *i* and *j* were assigned to a treatment group. Control variables include the following dummies: *i* and *j* are both female, *i* and *j* are both male, *i* is a group leader, *j* is a group leader, *i* and *j* are both group leaders, the number of agricultural links *i* named outside of the group (external links), the number of agricultural links *j* named outside of the group (external links), *i* and *j* share a same plot border. Other controls are the sums and differences of age in years, years of education as well as land size. Results including the set of control variables are shown in Table A7 in the Appendix. Coefficients are shown with robust standard errors clustered at farmer group level. Asterisks *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

6.3. Attendance and new link formation

Cluster randomization implies that the farmer groups assigned to treatment indeed received extension; however, to what extent group members complied with their treatment status and attended the offered extension sessions varies and is subject to self-selection. Attendance statistics (Table 5) show that the overall compliance rate, including partial compliance, is 53 percent. This means that of the 608 interviewed group members, who were assigned to treatment, only 320 attended one or more training sessions. On the average, group members attended less than two extension sessions. Figure 3 shows the distribution of attended sessions over the treated sample. In general, few farmers attended more than two sessions and hardly any farmer reached nine sessions, the average number of sessions offered to the treated farmer groups.

In the conceptual framework, we hypothesized that the treatment will have positive effects on network activity within farmer groups by reducing the costs and increasing the (visible) benefits of link formation. These mechanisms can only be at work if farmers actually meet each other at the extension sessions. The relatively low and imperfect compliance rate raises some doubts in this regard. We therefore explore to what extent the formation of new links is driven by (joint) attendance of training sessions. Of all dyadic pairs, in 40 percent of the cases both farmers attended at least one training session, although not necessarily the same session. In 34 percent of the cases, both farmers actually attended at least one session jointly. Overall, the average number of training sessions attended jointly is below one, reflecting the high number of dyadic pairs who did not attend a session together.

The *TOT* effect of training attendance on new link formation is significant (Table 6) and substantially larger than the intent-to-treat effect. If i and j each attended at least one session, the likelihood of creating a link increases by 18 percentage points on the average, and thus more than doubles compared to the *ITT* effect. This implies that actual treatment attendance increases the benefits of link formation, since farmers might want to discuss the offered technologies with other group members who also attended one of the training sessions, even if not the same. It is also possible that farmers agree to update each other on the contents of a session, in case one of them cannot attend. How important is it that both farmers attend at least one session jointly to stimulate the creation of a new information link? If *i* and *j* attended at least one session jointly, the likelihood of creating a link increases by 21 percentage points on the average (Table 6). The effect is slightly larger, which may be due to the reduction in the transaction costs of link formation (setting up a time and date to meet) from which two farmers jointly attending an extension meeting can benefit. Thus, our results suggest that joint attendance of extension sessions, but also attendance in general, are important pathways through which new links are promoted.

Table 5: Attendance statistics within treatment group

	Mean (s.d.)	Min.	Max.
Individual level ($N_{Household}$=608)			
Training attendance (1=yes)	0.53 (0.50)	0	1
Number of training sessions attended	1.76 (2.41)	0	13
Dyadic level (N_{Dyads}=9,908)			
Both attended at least one training session (1=yes)	0.40 (0.49)	0	1
Both attended at least one training session **jointly** (1=yes)	0.34 (0.48)	0	1
Number of training sessions attended jointly	0.74 (1.39)	0	13

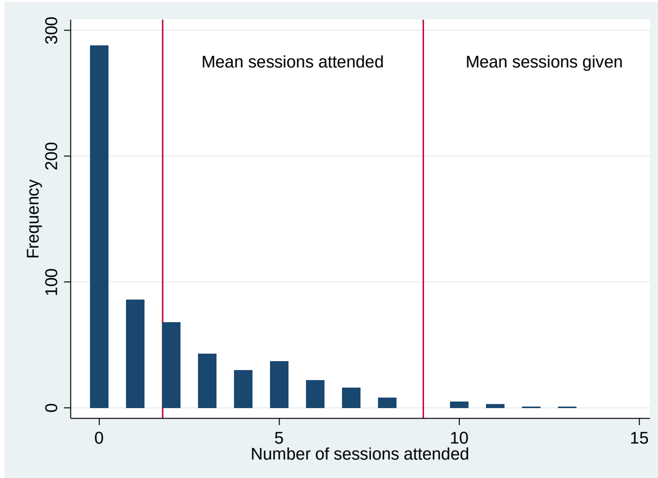


Figure 3: Distribution of attended sessions (only treatment farmers, n=608)

Table 6: Effects of training attendance on new link formation (IV results)

	(1) *New link*	(2) *New link*
Both attended at least one training session (1=yes)	0.183***	
	(0.0553)	
Both attended at least one training session ***jointly*** (1=yes)		0.213***
		(0.0652)
Constant	0.0417	0.0478
	(0.0776)	(0.0786)
Baseline controls	Yes	Yes
N_{Dyads}	13,318	13,318

Note: Coefficient estimates are shown with robust standard errors clustered at farmer group level in parentheses. The treatment variable is a dummy that takes a value of one if both attended at least one training session (jointly). Control variables include the following dummies: *i* and *j* are both female, *i* and *j* are both male, *i* is a group leader, *j* is a group leader, *i* and *j* are both group leaders, the number of agricultural links *i* named outside of the group (external links), the number of agricultural links *j* named outside of the group (external links), *i* and *j* share a same plot border. Other controls are the sums and differences of age in years, years of education as well as land size. Asterisks *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. First and second stage regressions with control variables are shown in Table A8 and A9 in the Appendix.

7. Conclusion

Little is known about the flow of information within farmer groups and how interventions affect networks. This knowledge can however be crucial to cost-effectively deliver information to farmers. In this article, we analyze how group-based extension influences agricultural communication networks. Our results show that group-based extension significantly increases link formation in comparison to the control group. We also show that this increase in network activity is predominantly driven by the creation of new communication links. Further, we find that (joint) training attendance more than doubles the likelihood of new link formation, indicating that the extension meetings can lower transaction costs attached to link formation or increase the benefits of sharing information.

These findings have important implications since they demonstrate that farmer groups can indeed serve as efficient information platforms that reduce costs attached to building up a network, as well as increase the benefits of link formation. Our study indicates that communication networks of farmers can be positively influenced by group-based extension – especially through new link formation. In particular new link formation is welcome, since it may expand ones exposure to new information and perspectives (McPherson et al. 2001). By fostering positive network activity, group-based extension can thus be an efficient approach for technology delivery. This becomes especially relevant in times where lead farmers become a popular target of agricultural interventions – an approach that is prone to the empowerment of single individuals with little spill-overs to the community (Kondylis et al. 2017).

Our study is among the first using detailed network panel data to illustrate network changes within farmer groups in response to a randomized agricultural intervention. Collecting detailed network data is time-consuming; however, important to understand how information flows within networks. We believe that for the collection of network data, which is usually costly, researchers should carefully consider the existing network sampling strategies and the local setting to find the most feasible, context-specific solution allowing them to address their research questions. Collecting data with smart devices may facilitate the collection of network data in the future.

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Appendix

Table A1: Additional effects of treatment 2 and treatment 3 on network changes

	Treatment 1 vs. Control	Treatment 2 vs. Treatment 1	Treatment 3 vs. Treatment 2
	$Link(t_1)$	$Link(t_1)$	$Link(t_1)$
ET	0.123**	-0.0482	0.0523
	(0.0536)	(0.0489)	(0.0482)
Constant	0.203	0.194	-0.0768
	(0.144)	(0.127)	(0.152)
Controls	Yes	Yes	Yes
Test H_0 : T1=T2 (*p*-value)		0.47	
Test H_0 : T2=T3 (*p*-value)			0.39
N_{Dyads}	6,762	6,706	6,556

Note: Treatment 1: agricultural training (assigned to 7 sessions), treatment 2: agricultural training plus nutrition training, treatment (assigned to 10 sessions) 3: agricultural training plus nutrition training, plus market training (assigned to 13 sessions). $Link(t_1)$ is a dummy turning 1 if an agricultural link between *i* and *j* was reported at follow-up. Control variables include the following dummies: *i* and *j* are both female, *i* and *j* are both male, *i* is a group leader, *j* is a group leader, *i* and *j* are both group leaders, the number of agricultural links *i* named outside of the group (external links), the number of agricultural links *j* named outside of the group (external links), *i* and *j* share a same plot border. Other controls are the sums and differences of age in years, years of education as well as land size. LPM coefficients are shown with robust standard errors clustered at a farmer group level. Asterisks *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table A2: Attrition per treatment arm on farmer group level

Treatment group	Interviewed 2015	Interviewed 2016	Attrition	Attrition %
Control	207	183	24	0.12
Treatment	608	536	72	0.12
Treatment 1	*203*	*188*	*15*	*0.07*
Treatment 2	*205*	*170*	*35*	*0.17*
Treatment 3	*200*	*178*	*22*	*0.11*
$N_{Household}$	815	719	96	0.12

Note: 824 farmers were interviewed during baseline, but only 815 had completed the network part. During Follow-up 746 household were interviewed, however, due to missing network data our analysis is based on 719 observations.

Table A3: Descriptive statistics of sampled farmers

	Full sample Mean (s.d.)
Gender (1=male)	0.38
	(0.49)
Age in years	46.50
	(12.51)
Education in years	8.68
	(3.67)
External links named	4.46
	(2.74)
Married (1=yes)	0.75
	(0.43)
Single or divorced (1=yes)	0.03
	(0.17)
Widowed (1=yes)	0.22
	(0.42)
Household head (1=yes)	0.60
	(0.49)
Male household head (1=yes)	0.38
	(0.49)
Female household head (1=yes)	0.23
	(0.42)
Group leadership position (1=yes)	0.30
	(0.46)
Number of memberships in different groups	1.32
	(0.59)
Land size (acres)	1.40
	(1.18)
Household size	5.62
	(2.07)
Main occupation farming (1=yes)	0.86
	(0.35)
$N_{Household}$	815

Note: s.d. refers to standard deviation. The variable "external links named" refers to the number of agricultural contacts the farmer listed outside of the farmer group, based on the following question: *please name the persons outside of your common interest group you most frequently exchanged information about agriculture between Oct14/Sept15. Please name a maximum of 5 persons.* Group leadership position entails all group officials, namely group leader, treasurer and secretary.

Table A4: Group level balance check of baseline covariates

	(1) Full sample Mean (s.d.)	(2) Control Mean (s.d.)	(3) Treatment Mean (s.d.)	(4) Control-Treatment Diff. (t-stat.)
Group Characteristics				
Group's age in years	7.16	9.21	6.47	2.736
	(4.55)	(6.68)	(3.49)	(1.84)
Share of men within CBO[s]	0.39	0.35	0.41	-0.0553
	(0.24)	(0.17)	(0.26)	(-0.67)
Female only (1=yes)	0.08	0.08	0.08	0
	(0.28)	(0.29)	(0.28)	(0.00)
Female dominated (>60%) (1=yes)	0.46	0.58	0.42	0.167
	(0.50)	(0.51)	(0.50)	(0.99)
Mixed gender (40-59%) (1=yes)	0.33	0.33	0.33	0
	(0.47)	(0.49)	(0.48)	(0.00)
Male dominated (>60%) (1=yes)	0.19	0.00	0.25	-0.250[a]
	(0.40)	(0.00)	(0.44)	(-1.87)
Share of kinship relations	0.54	0.47	0.56	-0.0948
	(0.19)	(0.16)	(0.20)	(-1.51)
Main function agriculture (1=yes)	0.52	0.58	0.50	0.0833
	(0.50)	(0.51)	(0.51)	(0.49)
KAPAP group (1=yes)	0.27	0.33	0.25	0.0833
	(0.45)	(0.49)	(0.44)	(0.55)
Actual group size[s]	21.13	21.25	21.08	0.167
	(3.72)	(4.11)	(3.67)	(0.13)
County (1=Kisii)[s]	0.67	0.67	0.67	0
	(0.47)	(0.49)	(0.48)	(0.00)
N_{Group}		12	36	48

Note: [a] Additional to t-tests, a two-sample Wilcoxon rank-sum (Mann-Whitney) test has been reformed to correct for the small sample size. Variables remain balanced. An exception is that there are significantly more male-dominated in the treatment group (significant at a 10 percent level). [s] refers to our stratification variables.

Table A5: Balance check of baseline covariates on an individual level

	(1) Full sample Mean (s.d.)	(2) Control Mean (s.d.)	(3) Treatment Mean (s.d.)	(4) Control-Treatment Diff. (t-stat.)
Gender (1=male)	0.38	0.34	0.40	-0.0550
	(0.49)	(0.48)	(0.49)	(-1.41)
Age in years	46.50	43.76	47.44	-3.674***
	(12.51)	(11.35)	(12.75)	(-3.68)
Education in years	8.68	9.14	8.52	0.617*
	(3.67)	(3.50)	(3.72)	(2.09)
External links named	4.46	4.60	4.40	0.199
	(2.74)	(2.68)	(2.76)	(0.90)
Married (1=yes)	0.75	0.85	0.72	0.128***
	(0.43)	(0.36)	(0.45)	(3.71)
Single or divorced (1=yes)	0.03	0.04	0.02	0.0188
	(0.17)	(0.20)	(0.16)	(1.38)
Widow (1=yes)	0.22	0.11	0.26	-0.147***
	(0.42)	(0.32)	(0.44)	(-4.45)
Household head (1=yes)	0.60	0.47	0.65	-0.183***
	(0.49)	(0.50)	(0.48)	(-4.70)
Male household head (1=yes)	0.38	0.34	0.39	-0.0468
	(0.49)	(0.48)	(0.49)	(-1.20)
Female household head (1=yes)	0.23	0.13	0.26	-0.136***
	(0.42)	(0.33)	(0.44)	(-4.07)
Group leadership position (1=yes)	0.30	0.27	0.31	-0.0436
	(0.46)	(0.45)	(0.46)	(-1.18)
Number of group memberships	1.32	1.32	1.32	-0.00353
	(0.59)	(0.53)	(0.61)	(-0.07)
Land size (acres)	5.62	5.97	5.50	-0.103
	(1.18)	(1.02)	(1.23)	(-1.08)
Household size	5.62	5.97	5.50	0.461**
	(2.07)	(2.13)	(2.04)	(2.78)
$N_{Household}$	815	207	608	815

Note: Asterisks *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table A6: Balance check of baseline covariates on dyadic level

	(1) Control	(2) Treatment	(3) Control-Treatment
	Mean (s.d.)	Mean (s.d.)	Diff. (t-stat.)
Dependent variables			
Agricultural Link (1=yes)	0.50	0.50	0.00424
	(0.50)	(0.50)	(0.43)
Proximity			
Both male (1=yes)	0.13	0.22	-0.0890***
	(0.33)	(0.41)	(-11.37)
Both female (1=yes)	0.46	0.44	0.0222*
	(0.50)	(0.50)	(2.25)
i is group leader (1=yes)	0.24	0.29	-0.0464***
	(0.43)	(0.45)	(-5.23)
j is group leader (1=yes)	0.24	0.29	-0.0464***
	(0.43)	(0.45)	(-5.23)
Both are group leaders (1=yes)	0.06	0.08	-0.0282***
	(0.23)	(0.28)	(-5.37)
External links *i*	4.61	4.41	0.196***
	(2.66)	(2.77)	(3.61)
External links *j*	4.61	4.41	0.196***
	(2.66)	(2.77)	(3.61)
Plots sharing same border (1=yes)	0.08	0.09	-0.0136*
	(0.27)	(0.29)	(-2.42)
Sum of:			
Land size in acre	2.64	2.86	-0.224***
	(1.55)	(1.85)	(-6.34)
Years of education	18.28	17.02	1.263***
	(4.95)	(5.54)	(11.79)
Years of age	87.52	95.02	-7.505***
	(17.33)	(19.60)	(-19.85)
Diff in:			
Land size in acre	0.00	0.00	0
	(1.31)	(1.69)	(0.00)
Years of education	0.00	-0.00	0.000303
	(4.92)	(5.02)	(0.00)
Years of age	0.00	0.00	-0.00161
	(14.61)	(16.60)	(-0.01)
N_{Dyads}	3,410	9,908	13,318

Note: Asterisks *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table A7: Effects of treatments on new links or maintaining links (difference-in-difference)

	(1) *New link*	(2) *Broke-up link*
Post**ET*	0.0701***	-0.0403
	(0.0216)	(0.0368)
Post (Dummy)	0.106***	0.302***
	(0.0173)	(0.0347)
ET (Dummy)	0.00101	-0.00126
	(0.00223)	(0.00310)
Both male (1=yes)	-0.00145	0.00898
	(0.00618)	(0.00884)
Both female (1=yes)	0.00908	0.00210
	(0.00797)	(0.00814)
i is group leader (1=yes)	-0.0116	0.00634
	(0.00933)	(0.0145)
j is group leader (1=yes)	-0.00248	0.00188
	(0.00470)	(0.00558)
Both are group leaders (1=yes)	-0.0112	-0.0121
	(0.00832)	(0.0110)
External links *i*	-0.00213	0.00597***
	(0.00174)	(0.00188)
External links *j*	-0.000163	0.000270
	(0.000704)	(0.000755)
Plots sharing same border (1=yes)	0.00879	0.00832
	(0.00674)	(0.00922)
Sum of:		
Land size in acre	-0.000250	0.000439
	(0.00187)	(0.00241)
Years of education	0.00104	-0.000560
	(0.000724)	(0.000794)
Years of age	0.000145	0.000104
	(0.000286)	(0.000321)
Diff in:		
Land size in acre	0.00289	-0.00181
	(0.00183)	(0.00278)
Years of education	0.000264	-0.000624
	(0.000622)	(0.000825)
Years of age	-0.000135	-8.90e-05
	(0.000216)	(0.000296)
Constant	-0.0212	-0.0329
	(0.0342)	(0.0359)
N_{Dyads}	26,636	26,636
R-squared	0.094	0.161

Table A8: Effects of Extension Treatments on new link formation at follow-up, Treatment-On-The-Treated Estimates (IV Results with training attendance dummy)

	(1)	(2)	(3)
	LPM	Two-stage least square regressions	
		First stage	Second stage
	New link		*New link*
Both attended at least one training session (1=yes)	0.0426**		0.183***
	(0.0179)		(0.0553)
Both male (1=yes)	0.00395	-0.0170	0.000215
	(0.0115)	(0.0388)	(0.0126)
Both female (1=yes)	0.0157	0.0770**	0.00410
	(0.0173)	(0.0370)	(0.0173)
i is group leader (1=yes)	-0.0237	0.0727***	-0.0364**
	(0.0181)	(0.0221)	(0.0183)
j is group leader (1=yes)	-0.00555	0.0727***	-0.0182*
	(0.0101)	(0.0221)	(0.0102)
Both are group leaders (1=yes)	-0.0215	-0.00614	-0.0213
	(0.0169)	(0.0256)	(0.0176)
External links i	-0.00440	-0.00128	-0.00403
	(0.00355)	(0.00435)	(0.00381)
External links j	-0.000457	-0.00128	-9.16e-05
	(0.00149)	(0.00435)	(0.00163)
Plots sharing same border (1=yes)	0.0177	0.0178	0.0143
Sumo f:	(0.0133)	(0.0300)	(0.0142)
Land size in acre	0.000341	-0.00943	0.00122
	(0.00373)	(0.00681)	(0.00378)
Years of education	0.00199	-0.00559	0.00311**
	(0.00151)	(0.00336)	(0.00157)
Years of age	0.000467	-0.000568	0.000394
Diff in:	(0.000584)	(0.00118)	(0.000603)
Land size in acre	0.00578	6.98e-06	0.00577
	(0.00365)	(7.34e-06)	(0.00361)
Years of education	0.000527	4.85e-07	0.000527
	(0.00124)	(7.20e-07)	(0.00123)
Years of age	-0.000270	-1.77e-06	-0.000270
	(0.000433)	(1.61e-06)	(0.000428)
Treated (1=yes)		0.395***	
		(0.0407)	
Constant	0.0884	0.119	0.0417
	(0.0685)	(0.129)	(0.0776)
N_{Dyads}	13,318	13,318	13,318
R-squared	0.007	0.171	

Note: Coefficient estimates are shown with robust standard errors clustered at farmer group level in parentheses. The treatment variable is a dummy that takes a value of one if both attended at least one training session jointly. Asterisks *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table A9: Effects of Extension Treatments on new link formation at follow-up, Treatment-On-The-Treated Estimates (IV Results with joined training attendance dummy)

	(1)	(2)	(3)
	LPM	Two-stage least square regressions	
		First stage	Second stage
	New link		*New link*
Both attended at least one training session jointly (1=yes)	0.0451**		0.213***
	(0.0181)		(0.0652)
Both male (1=yes)	0.00394	-0.0121	-0.000316
	(0.0117)	(0.0360)	(0.0138)
Both female (1=yes)	0.0157	0.0741*	0.00238
	(0.0171)	(0.0375)	(0.0176)
i is group leader (1=yes)	-0.0242	0.0825***	-0.0407**
	(0.0182)	(0.0217)	(0.0189)
j is group leader (1=yes)	-0.00610	0.0825***	-0.0225**
	(0.0102)	(0.0217)	(0.0104)
Both are group leaders (1=yes)	-0.0213	-0.00927	-0.0205
	(0.0169)	(0.0278)	(0.0180)
External links i	-0.00449	0.000734	-0.00442
	(0.00353)	(0.00421)	(0.00382)
External links j	-0.000550	0.000734	-0.000482
	(0.00149)	(0.00421)	(0.00164)
Plots sharing same border (1=yes)	0.0172	0.0292	0.0114
Sumo f:	(0.0132)	(0.0267)	(0.0142)
Land size in acre	0.000378	-0.00945	0.00152
	(0.00375)	(0.00722)	(0.00386)
Years of education	0.00196	-0.00474	0.00310**
	(0.00150)	(0.00311)	(0.00157)
Years of age	0.000469	-0.000489	0.000394
Diff in:	(0.000588)	(0.00105)	(0.000620)
Land size in acre	0.00578	6.13e-06	0.00577
	(0.00365)	(6.65e-06)	(0.00361)
Years of education	0.000527	3.90e-07	0.000527
	(0.00124)	(5.83e-07)	(0.00123)
Years of age	-0.000270	-1.41e-06	-0.000270
	(0.000433)	(1.37e-06)	(0.000428)
Treated (1=yes)		0.338***	
		(0.0391)	
Constant	0.0910	0.0738	0.0478
	(0.0682)	(0.117)	(0.0786)
N_{Dyads}	13,318	13,318	13,318
R-squared	0.007	0.145	

Note: Coefficient estimates are shown with robust standard errors clustered at farmer group level in parentheses. The treatment variable is a dummy that takes a value of one if both attended at least one training session jointly. Asterisks *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.