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Limited Attention and Information Loss in the Lab-to-Farm Knowledge Chain

The Case of Malawian Agricultural Extension Programs

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ABSTRACT

The International Food Policy Research Institute is leading a three-year research program to assess the state of agricultural extension and advisory services provision in Malawi in order to inform the national extension policy review and reformation of government and donor processes and programming. This research program includes a series of studies undertaken in response to a request by the Ministry of Agriculture, Irrigation and Water Development to look closely at the state of extension services provision with the intent to further strengthen the contribution of these services to food security, economic growth, and the achievement of sustainable development goals.

In this paper, we assess the flow of technical advice along the knowledge chain from scientists to farmers to identify the challenges in information provision. The advancement of social network literature has fostered the lead or contact farmer modality or farmer-to-farmer approach of information transmission. However, there is limited evidence regarding the information efficiency of this modality, and the reasons of the potential information loss. In this article, we assess information efficiency along the knowledge transmission chain from researchers to agricultural extension agents (EAs) to lead farmers (LFs) to other farmers. By asking the same set of questions about a fairly well known technology, pit planting, we construct a measure of knowledge at each node of the knowledge transmission chain. Descriptive evidence shows that the majority of information loss happens at the EA-to-LF link, and that the loss is potentially caused by limited attention of both EAs and LFs to all important details of the technology. With more evidence about the importance of knowledge for technology adoption, we suggest that EAs emphasize all crucial dimensions of an agricultural technique during demonstrations and visits in order to reduce information loss.

Keywords: information efficiency; knowledge chain; limited attention; technology adoption; extension services

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1. INTRODUCTION

Agricultural extension plays a crucial role in promoting agricultural productivity, increasing food security, improving rural livelihoods, and promoting agriculture as an engine of economic growth in developing countries. As one of their major functions, extension services are critical to move research from the lab to the field, and to ensure a return on investment in research by translating new knowledge into innovative practices. In other words, agricultural extension is the application of scientific research and knowledge to agricultural practices through farmer education.

However, we know of only limited objective measures that assess the quality of extension services and other modalities of information transmission (Buadi, Anaman, and Kwarteng 2013). This makes it hard to ensure that scientific knowledge is successfully received by farmers. If farmers do not fully understand a technology, how can they fully avail themselves of its benefits? If farmers cannot benefit from the technology, why would they keep adopting it? This research attempts to evaluate the efficiency of information transmission along the knowledge chain from lab to farm and assess the types of information failure using a limited attention model (Hanna et al. 2014). By tracking knowledge scores of geographically linked extension agents (EAs), lead farmers (LFs), and other farmers (OFs), we provide an objective measure of information loss for the current extension modality in Malawi. We focus our analysis on Malawi, which is among the poorest and most food-insecure countries in Africa (Malawi, MoAIWD 2016), because in recent years the Malawian government has pioneered several modalities in disseminating knowledge from research to farmers. These include the promotion of pluralistic and demand-driven extension systems in 2000, and the LF (or farmer-to-farmer) approach in 2003, which was formally institutionalized in the Malawi Department of Agricultural Extension Services programs in 2007 (Kundhlande et al. 2014). These policies make Malawi an ideal country in which to assess the information efficiency of different information transmission modalities. The results of our analysis in Malawi also have the potential to exert a major influence on many other developing countries.

We find that the majority of information loss occurs at the EA-to-LF link, because an EA's knowledge is well above that of an LF, but an LF's knowledge is not statistically different from that of OFs. We further unpack information loss and assess whether it is likely due to teaching failure (EA side) or learning failure (LF and OF side). By comparing and contrasting the models of overall knowledge and knowledge by single dimensions, we find that when considering all farmers (OFs plus LFs), the advice of EAs on pit planting can significantly increase farmers' overall knowledge. However, the incremental increase in knowledge is concentrated in only one of six dimensions. These results indicate that farmers have limited attention in learning a multidimensional technology. When we consider only the interaction between EAs and LFs, we find that the EAs' teaching is not effective in increasing LFs' overall knowledge, which serves as the evidence for teaching failure at the EA-LF link. The information failure identified here could be explained by a limited attention model (Hanna et al. 2014), where information loss occurs not because of unavailability of data but because of the lack of ability to pay attention to all details of data. This implies that some low-cost information devices are necessary in maintaining information efficiency. For example, if EAs were to distribute a handout during their teaching sessions that summarized all important details of implementing the technology, this could reduce information loss due to limited attention.

Lack of information has long been recognized as one explanation for low adoption of agricultural technology that promotes productivity (Foster and Rosenzweig 1995; Conley and Udry 2010; Levitt, List, and Syverson 2013; Micheels and Nolan 2016), along with other explanations such as credit constraints, differences in preferences, differences in agroecological conditions, and spatially heterogeneous costs and benefits (Duflo, Kremer, and Robinson 2011; Suri 2011). Research on information failure mostly focuses on diffusion through a social network, and the policy recommendation of such research is to target the most socially connected people in the networks to reduce cost and increase information efficiency. The modality of lead farmers (or contact farmers) aligns with this line of research. In Malawi, as in many other countries, both governmental and nongovernmental agencies have adopted the LF concept. An LF is supposed to learn from the EA and then diffuse the information to other farmers in his or her community.

However, recent studies on this modality provide mixed evidence regarding its efficacy. Fisher, Holden, and Katengeza (2017) link 180 LFs and 455 followers in four districts in Malawi and find that LFs' motivation, awareness, and adoption of conservation agriculture techniques are positively associated with OFs' awareness and adoption. But they do not address the information efficiency problem among LFs and OFs. Some analyses find that training LFs might not increase information efficiency or technology adoption of farmers in the community in the context of Mozambique (Kondylis, Mueller, and Zhu 2017; Beaman et al. 2015) and raise questions about the effectiveness of this modality of information transmission. Kondylis, Mueller, and Zhu (2017) use field experiments to show that even though after training LFs increase their adoption, their knowledge about the technologies does not increase significantly. Additionally, the training of EAs and LFs does not affect the adoption of OFs. Our analysis is consistent with their result that inefficiency happens at the EA-to-LF node and provides further evidence that information loss at the LF node might be due to LFs' limited attention to learning all necessary details of a technology. Alternatively, EAs might not fully emphasize the importance of paying attention to various details during their teaching sessions. Instead of focusing on the training, Beaman et al. (2015) use a randomized control trial to show that the mode of selecting the LFs also matters for information efficiency. They argue that selecting and training multiple LFs is critical, because their results show that farmers learn and adopt more in an environment where multiple people are adopting the technology and are knowledgeable about it, compared with an environment where only a single trained LF exists in the community. Our results complement their analysis, because even if LFs are "correctly" chosen based on merits about social connectivity, lack of attention during the training will still result in information loss during knowledge transmission.

Agricultural technologies do exist that potentially can improve Malawi's agricultural productivity, food security, and nutrition; however, there are constraints to their adoption. Among the potential constraints is information failure due to poor understanding of a multidimensional technology, which means that several important parameters or details are attached to the successful implementation of a particular technique. In order to best test the limited attention theory of information failure, we use *pit* *planting*—a technology proven to promote yields (Haggblade and Tembo 2003)—as our focus in this analysis. Pit planting is among the improved agricultural technologies widely promoted by governmental and nongovernmental service providers in Malawi to boost productivity and at the same time adapt to extreme weather.[1] Pit planting is ranked at the top of all technologies on which Malawian farmers have received advice from extension agents (Ragasa and Niu 2017). The technique is also relatively well known among Malawian farmers, with an awareness of 26 percent (Ragasa and Niu 2017).

Another reason for choosing pit planting as our focus is that the costs of the technique are mostly for labor—monetary costs are low—and therefore we can isolate the information failure hypothesis from alternatives such as credit constraints. Most important, pit planting is rather complicated and multidimensional. According to agronomic researchers, one needs to consider potentially six dimensions when pit planting in order to maximize the benefits: depth of the pits (5 to 15 centimeters), diameter of the pits (15 to 50 centimeters), distribution of the pits (straight row or along the contour lines), distance between pits (50 to 100 centimeters), whether to use fertilizer (should use fertilizer), and the optimal type of fertilizer that should be used in the pits (organic fertilizer) (Anschütz et al. 2003; Malesu, Oduor, and Odhiambo 2008 UNEP 2012; WOCAT 2007). Of all the technologies EAs promote, they consider pit planting the most difficult, followed by conservation agriculture and animal house construction (Ragasa et al. 2017). Out of 10, which is the highest level of difficulty, EAs rated pit planting 2.5 on average in terms of difficulty in mastering pit planting technology and 4.38 on average in terms of perceived difficulty for farmers in understanding pit panting technology, which can also be interpreted as the difficulty in teaching this technology to the farmers (Ragasa et al. 2017). For all technologies, EAs' subjective ratings were moderate in terms of farmers' difficulty understanding the technology. However, we would like to evaluate the information transmission process in a more rigorous way in case the EA's subjective measures are not revealing the full picture.

[1] Other heavily promoted technologies are chemical and organic fertilizer use, conservation agriculture, one seed-one hole maize planting, and use of improved varieties (Ragasa et al. 2017).

We hypothesize that during their teaching sessions, the EAs might not emphasize all of the important details (teaching failure) or the farmers might not pay full attention to all of the dimensions (learning failure), or both. As a result, when farmers go back and try the technology on their own plots, their pits are not correctly implemented, which results in unsatisfactory return on the technology investment and finally leads to low adoption. Nowadays, many technologies are grouped into packages and promoted to the farmers. Besides the complementarity of the technologies in the package, the knowledge involved to use the package is multidimensional and potentially hard to comprehend fully. Thus, it is crucial to understand the nature of information failure along the chain formed by EAs, LFs, and ordinary farmers and to determine how transmission can be improved. We contribute to the literature on technology diffusion by constructing a complete information chain from the researchers to the farmers and identifying the link at which information loss takes place. In addition, to our knowledge, we are the first to apply a limited attention model to explain information efficiency in the context of evaluating extension services. Lastly, while there is perhaps too much attention in the literature on adoption of external inputs (mainly fertilizer or improved varieties), given that liquidity constraints and heterogeneous profits can be the main issues, we focus on pit planting, which is not much researched but is heavily promoted in Malawi and other countries, to illustrate what constrains the adoption of a technology package with relatively low external input requirements.

Section 2 of the paper introduces the theoretical background, Section 3 describes the dataset and analytical methods, and Section 4 introduces the researcher-to-farmer knowledge chain. Section 5 discusses the results that try to separate teaching failure from learning failure. Section 6 shows the cluster, or localization, analysis of knowledge, Section 7 investigates how extension delivery methods and intensity are related to knowledge scores, and Section 8 summarizes the association of knowledge scores and adoption results. Section 9 concludes and provides policy implications.

2. THEORETICAL BACKGROUND

We base our analysis on a theoretical model of technological learning under which people learn through noticing: they choose which technical dimensions to attend to when learning to apply a technology from EAs or OFs. Hanna et al. (2014) point out that learning is about not only the availability of data but also what people notice in those data. In the context of dissemination of agricultural technology, learning usually takes place at demonstrations by EAs or LFs. Even though the essential details of a technology are demonstrated during the teaching sessions, farmers might not pay attention to every one of those details. And when the farmers experiment with the technology by themselves, they tend to consistently ignore the dimensions that they did not pay attention to at the beginning. A vicious feedback loop arises: even with readily available data generated from their experimentations, farmers who initially ignore an important dimension of a technology will not attend to it, and consequently will not learn whether it does matter.

The limited attention model builds on Schwartzstein's (2014) study in psychology. Three major assumptions are used to set up the model. First, there are N parameters associated with a technology. Those parameters are unknown to the farmers and need to be learned through demonstrations and experiences. In addition, farmers attach prior weights of importance to the various parameters; farmers might not think all parameters are equally important. Second, attention is costly in the sense that there is a shadow cost of mental energy and time associated with paying attention to each dimension of the N parameters. The more dimensions farmers attend to, the greater the cost they will incur. Third, farmers maximize the expected net payoff, which is the yield minus attentional costs.

The model produces several predictions that are relevant for our analysis. First, farmers may fail to attend to some dimensions.[2] This naturally arises from the consideration of costly attention. Second, farmers persistently choose only suboptimal parameter levels along dimensions that they do not attend to. Third, farmers may fail to optimize parameter levels of neglected dimensions even if they are generating data during experiments that would allow them to optimize. This prediction points out the possibility that

[2] All propositions and predictions can be found in Hanna et al. (2014).

farmers might not be able to learn a technology fully by themselves if no one reminds them of the dimensions that they have neglected from the beginning. Fourth, summaries of data can change farmers' behaviors. Thus, a low-cost device, such as a handout after farm demos or field visit days with all important details of a technology, could mitigate the information inefficiency arising from limited attention.

3. DATA AND ANALYTICAL METHODS

This research is based on data from multiple sources that include a household survey, a community survey, and in-depth interviews with LFs and EAs. The surveys and interviews were conducted by the International Food Policy Research Institute (IFPRI) between August and October 2016. The surveys cover 3,001 households and 299 sections (communities) in all 29 districts in Malawi. Among the 5,065 interviewed individuals, 544 were LFs. The service provider surveys cover 72 extension agents from both governmental and nongovernmental organizations. The full list of districts, extension planning areas, and sections was obtained from Malawi's Ministry of Agriculture, Irrigation, and Water Development. The number of communities and households per district were determined using probability proportional to size (PPS) sampling. We randomly selected 300 sections based on the required sample per district according to the PPS method. For each randomly selected section, one group village was randomly selected as the enumeration area. The enumeration areas are randomly selected for each district based on equal probability sampling so that each enumeration area has an equal chance to be included. For each sample enumeration area, a full list of households was generated by the survey team with the help of village leaders. The list was stratified into households with LFs and households without LFs, and a total of 10 households were randomly selected so that eight to 10 households without LFs and zero to two households with LFs are selected, depending on the presence of LFs in the community. Community leaders and the representatives of the village development or agricultural committee are interviewed for community surveys. Household head and the spouse are interviewed for household surveys whenever applicable.

After the sample households were selected, a single member or two of the selected households who were most knowledgeable about agricultural production, agricultural marketing, and food preparation were selected for face-to-face interviews. We also collected plot-level data to enable measurement of production and productivity.

To produce a credible assessment, we paid close attention to quality control processes. First, the questionnaires for the household and community surveys underwent various reviews, inputs, and iterations among IFPRI researchers and other research organizations, as well as the Malawian key stakeholders. Second, we used various methods and sources to complement and triangulate data and evidence. Third, implementation of the surveys involved extensive training of enumerators and the use of computer-assisted personal interviewing on tablet computers, which reduces measurement errors and enables day-to-day monitoring of the data collection process. For a more comprehensive summary of the data collection and sample characteristics, please refer to the IFPRI reports (Ragasa and Niu 2017; Ragasa and Qi 2016.

In this research, we focus on the part of the sample that is aware of pit planting, and we regard the rest of the sample as having zero knowledge of this technology. To measure the completeness of the farmers' knowledge, we ask the farmers who are aware of pit planting the following six questions about the technology:

1. How long should the diameter of the pit be (centimeters)?
2. How deep should the pit be (centimeters)?
3. What is the distance between the pits (centimeters)?
4. Do you use fertilizer in the pits?
5. What type of fertilizer is used?
6. How are your pits distributed on the ground?

Farmers' answers to these questions are recorded and compared to the suggested range of correct answers provided by the agronomic researchers. Appendix Table A.1 shows a summary of farmers' answers and the suggested range of correct answers. Using that information, we construct six binary variables of whether the farmer's answer falls in the suggested range, and the summation of those six binary variables is called the knowledge dimension variable, which measures the farmers' overall knowledge of pit planting.

Table 3.1 Summary statistics

Variable	Mean	Std. Dev.	Min	Max
	3.79	1.13	0	6
Binary knowledge variables for each dimension (falls in correct range = 1)				
1st dimension (diameter of pits)	0.84	0.36	0	1
2nd dimension (depth of pits)	0.22	0.42	0	1
3rd dimension (distance between pits)	0.38	0.49	0	1
4th dimension (whether use fertilizer)	0.85	0.36	0	1
5th dimension (type of fertilizer)	0.94	0.23	0	1
6th dimension (distribution of pits)	0.80	0.40	0	1
Self-report adoption of pit planting	0.44	0.50	0	1
Plot adoption of pit planting	0.18	0.38	0	1
Receive pit planting advice from … (yes = 1)				
Any EA	0.14	0.35	0	1
Government EA	0.13	0.33	0	1
Private EA	0.01	0.10	0	1
Nongovernmental organization EA	0.05	0.23	0	1
Farm organization EA	0.01	0.08	0	1
Number of months with abnormal rainfall	3.00	0.97	1	4
Participation in activities … (yes = 1)				
Attend farmer cluster	0.08	0.28	0	1
Attend farm demonstrations	0.22	0.41	0	1
Use print materials on agriculture	0.03	0.18	0	1
Use library or resource centers	0.00	0.06	0	1
Attend agricultural training centers	0.04	0.20	0	1
Use radio	0.29	0.45	0	1
Attend listening clubs	0.02	0.13	0	1
Use TV	0.01	0.11	0	1
Use phone/SMS	0.05	0.21	0	1
Attend VAC	0.17	0.37	0	1
Attend GAC	0.11	0.31	0	1
Attend meetings in the community	0.34	0.47	0	1
Receive information from mobile vans	0.03	0.17	0	1
Total livestock units	17.92	22.28	0	227
Household asset value (million MWK)	1.36	45.40	0	1.60E+03
Landholding (acres)	3.16	2.84	0	33.0014
Education (years)	6.32	3.93	0	15
Number of adults in the household	2.25	0.93	0	13
North	0.10	0.30	0	1
Central	0.56	0.50	0	1
South	0.34	0.47	0	1
Quintile of distance to roads	2.85	1.44	1	5
Connectivity index	-0.25	0.90	-2.157	2.78976
Number of people in network	1.40	1.56	0	30
Number of associations attended	0.55	0.85	0	7
Number of observations			1,243	

Source: Data are extracted from Malawi household survey (IFPRI 2016).
Note: Knowledge dimension is the number of questions answered correctly; landholding is in acres; connectivity index is constructed with Principal Component analysis on the frequency of listening to radio, watching TV, going to the nearest town, talking on the phone, and going to the nearest market. EA = extension agent; SMS = short message service; VAC = village agricultural committee; GAC = group agricultural committee; MWK = Malawian kwacha.

Table 3.1 shows the summary statistics of our analytical sample. There are 1,243 individuals who are aware of pit planting; that number includes 283 LFs and 960 OFs. On average, farmers correctly answered 3.79 out of 6 questions. Of those who are aware of pit planting, 44 percent reported having adopted it at some point, including those who are not currently adopting it on their plot. Eighteen percent of farmers are currently adopting pit planting (2015/2016 cropping season). Fourteen percent of those farmers have received advice on pit planting from an EA regardless of the EA's organization. Most such advice comes from government EAs (13 percent), with 5 percent coming from nongovernmental organization (NGO) EAs and 1 percent coming from both private and farm organization EAs.

Weather conditions are an important part of spatial heterogeneity, and such conditions potentially affect both knowledge and adoption behaviors. The variable "number of months with abnormal rainfall" is constructed with 10 recent years of rainfall data from the Climatic Research Unit TS (CRU TS) dataset. We find the monthly rainfall according to the geographical coordinates of each surveyed household, and calculate the 10-year average and standard deviation for each month in order to obtain a z-score for the monthly rainfall distribution. Using the distribution, we are able to find the number of months with abnormal (|z-score| > 1.5) rainfall at each households' residence region. On average, farmers experienced three months of abnormal rainfall in 2015 that largely deviates from the 10-year average.

We also have information about other channels and activities from which the farmers can learn about pit planting without directly consulting EAs. Those include farmer clusters, farm demonstrations, village agricultural committees, group agricultural committees, agricultural training centers, listening clubs and community meetings, use of print material and library, listening to the radio, and receiving information from mobile vans. Information on financial capital and wealth is captured by household asset values and total livestock units in 2015. The variable "household asset value" is the total monetary value of 11 types of household assets—air conditioner, radio, CD player, TV, refrigerator, washing machine, bicycle, motorcycle, automobile, oxcart, and tractor.

Physical land capital is captured by the variable "landholding," which reflects the total landholding in acres in 2015. Human capital is represented by the years of education of the household's head and the number of adults in the household, which is also a proxy for labor supply in the household. Geospatial controls include whether the individual comes from northern, central, or southern Malawi. Other social capital variables include the distance to the nearest road, number of people in one's social network, number of associations attended, and an index for connectivity, which is constructed from principal component analysis with binary variables of the frequency of listening to radio, watching TV, going to the nearest town, talking on the phone, and going to the nearest market.

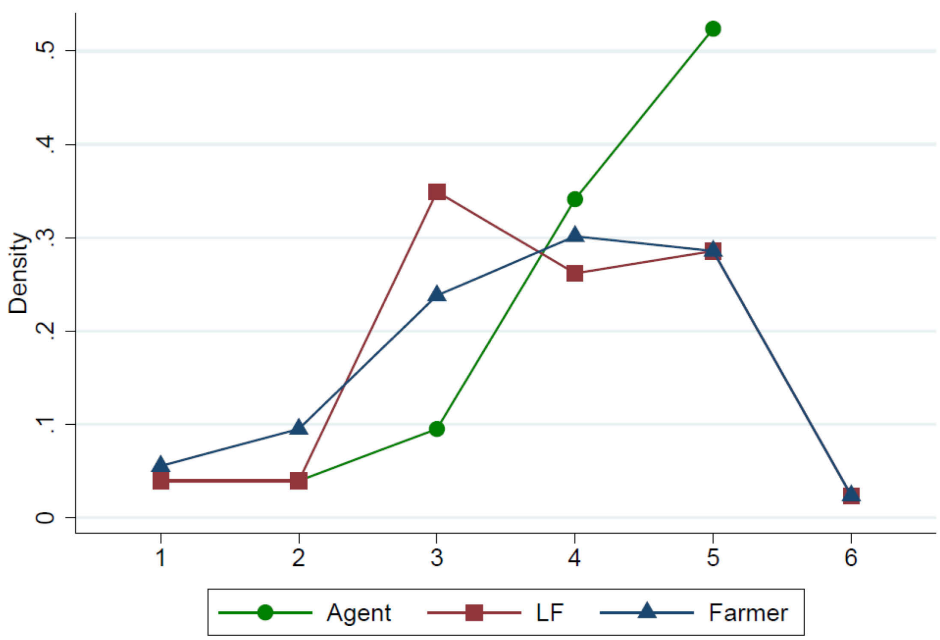
We use two kinds of analytical method to analyze the data. First, to identify the node that loses the most information along the information chain from lab to field, we link EAs, LFs, and OFs geographically to construct the information chain, and use paired t-tests to see whether the knowledge scores of the three groups differ from each other. Ideally, if the information chain is perfectly efficient, there should be no information loss from lab to field. In other words, the knowledge scores of EAs, LFs, and ordinary farmers should be the same and perfect. However, if there is information loss, the scores might not be perfect and might differ. We first obtain the information loss at the EA-LF node, which is the difference between EA's and LF's scores. We then find the information loss at the LF-OF node. By testing the differences between the EA-LF difference and LF-OF difference, we can tell which node incurs the most information loss.

Second, to further analyze whether the information loss is caused by teaching failure or learning failure, we use regression models to find the correlates between the knowledge variables and the extension service variables. In one model, we regress the knowledge dimension variable on the extension service variables while controlling for other forms of access to information, financial capital, land capital, human capital, geospatial variables, and social capital variables. In the other model, we replace the dependent variable in the previous model with the binary knowledge variables for each dimension. If we observe that the extension service variables are positive and statistically significant in the knowledge dimension regression, we then know that there is less of a teaching problem, because the EAs are able to raise the overall knowledge scores of the farmers. If we further observe that in the single-dimension regressions, the extension variables are positive and significant in only one or two dimensions, then there are potentially learning failures due to farmers not paying enough attention to all the dimensions in the technology package. However, if the extension service variables are not significant in the overall knowledge dimension regression and, in addition, they are not significant in the single-dimension regressions, then teaching failure may exist. Even if the extension service variables are significant in only one or two single-dimension regressions, that could still be due to teaching failures where the teachers (EAs) are not emphasizing all important details of the technology.

4. KNOWLEDGE CHAIN ANALYSIS

Before examining the geographically linked knowledge chains, we use all available knowledge information we have for EAs, LFs, and OFs and plot that distribution in Figure 4.1. We can see that the EAs are more likely to achieve higher scores than farmers; however, none of them achieves a perfect score on all six dimensions, which reflects the potential inefficiency in the EA trainings. The distributions of LFs and OFs are not obviously different, which means that in general, LFs' knowledge is not superior to that of the other farmers. We show additional statistical evidence regarding this argument in the latter part of this section. Some farmers in the sample do achieve full scores on all dimensions, whereas no EAs in the sample achieve full scores. This observation reflects the possibility of localization of knowledge, meaning that farmers might adjust their knowledge according their local environment. We present detailed analysis regarding clustering, or localization, in Section 5.

Figure 4.1 Knowledge distribution of extension agents, lead farmers, and other farmers



Source: Data are extracted from Malawi household survey (IFPRI 2016), and extension service provider survey (IFPRI 2017).
Note: The knowledge dimension variable is defined as the number of questions answered correctly about pit planting.

To determine whether any information loss occurs along the lab-to-field knowledge transmission chain, we link EAs, LFs, and OFs by the agents' operational and farmers' residential areas. This geographical information is covered in both the extension provider surveys and the household surveys, where EAs and LFs are asked about their respective operational areas. Using this information, we construct one complete knowledge chain (EA-LF-OF) with 253 OFs, 89 LFs, and 47 EAs. For the rest of the sample, we either do not know the farmers' LF or we do not know their EAs. To fully utilize the data, we also construct two partial chains: an EA-LF chain with 37 EAs and 123 LFs, and an LF-OF chain with 240 LFs and 1,063 other farmers.

With the EA-LF partial chain, we use a paired t-test to see whether the knowledge scores or overall knowledge dimensions of the EAs are the same as those of the LFs. Table 4.1 shows the test results. Within this partial chain, the EAs score an average of 4.35 dimensions correctly about pit planting, which is significantly higher than the LFs' average score. The difference is 0.56 and is statistically significant at the 1 percent level. These results show that, first, EAs' knowledge about pit planting is not perfect and provides cause for worry because they are supposed to be the experts on agricultural technologies and are the first step in transmitting lab research to the field. Second, the EAs are at least better trained than the LFs. Third, that the knowledge scores of the EAs are different than those of the LFs reveals information loss in this part of the knowledge chain.

Table 4.1 T-test of EA and LF knowledge

	Mean	Std. Err.	95% CI	
Knowledge dimension of EA	4.35	0.07	4.21	4.49
Knowledge dimension of LF	3.79	0.09	3.59	3.98
Difference	0.56***	0.12	0.33	0.79

Source: Data are extracted from Malawi household survey (IFPRI 2016), and extension service provider survey (IFPRI 2017).
Note: The partial information chain is constructed by merging EAs and LFs by their operational area. The knowledge dimension variable is the number of questions answered correctly about pit planting. EA = extension agent; LF = lead farmer.

We look at the LF-OF partial chain in Table 4.2. The paired t-test results show that the average knowledge of LFs is slightly better than that of the OFs; however, the difference is not statistically different from zero. This means that there is not much difference between the LFs' knowledge and the ordinary farmers' knowledge of pit planting. The results show that information loss is minimal at the link between LFs and OFs. However, both types of farmers know only slightly more than half of the dimensions that are required to maximize the benefits of the technology. These observations are consistent with the literature that looks at learning from neighbors, where the impact of EAs is significant at the beginning, but in the long term, learning from neighbors (or LFs) plays a more critical role in the learning process (Krishnan and Patnam 2013; Conley and Udry 2010).

Table 4.2 T-test of LF and other farmer knowledge

	Mean	Std. Err.	95% CI	
Knowledge dimension of LF	3.79	0.07	3.65	3.93
Knowledge dimension of farmer	3.69	0.08	3.53	3.84
Difference	0.11	0.09	-0.07	0.28

Source: Data are extracted from Malawi household survey (IFPRI 2016), and extension service provider survey (IFPRI 2017).
Note: The partial information chain is constructed by merging LFs and other farmers by their operational area. The knowledge dimension variable is the number of questions answered correctly about pit planting. LF = lead farmer.

Next, we use the complete knowledge chain (EA-LF-OF) to determine whether more information loss occurs at the EA-LF link or the LF-OF link. Table 4.3 shows the result of this test. Using the complete knowledge chain, we see that information loss at the EA-LF link is 0.56 and the loss at the LF-farmer link is 0.05. So the loss at the EA-LF link is significantly greater than that at the LF-farmer link. Therefore, most of the information loss occurs during the transmission process between EAs and LFs. In addition to that test, we also find that 19 out of 253 OFs in this complete chain have received advice about pit planting directly from EAs. So we further test whether those OFs' knowledge is different from that of the rest of the OFs. Table 4.4 shows that the knowledge of the OFs who directly receive advice from an EA is significantly greater than the knowledge of those who do not. This indicates that the LFs might play a weak role in transmitting knowledge. Even though this part of the analysis cannot reveal the exact nature of the inefficiency, it does raise questions about the efficiency of the LF modality for technology diffusion.

Table 4.3 T-test of EA-LF info loss and LF-farmer info loss

	Mean	Std. Err.	95% CI	
Difference EA-LF	0.56	0.12	0.33	0.79
Difference LF-farmer	0.05	0.13	-0.2	0.3
Difference	0.52***	0.2	0.11	0.92

Source: Data are extracted from Malawi household survey (IFPRI 2016), and extension service provider survey (IFPRI 2017).
Note: Complete information chain is constructed by merging EA and LF by their operational area. The knowledge dimension variable is the number of questions answered correctly about pit planting. EA = extension agent; LF = lead farmer.

Table 4.4 T-test of OFs' knowledge with and without direct EA contact

Knowledge dimension of OF	Mean	Std. Err.	95% CI	
with direct contact of EA	3.62	0.08	3.46	3.78
without direct contact of EA	4.53	0.23	4.03	5.02
Difference	-0.91***	0.3	-1.49	-0.33

Source: Data are extracted from Malawi household survey (IFPRI 2016), and extension service provider survey (IFPRI 2017).
Note: Complete information chain is constructed by merging EA and LF by their operational area. The knowledge dimension variable is the number of questions answered correctly about pit planting. OF = other farmer; EA = extension agent.

To further identify the type of the inefficiency problem, we use regression analysis to determine whether the problem consists of a teaching failure on the part of the EAs or a learning failure on the part of the farmers. We discuss those results in the next section.

5. TEACHING FAILURE OR LEARNING FAILURE

As stated in the data and analytical methods section, we compare and contrast the regressions of the overall knowledge dimension variable and the binary single-dimension variables to understand the nature of the information loss.

Table 5.1 presents the regression results of overall knowledge dimension variables on extension service variables and a set of control variables using all farmers who are aware of pit planting. Specification (1) is the simple model that shows the correlation between overall knowledge and receiving advice about pit planting from any EAs, regardless of the type of the EA. This extension variable is positive and significant in explaining farmers' overall knowledge, which means that extension services are effective in terms of increasing farmers' overall knowledge, so this does not support the teaching failure hypothesis. Specification (2) includes the control variables that represent other forms of access to information, financial and land capital, human capital, geospatial variables, and social capital. The coefficient on the extension service variable remains positive and significant after adding the control variables into the regression. We can see that abnormal rainfall conditions tend to decrease farmers' knowledge, but the effect is only marginally significant. Attending agricultural training centers has a negative impact on knowledge, which suggests that the educational content of such training centers could be misleading. Attending community meetings is helpful in learning about pit planting. More landholdings decrease the knowledge of pit planting. This could be due to the large labor cost involved with planting pits on a large amount of land. People who live in southern Malawi tend to know less about pit planting than those who live in the central region. Even though the number of people in one's social network has a negative impact on pit planting knowledge, the magnitude of the impact is very small compared with other significant factors. The more associations attended, the more the farmers would know about pit planting.

Table 5.1 Impact of extension services on knowledge dimension of all farmers

Specifications	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ordinary least squares				Poisson			
Variables	Knowledge dimension				Knowledge dimension			
Receive advice about pit planting from …								
Any EA	0.389***	0.233**			0.099**	0.058		
	(0.108)	(0.110)			(0.047)	(0.050)		
Government EA			0.484***	0.304***			0.122***	0.075
			(0.108)	(0.114)			(0.047)	(0.051)
Private EA			-0.117	0.038			-0.028	0.014
			(0.344)	(0.343)			(0.151)	(0.154)
NGO EA			-0.023	-0.029			-0.005	-0.007
			(0.158)	(0.159)			(0.070)	(0.072)
Farmer organization EA			0.349	0.432			0.083	0.109
			(0.409)	(0.410)			(0.175)	(0.181)
Number of months with abnormal rainfall		-0.105*		-0.100*		-0.028		-0.027
		(0.059)		(0.059)		(0.027)		(0.028)
Attend farmer cluster		-0.109		-0.105		-0.029		-0.028
		(0.129)		(0.130)		(0.059)		(0.060)
Attend farm demonstrations		-0.066		-0.072		-0.017		-0.019
		(0.089)		(0.089)		(0.041)		(0.041)
Use print materials on agriculture		-0.208		-0.214		-0.054		-0.055
		(0.192)		(0.192)		(0.089)		(0.089)
Use library or resource centers		0.543		0.619		0.133		0.153
		(0.579)		(0.579)		(0.250)		(0.251)
Attend agricultural training centers		-0.418**		-0.459**		-0.110		-0.121
		(0.178)		(0.179)		(0.084)		(0.085)
Use radio		0.127*		0.133*		0.033		0.035
		(0.075)		(0.075)		(0.035)		(0.035)
Attend listening clubs		-0.281		-0.231		-0.074		-0.061
		(0.262)		(0.262)		(0.121)		(0.121)
Use TV		-0.167		-0.167		-0.045		-0.045
		(0.306)		(0.306)		(0.147)		(0.147)
Use phone/SMS		0.019		0.017		0.004		0.003
		(0.165)		(0.165)		(0.075)		(0.075)
Attend VAC		0.112		0.082		0.029		0.021
		(0.118)		(0.119)		(0.054)		(0.055)

Table 5.1 Continued

Specifications	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ordinary least squares				Poisson			
Variables	Knowledge dimension				Knowledge dimension			
Attend GAC		0.228		0.205		0.057		0.052
		(0.141)		(0.142)		(0.064)		(0.065)
Attend meetings in the community		0.308***		0.297***		0.081**		0.078**
		(0.077)		(0.077)		(0.035)		(0.036)
Receive information from mobile vans		-0.038		-0.038		-0.009		-0.009
		(0.196)		(0.196)		(0.092)		(0.092)
Total livestock units		-0.001		-0.001		-0.000		-0.000
		(0.002)		(0.002)		(0.001)		(0.001)
Household asset value (1,000 MWK)		-0.000		-0.000		-0.000		-0.000
		(0.000)		(0.000)		(0.000)		(0.000)
Landholding		-0.025**		-0.026**		-0.007		-0.007
		(0.012)		(0.012)		(0.006)		(0.006)
Household head education in years		0.011		0.011		0.003		0.003
		(0.009)		(0.009)		(0.004)		(0.004)
Number of adults in the household		0.050		0.051		0.013		0.013
		(0.036)		(0.036)		(0.016)		(0.016)
North		-0.174		-0.176		0.042		0.040
		(0.150)		(0.150)		(0.056)		(0.056)
South		-0.331***		-0.325***		0.089		0.088
		(0.119)		(0.119)		(0.056)		(0.056)
Quintile of distance to roads		0.018		0.022		0.005		0.006
		(0.022)		(0.022)		(0.010)		(0.010)
Connectivity index		-0.019		-0.017		-0.006		-0.005
		(0.040)		(0.040)		(0.019)		(0.019)
Number of people in network		-0.048**		-0.050**		-0.014		-0.015
		(0.021)		(0.021)		(0.011)		(0.011)
Number of associations attended		0.169***		0.161***		0.043**		0.042**
		(0.041)		(0.041)		(0.018)		(0.019)
Constant	3.752***	3.903***	3.729***	3.874***	1.322***	1.276***	1.316***	1.270***
	(0.034)	(0.257)	(0.034)	(0.257)	(0.015)	(0.086)	(0.016)	(0.087)
Observations	1,243	1,240	1,243	1,240	1,243	1,240	1,243	1,240

Source: Data are extracted from Malawi household survey (IFPRI 2016).
Note: The knowledge dimension variable is the number of questions answered correctly about pit planting. Standard errors in parentheses. EA = extension agent; NGO = nongovernmental organization; SMS = short message service; VAC = village agricultural committee; GAC = group agricultural committee; MWK = Malawian kwacha. *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

Specifications (3) and (4) are similar to (1) and (2) but replace the extension service variable with variables that differentiate the types of EA. We observe that only advice from government EAs has a significant impact on farmers' overall knowledge about pit planting. Potentially, this could indicate that government EAs are more efficient than nongovernment EAs in teaching farmers about this technology.

Because the dependent variable is a discrete variable ranging from 1 to 6, we further use Poisson models as robustness checks. However, the Poisson models require the value of the dependent variable to be independent, which means that the answer to one knowledge question is independent from the other questions. Thus, our overall knowledge dimension variable might not satisfy this assumption. As a result, the Poisson regressions have limited explanatory powers compared with the ordinary least squares models. We observe in specifications (5) and (7) that the extension variables still have a positive and significant impact on farmers' overall knowledge, but the coefficients lose significance when control variables are included, which might be because of the unsatisfied assumption of Poisson models.

To investigate possible learning failures, we further look at the impact of extension services on each dimension of pit planting knowledge. Table 5.2 shows the results of these regressions with controls. We see that the extension service variable has significant impact only on the third dimension (distance between pits) and not on the other dimensions. This means that even though in Table 5.1 we find EAs to be effective in teaching, farmers can improve only on limited dimensions of knowledge. The limited attention model of learning (Hanna et al. 2014) can be applied to understand this result—that is, students can attend to only limited dimensions of a new technology, especially when learning a multidimensional technology such as pit planting. Since the dependent variables here are binary, we use probit models as robustness checks, and the results in Table 5.3 are consistent with those in Table 5.2.

Table 5.2 Impact of extension services on each dimension of pit planting knowledge

Specifications Variables	(1) 1st dimension	(2) 2nd dimension	(3) 3rd dimension	(4) 4th dimension	(5) 5th dimension	(6) 6th dimension
Receive advice about pit planting from …						
Government EA	0.007	-0.006	0.120**	0.044	0.037	-0.030
	(0.037)	(0.043)	(0.050)	(0.036)	(0.025)	(0.040)
Private EA	0.112	0.243*	-0.162	-0.093	-0.084	0.106
	(0.111)	(0.128)	(0.149)	(0.109)	(0.079)	(0.122)
NGO EA	0.036	-0.043	-0.006	0.007	-0.002	-0.021
	(0.052)	(0.060)	(0.070)	(0.051)	(0.035)	(0.057)
Farmer organization EA	0.123	-0.033	-0.117	0.136	0.065	0.085
	(0.133)	(0.153)	(0.178)	(0.131)	(0.087)	(0.146)
Number of months with abnormal rainfall	-0.036*	-0.029	-0.012	0.013	-0.006	-0.100***
	(0.020)	(0.023)	(0.026)	(0.019)	(0.014)	(0.021)
Attend farmer cluster	-0.060	0.007	-0.103*	-0.023	-0.028	0.084*
	(0.043)	(0.050)	(0.057)	(0.041)	(0.028)	(0.046)
Attend farm demonstrations	0.002	-0.032	-0.003	0.008	0.012	-0.076**
	(0.030)	(0.034)	(0.040)	(0.029)	(0.020)	(0.032)
Use print materials on agriculture	-0.072	0.027	-0.008	-0.069	0.000	0.164**
	(0.067)	(0.079)	(0.090)	(0.061)	(0.044)	(0.068)
Use library or resource centers	0.141	0.587***	-0.150	0.125	-0.248**	-0.078
	(0.188)	(0.217)	(0.252)	(0.185)	(0.122)	(0.206)
Attend agricultural training centers	-0.074	-0.131*	-0.056	-0.058	0.008	-0.080
	(0.059)	(0.068)	(0.079)	(0.057)	(0.040)	(0.064)
Use radio	0.002	0.034	0.022	0.027	-0.049***	0.076***
	(0.025)	(0.029)	(0.034)	(0.024)	(0.017)	(0.027)
Attend listening clubs	0.023	0.017	-0.090	-0.145*	-0.003	-0.013
	(0.085)	(0.098)	(0.114)	(0.084)	(0.059)	(0.093)
Use TV	-0.056	-0.120	-0.087	0.030	-0.085	0.035
	(0.103)	(0.123)	(0.138)	(0.098)	(0.070)	(0.109)
Use phone/SMS	-0.007	0.103	0.060	-0.063	0.075**	-0.013
	(0.056)	(0.065)	(0.075)	(0.053)	(0.037)	(0.058)
Attend VAC	0.001	-0.034	-0.031	0.024	-0.030	0.037
	(0.039)	(0.045)	(0.053)	(0.038)	(0.026)	(0.042)
Attend GAC	0.059	-0.018	0.045	0.044	0.020	0.028
	(0.047)	(0.054)	(0.063)	(0.045)	(0.032)	(0.051)
Attend meetings in the community	0.096***	-0.014	0.084**	0.082***	0.032*	-0.006
	(0.026)	(0.030)	(0.035)	(0.025)	(0.017)	(0.027)
Receive information from mobile vans	-0.222***	0.191**	-0.102	0.037	-0.003	0.084
	(0.067)	(0.079)	(0.093)	(0.063)	(0.044)	(0.070)
Total livestock units	-0.001*	-0.001	0.001	0.000	0.000	-0.001**
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)
Household asset value (1,000 MWK)	0.000	-0.000	-0.000	0.000	-0.000***	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Table 5.2 Continued

Specifications Variables	(1) 1st dimension	(2) 2nd dimension	(3) 3rd dimension	(4) 4th dimension	(5) 5th dimension	(6) 6th dimension
Landholding	-0.002	0.004	-0.000	-0.013***	-0.005	0.000
	(0.004)	(0.005)	(0.005)	(0.004)	(0.003)	(0.004)
Household head education in years	0.006**	0.002	-0.002	0.005*	0.003	-0.003
	(0.003)	(0.003)	(0.004)	(0.003)	(0.002)	(0.003)
Number of adults in the household	0.027**	-0.019	-0.002	0.012	-0.012	0.021*
	(0.012)	(0.014)	(0.016)	(0.011)	(0.008)	(0.013)
North	0.005		0.139**	-0.068	-0.001	-0.225***
	(0.050)		(0.068)	(0.048)	(0.035)	(0.053)
South	-0.105***	0.081*	0.041	-0.111***	-0.068**	-0.096**
	(0.040)	(0.046)	(0.054)	(0.038)	(0.028)	(0.042)
Quintile of distance to roads	0.010	0.007	-0.014	0.007	0.011**	-0.005
	(0.008)	(0.009)	(0.010)	(0.007)	(0.005)	(0.008)
Connectivity index	-0.028**	0.022	-0.010	-0.010	0.008	0.004
	(0.014)	(0.016)	(0.018)	(0.013)	(0.009)	(0.014)
Number of people in network	0.003	-0.008	-0.002	-0.007	-0.005	-0.023***
	(0.007)	(0.008)	(0.009)	(0.007)	(0.005)	(0.007)
Number of associations attended	0.011	0.001	0.070***	0.028**	0.015	-0.013
	(0.014)	(0.016)	(0.018)	(0.013)	(0.009)	(0.015)
Constant	0.836***	0.291***	0.353***	0.769***	0.963***	1.182***
	(0.087)	(0.082)	(0.116)	(0.082)	(0.060)	(0.091)
Observations	1,150	1,147	1,149	1,240	1,055	1,240
R-squared	0.066	0.045	0.058	0.061	0.067	0.070

Source: Data are extracted from Malawi household survey (IFPRI 2016).
Note: Knowledge dimension variable is the number of questions answered correctly about pit planting. Standard errors in parentheses. EA = extension agent; NGO = nongovernmental organization; SMS = short message service; VAC = village agricultural committee; GAC = group agricultural committee; MWK = Malawian kwacha. *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

Table 5.3 Impact of extension services on each dimension of pit planting knowledge (probit)

Specifications Variables	(1) 1st dimension	(2) 2nd dimension	(3) 3rd dimension	(4) 4th dimension	(5) 5th dimension	(6) 6th dimension
Receive advice about pit planting from …						
Government EA	0.042	-0.019	0.314**	0.272	0.462	-0.101
	(0.183)	(0.155)	(0.134)	(0.202)	(0.310)	(0.149)
Private EA	0.236	-0.164	-0.016	-0.014	0.131	-0.093
	(0.274)	(0.221)	(0.191)	(0.277)	(0.419)	(0.210)
NGO EA		0.795*	-0.426	-0.458	-0.972	0.252
		(0.421)	(0.413)	(0.541)	(0.659)	(0.463)
Farmer organization EA		-0.034	-0.381			0.406
		(0.557)	(0.529)			(0.625)
Number of months with abnormal rainfall	-0.168*	-0.104	-0.036	0.072	-0.044	-0.361***
	(0.087)	(0.079)	(0.071)	(0.082)	(0.133)	(0.081)
Attend farmer cluster	-0.238	0.022	-0.295*	-0.130	-0.222	0.319*
	(0.197)	(0.183)	(0.160)	(0.206)	(0.289)	(0.184)
Attend farm demonstrations	-0.040	-0.129	-0.004	0.074	0.186	-0.256**
	(0.139)	(0.124)	(0.108)	(0.140)	(0.205)	(0.116)
Use print materials on agriculture	-0.384	0.089	-0.011	-0.358	0.123	0.782**
	(0.287)	(0.285)	(0.245)	(0.291)	(0.538)	(0.341)
Use library or resource centers		1.992**	-0.457		-1.426	-0.335
		(0.813)	(0.733)		(0.958)	(0.752)
Attend agricultural training centers	-0.371	-0.623**	-0.138	-0.299	0.022	-0.261
	(0.275)	(0.301)	(0.217)	(0.271)	(0.447)	(0.238)
Use radio	0.020	0.127	0.060	0.148	-0.425***	0.264**
	(0.114)	(0.101)	(0.091)	(0.114)	(0.148)	(0.103)
Attend listening clubs	0.318	0.013	-0.251	-0.756**	-0.169	-0.061
	(0.516)	(0.386)	(0.310)	(0.366)	(0.584)	(0.350)
Use TV	-0.235	-0.464	-0.230	-0.021	-0.438	0.200
	(0.423)	(0.477)	(0.381)	(0.450)	(0.503)	(0.464)
Use phone/SMS	-0.024	0.388*	0.169	-0.297		-0.048
	(0.272)	(0.225)	(0.204)	(0.249)		(0.237)
Attend VAC	0.007	-0.123	-0.082	0.099	-0.239	0.126
	(0.183)	(0.161)	(0.142)	(0.183)	(0.237)	(0.161)
Attend GAC	0.360	-0.076	0.111	0.282	0.160	0.075
	(0.240)	(0.199)	(0.169)	(0.234)	(0.306)	(0.192)
Attend meetings in the community	0.457***	-0.046	0.227**	0.361***	0.212	0.002
	(0.123)	(0.105)	(0.094)	(0.119)	(0.160)	(0.106)
Receive information from mobile vans	-0.801***	0.598**	-0.294	0.133	-0.057	0.396
	(0.262)	(0.249)	(0.262)	(0.304)	(0.365)	(0.318)
Total livestock units	-0.004	-0.002	0.003	-0.001	0.003	-0.004**
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
Household asset value (1,000 MWK)	0.000	-0.000	-0.000	0.000**	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Table 5.3 Continued

Specifications Variables	(1) 1st dimension	(2) 2nd dimension	(3) 3rd dimension	(4) 4th dimension	(5) 5th dimension	(6) 6th dimension
Landholding	-0.011	0.014	-0.001	-0.065***	-0.036	0.003
	(0.020)	(0.017)	(0.015)	(0.017)	(0.025)	(0.017)
Household head education in years	0.026**	0.007	-0.004	0.017	0.040**	-0.011
	(0.013)	(0.011)	(0.011)	(0.012)	(0.020)	(0.011)
Number of adults in the household	0.129**	-0.072	-0.007	0.063	-0.090	0.078
	(0.059)	(0.050)	(0.043)	(0.052)	(0.077)	(0.051)
North	0.643***	-0.289*	0.258*	0.175	0.530*	-0.415***
	(0.214)	(0.163)	(0.145)	(0.161)	(0.294)	(0.158)
South	0.470***	-0.140	-0.110	0.423**	0.574**	0.337**
	(0.175)	(0.161)	(0.146)	(0.166)	(0.260)	(0.162)
Quintile of distance to roads	0.041	0.028	-0.038	0.025	0.110**	-0.020
	(0.033)	(0.030)	(0.027)	(0.032)	(0.050)	(0.030)
Connectivity index	-0.107*	0.065	-0.032	-0.009	0.071	0.015
	(0.059)	(0.054)	(0.051)	(0.057)	(0.085)	(0.055)
Number of people in network	0.016	-0.045	-0.004	-0.031	-0.043	-0.076**
	(0.036)	(0.039)	(0.027)	(0.027)	(0.032)	(0.032)
Number of associations attended	0.036	0.002	0.186***	0.159**	0.153	-0.049
	(0.064)	(0.057)	(0.049)	(0.069)	(0.098)	(0.053)
Constant	0.571**	-0.240	-0.266	0.226	1.135***	1.893***
	(0.282)	(0.251)	(0.226)	(0.258)	(0.411)	(0.261)
Observations	1,128	1,147	1,149	1,227	999	1,240

Source: Data are extracted from Malawi household survey (IFPR, 2016).
Note: Knowledge dimension variable is the number of questions answered correctly about pit planting. Standard errors in parentheses. EA = extension agent; NGO = nongovernmental organization; SMS = short message service; VAC = village agricultural committee; GAC = group agricultural committee; MWK = Malawian kwacha. *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

Because in the previous section, we show that the majority of information loss occurs at the EA-LF link, we want to further focus the regression analysis on the sample with only LFs, and see what is causing the information failure. Table 5.4 shows the results with only LFs. In contrast to the results in Table 5.1, we see that receiving advice from any EA variable does not have significant impact on LFs' overall knowledge. When we differentiate the source of advice, the only significant extension service impact is from the farmer organization EAs, which constitute the fewest number of EAs in Malawi. These results suggest that there could be a teaching failure between the majority of EAs and LFs, because government, private, and NGO EAs cannot effectively increase the knowledge of the LFs. When we analyze knowledge by single dimensions, the findings in Table 5.5 also support the teaching failure hypothesis. This is because we observe that the government EAs do not help increase the knowledge of any of the dimensions. In addition, even though private EAs significantly improve knowledge on the second dimension, they seem to provide confusing advice on the fifth dimension, which leads to a decrease in farmers' knowledge. A similar negative impact on knowledge is found with NGO EAs on the sixth dimension. The probit analysis in Table 5.6 confirms the findings in Table 5.5. Even though we cannot fully rule out the existence of LFs' learning failures, the evidence from the analysis with only LFs tends to support the hypothesis of EAs' teaching failures, which include failing to emphasize all important dimensions and offering confusing advice that decreases farmers' knowledge scores.

To summarize, we find that when considering all farmers, the analysis reveals failures in learning due to farmers' limited attention. They might not be able to observe all the crucial details of EAs' demonstrations. Turning to the analysis with only LFs, the evidence supports teaching failures on the part of EAs who might not be comprehensive and always right about the content they are imparting. Additionally, less than one-third of the whole population is aware of pit planting, and that low level of awareness could itself also be counted as a teaching failure on the part of the EAs.

However, we have been assuming that there is no localization of knowledge. Even though the lab researchers' answers are in the form of suggested ranges, the technology knowledge that is locally correct could still fall outside these ranges. In the following section, to determine whether localization, or clustering, of knowledge about pit planting is present, we use cluster analysis and present the results with dendrograms.

Table 5.4 Impact of extension services on knowledge dimension of lead farmers

Specifications	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ordinary least squares				Poisson			
Variables	Knowledge dimension				Knowledge dimension			
Receive advice about pit planting from …								
Any EA	0.082	-0.024			0.020	-0.007		
	(0.165)	(0.169)			(0.082)	(0.086)		
Government EA			0.122	0.002			0.030	0.000
			(0.158)	(0.167)			(0.079)	(0.085)
Private EA			-0.581	-0.310			-0.143	-0.074
			(0.523)	(0.534)			(0.268)	(0.282)
NGO EA			-0.294	-0.235			-0.074	-0.060
			(0.206)	(0.221)			(0.105)	(0.115)
Farmer organization EA			1.210*	1.308**			0.282	0.313
			(0.630)	(0.661)			(0.298)	(0.324)
Number of months with abnormal rainfall		-0.162		-0.157		-0.041		-0.039
		(0.103)		(0.103)		(0.052)		(0.053)
Attend farmer cluster		-0.050		-0.032		-0.012		-0.008
		(0.167)		(0.167)		(0.085)		(0.086)
Attend farm demonstrations		-0.048		-0.012		-0.012		-0.003
		(0.144)		(0.145)		(0.074)		(0.075)
Use print materials on agriculture		-0.393*		-0.400*		-0.099		-0.101
		(0.236)		(0.235)		(0.122)		(0.122)
Use library or resource centers		0.516		0.606		0.120		0.144
		(0.617)		(0.618)		(0.296)		(0.299)
Attend agricultural training centers		-0.216		-0.323*		-0.056		-0.084
		(0.183)		(0.190)		(0.094)		(0.100)
Use radio		0.023		0.021		0.006		0.006
		(0.128)		(0.129)		(0.066)		(0.066)
Attend listening clubs		-0.334		-0.326		-0.087		-0.085
		(0.293)		(0.294)		(0.150)		(0.151)
Use TV		0.548		0.508		0.145		0.135
		(0.761)		(0.758)		(0.391)		(0.392)
Use phone/SMS		-0.066		-0.098		-0.015		-0.023
		(0.202)		(0.202)		(0.102)		(0.104)
Attend VAC		0.017		0.032		0.003		0.007
		(0.182)		(0.181)		(0.094)		(0.094)
Attend GAC		0.281		0.230		0.074		0.061
		(0.196)		(0.197)		(0.101)		(0.102)
Attend meetings in the community		0.263**		0.286**		0.066		0.072
		(0.132)		(0.134)		(0.068)		(0.069)

Table 5.4 Continued

Specifications	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ordinary least squares				Poisson			
Variables	Knowledge dimension				Knowledge dimension			
Receive information from mobile vans		0.065		-0.025		0.018		-0.003
		(0.311)		(0.313)		(0.159)		(0.161)
Total livestock units		-0.002		-0.002		-0.000		-0.000
		(0.003)		(0.003)		(0.001)		(0.001)
Household asset value (1,000 MWK)		-0.000		0.000		-0.000		0.000
		(0.000)		(0.000)		(0.000)		(0.000)
Landholding		-0.041**		-0.038**		-0.011		-0.010
		(0.017)		(0.017)		(0.009)		(0.009)
Household head education in years		0.016		0.014		0.004		0.004
		(0.020)		(0.020)		(0.010)		(0.010)
Number of adults in the household		0.017		0.016		0.004		0.004
		(0.051)		(0.051)		(0.026)		(0.026)
North		0.042		0.048		0.145		0.138
		(0.254)		(0.254)		(0.105)		(0.107)
South		-0.570***		-0.536**		0.155		0.150
		(0.208)		(0.211)		(0.105)		(0.106)
Quintile of distance to roads		-0.013		-0.008		-0.003		-0.002
		(0.041)		(0.042)		(0.021)		(0.021)
Connectivity index		0.098		0.106		0.025		0.027
		(0.091)		(0.092)		(0.047)		(0.047)
Number of people in network		-0.067**		-0.068**		-0.020		-0.020
		(0.030)		(0.029)		(0.018)		(0.018)
Number of associations attended		0.139**		0.148**		0.036		0.038
		(0.062)		(0.062)		(0.031)		(0.032)
Constant	3.987***	4.650***	4.000***	4.613***	1.383***	1.406***	1.386***	1.406***
	(0.064)	(0.416)	(0.068)	(0.427)	(0.032)	(0.183)	(0.034)	(0.186)
Observations	283	283	283	283	283	283	283	283

Source: Data are extracted from Malawi household survey (IFPRI 2016).
Note: Knowledge dimension variable is the number of questions answered correctly about pit planting. Standard errors in parentheses. EA = extension agent; NGO = nongovernmental organization; SMS = short message service; VAC = village agricultural committee; GAC = group agricultural committee; MWK = Malawian kwacha. *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

Table 5.5 Impact of extension services on each dimension of pit planting knowledge, lead farmers only

Specifications Variables	(1) 1st dimension	(2) 2nd dimension	(3) 3rd dimension	(4) 4th dimension	(5) 5th dimension	(6) 6th dimension
Receive advice about pit planting from …						
Government EA	-0.012	-0.001	-0.026	-0.050	0.062	0.035
	(0.065)	(0.061)	(0.086)	(0.054)	(0.041)	(0.069)
Private EA	0.178	0.501**	-0.443	-0.104	-0.357**	-0.067
	(0.207)	(0.194)	(0.274)	(0.173)	(0.147)	(0.220)
NGO EA	0.013	-0.033	0.005	-0.006	-0.023	-0.170*
	(0.086)	(0.081)	(0.114)	(0.072)	(0.055)	(0.091)
Farmer organization EA	0.088	-0.269	0.564*	0.228	0.209	0.259
	(0.257)	(0.241)	(0.340)	(0.215)	(0.167)	(0.272)
Number of months with abnormal rainfall	-0.038	-0.070*	0.007	0.012	-0.008	-0.085**
	(0.040)	(0.038)	(0.053)	(0.033)	(0.026)	(0.042)
Attend farmer cluster	0.021	0.056	-0.106	-0.060	-0.017	0.104
	(0.066)	(0.062)	(0.087)	(0.054)	(0.041)	(0.069)
Attend farm demonstrations	-0.011	-0.028	-0.007	0.010	0.014	-0.012
	(0.057)	(0.053)	(0.076)	(0.047)	(0.036)	(0.060)
Use print materials on agriculture	-0.073	-0.077	-0.045	-0.064	-0.023	0.080
	(0.095)	(0.091)	(0.127)	(0.076)	(0.059)	(0.097)
Use library or resource centers	0.093	0.513**	-0.148	0.111	0.002	-0.086
	(0.239)	(0.225)	(0.317)	(0.201)	(0.146)	(0.254)
Attend agricultural training centers	-0.024	-0.114	-0.092	-0.034	0.038	-0.054
	(0.075)	(0.070)	(0.099)	(0.062)	(0.048)	(0.078)
Use radio	-0.042	0.045	-0.092	0.016	-0.036	0.128**
	(0.050)	(0.047)	(0.067)	(0.042)	(0.032)	(0.053)
Attend listening clubs	-0.007	-0.031	0.065	-0.121	-0.058	-0.141
	(0.114)	(0.107)	(0.151)	(0.096)	(0.072)	(0.121)
Use TV	0.194	-0.072	-0.083	0.126	0.091	-0.064
	(0.301)	(0.283)	(0.399)	(0.246)	(0.180)	(0.312)
Use phone/SMS	0.012	0.050	-0.017	-0.051	0.095*	-0.058
	(0.080)	(0.076)	(0.106)	(0.066)	(0.050)	(0.083)
Attend VAC	-0.055	0.037	-0.069	0.033	-0.008	0.031
	(0.070)	(0.066)	(0.093)	(0.059)	(0.045)	(0.075)
Attend GAC	0.068	0.036	0.035	0.051	-0.035	0.019
	(0.077)	(0.072)	(0.102)	(0.064)	(0.048)	(0.081)
Attend meetings in the community	0.138***	0.026	0.017	0.059	0.028	-0.018
	(0.053)	(0.050)	(0.070)	(0.044)	(0.034)	(0.055)
Receive information from mobile vans	-0.248*	0.231*	-0.294*	0.099	0.083	0.079
	(0.127)	(0.119)	(0.177)	(0.102)	(0.074)	(0.129)
Total livestock units	-0.000	0.000	0.000	-0.002**	0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)

Table 5.5 Continued

Specifications Variables	(1) 1st dimension	(2) 2nd dimension	(3) 3rd dimension	(4) 4th dimension	(5) 5th dimension	(6) 6th dimension
Household asset value (1,000 MWK)	-0.000	0.000	0.000	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Landholding	-0.001	-0.001	-0.004	-0.013**	-0.004	-0.007
	(0.007)	(0.006)	(0.009)	(0.006)	(0.005)	(0.007)
Household head education in years	-0.004	0.010	0.002	-0.007	0.013**	0.012
	(0.008)	(0.007)	(0.010)	(0.006)	(0.005)	(0.008)
Number of adults in the household	0.029	0.010	-0.007	-0.006	-0.012	0.006
	(0.020)	(0.019)	(0.027)	(0.016)	(0.015)	(0.021)
North	0.061		-0.178	-0.080		0.262**
	(0.099)		(0.131)	(0.082)		(0.104)
South	-0.042	-0.010	-0.255**	-0.206***	-0.010	0.094
	(0.082)	(0.076)	(0.109)	(0.068)	(0.053)	(0.087)
Quintile of distance to roads	-0.015	-0.003	-0.022	0.003	0.017	0.014
	(0.016)	(0.015)	(0.022)	(0.014)	(0.011)	(0.017)
Connectivity index	-0.045	0.016	0.042	-0.008	0.037	0.052
	(0.036)	(0.034)	(0.048)	(0.030)	(0.023)	(0.038)
Number of people in network	0.002	-0.003	-0.028*	-0.007	-0.002	-0.018
	(0.011)	(0.011)	(0.015)	(0.010)	(0.007)	(0.012)
Number of associations attended	0.015	0.029	0.025	0.029	0.020	-0.018
	(0.024)	(0.023)	(0.032)	(0.020)	(0.015)	(0.026)
Constant	0.863***	0.206	0.910***	1.076***	0.832***	0.776***
	(0.167)	(0.180)	(0.222)	(0.139)	(0.125)	(0.176)
Observations	275	274	275	283	252	283
R-squared	0.095	0.143	0.110	0.112	0.123	0.122

Source: Data are extracted from Malawi household survey (IFPRI 2016).
Note: Knowledge dimension variable is the number of questions answered correctly about pit planting. Standard errors in parentheses. EA = extension agent; NGO = nongovernmental organization; SMS = short message service; VAC = village agricultural committee; GAC = group agricultural committee; MWK = Malawian kwacha. *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

Table 5.6 Impact of extension services on each dimension of pit planting knowledge (probit), lead farmers only

Specifications Variables	(1) 1st dimension	(2) 2nd dimension	(3) 3rd dimension	(4) 4th dimension	(5) 5th dimension	(6) 6th dimension
Receive advice about pit planting from …						
Government EA	-0.012	-0.001	-0.026	-0.050	0.062	0.035
	(0.065)	(0.061)	(0.086)	(0.054)	(0.041)	(0.069)
Private EA	0.178	0.501**	-0.443	-0.104	-0.357**	-0.067
	(0.207)	(0.194)	(0.274)	(0.173)	(0.147)	(0.220)
NGO EA	0.013	-0.033	0.005	-0.006	-0.023	-0.170*
	(0.086)	(0.081)	(0.114)	(0.072)	(0.055)	(0.091)
Farmer organization EA	0.088	-0.269	0.564*	0.228	0.209	0.259
	(0.257)	(0.241)	(0.340)	(0.215)	(0.167)	(0.272)
Number of months with abnormal rainfall	-0.038	-0.070*	0.007	0.012	-0.008	-0.085**
	(0.040)	(0.038)	(0.053)	(0.033)	(0.026)	(0.042)
Attend farmer cluster	0.021	0.056	-0.106	-0.060	-0.017	0.104
	(0.066)	(0.062)	(0.087)	(0.054)	(0.041)	(0.069)
Attend farm demonstrations	-0.011	-0.028	-0.007	0.010	0.014	-0.012
	(0.057)	(0.053)	(0.076)	(0.047)	(0.036)	(0.060)
Use print materials on agriculture	-0.073	-0.077	-0.045	-0.064	-0.023	0.080
	(0.095)	(0.091)	(0.127)	(0.076)	(0.059)	(0.097)
Use library or resource centers	0.093	0.513**	-0.148	0.111	0.002	-0.086
	(0.239)	(0.225)	(0.317)	(0.201)	(0.146)	(0.254)
Attend agricultural training centers	-0.024	-0.114	-0.092	-0.034	0.038	-0.054
	(0.075)	(0.070)	(0.099)	(0.062)	(0.048)	(0.078)
Use radio	-0.042	0.045	-0.092	0.016	-0.036	0.128**
	(0.050)	(0.047)	(0.067)	(0.042)	(0.032)	(0.053)
Attend listening clubs	-0.007	-0.031	0.065	-0.121	-0.058	-0.141
	(0.114)	(0.107)	(0.151)	(0.096)	(0.072)	(0.121)
Use TV	0.194	-0.072	-0.083	0.126	0.091	-0.064
	(0.301)	(0.283)	(0.399)	(0.246)	(0.180)	(0.312)
Use phone/SMS	0.012	0.050	-0.017	-0.051	0.095*	-0.058
	(0.080)	(0.076)	(0.106)	(0.066)	(0.050)	(0.083)
Attend VAC	-0.055	0.037	-0.069	0.033	-0.008	0.031
	(0.070)	(0.066)	(0.093)	(0.059)	(0.045)	(0.075)
Attend GAC	0.068	0.036	0.035	0.051	-0.035	0.019
	(0.077)	(0.072)	(0.102)	(0.064)	(0.048)	(0.081)
Attend meetings in the community	0.138***	0.026	0.017	0.059	0.028	-0.018
	(0.053)	(0.050)	(0.070)	(0.044)	(0.034)	(0.055)

Table 5.6 Continued

Specifications Variables	(1) 1st dimension	(2) 2nd dimension	(3) 3rd dimension	(4) 4th dimension	(5) 5th dimension	(6) 6th dimension
Receive information from mobile vans	-0.248*	0.231*	-0.294*	0.099	0.083	0.079
	(0.127)	(0.119)	(0.177)	(0.102)	(0.074)	(0.129)
Total livestock units	-0.000	0.000	0.000	-0.002**	0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Household asset value (1,000 MWK)	-0.000	0.000	0.000	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Landholding	-0.001	-0.001	-0.004	-0.013**	-0.004	-0.007
	(0.007)	(0.006)	(0.009)	(0.006)	(0.005)	(0.007)
Household head education in years	-0.004	0.010	0.002	-0.007	0.013**	0.012
	(0.008)	(0.007)	(0.010)	(0.006)	(0.005)	(0.008)
Number of adults in the household	0.029	0.010	-0.007	-0.006	-0.012	0.006
	(0.020)	(0.019)	(0.027)	(0.016)	(0.015)	(0.021)
North	0.061		-0.178	-0.080		0.262**
	(0.099)		(0.131)	(0.082)		(0.104)
South	-0.042	-0.010	-0.255**	-0.206***	-0.010	0.094
	(0.082)	(0.076)	(0.109)	(0.068)	(0.053)	(0.087)
Quintile of distance to roads	-0.015	-0.003	-0.022	0.003	0.017	0.014
	(0.016)	(0.015)	(0.022)	(0.014)	(0.011)	(0.017)
Connectivity index	-0.045	0.016	0.042	-0.008	0.037	0.052
	(0.036)	(0.034)	(0.048)	(0.030)	(0.023)	(0.038)
Number of people in network	0.002	-0.003	-0.028*	-0.007	-0.002	-0.018
	(0.011)	(0.011)	(0.015)	(0.010)	(0.007)	(0.012)
Number of associations attended	0.015	0.029	0.025	0.029	0.020	-0.018
	(0.024)	(0.023)	(0.032)	(0.020)	(0.015)	(0.026)
Constant	0.863***	0.206	0.910***	1.076***	0.832***	0.776***
	(0.167)	(0.180)	(0.222)	(0.139)	(0.125)	(0.176)
Observations	275	274	275	283	252	283
R-squared	0.095	0.143	0.110	0.112	0.123	0.122

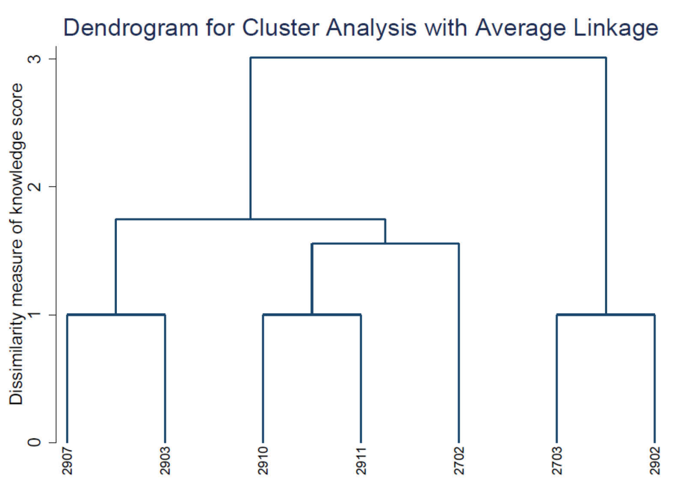
Source: Data are extracted from Malawi household survey (IFPRI 2016).
Note: Knowledge dimension variable is the number of questions answered correctly about pit planting. Standard errors in parentheses. EA = extension agent; NGO = nongovernmental organization; SMS = short message service; VAC = village agricultural committee; GAC = group agricultural committee; MWK = Malawian kwacha. *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

6. CLUSTER ANALYSIS OF KNOWLEDGE

We turn to the question of whether there is localization of knowledge. That is, are the knowledge data clustered within geographical areas? If localization of knowledge is present, we would need to reconsider the way we define the correct answers to our knowledge questions. Since the smallest geographical unit that we use to sample is the *section* (which is composed of various villages), it is natural to test whether the knowledge variables are clustered at the section level.

Figure 6.1 shows the dendrogram for cluster analysis of the overall knowledge dimension variable with average linkage. The height of the graph represents the dissimilarity of knowledge within a section as compared to the other sections. From the dendrogram, only seven out of 268 sections are statistically different from the other 261 sections, which means that the majority of the sections do not form any clusters. As a result, 97 percent (261/268) of the sample is not clustered or localized, so that we do not need to worry about localizing the correct solutions to knowledge questions. We further analyze single-dimension knowledge with dendrograms. Figure 6.2 shows that for each dimension, there are at most two sections that are different from the other sections, whose section IDs are labeled on the horizontal axis in each dendrogram.

Figure 6.1 Dendrogram for cluster analysis of overall knowledge dimension variable with average linkage



Source: Data are extracted from Malawi household survey (IFPRI 2016).
Note: Analysis is based on the knowledge dimension variable, which is defined as the number of questions answered correctly about pit planting. Horizontal axis provides section ID numbers. The rest of the sections have a zero dissimilarity measure.

Figure 6.2 Dendrograms for cluster analysis for each knowledge dimension

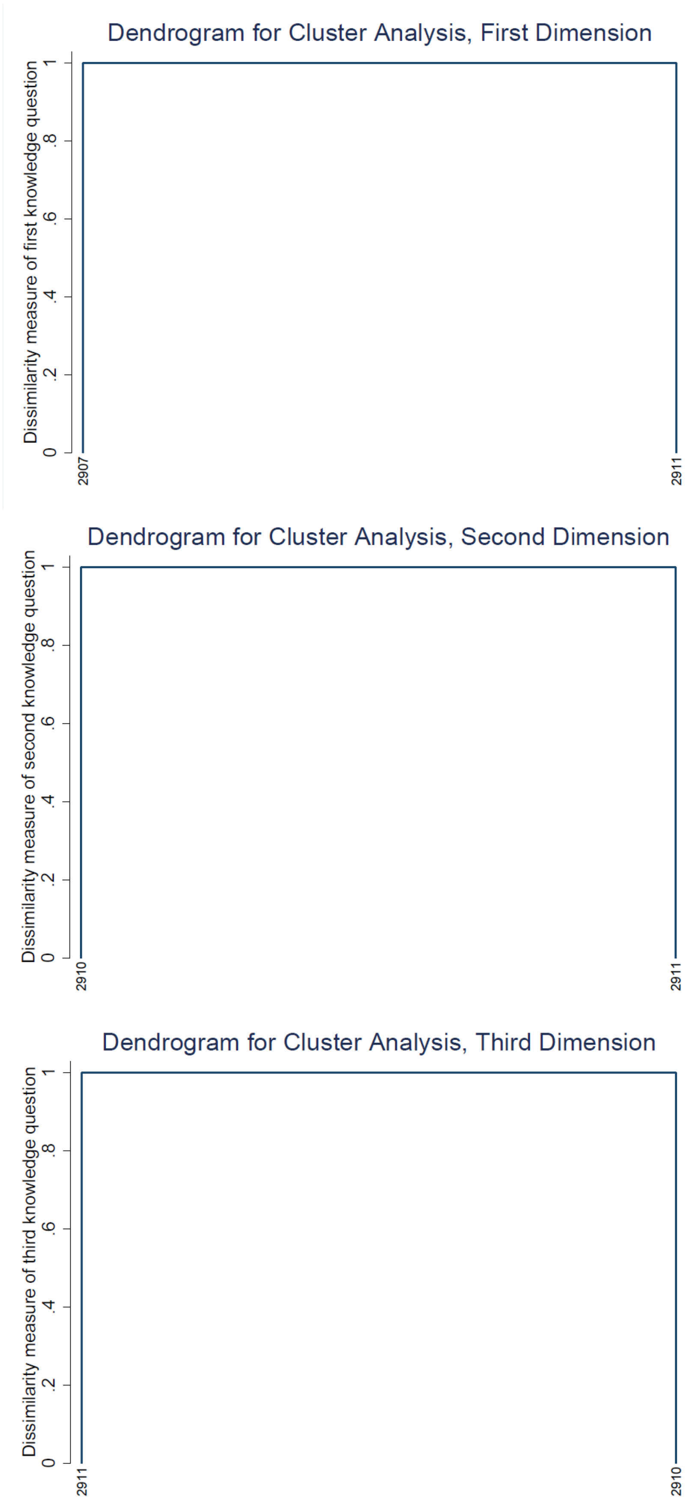
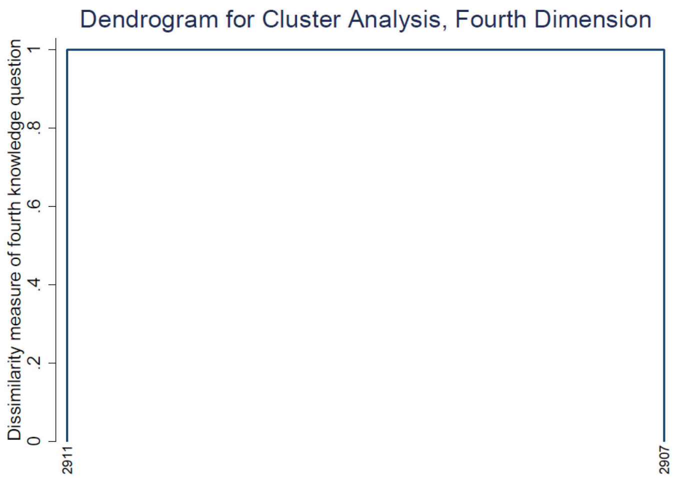
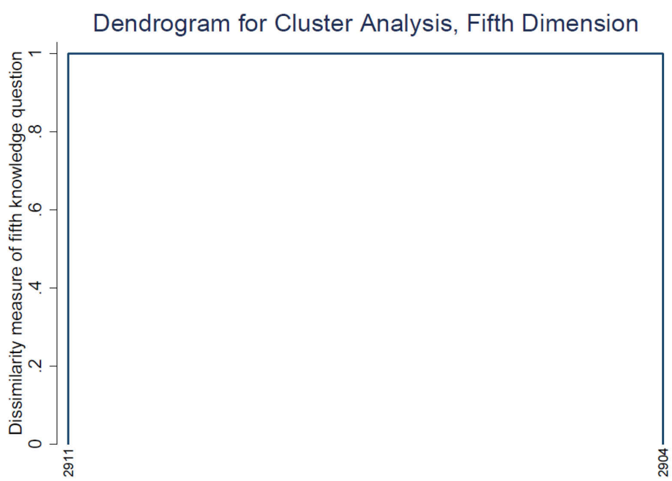
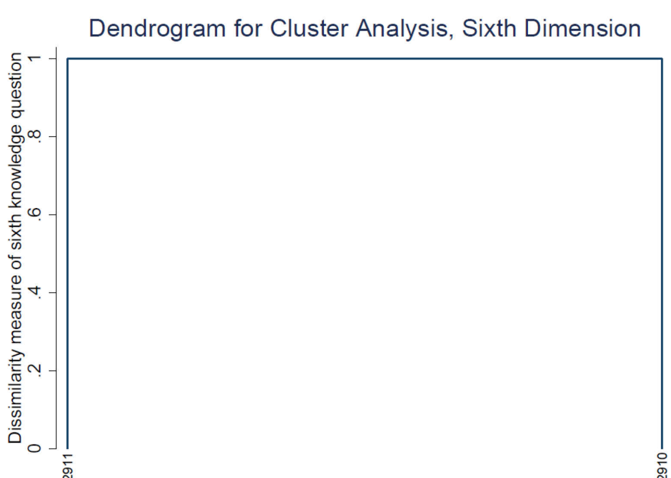


Figure 6.2 Continued







Source: Data are extracted from Malawi household survey (IFPRI 2016).
Note: Analysis is based on the binary knowledge variable for each knowledge dimension, and each graph shows cluster analysis on one of six dimensions of knowledge. Horizontal axis provides section ID numbers. The rest of the sections have a dissimilarity measure of zero and are omitted from the graphs.

7. METHODS AND INTENSITY OF EXTENSION AGENTS' TRAINING OF FARMERS

We now turn to the question of whether certain types of EA training methods work better in delivering information and increasing farmers' overall knowledge of pit planting. Table 7.1 shows the regression models of the knowledge dimension on different delivery methods. Those methods include face-to-face individual visits from the EAs, short-term training, listening to radio, watching TV, and village meetings. We use information on how the farmers receive information about pit planting to construct the method variables. The results show that only face-to-face individual visits and group/village meetings with government EAs have positive and significant effects on farmers' overall knowledge. This means that compared with listening to the radio and watching TV about pit planting, the more intensive and personal sessions such as face-to-face visits and village/group meetings are more effective information delivery methods. The effects of short-term training are not significant, which aligns with the results in Kondylis, Mueller, and Zhu (2017). This could be because during individual visits and group meetings, where farmers are more engaged, farmers and EAs can pay more attention to details, which does much to ensure successful implementations of the technology. Surprisingly, none of the farmers who were aware of pit planting reported that they had received advice through a farm demonstration, which is considered to be one of the major strategies in disseminating the technology. Potentially, Malawian farmers' lack of awareness about pit planting could be because of insufficient farm demonstration of the technology.

Table 7.1 Impact of extension services on knowledge dimension by intensity of training

Specifications Variables	(1) Knowledge dimension	(2) Knowledge dimension
Receive advice from government EA through …		
Face-to-face, individual visits	0.491**	0.476*
	(0.246)	(0.244)
Short-term training	-0.045	-0.228
	(0.329)	(0.328)
Radio	-0.473	-0.610
	(0.423)	(0.420)
TV	1.242	1.301
	(1.126)	(1.117)
Village/group meeting	0.355**	0.321*
	(0.178)	(0.179)
Receive advice from nongovernment EA through …		
Face-to-face, individual visits	-0.078	-0.070
	(0.271)	(0.269)
Short-term training	-0.823	-0.828
	(0.598)	(0.592)
Radio	0.309	0.374
	(0.428)	(0.425)
TV		-0.172
		(1.024)
Village/group meeting	0.040	0.101
	(0.280)	(0.278)
Number of months with abnormal rainfall		-0.102*
		(0.058)
Total livestock units		-0.001
		(0.002)
Household asset value (1,000 MWK)		-0.000
		(0.000)
Landholding		-0.020
		(0.012)
Household head education in years		0.016*
		(0.009)
Number of adults in the household		0.057
		(0.036)
North		0.201
		(0.150)
South		-0.051
		(0.118)
Quintile of distance to roads		0.025
		(0.022)
Connectivity index		-0.037
		(0.040)
Number of people in network		-0.043**
		(0.021)
Number of associations attended		0.174***
		(0.040)
Constant	3.760***	3.699***
	(0.033)	(0.210)
Observations	1,243	1,243

Source: Data are extracted from Malawi household survey (IFPRI 2016).

Note: Knowledge dimension variable is the number of questions answered correctly about pit planting. Standard errors in parentheses. EA = extension agent; MWK = Malawian kwacha. *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

8. KNOWLEDGE AND ADOPTION

We have analyzed information transmission along the knowledge chain, looking at the types of failures that result in the loss of information, as well as considering the localization of knowledge. Now we would like to show whether our measure of knowledge is important in explaining adoption behavior. If the knowledge variable has no significant impact on adoption behavior, then efforts to improve information transmission might not result in satisfactory behavioral change. Table 8.1 shows the regressions of the binary pit planting adoption variable. Specification (1) includes only the extension variables and the same set of controls that we used in Section 4. We find that receiving advice during an extension provider's visit does not affect adoption behavior. Attending a farmer cluster or visiting an agricultural training center significantly increases the likelihood of adopting the technology. Having more adults in the household is also positively associated with adoption—possibly because the number of adults in the household serves as a proxy for labor supply. Especially for pit planting, which is considered to be labor intensive, availability of family labor or hired labor, or both, is an important factor for adoption. The more organizations or associations the farmers attend, the more likely it is that they will adopt the technology.

Table 8.1 Impact of knowledge dimension on adoption of pit planting

	(1)	(2)	(3)	(4)
	Adoption of pit planting			
Variables	All farmers		Lead farmers	
Knowledge dimension		0.029**		0.091***
Receive advice about pit planting from …		(0.012)		(0.031)
Government EA	0.058	0.051	0.128	0.123
	(0.057)	(0.057)	(0.100)	(0.099)
Private EA	-0.001	0.018	0.225	0.318
	(0.187)	(0.187)	(0.333)	(0.330)
NGO EA	0.100	0.096	-0.023	-0.010
	(0.084)	(0.084)	(0.152)	(0.150)
Farmer organization EA	0.089	0.073	0.106	-0.029
	(0.233)	(0.233)	(0.397)	(0.394)
Number of months with abnormal rainfall	-0.028	-0.025	0.022	0.036
	(0.025)	(0.025)	(0.051)	(0.051)
Attend farmer cluster	0.254***	0.257***	0.171**	0.175**
	(0.056)	(0.056)	(0.084)	(0.083)
Attend farm demonstrations	0.052	0.053	0.090	0.091
	(0.039)	(0.039)	(0.072)	(0.071)
Use print materials on agriculture	-0.033	-0.027	0.011	0.045
	(0.084)	(0.083)	(0.118)	(0.117)

Table 8.1 Continued

Variables	(1)	(2)	(3)	(4)
	Adoption of pit planting			
	All farmers		Lead farmers	
Use library or resource centers	0.132	0.115	0.085	0.032
	(0.251)	(0.251)	(0.308)	(0.304)
Attend agricultural training centers	0.224***	0.237***	0.173*	0.198**
	(0.077)	(0.077)	(0.093)	(0.092)
Use radio	0.008	0.005	0.018	0.014
	(0.032)	(0.032)	(0.064)	(0.063)
Attend listening clubs	-0.141	-0.133	-0.007	0.022
	(0.113)	(0.113)	(0.146)	(0.144)
Use TV	-0.037	-0.033	0.322	0.267
	(0.133)	(0.133)	(0.384)	(0.379)
Use phone/SMS	-0.083	-0.084	-0.071	-0.065
	(0.071)	(0.071)	(0.101)	(0.100)
Attend VAC	-0.034	-0.037	-0.052	-0.053
	(0.051)	(0.051)	(0.091)	(0.089)
Attend GAC	-0.032	-0.038	-0.028	-0.051
	(0.062)	(0.062)	(0.098)	(0.097)
Attend meetings in the community	-0.028	-0.037	-0.065	-0.088
	(0.033)	(0.033)	(0.066)	(0.065)
Receive information from mobile vans	0.112	0.113	0.040	0.033
	(0.085)	(0.085)	(0.155)	(0.153)
Total livestock units	0.001	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Household asset value (1,000 MWK)	0.000	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Landholding	0.008	0.008	0.001	0.005
	(0.005)	(0.005)	(0.009)	(0.009)
Household head education in years	0.002	0.002	0.007	0.006
	(0.004)	(0.004)	(0.010)	(0.010)
Number of adults in the household	0.044***	0.043***	0.028	0.026
	(0.015)	(0.015)	(0.025)	(0.025)
North	0.061	0.066	-0.185	-0.190
	(0.065)	(0.065)	(0.127)	(0.125)
South	0.104**	0.114**	-0.127	-0.078
	(0.051)	(0.051)	(0.104)	(0.104)
Quintile of distance to roads	-0.006	-0.006	-0.045**	-0.044**
	(0.010)	(0.010)	(0.021)	(0.020)
Connectivity index	-0.018	-0.018	0.016	0.006
	(0.017)	(0.017)	(0.046)	(0.045)
Number of people in network	0.009	0.011	-0.002	0.004
	(0.009)	(0.009)	(0.015)	(0.015)
Number of associations attended	0.054***	0.049***	-0.032	-0.045
	(0.018)	(0.018)	(0.031)	(0.031)
Constant	0.269**	0.155	0.657***	0.242
	(0.112)	(0.121)	(0.211)	(0.251)
Observations	1,240	1,240	283	283
R-squared	0.101	0.105	0.104	0.134

Source: Data are extracted from Malawi household survey (IFPRI 2016).
Note: Knowledge dimension variable is the number of questions answered correctly about pit planting. Standard errors in parentheses. EA = extension agent; NGO = nongovernmental organization; SMS = short message service; VAC = village agricultural committee; GAC = group agricultural committee; MWK = Malawian kwacha. *** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

Specification (2) includes our measure of knowledge, that is, the knowledge dimension variable. We see that the knowledge variable is positive and significant in explaining adoption behavior, and the magnitude tends to be larger than those of the extension service variables. There could be two explanations for this observation. First, receiving extension services is important in determining the farmers' adoption behavior, but the effect operates only through the knowledge variable. In other words, after controlling for farmers' knowledge, the extension services variables do not provide additional information in explaining adoption. Second, it is possible that extension services have effects other than teaching farming techniques, such as urging and persuading farmers to adopt the technologies, but these other effects are not as important as farmers' knowledge in contributing to adopt a technology. Although we cannot determine the causal impact of extension services on adoption, the observation here suggests that the knowledge variable could serve as an important subjective measure of knowledge, which explains well adoption behavior.

Specifications (3) and (4) use the sample with LFs only, and the results are consistent with those in (1) and (2). The analysis here confirms our understanding that receiving advice or observing the technology during an EA's demonstration might not be sufficient in helping farmers adopt the technology. Instead, understanding the technology is more important in the adoption process. This could be because when farmers have a better understanding of the technology, they receive more of its benefits, which contributes to continued adoption.

Another observation that can help confirm the importance of knowledge in determining adoption is the distribution of pit planting adoption among different plots in the same household. If farmers' knowledge is an important determinant of adoption, then farmers would tend to adopt on all of their plots. If other variables such as labor are more important than knowledge, then we would see adoption taking place only on part of farmers' plots. However, the actual adoption of pit planting might be contingent on crop type. To control for potential crop-type effects, we restrict analysis to the plots with only maize, which is the major crop in Malawi. We find that out of 641 households that own 876 maize plots, 467 (72.3 percent of 641) households own only one maize plot, and all of those households have adopted pit planting. For the other 174 households that own multiple maize plots, 165 (94.8 percent of 174) have adopted pit planting on all of their maize plots. This evidence also favors our hypothesis that knowledge is significant in determining adoption behavior.

9. CONCLUSION

In this research, we assess the efficiency of information transmission along the lab-to-field knowledge chain. Because LFs have become an important modality of transmitting knowledge to farmers in the Malawi context, we link the EAs, LFs, and OFs within their respective geographical section. Using the complete knowledge chain, we find that most information loss occurs at the EA-LF link. We further unpack information loss, asking whether it is likely due to teaching failure (EA side) or learning failure (LF and OF side). Further regression analyses with the impact of extension on overall and single-dimension knowledge show that the information failure between EAs and LFs is potentially caused by teaching failures of EAs, who might not emphasize all of the important details for a successful implementation of pit planting. Some EAs even have a negative effect on farmers' knowledge. However, when we consider the other farmers, the analysis reveals the limited attention of farmers in learning a multidimensional technology.

Because we find that the knowledge variable better explains adoption behavior than extension service variables, we argue that receiving advice itself might not be enough to induce adoption, and that a better understanding of the technology and more intensive training and learning is more important in altering behavior. Even though most of the results in this analysis are descriptive and lack a standard causal inference, they raise questions about the efficiency of the LF modality in transmitting information and about the teaching methods employed by the extension services.

This research has some straightforward policy implications. Governmental and nongovernmental extension providers should focus on modifying the LFs' training programs. We suggest that during demonstrations, visits, group meetings, and other training sessions, EAs explicitly point out the importance of fully understanding a complicated technology. A low-cost, one-page handout or a short video for farmers with a checklist of important details of the technology might be useful in reducing the loss of information. In terms of the extension method or approach, our evidence suggests that more intensive and face-to-face interactions (face-to-face visits and group/village meetings) improve knowledge scores and reduce information loss. In the case of complex technologies, follow-ups and continued mentoring by EAs of both LFs and OFs are necessary. EAs report that it will take two to three years on average of continuous teaching and follow-up by EAs and intensive learning by farmers for farmers to master and adopt the technology. As more and more technology comes in the form of packages of multiple techniques, the adoption of a package might not only depend on the complementarity of the techniques (Ward et al. 2016) but could also be limited by farmers' knowledge. This makes fixing information inefficiencies along the knowledge chain a priority among the tasks of promoting agricultural technologies.

Further analysis is necessary to better purge away the other behavioral alternatives in the information transmission process. Because this research is embedded in the early phase of the more comprehensive extension service research project led by IFPRI, we would be able to revisit the question when more data become available, such as a panel dataset where time-invariant fixed effects could be used to control for individual heterogeneity.

Table A.1 Ranges and suggested answers for each knowledge dimension

OF	**Continuous responses to …**	**Mean**	**Median**	**Min**	**Max**	**Suggested answer**
	How should the diameter of pits be …	29.15	30	2.5	100	5 ~ 15
	How deep should the pits be …	22.12	20	1	75	15 ~ 50
	What is the distance between the pits …	43.13	35	3	500	50 ~ 100
	Categorical responses to …	**Category 1**	**Category 2**	**Category 3**		
	Do you use fertilizer in the pits …	16.16% (no)	83.84% (yes)			yes
	What type of fertilizer should be used …	17.52% (organic)	5.96% (chemical)	76.52% (both)		organic or both
	How should the pits distribute on the ground …	65.17% (straight row)	15.02% (along contour)	19.81% (randomly scattered)		straight row or along contour
LF	**Continuous responses to …**	**Mean**	**Median**	**Min**	**Max**	**Suggested answer**
	How should the diameter of pits be …	33.13	30	12	100	5 ~ 15
	How deep should the pits be …	26.18	25	10	150	15 ~ 50
	What is the distance between the pits …	53.8	60	10	160	50 ~ 100
	Categorical responses to …	**Category 1**	**Category 2**	**Category 3**		
	Do you use fertilizer in the pits …	11.31% (no)	88.69% (yes)			yes
	What type of fertilizer should be used …	15.48% (organic)	5.56% (chemical)	78.97% (both)		organic or both
	How should the pits distribute on the ground …	64.31% (straight row)	15.19% (along contour)	20.49% (randomly scattered)		straight row or along contour
EA	**Continuous responses to …**	**Mean**	**Median**	**Min**	**Max**	**Suggested answer**
	How should the diameter of pits be …	33.64	30	15	75	5 ~ 15
	How deep should the pits be …	25.98	30	15	50	15 ~ 50
	What is the distance between the pits …	61.89	70	10	90	50 ~ 100
	Categorical responses to …	**Category 1**	**Category 2**	**Category 3**		
	Do you use fertilizer in the pits …	7.59% (no)	92.41% (yes)			yes
	What type of fertilizer should be used …	30.14% (organic)	4.11% (chemical)	65.75% (both)		organic or both
	How should the pits distribute on the ground …	29.73% (straight row)	37.84% (along contour)	21.62% (randomly scattered)		straight row or along contour

Source: Data are extracted from Malawi household survey (IFPRI 2016), and extension service provider survey (IFPRI 2017). Suggested answers are obtained from agronomic research (Anschütz et al. 2003; Malesu, Oduor, and Odhiambo 2007; UNEP 2012; WOCAT 2007).
Note: OF = other farmer; LF = lead farmer; EA = extension agent.

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