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An Empirical Analysis of Expanding Rice Production in Sub-Sahara Africa

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The Impact of Training on Technology Adoption and Productivity of Rice Farming in Tanzania: Is Farmer-to-Farmer Extension Effective?

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Abstract

How far can new technologies taught to a small number of selected farmers diffuse to other farmers in a village? In order to answer this question, this paper investigates the impact of JICA training on the adoption of rice cultivation technologies and productivity in an irrigation scheme in Tanzania. By using a unique five-year panel data set and spatial econometric techniques, we found that non-trained farmers learned new technologies from trained farmers through social networks and by observing their plots. As a result, the paddy yield of directly trained farmers increased from 3.1 tons per hectare in 2008 to 4.7 tons per hectare in 2012, while that of non-trained farmers increased from around 2.6 tons per hectare in 2008 to 3.7 tons per hectare in 2012.

Keywords: technology adoption, agricultural training, social learning, rice, Sub-Saharan Africa

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1. Introduction

Technological change is a necessary step in the development process. This is especially true for agricultural development in Sub-Saharan Africa (SSA), where agricultural productivity has been largely stagnant for many years. This is in sharp contrast to the experience of Asia where the Green Revolution has significantly improved the grain yields for the last several decades (Otsuka and Kalirajan 2005; Otsuka and Yamano 2005). Among major cereals rice is considered to be one of the most promising crops to achieve the African Green Revolution (Otsuka and Kijima 2010; Seck et al. 2010; Tsusaka and Otsuka 2013). Fertilizer-responsive high-yielding modern varieties developed in Asia have exhibited high yield potential and adaptability in SSA (Otsuka and Larson 2013; Nakano et al. 2013). Despite the significant high yield potential, however, modern varieties, chemical fertilizers, and improved agronomic practices, have yet to be widely adopted in SSA (Nakano et al. 2014). Since technologies with high-potential are already available, it is vitally important to investigate how technologies diffuse among small-scale farmers for the improvement of rice productivity in SSA.

Among major determinants of the diffusion of new technology, social learning or knowledge spillover is considered as one of the most important factors in technology dissemination (Feder et al. 1985; Besley and Case 1993; Foster and Rosenzweig 1995; Munshi 2004). Recently there has been increasing empirical interest in social learning at the individual level, and some studies observe that social leaning or "learning from others" plays a significant role in technology adoption (Case 1992; Foster and Rosenzweig 1995; Munshi 2004; Bandiera and Rasul 2006; Adegbola and Gardebroek 2007; Conley and Udry 2010). However, little is known as to whether, and to what extent, new technologies taught to a small number of selected farmers can diffuse to and increase the productivity of other farmers in a village. In other words, the question is whether a farmer-to-farmer technology dissemination approach is effective.

Although very crucial in designing the extension strategies, this question has not received sufficient attention in the literature.[1]

By using a unique household-level data set collected in an irrigation scheme in Tanzania, this paper investigates the effectiveness of farmer-to-farmer training programs provided by Japan International Cooperation Agency (JICA) and Ministry of Agriculture Training Institute (MATI) of Tanzania in 2009, on rice cultivation technologies. JICA and MATI intended to establish a farmer-to-farmer training scheme, called TANRICE training,[2] in searching for the cost-effective way of disseminating agricultural technologies. They first trained 20 farmers ("key farmers") in the irrigation scheme intensively at the nearby training institute for 12 days before the cultivating season of 2009 started. Key farmers together with officers of MATI held training sessions during the season at the demonstration plot in the irrigation scheme. In these training sessions, each key farmer was responsible for inviting 5 farmers. These farmers were referred to as intermediary farmers, and were expected to train other non-trained ordinary farmers later as well.

We have constructed a panel data set for five years to cover the period before and after TANRICE training by combining survey data from 2010 to 2012 and recall data for 2008 and 2009. First, we hypothesize that key farmers adopt new technologies and achieve higher yield than intermediary and ordinary farmers because they are most intensively trained. Then, intermediary farmers would follow key farmers, and the yield gap between intermediary and ordinary farmers would also be widened. However, as time goes on, ordinary farmers would catch up with key and intermediary farmers by learning technologies from them, and the gaps in yield and technology among them would become negligible. We also hypothesize that the social network and geographical proximity with key and intermediary farmers play an important role in

[1] Several impact evaluation studies on Farmers Field School (FFS) have been conducted (Feder et al. 2004; Gotland et al. 2004; Tripp et al. 2005). In FFS, extension officers provide training to surrounding farmers typically by managing demonstration plots.

[2] The formal name of TANRICE training is Technical Cooperation in Supporting Service Delivery Systems of Irrigated Agriculture (TC-SDIA).

technology adoption by ordinary farmers because ordinary farmers were not trained directly in TANRICE training.

In order to examine our first hypothesis, we estimate the impact of TANRICE training on the adoption of technologies by key, intermediary, and ordinary farmers, and on their productivity. Second, we investigate the role of social networks, and plot proximity with key and intermediary farmers, on the adoption of technologies by ordinary farmers, by using spatial econometric models. We aincorporate possible spillover effects from ordinary farmers, as the early adopters may influence other ordinary farmers' behavior. We capture the heterogeneous influence of the adoption of technologies by key, intermediary, and other ordinary farmers on ordinary farmers' behavior by constructing neighborhood structures that give greater weight to farmers who cultivate the plots nearby from ordinary farmer's.

The paper is organized as follows: Section 2 explains the study site and the data collection method, followed by the descriptive analyses in Section 3. Section 4 shows the regression analyses of the impact of TANRICE training on the adoption of technologies and the paddy yield of key, intermediary, and ordinary farmers. In section 5 we perform spatial econometric analyses to examine whether knowledge spills over from key and intermediary farmers to ordinary farmers, and possibly among ordinary farmers, through social and geographical networks. Section 6 concludes the paper.

2. Study Site and Data

The surveys were conducted in the Ilonga irrigation scheme in Kilosa district, Morogoro region, Tanzania. The Ilonga irrigation scheme is approximately 15km away from the nearest town, Kilosa. During the main season at the study site (i.e., October to June), farmers grow rice in irrigated plots, and other crops, such as maize, beans, and vegetables, in upland plots. During the short cultivation season from July to September, some farmers grow vegetables in the irrigation scheme.

In the irrigation scheme, JICA conducted training on basic rice cultivation technologies, before and during the main season of 2008–09 (from November 2008 to August 2009, which will hereinafter be referred to as "2009"). The contents of TANRICE training include the use of modern varieties, chemical fertilizer, improved bund construction, plot leveling, and transplanting in rows. Improved bund construction involves piling soil firmly around plots, while levelling entails making the ground flat for storing and distributing water equally in paddy fields. By transplanting seedlings in rows, a rice grower can control the plant density accurately and remove weeds easily.

As we discussed earlier, JICA and MATI first trained 20 farmers, called key farmers, at the nearby training center, for 12 days in November 2008 before the cultivation season of 2009 started.[3] Second, during the main season in 2009, key farmers, with the support of the officers of MATI, provided three-day training sessions at the nursery preparation, transplanting, and harvesting stages at the demonstration plot in the irrigation scheme. These training sessions were called "in-field training" and each key farmer was supposed to invite five intermediary farmers, who would also be responsible for training other farmers later in the scheme. One day of in-field training was open to all the farmers in the scheme, including ordinary farmers.

The first interview was conducted from September to December 2010. A total of 208 farmers were interviewed on their rice cultivation practices during the main season of 2010 (2009-2010). During the interview, farmers were asked to identify the most important rice plot for their livelihood and asked in detail about their rice cultivation practices on that plot. We refer to this as the "sample plot". In the first survey we collected the GPS coordinates of sample plots in order to calculate geographical distances among sample plots. Figure 1 shows the map of

[3] TANRICE officers asked villagers to select key farmers on the basis of criteria such as farmer's age, ability to read and write, gender balances, residency of the Ilonga irrigation scheme, and practicing rice farming. According to the farmers, they selected key farmers during the all-villagers meeting.

sample plots cultivated by key, intermediary, and ordinary farmers. We also collected recall data on the rice cultivation practices in the sample plot for the main seasons of 2008 and 2009, which were before and during the TANRICE training respectively. In the second and third round of interviews we revisited the same households in 2011 and 2012, and asked about rice cultivation on the sample plot in the 2011 and 2012 main seasons.

After dropping those observations which had unrealistic value in key variables, and those who did not cultivate rice on the sample plot, the number of sample households became 171 in 2008, 182 in 2009, 202 in 2010, 168 in 2011, and 167 in 2012.[4] For cross sectional analyses, we use these data sets. For panel data analysis we omit those households who did not grow rice in any single year from 2008 to 2012, and construct a balanced data set of 121 households for five years, generating a total sample size of 605. Summary statistics of all the variables used in the following descriptive and regression analyses are provided in Appendix Table A1.

3. Descriptive Analyses and Testable Hypotheses

Table 1 presents descriptive analyses of paddy yields and technology adoption by key, intermediary, and ordinary farmers from 2008 to 2012. We also show the results of *t*-tests comparing between ordinary and key farmers, and between ordinary and intermediary farmers in each year. Note that the TANRICE training was conducted before and during the cultivation season of 2009, for key and intermediary farmers respectively, and the recall data for 2008 and 2009 were collected during the survey in 2010.

As shown in the table, even prior to the TANRICE training in 2008, key farmers achieved slightly higher yield than ordinary farmers. However, the difference in yield between key and ordinary farmers was merely 0.5 tons per hectare and there was no statistically

[4] Note that the number of sample households in 2010 is larger than in 2009 and 2008, because we use recall data for 2009 and 2008, which is collected during the survey conducted in 2010.

significant difference in yield between intermediary and ordinary farmers. The key farmers' paddy yield increased soon after the training from 3.1 tons per hectare in 2008 to 4.4 tons per hectare in 2009, due to their high technology adoption rate. After the TANRICE training, the adoption rate of modern varieties, improved bund construction, plot leveling, and transplanting in rows by key farmers increased rapidly from 2009, remaining high until 2012. As a result, key farmers achieved higher yield than ordinary farmers by about 2 tons per hectare from 2009 to 2011 and the differences are statistically highly significant.

Soon after the training in 2009, intermediary farmers started adopting new technologies including modern varieties, improved bund, and transplanting in rows. However, the increase in the paddy yield of the intermediary farmers was not as sharp as that of the key farmers; it increased from 2.5 tons per hectare in 2008 to 4.6 tons per hectare in 2011. The difference in paddy yield between ordinary and intermediary farmers became significant only in 2011.

The paddy yield of ordinary farmers also increased from 2.6 tons per hectare in 2008 to 3.7 tons per hectare in 2012. This increment can also be attributed to an increase in the application of chemical fertilizer and the adoption of improved agronomic practices among ordinary farmers, although the change was neither rapid nor drastic compared with the key and intermediary farmers. Since only the one-day in-field training was open to all the farmers in the scheme, ordinary farmers had very limited opportunity to learn new technologies directly from TANRICE training. Nonetheless, the adoption of technologies and the paddy yield of ordinary farmers have increased. These results support our hypothesis that technologies taught in TANRICE training were diffused slowly from key and intermediary farmers to ordinary farmers.

Table 2 summarizes the answers to the questions regarding the major sources of information which drove technology adoption in 2010. Most key and intermediary farmers received information on new technologies from the TANRICE training, with the exception of plot leveling, which is not a new technology in the study site. On average, 80-90% of key and intermediary farmers learned modern varieties, improved bund, and transplanting in rows from the TANRICE training. In contrast, for the ordinary farmers, other farmers were an important source of information. About 60% of ordinary farmers learned technologies, including modern varieties (MVs), improved bund construction, and transplanting in rows, by observing the practices of other farmers. This suggests the importance of social and geographical networks with key and intermediary farmers in technology adoption, especially for ordinary farmers.

Table 3 examines the paddy yield and the adoption of technologies by ordinary farmers in 2010 according to their relationships with key and intermediary farmers. We show the mean difference and the results of *t*-tests, comparing ordinary farmers with and without relatives, residential neighbors within 300m radius of their homesteads, and the same church or mosque members, who are key or intermediary farmers.[5] Ordinary farmers whose relatives are key and intermediary farmers adopted plot leveling and transplanting in rows significantly more than those without such relatives. Similarly, ordinary farmers who have key and intermediary farmers as their residential neighbors were more likely to adopt MVs and apply more chemical fertilizer than those without such neighbors. Ordinary farmers who attended the same church or mosque as key and intermediary farmers adopted MVs and plot leveling more often than those who did not. These results support our hypothesis that the social networks facilitate the diffusion of new technologies from key and intermediary farmers to ordinary farmers.

[5] During the interview we showed the list of key and intermediary farmers in our sample to sample farmers and asked if he or she is a relative of one of the farmers, is a residential neighbor within 300m radius of one of the farmers, or attends the same church or mosque as someone on the list.

4. Impact of TANRICE Training on Technology Adoption and Productivity

4.1 Methodology and Variable Construction

We estimate the impact of TANRICE training on the adoption of rice cultivation technologies and paddy yield by regression analyses. We employ two sets of methods: the first ones are average treatment effect (ATE) models, while the second ones are household fixed effect models (Imbens and Wooldridge 2007; Wooldridge 2010). In both models, the dependent variables are paddy yield (t/ha) and the following sets of technology adoption variables: the dummy variable that takes one if a farmer adopts MVs; amount of chemical fertilizer use (kg/ha); and dummy variables that take one if improved bund construction, plot leveling , and transplanting in rows are adopted.

Let y_1 denote the outcome of interest with training, and y_0 the outcome of the same household without training. Let the variable w be a binary treatment indicator, where w=1 denotes treatment and w=0 otherwise. Average treatment effect (ATE) can be defined as:

$ATE = E(y_1 - y_0)$ (1).

This can be considered as the expected effect of treatment on a randomly drawn person from the population. A fundamental problem here is that we cannot observe both y_1 and y_0 as an individual cannot be in both states at the same time.

Let x denote a vector of observable household characteristics and p(x) the probability of receiving treatment such that $p(x) = p(w=1|x)$. By using the inverse probability weight 1/p(x), ATE can be defined as:

$$ATE = E\left\{ \frac{[(w - p(x)y]}{p(x)[1 - p(x)]} \right\} \quad (2).$$

Thus, by estimating the probability of receiving treatment, we can estimate ATE (StataCorp, 2013).

Since our treatment status has two categories (being key and intermediary farmers), we use a multinomial-logit model in estimating $p(x)$.[6] The dependent variable is a categorical variable which takes one for being a key farmer and two for being an intermediary farmer. As independent variables, we include age of household head and its squared term, average years of schooling of adult household members, and the number of adult household members and its squared term, and the female headed household dummy to control for household human capital endowment. In order to control for the physical and land asset endowment, we include total size of owned plots and value of household asset (in million Tanzanian Shillings). We also include the dummy variables that take one if a farmer has any key farmer being a relative, a member of the same church or mosque, and a residential neighbor, which allows us to examine the impact of social relationships with key farmers on being selected as intermediary farmers.

In ATE estimation, we assume ignorability in mean:

$E(y_0 \mid x, w) = E(y_0 \mid x)$ and $E(y_1 \mid x, w) = E(y_1 \mid x)$ (3).

This assumption implies that if we can observe enough information (contained in x) that determines treatment, then the outcome can be mean independent of w, conditional on x (Wooldridge, 2010). Since the validity of this assumption is not directly testable, we also estimate a household fixed effect model by utilizing the panel feature of our data set to check for robustness (Imbens and Wooldridge, 2007). Specifically, the following model is estimated.

$y_{it} = \delta_t + \tau w_{it} + c_i + u_{it}$, t=1,…T (4), where

δ_t: time dummy

w_{it}: treatment status of the household i at time t

c_i: time invariant household characteristics

u_{it}: error term.

The advantage of this model is that we can control unobservable time-invariant household characteristics, denoted here as c_i, which might affect program participation. In order

[6] For more technical detail, see StataCorp (2013) and Wooldridge (2010).

to estimate the year-specific impact of being key or intermediary farmers, we include, in w, interaction terms of the year dummy and training status dummy variables that take one if a farmer is a key farmer or intermediary farmer. Thus, these terms capture the impact of the difference in being a key or intermediary farmer and an ordinary farmer in each year. The base category is all the farmers in 2008, which is before the TANRICE training. We also control for year dummies in δ_t, which capture the general trend as well as yearly shocks in outcome variables.

4.2 Regression Results

Table 4 shows the estimation results for the average treatment effect of being key and intermediary farmers on technology adoption and yield in each year.[7] Before the TANRICE training was implemented in 2008, the average paddy yield of key farmers was higher by 1.0 tons per hectare than that of ordinary farmers, suggesting that the productivity of key farmers was slightly higher than that of ordinary farmers even before TANRICE training. However, when it comes to technology adoption, there was no significant difference among the three categories, except for the higher adoption rate of improved bund construction by intermediary farmers.

After the training, the technology adoption rate of key and intermediary farmers became higher than those for ordinary farmers. As a result, the paddy yields of key farmers were higher than those of ordinary farmers by 2.1 tons per hectare in 2009 and by 2.4 tons per hectare in 2010. Furthermore, the paddy yield of intermediary farmers was also higher by 0.6 tons per hectare than ordinary farmers in 2010. These results support our first hypothesis that the adoption of technologies and the paddy yield of key and intermediary farmers, increase soon

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7 In Appendix Table A2, we show the estimation results of multinomial logit models for the determinants of training status, which works as the first stage regression of ATE estimation shown in Table 4. The coefficients are jointly significantly different from zero at the 10% level, suggesting the effectiveness of the estimation result as the first stage regression.

after the training and the gap between key and intermediary farmers and ordinary farmers would be widened at first.

However, as time went on, the difference in paddy yield between key and ordinary farmers decreased in 2011 and 2012. The yield gap between key and ordinary farmers reduced to 2.0 tons per hectare in 2011 and 1.5 tons per hectare in 2012. The difference in paddy yield between intermediary farmers and ordinary farmers also declined and became insignificant in 2012. Moreover, as shown in Table 1, the average paddy yield for ordinary farmers steadily increased from 2.6 tons per hectare in 2008 to 3.7 tons per hectare in 2012. We also observe a steady increase in the adoption of all the technologies by ordinary farmers. These results support our hypothesis that the difference between key and intermediary farmers and ordinary farmers became smaller as time went on after the training because ordinary farmers would catch up with key and intermediary farmers.

Table 5 shows the estimation results for household fixed effect models. The coefficient of the year dummies can be interpreted as the change in paddy yield and technology adoption for ordinary farmers compared with 2008. The interaction terms of key or intermediary farmer dummies and year dummies capture the difference in the paddy yield and technology adoption by key and intermediary farmers compared with ordinary farmers in the same year. Note that in these models, we control for households' unobservable innate characteristics. The year dummies have positive and significant coefficients in the adoption of chemical fertilizer and plot leveling from 2009 to 2012, suggesting that the adoption rate of these technologies increases steadily after the training for ordinary farmers. The adoption rate of other technologies including MVs, improved bund construction, and transplanting in rows became significant only in 2011 and 2012, suggesting that ordinary farmers adopted these technologies relatively slowly.

The interaction term of years 2009 and 2010 and the key farmer dummies, and that of intermediary and the year 2011 dummies, are significant on paddy yield, suggesting that key and intermediary farmers' yields grew faster than that of ordinary farmers initially. The coefficient of the year dummy on paddy yield became significant only in 2011 and 2012, suggesting that the paddy yield for ordinary farmers started increasing in 2011. A more significant finding, however, is that the interaction terms of the key farmer dummy and the 2011 and 2012 dummies, or that of the intermediary farmer dummy and the 2012 dummy have no significant impact on paddy yield. These results are consistent with our hypothesis that the impacts of direct training became negligible in the long run because ordinary farmers' productivity caught up with key and intermediary farmers.

5. Spatial Econometric Analyses on Knowledge SpillOver

5.1 Estimation Model

In this section, we estimate spatial models to investigate the impact of knowledge spillover from key and intermediary farmers to ordinary farmers. In this analysis, we focus on technology adoption by ordinary farmers, and thus, the sample here consists only of ordinary farmers. As we discussed earlier, we hypothesize that social networks and geographical proximity with key and intermediary farmers play important roles in the adoption of technologies by ordinary farmers because ordinary farmers were not trained directly at the TANRICE training. We also incorporate the possible spillover effect from neighboring ordinary farmers as the early adopters of technologies may influence the behavior of other ordinary farmers.

Let K, I, and O represent the numbers of key, intermediary, and ordinary farmers in our sample, respectively, and then we start by estimating the following cross-sectional model for each year:[8]

$$Y_o = X_o\beta + \rho W Y_o + \gamma W_k Y_k + \zeta W_i Y_i + u_o$$

$$u_o = \lambda W u_o + \varepsilon_o \qquad (5),$$

where

[8] For the details of spatial model derivation, see Anselin (2010), for example.

Y_o: The O-by-1 vector of adoption of a specific technology by O ordinary farmers

X_o: The O-by-m matrix of m household characteristics variables of O ordinary farmers

Y_k: The K-by-1 vector of adoption of technologies by K key farmers

Y_i: The I-by-1 vector of adoption of technologies by I intermediary farmers

W: The O-by-O weight matrix representing the quadratic distance decay among O ordinary farmers (row standardized)

W_k: The O-by-K weight matrix representing the quadratic distance decay between O ordinary farmers and K key farmers (row standardized)

W_i: The O-by-I weight matrix representing the quadratic distance decay between O ordinary farmers and I intermediary farmers (row standardized)

u_o: The O-by-1 vector of error term that may have a spatial process

ε_o: The O-by-1 vector of random error term assumed be i.i.d. with constant variance.

The dependent variables are the set of technology adoption variables: the dummy variable which takes one if an ordinary farmer adopts MVs; the amount of chemical fertilizer use (kg/ha); and dummy variables which take one if improved bund construction, leveling of plot, and transplanting in rows are adopted. In order to capture knowledge spillover from different types of farmers, we explicitly include the adoption of the same technology by key, intermediary, and other ordinary farmers as explanatory variables Y_k, Y_i, and Y_o, respectively. The adoption of technologies by farmers who cultivate far away from a particular farmer's plot is likely to have limited impact on technology adoption by that farmer. We attempt to take this into account by including the weight matrices W_k, W_i, and W, where the squared inverse distance is applied to each element of these matrices to account for the distance decay in neighborhood effects. We calculated the distance between plots by using GPS coordinates that were collected in the first survey.

WY_o is the spatial lag term, and its coefficient ρ captures the direct impact of the adoption of technologies by other ordinary farmers, who cultivate plots nearby, on the adoption by each sample farmer. Consequently, we interpret the coefficient ρ as the spillover effect among ordinary farmers. Likewise, $W_k Y_{kt}$ and $W_i Y_{it}$ represent the adoption by key and intermediary farmers, respectively, who cultivate plots near to each ordinary farmer. We interpret the coefficients γ and δ as the spillover effects from key and intermediary farmers. Spatially correlated effects of unobservable factors in the neighborhood (characterized by Wu_o) need to be separated from the endogenous effects (ρ). The coefficient λ absorbs such correlated effects.[9] The structural forms of the spatial models expressed above are further transformed into reduced forms and are estimated by maximum likelihood estimation (MLE).[10]

Further, in order to capture the effect of social relationship with key and intermediary farmers, we include the separate dummy variables which take one if the ordinary farmer has any key or intermediary farmer who is a relative, a member of the same church or mosque, and a residential neighbor. Other household characteristics are also controlled for, as done in the training status model.

For the spatial estimation we employ two specifications: one is the spatial lag model, which is also known as the spatial autoregressive model (SAR), where only spatial dependence in the dependent variable is incorporated, and the other is the SAR with a spatial autoregressive disturbance (SARAR) model, where the spatial dependence in both dependent variables and the disturbance term is controlled for (LeSage and Pace, 2009). Eq. (1) represents the SARAR model, whereas it reduces to the SAR model when λ = 0. In spatial econometrics, Lagrange Multiplier (LM) tests are commonly performed to select between different models (i.e., OLS, SAR, spatial error model (SEM), and SARAR). We also followed suit and in most cases, SAR and SARAR were suggested as the most suitable models. Accordingly, since our interest is in

[9] For detailed discussions of correlated social effects and the associated estimation problems known as *reflection problem*, see the pioneer work by Manski (1993). To ensure the identification of spillover effects, we also conducted the convenient test for necessary and sufficient conditions for identification proposed by Bramoullé et al. (2009) and passed it with rank 4.

[10] These spatial models need to be estimated by MLE or GMM as use of least squares regressions would suffer severe endogeneity bias. For IV or 2SLS estimations of spatial models, see Bramoullé et al. (2009) and Ward and Pede (2014).

looking into the spillover effect (including ρ) and comparing it across different technologies and years, we focus on presenting the estimation results for SAR and SARAR throughout the process. The result of the likelihood ratio (LR) test is also presented as the difference in the log likelihood of the models with and without spatial terms follows a chi-squared distribution.[11]

In addition to the cross-sectional approach, we take advantage of the panel feature of our data and estimate the spatial panel mode as well, whereby household and year fixed effects are controlled for (i.e., two-way fixed effect model).[12]

5.2 Estimation Results

Table 6 shows the regression results for the adoption of technologies by ordinary farmers in 2010. Columns (1) and (2) present the results for MVs; (3) and (4) for chemical fertilizer use; (5) and (6) for improved bund; (7) and (8) for plot leveling; and (9) and (10) for transplanting in rows. We show the results of SAR and SARAR models for each of the technologies. The results of the OLS models are largely significant with SAR and SARAR models, though the results are not shown here. The dummy variable for being a residential neighbor with key or intermediary farmers has a positive coefficient on the adoption of MVs and chemical fertilizer. These results suggest that social networks with key and intermediary farmers play a significant role in the adoption of MVs and chemical fertilizer by ordinary farmers. Furthermore, the coefficient ρ is positive in models (2), and (4), while the results of robust Lagrange multiplier (LM) tests support the validity of our SARAR models. The results suggest that the adoption of MVs and chemical fertilizer use by the plots neighboring ordinary farmers also has a positive impact on the adoption of these technologies by ordinary farmers in 2010. Our results imply that the information transmits not only from key and intermediary farmers to ordinary farmers, but also from early adopting ordinary farmers to other ordinary farmers.

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[11] The degree of freedom is the number of additional parameter(s), i.e., one for SAR and two for SARAR model.

[12] The detailed routine for spatial panel estimation is provided by Elhorst (2003).

Table 7 shows the results of the spatial estimation of the determinants of technology adoption by ordinary farmers in 2011. The structure of the table is the same as Table 6. Chemical fertilizer use by plot neighboring key farmers has a positive and significant coefficient in model (3), suggesting that there are some spillover effects on chemical fertilizer use from neighboring key farmers to ordinary farmers. Being residential neighbors with key and intermediary farmers has a positive and significant coefficient in the SAR model shown in (1), suggesting that social networks with key and intermediary farmers may have a positive impact on the adoption of MVs by ordinary farmers.

Table 8 summarizes the regression results for the adoption of technologies by ordinary farmers in 2012. The adoption by plot neighboring key and intermediary farmers has a positive and significant coefficient on the adoption of MVs by ordinary farmers in models (1) and (2). The adoption by neighboring intermediary farmers has a positive and significant impact on the adoption of transplanting in rows by ordinary farmers. Furthermore, being relatives with key and intermediary farmers has a positive and significant coefficient on the adoption of transplanting in rows in models (9) and (10). These results suggest that technologies taught to key and intermediary farmers spill over to neighboring ordinary farmers.

Lastly, Table 9 shows the estimation results for the panel spatial estimations on the adoption of technologies by ordinary farmers. Consistently with the results of cross-sectional analyses, we found the positive and significant coefficient of the adoption of MVs by neighboring key farmers on the adoption of MVs by ordinary farmers. Furthermore, the adoption of the same technology by neighboring intermediary farmer has positive and highly significant coefficient on the chemical fertilizer use and transplanting in rows. These results also support our hypothesis that the technologies taught in TANRIC training to key and intermediary farmers spill over to ordinary farmers. We observe a negative coefficient of the adoption of improved bund by neighboring key farmers, which is inconsistent with our hypothesis, and thus, further investigation is needed on this point.

6. Conclusion

While the adoption and dissemination of agricultural technologies among small-scale farmers are of paramount importance in achieving an African Green Revolution, little has been known as to whether and to what extent technologies can disseminate from trained farmers to non-trained farmers within communities. In this regard, this paper investigates the impact of farmer-to-farmer training conducted by JICA on the adoption of rice cultivation technologies and the paddy yield in rural Tanzania. Our results show that new technologies were firstly adopted by key and intermediary farmers, and hence, the yield gap between key and intermediary farmers and ordinary famers widened initially. However, as time went on, the technologies diffused gradually from key and intermediary to ordinary farmers. As a result, the paddy yield of key farmers substantially increased from 3.1 tons per hectare in 2008 to 4.7 tons per hectare in 2012, while that of ordinary farmers was noticeably boosted from 2.6 tons per hectare in 2008 to 3.7 tons per hectare in 2012.

Our analysis also suggests that both social networks and plot proximity with key and intermediary farmers play an important role in the process of technology adoption by ordinary farmers. In particular, the geographical proximity of the plots of key and intermediary farmers and their technology adoption behavior have a highly significant impact on the adoption of MVs and transplanting in rows by ordinary farmers, for which the practice is visually identifiable. It is also observed that not only plot proximity but also social ties with key and intermediary farmers have positive impacts on the adoption of some technologies by ordinary farmers, namely, MV, chemical fertilizer, plot leveling, and transplanting in rows, particularly at the early stage of technology adoption process.

Overall, our results contribute to justifying farmer-to-farmer extension strategies. Given that extension officers or an aid agency can only train a limited number of farmers at once, this style of farmer-to-farmer extension strategy can be a reasonable option for technology dissemination programs. Another point is that in our study site it took a few years for non-trained farmers to adopt newly introduced technologies and increase their productivity through social learning from trained farmers. This implies that the impact evaluation of a farmer-to-farmer extension program should be conducted not in the short-run but at least a few years later, in order to fully capture the impact of spillover from trained farmers to non-trained farmers.

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Table 1. Paddy yield and the adoption of technologies by training status

	Key Farmers				
Variable	2008	2009	2010	2011	2012
Paddy yield(t/ha)	3.1*	4.4***	4.8***	5.3***	4.7**
Chemical fertilizer use (kg/ha)	63.4	115.8***	137.7***	164.5***	131.3***
Share of plots using modern varieties (%)	46.2*	69.2***	65.8***	54.8***	66.7***
Share of plots with improved bund (%)	15.4**	23.1***	31.3***	42.9***	15.4
Share of levelled plots (%)	46.2	76.9	81.3	85.7	76.9
Share of households who adopted transplanting in rows (%)	23.1	76.9***	93.8***	92.9***	92.3***
Observations	13	13	16	14	13

	Intermediary Farmers				
Variables	2008	2009	2010	2011	2012
Paddy yield(t/ha)	2.5	2.6	2.8	4.6***	3.9
Chemical fertilizer use (kg/ha)	22.2**	49.0	79.1	103.9*	95.2
Share of plots using modern varieties (%)	30.4	44.4**	40.8**	34.4	49.5**
Share of plots with improved bund (%)	13.0*	18.5***	22.6***	33.3**	33.3***
Share of levelled plots (%)	43.5**	70.4	74.2	79.2	62.5
Share of households who adopted transplanting in rows (%)	13.0	44.4***	64.5***	45.8**	58.3**
Observations	23	27	31	24	24

	Ordinary Farmers				
Variables	2008	2009	2010	2011	2012
Paddy yield(t/ha)	2.6	2.7	2.5	3.6	3.7
Chemical fertilizer use (kg/ha)	46.5	58.3	69.7	85.8	83.2
Share of plots using modern varieties (%)	26.7	26.8	25.7	23.6	32.9
Share of plots with improved bund (%)	3.0	4.9	7.7	16.2	11.5
Share of levelled plots (%)	54.8	64.1	69.0	76.2	66.9
Share of households who adopted transplanting in rows (%)	11.1	19.0	25.8	26.9	36.9
Observations	135	142	155	130	130

Note: Recall data for 2008 and 2009, collected in the survey in 2010. ***, **, and * denote significance at 1%, 5%, and 10%, respectively, in *t*-tests comparing between ordinary and key farmers and between ordinary and intermediary farmers in each year.

Table 2. Information sources of technology by training status in 2010 (%)

	Know this technology	TANRICE training	Own experience	Observing others	Informal conversation	Other sources	Observations
Key farmers							
Modern Variety (%)	100	93.8	0.0	6.3	0.0	0.0	16
Improved bunds (%)	100	100	0.0	0.0	0.0	0.0	16
Plot leveling (%)	100	43.8	50.0	12.5	0.0	0.0	16
Transplanting in rows (%)	100	93.8	0.0	6.3	0.0	0.0	16
Intermediary farmers							
Modern Variety (%)	100	80.6	3.2	12.9	0.0	3.2	31
Improved bunds (%)	96.8	83.3	0.0	13.3	0.0	3.3	31
Plot leveling (%)	100	32.3	35.5	32.3	6.5	0.0	31
Transplanting in rows (%)	100	77.4	3.2	16.1	3.2	3.2	31
Ordinary farmers							
Modern Variety (%)	72.1	1.8	15.3	58.6	20.7	9.0	155
Improved bunds (%)	56.5	3.4	8.0	66.7	17.2	9.2	155
Plot leveling (%)	88.3	2.9	41.2	46.3	12.5	3.7	155
Transplanting in rows (%)	88.3	2.2	15.6	60.7	19.3	10.4	155

Table 3. Technology adoption of ordinary farmers according to their relationship with key and intermediary farmers in 2010

	Relatives	No relatives	Difference	Residential neighbors	No residential neighbors	Difference	Same church/ mosque members	No church/ mosque members	Difference
	(a)	(b)	(a)-(b)	(c)	(d)	(c)-(d)	(e)	(f)	(e)-(f)
Area share of plots with modern varieties (%)	26.7	24.5	2.2	32.3	11.4	20.9***	28.4	15.1	13.3**
Chemical fertilizer use (kg/ha)	75.05	63.07	11.98	79.62	48.27	31.4***	73.03	56.45	16.6
Share of plots with improved bunds (%)	9.3	5.8	3.5	8.5	6.1	2.4	8.1	6.5	1.6
Share of the leveled plot (%)	76.7	59.4	17.3**	71.7	63.3	8.4	73.4	51.6	21.8***
Share of households who adopted transplanting in rows (%)	31.4	18.8	12.6**	27.4	22.4	5.0	25.8	25.8	0.0
Observations	86	69		106	49		124	31	

Note: ***, **, and * respectively significant at the 1%, 5%, and 10% level in *t*-test comparing between ordinary farmers with and without relatives, residential neighbors, or same church/mosque members, who are key or intermediary farmers.

Table 4. Average Treatment Effect of Key and Intermediary Farmers from 2008-2012

	(1) Yield	(2) MVs	(3) Fertilizer use (kg/ha)	(4) Improved bund	(5) Leveling	(6) Transplanting in rows
2008						
Key farmer	1.003**	-0.048	-3.596	0.03	-0.243	0.045
	[0.018]	[0.603]	[0.743]	[0.360]	[0.101]	[0.595]
Intermediary farmer	-0.009	-0.066	-11.733	0.253*	-0.082	-0.028
	[0.964]	[0.405]	[0.383]	[0.062]	[0.560]	[0.574]
2009						
Key farmer	2.136***	0.172	30.474	0.044	-0.111	0.651***
	[0.000]	[0.416]	[0.198]	[0.375]	[0.676]	[0.000]
Intermediary farmer	-0.056	0.141	-3.503	0.253**	0.158**	0.265**
	[0.847]	[0.121]	[0.717]	[0.012]	[0.030]	[0.011]
2010						
Key farmer	2.421***	0.541***	56.232***	0.159*	0.027	0.662***
	[0.000]	[0.000]	[0.008]	[0.058]	[0.826]	[0.000]
Intermediary farmer	0.582*	0.189*	15.858*	0.220**	0.142**	0.330***
	[0.092]	[0.072]	[0.065]	[0.026]	[0.042]	[0.002]
2011						
Key farmer	2.029***	0.546***	103.313***	0.534***	0.069	0.697***
	[0.001]	[0.000]	[0.000]	[0.000]	[0.485]	[0.000]
Intermediary farmer	1.165***	0.193*	13.573	0.244*	0.101	0.194
	[0.003]	[0.081]	[0.230]	[0.054]	[0.173]	[0.134]
2012						
Key farmer	1.547***	0.05	18.708	-0.001	0.239***	0.581***
	[0.000]	[0.851]	[0.290]	[0.986]	[0.000]	[0.000]
Intermediary farmer	0.749	0.167	13.582	0.191*	0.057	0.249**
	[0.189]	[0.103]	[0.378]	[0.065]	[0.518]	[0.018]

***, **, and * denote significance at 1%, 5%, and 10%, respectively. Robust *p*-values in parentheses.

Table 5. Determinants of paddy yield (tons per hectare) and the adoption of technologies from 2008-2012

	(1) Paddy yield (t/ha)	(2) MVs	(3) Chemical fertilizer use (kg/ha)	(4) Improved bund	(5) Plot leveling	(6) Transplant -ing in rows
Key farmer *2009	1.013*	0.202	34.652	0.070	0.221	0.595***
	[0.082]	[0.210]	[0.123]	[0.616]	[0.255]	[0.000]
Key farmer *2010	1.587***	0.262	76.403***	0.070	0.170	0.625***
	[0.007]	[0.104]	[0.001]	[0.616]	[0.381]	[0.000]
Key farmer *2011	0.821	0.313*	88.871***	-0.022	-0.033	0.503***
	[0.158]	[0.052]	[0.000]	[0.878]	[0.866]	[0.001]
Key farmer *2012	-0.264	0.090	48.790**	-0.203	0.180	0.422***
	[0.650]	[0.578]	[0.030]	[0.148]	[0.354]	[0.007]
Intermediary farmer *2009	0.048	0.122	5.531	-0.041	0.245	0.214*
	[0.920]	[0.354]	[0.764]	[0.722]	[0.125]	[0.095]
Intermediary farmer *2010	0.173	0.143	21.430	-0.041	0.194	0.347***
	[0.716]	[0.279]	[0.244]	[0.722]	[0.224]	[0.007]
Intermediary farmer *2011	0.786*	0.051	18.738	-0.061	0.102	0.194
	[0.100]	[0.699]	[0.309]	[0.594]	[0.522]	[0.131]
Intermediary farmer *2012	-0.403	0.153	16.244	-0.020	0.061	0.041
	[0.398]	[0.246]	[0.377]	[0.859]	[0.701]	[0.750]
year 2009	0.191	0.020	10.832*	0.041	0.112**	0.071
	[0.258]	[0.662]	[0.096]	[0.315]	[0.047]	[0.116]
year 2010	0.082	0.071	16.617**	0.041	0.163***	0.153***
	[0.625]	[0.126]	[0.011]	[0.315]	[0.004]	[0.001]
year 2011	0.922***	0.020	35.724***	0.133***	0.255***	0.163***
	[0.000]	[0.662]	[0.000]	[0.001]	[0.000]	[0.000]
year 2012	1.110***	0.133***	33.016***	0.092**	0.153***	0.245***
	[0.000]	[0.005]	[0.000]	[0.024]	[0.007]	[0.000]
Constant	2.540***	0.248***	42.317***	0.058**	0.504***	0.099***
	[0.000]	[0.000]	[0.000]	[0.026]	[0.000]	[0.001]
Observations	605	605	605	605	605	605
R-squared	0.184	0.048	0.170	0.037	0.070	0.157
Number of household	121	121	121	121	121	121

***, **, and * denote significance at 1%, 5%, and 10%, respectively. *p*-values in parentheses.

Table 6. Spatial estimation for the adoption of technologies by ordinary farmers in 2010

	(1) MV SAR	(2) MV SARAR	(3) Chemical fertilizer use (kg/ha) SAR	(4) Chemical fertilizer use (kg/ha) SARAR	(5) Improved bund SAR	(6) Improved bund SARAR	(7) Plot leveling SAR	(8) Plot leveling SARAR	(9) Transplanting in rows SAR	(10) Transplanting in rows SARAR
W_k*Adoption by key farmers	-0.112	-0.096	-0.028	-0.043	0.033	0.036	-0.095	-0.028	0.311	0.372
	[0.479]	[0.395]	[0.800]	[0.589]	[0.768]	[0.713]	[0.608]	[0.907]	[0.621]	[0.478]
W_i*Adoption by intermediary farmers	-0.205	-0.171	0.099	0.002	0.136	0.143	0.102	0.025	0.174	0.134
	[0.232]	[0.211]	[0.621]	[0.987]	[0.181]	[0.108]	[0.623]	[0.916]	[0.253]	[0.291]
Age of household head	0.032*	0.032**	2.437	3.018	-0.002	-0.002	0.019	0.021	0.033**	0.032**
	[0.070]	[0.042]	[0.323]	[0.182]	[0.858]	[0.834]	[0.273]	[0.216]	[0.050]	[0.039]
Age of household head squared	-0.000**	-0.000**	-0.038	-0.043*	-0.000	0.000	-0.000	-0.000	-0.000**	-0.000**
	[0.049]	[0.026]	[0.120]	[0.053]	[0.999]	[0.972]	[0.313]	[0.250]	[0.040]	[0.027]
Average years of schooling of adult household members	0.014	0.016	-0.937	-1.484	0.016	0.016	-0.011	-0.008	0.002	0.003
	[0.438]	[0.328]	[0.707]	[0.524]	[0.116]	[0.111]	[0.531]	[0.654]	[0.884]	[0.848]
Number of adult household members	-0.141	-0.132	-5.521	-4.281	-0.045	-0.043	-0.032	-0.025	-0.288***	-0.296***
	[0.215]	[0.219]	[0.729]	[0.780]	[0.484]	[0.495]	[0.774]	[0.815]	[0.009]	[0.006]
Number of adult squared	0.011	0.011	1.086	1.093	0.003	0.003	0.004	0.003	0.038**	0.039***
	[0.447]	[0.463]	[0.608]	[0.595]	[0.716]	[0.715]	[0.797]	[0.853]	[0.011]	[0.008]
Female headed household	-0.120	-0.122	-12.289	-9.596	-0.068	-0.077	-0.330***	-0.359***	-0.004	0.008
	[0.212]	[0.173]	[0.361]	[0.455]	[0.229]	[0.169]	[0.001]	[0.000]	[0.964]	[0.928]

Total size of owned plots	0.023	0.038	-2.415	-7.031	0.023	0.015	0.028	0.035	-0.058	-0.061
(ha)	[0.703]	[0.499]	[0.772]	[0.379]	[0.496]	[0.664]	[0.631]	[0.534]	[0.306]	[0.260]
Value of household asset	0.016	0.011	12.754**	12.469**	0.059***	0.063***	0.039	0.035	0.087**	0.074**
(million Tsh)	[0.665]	[0.742]	[0.013]	[0.012]	[0.005]	[0.003]	[0.272]	[0.314]	[0.013]	[0.037]
Relative with key or	-0.061	-0.058	-0.419	2.443	-0.011	-0.016	0.115	0.123*	0.135*	0.159**
intermediary farmers	[0.410]	[0.405]	[0.968]	[0.809]	[0.787]	[0.708]	[0.109]	[0.079]	[0.056]	[0.023]
Same church/mosque member with key or	0.154	0.118	5.974	2.299	0.039	0.035	0.233**	0.241**	0.008	-0.024
intermediary farmers	[0.131]	[0.228]	[0.679]	[0.871]	[0.512]	[0.551]	[0.021]	[0.012]	[0.937]	[0.802]
Residential neighbor with key or intermediary	0.150*	0.170**	26.825**	31.912***	0.007	-0.003	-0.015	-0.022	0.048	0.049
farmers	[0.086]	[0.040]	[0.032]	[0.009]	[0.893]	[0.959]	[0.862]	[0.788]	[0.561]	[0.547]
	-0.214	-0.381	32.636	2.346	0.042	0.040	0.289	0.417	-0.524	-0.606
Constant	[0.615]	[0.312]	[0.598]	[0.967]	[0.860]	[0.860]	[0.543]	[0.399]	[0.484]	[0.347]
Observations	155	155	155	155	155	155	155	155	155	155
ρ	0.211	0.542***	-0.056	0.318*	0.083	0.278	-0.243	-0.543**	-0.129	0.235
	[0.131]	[0.000]	[0.710]	[0.079]	[0.612]	[0.243]	[0.120]	[0.016]	[0.424]	[0.336]
λ		-0.565***		-0.552**		-0.292		0.373		-0.469
		[0.010]		[0.017]		[0.327]		[0.119]		[0.107]
Spatial error:										
Lagrange multiplier	0.381	[0.537]	1.006	[0.316]	0.002	[0.962]	0.661	[0.416]	0.973	[0.324]
Robust Lagrange multiplier	7.965	[0.005]	3.536	[0.06]	3.502	[0.061]	3.169	[0.075]	1.291	[0.256]
Spatial lag:										
Lagrange multiplier	2.344	[0.126]	0.131	[0.718]	0.214	[0.644]	2.089	[0.148]	0.573	[0.449]
Robust Lagrange multiplier	9.928	[0.002]	2.661	[0.103]	3.713	[0.054]	4.597	[0.032]	0.891	[0.345]

***, **, and * donates significance at 1%, 5%, and 10%, respectively. *p*-values in parentheses.

Table 7. Spatial estimation for the adoption of technologies by ordinary farmers in 2011

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	MV SAR	MV SARAR	Chemical fertilizer use (kg/ha) SAR	Chemical fertilizer use (kg/ha) SARAR	Improved bund SAR	Improved bund SARAR	Plot leveling SAR	Plot leveling SARAR	Transplanting in rows SAR	Transplanting in rows SARAR
W_k*Adoption by key	0.130	-0.003	0.283**	0.142	-0.200*	-0.210	-0.381	-0.400	0.211	0.142
farmers	[0.455]	[0.984]	[0.029]	[0.203]	[0.096]	[0.118]	[0.175]	[0.220]	[0.521]	[0.650]
W_i*Adoption by	0.208	0.170	0.258	0.173	-0.105	-0.089	-0.093	-0.092	0.200	0.180
intermediary farmers	[0.310]	[0.299]	[0.104]	[0.156]	[0.537]	[0.641]	[0.675]	[0.697]	[0.200]	[0.207]
Age of household head	-0.006	-0.001	-0.771	-0.147	0.021	0.021	0.018	0.019	0.031*	0.032*
	[0.733]	[0.953]	[0.730]	[0.943]	[0.150]	[0.161]	[0.304]	[0.303]	[0.079]	[0.067]
Age of household head	0.036	-0.017	-5.893	-11.153	-0.233	-0.230	-0.183	-0.189	-0.347**	-0.357**
squared	[0.850]	[0.922]	[0.790]	[0.579]	[0.110]	[0.120]	[0.302]	[0.304]	[0.049]	[0.040]
Average years of schooling	0.016	0.022	1.055	1.599	0.003	0.003	-0.006	-0.006	0.009	0.010
of adult household members	[0.398]	[0.206]	[0.629]	[0.435]	[0.850]	[0.860]	[0.736]	[0.737]	[0.586]	[0.567]
Number of adult household	-0.087	-0.129	8.982	14.877	-0.166*	-0.167*	0.067	0.067	-0.129	-0.106
members	[0.483]	[0.290]	[0.537]	[0.303]	[0.083]	[0.080]	[0.558]	[0.555]	[0.269]	[0.384]
Number of adult squared	0.010	0.016	-1.076	-1.991	0.015	0.015	-0.004	-0.004	0.012	0.010
	[0.533]	[0.335]	[0.582]	[0.309]	[0.241]	[0.237]	[0.811]	[0.811]	[0.432]	[0.542]
Female headed household	-0.125	-0.119	-4.029	-4.256	-0.173**	-0.170**	-0.134	-0.130	-0.088	-0.096
	[0.233]	[0.221]	[0.743]	[0.711]	[0.034]	[0.040]	[0.181]	[0.205]	[0.369]	[0.323]
Total size of owned plots	0.040	0.048	-8.007	-11.969*	-0.058	-0.056	0.005	0.002	-0.035	-0.037
(ha)	[0.519]	[0.406]	[0.273]	[0.091]	[0.229]	[0.247]	[0.932]	[0.972]	[0.538]	[0.514]
Value of household asset	-0.017	-0.025	10.070**	8.725**	0.062**	0.062**	-0.107***	-0.107***	0.101***	0.097***
(million Tsh)	[0.646]	[0.476]	[0.020]	[0.038]	[0.030]	[0.031]	[0.002]	[0.002]	[0.003]	[0.006]
Relative with key or	-0.066	-0.066	-4.760	-1.594	0.012	0.011	0.026	0.024	0.098	0.105
intermediary farmers	[0.423]	[0.386]	[0.623]	[0.863]	[0.859]	[0.866]	[0.735]	[0.760]	[0.198]	[0.171]
Same church/mosque	-0.069	-0.048	-1.443	-3.059	-0.062	-0.062	-0.123	-0.117	0.151	0.146

member with key or intermediary farmers	[0.531]	[0.641]	[0.911]	[0.806]	[0.466]	[0.472]	[0.235]	[0.294]	[0.141]	[0.154]
Residential neighbor with	0.171*	0.128	5.506	13.800	0.025	0.027	0.051	0.044	0.060	0.053
key or intermediary farmers	[0.085]	[0.171]	[0.642]	[0.235]	[0.747]	[0.727]	[0.587]	[0.679]	[0.505]	[0.554]
	0.367	0.228	45.925	14.718	0.157	0.172	0.676	0.780	-0.639	-0.663
Constant	[0.412]	[0.561]	[0.431]	[0.779]	[0.654]	[0.632]	[0.181]	[0.366]	[0.231]	[0.188]
Observations	130	130	130	130	130	130	130	130	130	130
ρ	0.089	0.539***	-0.024	0.355*	0.259	0.217	0.116	-0.010	-0.246	-0.05
	[0.583]	[0.003]	[0.892]	[0.067]	[0.137]	[0.420]	[0.502]	[0.991]	[0.204]	[0.878]
λ		-0.657**		-0.627**		0.069		0.132	-0.246	-0.265
		[0.012]		[0.019]		[0.829]		[0.877]	[0.204]	[0.479]
Spatial error:										
Lagrange multiplier	0.051	[0.822]	0.545	[0.46]	1.141	[0.285]	0.452	[0.501]	1.377	[0.241]
Robust Lagrange multiplier	1.845	[0.174]	3.178	[0.075]	1.003	[0.317]	0.014	[0.905]	0.13	[0.719]
Spatial lag:										
Lagrange multiplier	0.333	[0.564]	0.016	[0.898]	1.852	[0.174]	0.438	[0.508]	1.249	[0.264]
Robust Lagrange multiplier	2.127	[0.145]	2.649	[0.104]	1.713	[0.191]	0	[0.988]	0.001	[0.971]

***, **, and * donates significance at 1%, 5%, and 10%, respectively. *p*-values in parentheses.

Table 8. Spatial estimation for the adoption of technologies by ordinary farmers in 2012

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	MV SAR	MV SARAR	Chemical fertilizer use (kg/ha) SAR	Chemical fertilizer use (kg/ha) SARAR	Improved bund SAR	Improved bund SARAR	Plot leveling SAR	Plot leveling SARAR	Transplanting in rows SAR	Transplanting in rows SARAR
W_k*Adoption by key farmers	0.433*** [0.009]	0.304** [0.037]	0.223 [0.209]	0.173 [0.192]	0.004 [0.986]	-0.000 [0.999]	0.097 [0.775]	0.103 [0.744]	-0.111 [0.772]	-0.114 [0.762]
W_i*Adoption by intermediary farmers	0.486*** [0.004]	0.365** [0.019]	0.213 [0.291]	0.123 [0.435]	0.076 [0.637]	0.065 [0.661]	0.087 [0.670]	0.073 [0.688]	0.397** [0.010]	0.386** [0.046]
Age of household head	0.024 [0.194]	0.024 [0.165]	0.054 [0.983]	-0.265 [0.907]	0.001 [0.937]	0.002 [0.879]	0.006 [0.776]	0.005 [0.789]	0.032 [0.105]	0.032 [0.125]
Age of household head squared	-0.276 [0.127]	-0.272 [0.104]	-14.422 [0.556]	-10.159 [0.651]	-0.037 [0.780]	-0.045 [0.731]	-0.079 [0.689]	-0.072 [0.707]	-0.353* [0.070]	-0.348* [0.087]
Average years of schooling of adult household members	0.038** [0.033]	0.035** [0.037]	-2.466 [0.307]	-2.319 [0.314]	0.007 [0.607]	0.007 [0.584]	0.005 [0.806]	0.008 [0.705]	-0.003 [0.875]	-0.003 [0.893]
Number of adult household members	-0.143 [0.238]	-0.166 [0.164]	13.041 [0.425]	10.273 [0.526]	-0.123 [0.169]	-0.135 [0.138]	-0.144 [0.279]	-0.161 [0.236]	-0.136 [0.297]	-0.139 [0.299]
Number of adult squared	0.017 [0.310]	0.020 [0.216]	-1.334 [0.543]	-1.068 [0.623]	0.020* [0.093]	0.021* [0.080]	0.021 [0.235]	0.024 [0.194]	0.015 [0.389]	0.016 [0.391]
Female headed household	-0.054 [0.573]	-0.046 [0.620]	-10.050 [0.443]	-7.431 [0.559]	-0.010 [0.895]	-0.018 [0.807]	0.028 [0.797]	0.029 [0.794]	0.082 [0.434]	0.084 [0.431]
Total size of owned plots (ha)	0.110 [0.130]	0.114 [0.100]	-17.419* [0.076]	-17.405* [0.064]	0.016 [0.768]	0.017 [0.743]	0.060 [0.455]	0.066 [0.410]	-0.023 [0.772]	-0.020 [0.810]
Value of household asset (million Tsh)	-0.029 [0.412]	-0.023 [0.504]	0.875 [0.854]	0.741 [0.874]	0.059** [0.024]	0.061** [0.021]	-0.091** [0.020]	-0.088** [0.027]	0.036 [0.350]	0.035 [0.399]
Relative with key or intermediary farmers	0.015 [0.843]	0.013 [0.864]	-4.241 [0.682]	-1.328 [0.896]	0.007 [0.899]	0.012 [0.835]	0.057 [0.502]	0.063 [0.456]	0.206** [0.013]	0.209** [0.022]

Same church/mosque member	0.052	0.063	9.260	7.810	0.007	0.002	0.086	0.096	0.191	0.190
with key or intermediary farmers	[0.625]	[0.551]	[0.525]	[0.589]	[0.932]	[0.976]	[0.470]	[0.432]	[0.103]	[0.109]
Residential neighbor with key or	-0.105	-0.104	-5.451	-3.149	-0.037	-0.039	-0.164	-0.168	-0.055	-0.056
intermediary farmers	[0.263]	[0.256]	[0.666]	[0.797]	[0.598]	[0.582]	[0.111]	[0.104]	[0.588]	[0.584]
	-0.662	-0.605	95.557	72.934	0.221	0.197	0.802	0.632	-0.414	-0.407
Constant	[0.127]	[0.127]	[0.137]	[0.201]	[0.496]	[0.531]	[0.156]	[0.299]	[0.491]	[0.499]
Observations	130	130	130	130	130	130	130	130	130	130
ρ	0.190	0.483**	-0.305*	0.228	-0.076	0.137	-0.218	0.038	0.034	0.070
	[0.230]	[0.016]	[0.068]	[0.410]	[0.684]	[0.705]	[0.241]	[0.935]	[0.847]	[0.871]
λ		-0.455*		-0.610**		-0.262		-0.293		-0.046
		[0.100]		[0.043]		[0.533]		[0.572]		[0.929]
Spatial error:										
Lagrange multiplier	0.174	[0.677]	3.643	[0.056]	0.297	[0.586]	1.262	[0.261]	0.016	[0.900]
Robust Lagrange multiplier	3.601	[0.058]	0.485	[0.486]	0.804	[0.370]	0.087	[0.768]	0.047	[0.829]
Spatial lag:										
Lagrange multiplier	1.426	[0.232]	3.183	[0.074]	0.146	[0.703]	1.184	[0.276]	0.035	[0.852]
Robust Lagrange multiplier	4.854	[0.028]	0.025	[0.873]	0.653	[0.419]	0.01	[0.92]	0.066	[0.798]

***, **, and * donates significance at 1%, 5%, and 10%, respectively. *p*-values in parentheses.

Table 9. Spatial panel estimation for the adoption of technologies by ordinary farmers from 2010-2012

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	MV		Chemical fertilizer use (kg/ha)		Improved bund		Plot leveling		Transplanting in rows	
	SAR	SARAR	SAR	SARAR	SAR	SARAR	SAR	SARAR	SAR	SAC
W_k *adoption by key farmers	0.113*	0.107*	0.072	0.07	-0.142**	-0.146*	-0.176	-0.163	-0.029	-0.019
	[0.066]	[0.082]	[0.154]	[0.144]	[0.016]	[0.051]	[0.117]	[0.135]	[0.746]	[0.814]
W_i * adoption by intermediary farmers	-0.023	-0.026	0.315***	0.303***	-0.044	-0.044	0.005	0.01	0.170**	0.158**
	[0.772]	[0.738]	[0.005]	[0.008]	[0.411]	[0.418]	[0.961]	[0.922]	[0.040]	[0.043]
Observations	490	490	490	490	490	490	490	490	490	490
ρ	-0.139	-0.082	-0.081	0.006	0.003	-0.037	-0.238**	-0.111	0.081	0.234
	[0.148]	[0.720]	[0.386]	[0.983]	[0.975]	[0.934]	[0.011]	[0.739]	[0.348]	[0.384]
λ		-0.063		-0.093		0.04		-0.133		-0.17
		[0.783]		[0.732]		[0.927]		[0.691]		[0.581]
LR test for spatial parameter(s)	2.089	2.174	0.749	0.873	0.001	0.009	6.325**	6.530**	0.872	1.06

Appendix Table A1. Summary Statistics

Dependent Variables	
Paddy yield (t/ha)	3.06
	(1.64)
Chemical fertilizer use (kg/ha)	66.69
	(60.85)
Share of plots using modern varieties	32.07
	(46.71)
Share of plots with improved bund	11.41
	(31.81)
Share of leveled plots	66.28
	(47.31)
Share of households who adopt transplanting in rows	27.60
	(44.74)
Observations	605
Independent Variables	
Key farmer dummy	0.08
	(0.27)
Intermediary farmer dummy	0.15
	(0.36)
Age of household head	47.29
	(13.94)
Average years of schooling of adult household members	6.45
	(2.09)
Number of adult household members	2.79
	(1.30)
Female headed household	0.20
	(0.40)
Total size of owned plots (ha)	0.74
	(0.62)
Value of household asset (million Tsh)	0.56
	(0.96)
=1 if he/she has relative among key and intermediary farmers	0.57
	(0.50)
=1 if he/she has same church/mosque member among key and intermediary farmers	0.83
	(0.38)
=1 if he/she has residential neighbor among key and intermediary farmers	0.73
	(0.44)
Observations	202

Standard deviations in parentheses. We used our panel data for dependent variables

Appendix Table A2. The determinants of training status

VARIABLES	(1) Key farmers	(2) Intermediary farmers
Age of household head	0.636**	0.308*
	[0.037]	[0.070]
Age of household head squared (1000)	-0.006**	-0.003*
	[0.042]	[0.086]
Average years of schooling of adult household members	0.161	0.062
	[0.403]	[0.611]
Number of adult household members	-1.672	-0.352
	[0.147]	[0.659]
Number of adults squared	0.234	0.035
	[0.101]	[0.748]
Female headed household	-1.024	0.976*
	[0.330]	[0.072]
Total size of owned plots (ha)	-0.627	-0.007
	[0.414]	[0.986]
Value of household asset (million Tsh)	0.179	0.118
	[0.853]	[0.804]
=1 if he/she has a relative among key farmers	0.398	0.007
	[0.545]	[0.990]
=1 if he/she has a same church/mosque member among key	1.214	0.513
	[0.278]	[0.409]
=1 if he/she has a residential neighbor among key farmers	1.498*	0.910
	[0.079]	[0.105]
Constant	-18.007**	-10.579**
	[0.011]	[0.011]
Observations	171	171
LRtest (chi-square)	31.63	
p-value	[0.084]	
Pseudo R square	0.1418	

***, **, and * denote significance at 1%, 5%, and 10%, respectively. *p*-values in parentheses

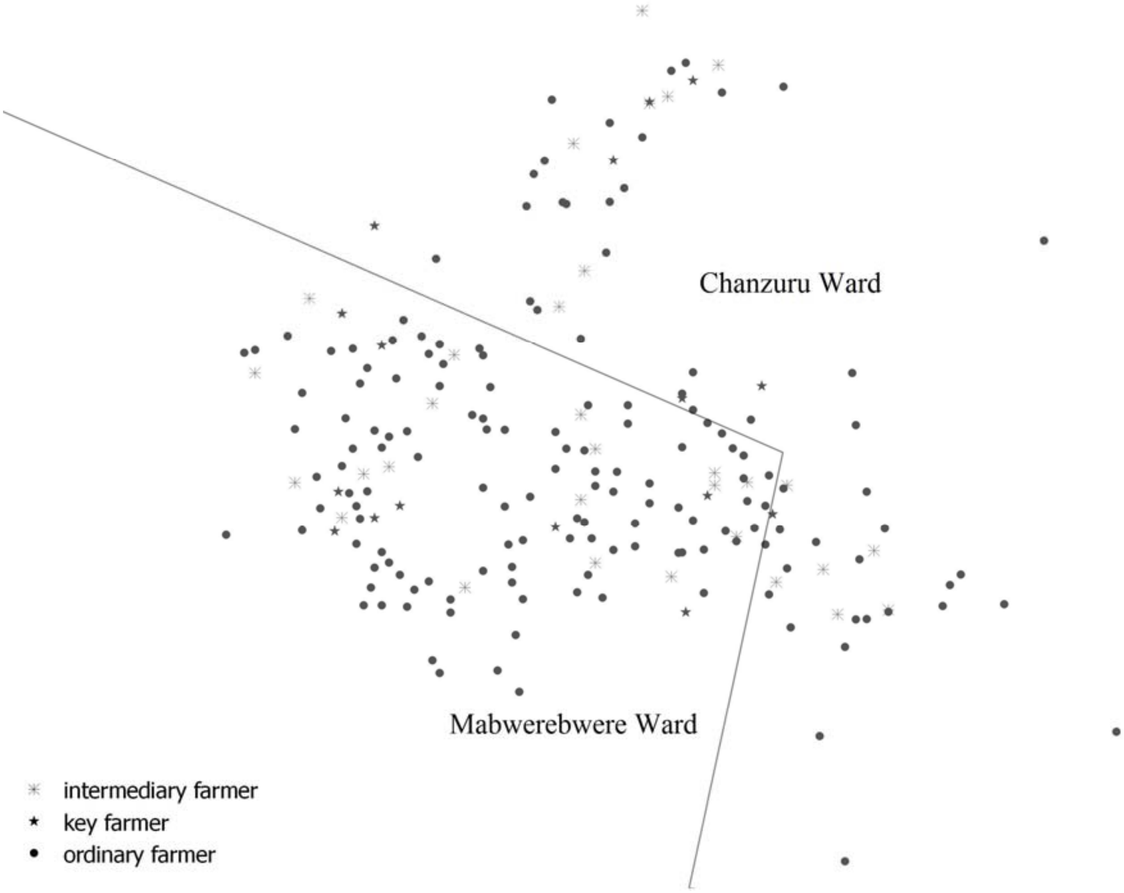

Figure 1. The map of sample plots

Sources: Adapted from the survey data and Esri boundary data

Abstract (in Japanese)

要約

少数の農家が受講した農業研修で伝えられた技術は、農家間の情報共有によって、受講者でない農家にどの程度伝播するのか。この問題は農業技術の普及戦略を策定する上で重要な問題であるにも関わらず、これまで十分な分析が行われてこなかった。本研究は、国際協力機構（JICA）がタンザニアの灌漑地区において行った稲作技術研修の技術普及と生産性への影響を、5 年間のパネルデータを用いて検証している。研修は受講農家が灌漑地区内の未受講農家に対して技術を教えることを想定して行われた。その結果、研修を受けなかった農家も、社会的紐帯が強く、近隣の圃場を耕作している研修受講農家から新たな技術を習得することで、生産性を向上させていることが明らかになった。研修前後を比較すると、受講者の平均収量は１ヘクタール当たり 3.1 トンから 4.7 トンに増加し、未受講者の平均収量も１ヘクタール当たり 2.6 トンから 3.7 トンへと増加した。これは農家間の技術普及を前提とした普及戦略がある程度機能しうることを示唆する結果である。

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