Sources of Information Diffusion and Adoption of Agricultural Technologies: Evidence from Cambodia

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ABSTRACT

Agricultural development remains a central component of rural economic development policies in Cambodia, but empirical studies on the association between access to agricultural extension services and adoption of agricultural technologies remains limited. This study uses the Cambodia Inter-Censal Agriculture Survey (CIAS) 2019 to investigate potential causal relationships between access to agricultural extension services and propensity of adopting agricultural technologies among rural farm households, including an effort to disentangle the channels through which information about new technologies could be diffused. Empirical results from instrumental variable (IV) regression show that access to agricultural extension services remains crucial to promote adoption of new technologies among farmers. However we also observe that peers and traders are important channels through which information about new technologies may be diffused, especially under resource-scarce conditions. Hence, policies and development strategies seeking to promote the adoption of agricultural technologies in Cambodia should prioritize both current extension models as well as the strengthening of social networks and relationships among farmers, traders and other actors in the agricultural value chain.

Keywords: Information diffusion, aromatic rice, instrumental variable (IV) regression, technology adoption, agriculture, Cambodia

I. INTRODUCTION

A foundation of agricultural transformation is that the economic sustainability of agricultural development in low-income countries requires a shift from subsistence farming to more productive and commercialized systems (Timmer, 1988). One approach to supporting agricultural transformation has centered on agricultural extension, an ongoing process of transferring information about new technologies, more effective management options, and improved farming practices to increase producers' ability to use and manage land and water resources in ways that improve production and productivity (Beaman & Dillon, 2018; Feder & Slade, 1986; Godtland, Sadoulet, de Janvry, Murgai, & Ortiz, 2004; Pan, Smith, & Sulaiman, 2018; Suvedi, Ghimire, & Channa, 2018).

From a theoretical perspective, farmers make management decisions with an aim to maximize their expected utility of returns, which is a function of a decision set of potential management choices whose perceived benefits are a function of the information farmers have received (Feder & Umali, 1993). Extension services may bring access to new agricultural techniques and new crop varieties directly, but particularly if a farmer is risk-averse, concerns about new technologies may remain a substantial constraint to farmers' adoption. Such uncertainty may be diminished through personal experience or when farmers become increasingly aware of new approaches undertaken by other farmers and see positive returns, e.g., improved yields through new technologies, changes in farming practices, or adoption of high-yielding crop varieties (Barham & Udry, 1999). Extension may thus play a key role not only in direct access to technologies, but also in providing access to improved information about potential risks and benefits associated with newly introduced techniques and crops, thereby alleviating a key barrier to adoption.

The linkages between access to agricultural extension services and agricultural performance have been well documented, with many studies showing positive associations (Aker, 2011; Baig & Aldosari, 2013). Nonetheless, the relationship in some studies has been inconclusive. For example, Feder & Slade (1986), Godtland et al. (2004), and Pan, Smith, & Sulaiman (2018) all report a positive and significant effect of agricultural extension on agricultural performance and household welfare, whereas others report no significant effects (see, for instance, Feder, Murgai, & Quizon; 2004; Schreinemachers et al., 2017). In other words, empirical evidence does not always suggest that access to extension has significant impacts on agricultural production decisions (including adoption of improved farm technologies) or outputs. In general, the effectiveness of agricultural extension varies depending on local conditions, including the presence of proper matches between new technologies and the capacity of farmers, but also depending upon access to information sources outside extension. For example, a seminal study of pineapple production in Ghana by Conley & Udry (2010) empirically showed that farmers were more likely to adjust their input choices given their capacity *after* learning of the harvest experiences of their neighbors who used improved inputs.

Cambodia's agriculture remains at an early stage of its transformation with low levels of value-added production compared to other developing countries, according to a recent draft policy document of the 2022-2030 Agriculture Development Policy (ADP) (RGC, 2022). Major constraints on Cambodia's agricultural development include low productivity, high input costs, limited supporting infrastructure, lack of investment in agro-processing, and limited institutional capacity (MAFF, 2019; RGC, 2022). More specifically, a lack of knowledge among farmers surrounding the application of improved farm technologies (i.e., modern inputs and improved farm practices) has been identified by the Government of Cambodia as a key barrier for the competitiveness and modernization of Cambodia's agriculture (RGC, 2022). As a result, the government and development partners have emphasized promoting the adoption of agricultural technologies as an important priority for agricultural development.

Though promoting farmers' access to agricultural extension services is included in the 2022-2030 Agricultural Development Policy, there has been a limited number of empirical studies exploring the effectiveness of agricultural extension in Cambodia. That is mainly because of data limitations, which have made it difficult to evaluate impacts of extension generally, or to compare across alternative models of extension services. Assessing the impacts of alternate approaches to agricultural extension may provide valuable insights into how best to support agricultural performance among farm households in Cambodia.

Most of the available studies on extension in Cambodia use descriptive statistics or case studies without rigorous empirical analysis. For example, Ngo & Chan (2010) conducted a case study giving an overview of agricultural extension services in Kandal and Takeo provinces, concluding that agricultural extension could help farmers reduce costs, improve yields and reduce damages resulting from insects or pests. Chhim, Theng, & Nou (2013) meanwhile explored some of the key shortcomings associated with agricultural extension services in Takeo province using qualitative and descriptive analysis. Their qualitative findings suggested that farmers' access to technical support from local extension services was limited, and that farmers often relied on merchants' advice when using yield-enhancing inputs. A more recent study by Suvedi, Ghimire, & Channa (2018) examined the knowledge of 39 agricultural extension professionals using a group-administered survey of 8 core agricultural competencies. Their findings revealed that extension workers in the study rated most of the 8 study competencies highly or very highly important to their extension work; but they also highlighted substantial gaps in knowledge relating to these same competency areas among the extension professionals surveyed.

Regarding quantitative studies about the productivity impacts of agricultural extension or development programs in Cambodia, Tong, Hem, & Santos (2011) empirically studied the causal relationship between agricultural extension services and agricultural intensification using econometric analysis and data from a two-period panel survey of 231 rural households. They concluded that access to agricultural extension services were a significant determinant of farmers' decisions to adopt double cropping. Keo & Theng (2013) further evaluated the impact of agricultural extension services on rice productivity by employing propensity score matching and a difference-in-differences approach with panel data from a two-period household survey in 9 rural Cambodian villages. They concluded that agricultural extension services had no significant impact on rice productivity. However, both of these empirical studies focused on the general impacts of agricultural extension services and ignored the possibility that farmers might have received other information from various sources such as government agents, relatives, friends and neighbors, and NGOs. Thus, the impacts estimated by the studies might be inconclusive in part since information sources that have no impact or have a negative impact on farm outcomes might cancel out positive impacts from others. For example, Schreinemachers et al. (2017) examined the linkage between farmers' knowledge and agricultural pest management and pesticide use in Southeast Asia including Cambodia. Their findings showed that advice from extension officers did not have a significant relationship with farming practices, but information and knowledge gained from peers and traders increased the adoption of improved farming practices. However, even this study did not address the likely endogeneity of having access to agricultural information from any source – indeed, to the best of our knowledge, there have been no studies estimating the impact of agricultural extension information (across multiple possible information channels) on farm production in Cambodia using nationally representative data and a rigorous econometric model.

The contribution of this study is thus threefold. First, we employ the Cambodia Inter-Censal Agriculture Survey (CIAS) 2019, the latest nationally representative data on the agriculture sector in Cambodia. Second, because this dataset includes measures of farm households' access to agricultural extension information from various sources including government, traders, peers, farmer groups and NGOs, it enables us to estimate the impact of access to agricultural extension services on agricultural performance across the various sources[1] through which farmers acquired information. As a result, the study could generate concrete empirical evidence for the government to adopt appropriate intervention points to further promote agricultural extension services in Cambodia. Finally, the study also contributes to the literature on agricultural technology adoption in Cambodia, which to date has received little attention (Sumner, Christie, & Boulakia, 2017).

We focus on the effect of access to extension services on the adoption of aromatic rice, one of the key modern rice varieties in Cambodia[2]. There are two important reasons for the choice of this outcome. First, high-yield varieties of seeds were central to the package of Green Revolution technologies which have transformed crop productivity globally since the late 1960s (Ogada, Mwabu, & Muchai, 2014). Second, aromatic rice is a major crop for Cambodia's agricultural exports (RGC, 2022). In view of the existing literature and the policy framework on agricultural development in Cambodia, we seek to respond to the following questions.

1) How does access to agricultural extension services by farm households relate to farmers' decisions to adopt aromatic rice?

2) How does access to different sources of agricultural extension services (i.e., government, peer, traders and others) affect these outcomes?

II. CONCEPTUAL FRAMEWORK / THEORETICAL BACKGROUND

This section briefly reviews how farm households' access to agricultural extension might influence their decision to adopt improved farm technologies. Among the factors affecting adoption, our study hypothesizes that farmers' access to information and their knowledge related to improved farm technologies plays an important role in adoption of those technologies. Overall, our study conceptualization is based on the diffusion of innovations theory which broadly argues that levels of uncertainty and perceived risk in the technology diffusion process can decline by enhancing access to information (Rogers, 2003). In this theory, mass media and interpersonal channels are the two main means of accessing new information. The former is more effective in creating knowledge of innovations, while the latter are more effective in changing farmers' attitudes toward new knowledge or innovations. This is relevant to our research questions aiming to examine how

[1] The sources or types of agricultural information or knowledge that are available in CIAS 2019 are: (1) Government or public institutions; (2) Other farmers or peer; (3) Farmer groups; (4) Traders, and (5) NGOs.
[2] We take aromatic rice as a proxy for improved farm technologies in Cambodia.

access to agricultural extension services by farm households through various alternative information channels might affect farmers' decisions to adopt agricultural technologies.

The conceptual framework by Rogers (2003) is relevant to interdisciplinary studies about adoption of new technology and has been applied across varied disciplines such as sociology, education, communication, marketing as well as anthropology. Also, its discussion does not necessarily rely on microeconomic concepts such as expected utility maximization or profit maximization for empirical specifications (Feder & Umali, 1993; Marenya & Barrett, 2009; Ogada et al., 2014; Smale & Olwande, 2014). Rather, Rogers (2003) focuses on dissemination and acquisition of knowledge, which is related to access to agricultural extension services – our study objective.

Differences across farmers in access to information and knowledge about a farm technology – aromatic rice in the case of this study – could meaningfully impact households' adoption decisions. This hypothesis is in line with recently emerging studies that focus on social networks shaping farmer decisions (Beaman & Dillon, 2018; Conley & Udry, 2010; Matuschke & Qaim, 2008). Previous research has suggested that under certain circumstances, farmers may not initially be able to apply agricultural technologies properly because of the complexity of the technologies (which Braham & Udry (1999) attribute to tacit elements of a technology, circumstantial sensitivity and institutional context of some agricultural technologies). In such cases, farmers may engage in a process of learning-by-doing, experimenting with a new improved farm technology to reveal tacit elements of the technology (Barham & Udry, 1999; Conley & Udry, 2010). Such learning might also take place from interactions with outside sources such as extension agents, or simply through observing the experiences of neighbors. It can be hypothesized that the effects of farmers' access to agricultural extension services might vary according to the alternative sources by which farmers might acquire information.

Diffusion of innovation theory further conceptualizes the main stages of dissemination of innovations, ranging from the time that a household acquires knowledge to the confirmation stage in which a household adopts (or dis-adopts) an innovation. Previous empirical research suggests that the level of knowledge acquisition is shaped by three main sets of characteristics of the decision-making unit, i.e., socioeconomic variables (Ghimire & Huang, 2015), personality factors (Schreinemachers et al., 2017) and communication behavior (Beaman & Dillon, 2018), which together represent the key determinants of technology adoption. In the context of farm households in Cambodia, farmers with higher socioeconomic status and more extensive social networks (such as membership in farmers' groups or relationships with business associations and traders inside or outside the village) might have more opportunities for exchange of information and thereby may be more likely to adopt new technologies (Kassie, Jaleta, Shiferaw, Mmbando, & Mekuria, 2013). Other studies have suggested early adopters may be more likely than late adopters to have higher levels of formal education, higher incomes, greater exposure to mass media, and more extensive interpersonal channels of communication (Kassie et al., 2013; Moser & Barrett, 2006; Rogers, 2003; Teklewold, Kassie, & Shiferaw, 2013).

In a recent example of the application of diffusion of innovation theory in empirical work in the agricultural sector, Mathenge, Smale, & Olwande (2014) used the idea of social learning to justify the choice of an instrumental variable (IV), namely the cumulative adoption rate of hybrid seed at the village level, to estimate the impact of hybrid seed use on household-level welfare (income, assets, inequality and poverty). Our study uses a similar approach to validate the choice of a similar instrumental variable – cumulative access rate of agricultural extension services at the village level – to examine the potential contributions of agricultural extension to increased rates of farm technology adoption.

III. DATA

The data used in this study are compiled from the Cambodia Inter-Censal Agriculture Survey (CIAS) 2019, the latest nationally representative survey on agriculture in Cambodia. The survey was conducted jointly by the National Institute of Statistics, Ministry of Planning, and the Ministry of Agriculture, Forestry and Fisheries. CIAS 2019 has a sample of 16,000 farm households across all 25 provinces throughout Cambodia, with the exception of 6 districts in the capital city of Phnom Penh and Preah Sihanouk Province, which are highly urbanized. The survey provides comprehensive information about households including their crop cultivation, livestock, aquaculture, and other agricultural activities. However, the survey collected no village-specific data such as distance from the village to the nearest national road, seasonal movement of labour, or soil types. It should be noted that CIAS 2019 is used by the Cambodian government as a fundamental guidance to formulate national strategies and policies and to monitor and evaluate the progress of agricultural development. The report by the National Institute of Statistics-NIS (2019) explains further details about sampling design and methodology.

It should be noted that not all households provided complete information about themselves. Some also did not grow any crops at all in the last 12 months. Therefore, without complete information, these households are dropped from data analysis, resulting in a final sample of 13,326 households for the empirical analysis.

3.1 Dependent variable

To understand factors associated with a household's adoption of agricultural technologies, we use an indicator variable for the adoption of aromatic rice which is equal to 1 if a household planted aromatic rice during the last 12 months, and 0 otherwise. In current global markets, aromatic rice is in high demand and being sold at a higher price compared to other rice varieties due to its pleasant aroma and superior quality (Ear et al., 2017; RGC, 2022). However, cultivating aromatic rice is quite distinct; it requires knowledge of agricultural technologies such as soil textures and water levels to obtain maximum yields.

3.2 Independent variables

Our independent variables of interest measure access to agricultural information by households. We employ four binary variables including access to agricultural information through government, peers, groups, and traders. They are defined as follows.

Access to agricultural information from the government:	1 if a farm household had access to agricultural information the government during the last 12 months; 0 otherwise

Access to agricultural information from peers	1 if a farm household had access to agricultural information from peers during the last 12 months; 0 otherwise
Access to agricultural information from farmer group	1 if a farm household had access to agricultural information from farmer groups during the last 12 months; 0 otherwise
Access to agricultural information from traders	1 if a farm household had access to agricultural information from traders during the last 12 months; 0 otherwise

3.3 Control Variables

Our concern when attempting to estimate a causal association between access to agricultural information and the adoption of aromatic rice is the possible household-level confounding factors that are correlated with measures of access to agricultural information. To address this concern, we control for several household-level characteristics including the following. *Agricultural training* is an indicator variable which is 1 if a household member received formal training related to agricultural production, and 0 otherwise. *Female* is 1 if a household head is female, and 0 otherwise. *Age* is age of household head in years. *Household size* is the total number of members in the household. Married is a binary variable which is 1 if a household head is married, and 0 otherwise. *Planted area* is the total planted area in hectares during the past 12 months.

We also examine other agronomic characteristics, specifically access to irrigation and the use of fertilizer and pesticides among aromatic rice growers and between aromatic and non-aromatic rice growers. Access to and use of these inputs are binary variables as the surveyed households were not asked about expenses or use rates of the inputs. There are clear differences in characteristics between non-growers and growers of aromatic rice (Table 1). For instance, aromatic rice growers tend to cultivate on larger plots averaging 3.6 hectares compared to 2.1 hectares cultivated by non-aromatic rice growers. Aromatic rice growers are also more likely to use irrigation, fertilizer and pesticides compared to non-aromatic rice growers. It should be noted that use of fertilizer and pesticides is high among both aromatic and non-aromatic rice producers – for instance, about 90 percent of households growing aromatic rice used organic and inorganic fertilizer as compared to 86 percent of those growing non-aromatic rice (NIS, 2020). We therefore do not include input use as a variable in our empirical models, rather we assume the outcome variable adoption of aromatic rice reflects adoption of a package of skills, complementary inputs, and seed for aromatic rice cultivation.

The descriptive results in Table 1 further indicate welfare gains among aromatic rice growers compared to non-aromatic rice growers in terms of sales, both total and per hectare of planted area. Although non-aromatic rice was the most common among the three rice types in the sample — non-aromatic, aromatic and sticky rice — and produced a higher average yield per hectare of harvested area compared to aromatic rice, aromatic rice growers often fetch a higher price per kilogram of paddy sold. For instance, in 2020 the average production per hectare harvested of non-aromatic rice was 2.5 tonnes compared to 2.2 tonnes per hectare harvested of aromatic rice varieties. But between July 2019 and June 2020, the average price of non-aromatic paddy was KHR918 per kilogram, whereas that of aromatic paddy was KHR1,019 per kilogram (NIS, 2020, p.94-95). The higher price indicates market demand for aromatic rice.

IV. EMPIRICAL METHODS

We use the Cambodia Inter-Censal Agriculture Survey (CIAS) 2019 to investigate the relationship between access to agricultural extension services and adoption of an improved farm technology among Cambodian farm households. Our study employs a binary outcome model to estimate the causal effect of access to agricultural extension services on the likelihood of adopting aromatic rice. The probit model can be written in the following form:

$$\mathrm{P}(Y_i = 1) = \phi(\alpha + \beta E_i + X_i'\delta + \varepsilon_i) \qquad (1)$$

where $\mathrm{P}(Y_i = 1)$ represents the probability of farming household i adopting the improved farm technology (i.e., aromatic rice), E_i represents the treatment variable namely the access to agricultural extension services, X_i is a vector of covariates that includes household characteristics and shocks, which may be correlated with the treatment variable E_i and affect the outcome variable Y_i, and ε_i is the disturbance term. By estimating model (1), we aim to provide evidence on whether households that receive agricultural extension services are more likely to adopt aromatic rice or allocate more cultivated land to produce this rice variety compared to households that do not, while controlling for differences in household characteristics and shocks.

One of the key assumptions when estimating equation (1) using the least squares estimator is that the treatment variable E_i is exogenous to factors that affect the outcome variable Y_i. However, this assumption is unlikely to hold in practice, given that access to agricultural extension services is not random, as has been documented in the literature (see, for example, Pan et al. 2018; Dercon et al. 2009; Godtland et al. 2004). On the demand side, households that are in dire need of agricultural information related to crop-improving technologies may be more likely to seek or receive access to agricultural extension services. On the supply side, agricultural extension service providers such as government or NGOs may target top-performing farm households who are more likely to adopt new farm technologies. As a result, the presence of an endogenous treatment variable due to selection bias can lead to biased and inconsistent estimates of the causal effect. Therefore, to account for this potential endogeneity, we employ an instrumental variables approach in our analysis.

Identification problems due to endogeneity of explanatory variable of interest can be addressed using a few techniques considering the cross-sectional nature of the CIAS 2019 data. One can employ matching methods such as propensity score matching (PSM) if the treatment variable like access to agricultural extension services is not random but assumed to be determined by a propensity score predicted by a combination of observable factors like household and region characteristics. However, the average treatment effect $\hat{\beta}$ estimated by the PSM method is still biased if the treatment variable E_i is explained by unobserved factors which also affect the potential outcome Y_i. To further respond to the potential issue of endogeneity due to omitted unobserved variables, we opt for the method of instrumental variable analysis. This approach relies on the availability of an external factor which satisfies two major assumptions (Wooldridge, 2010). One is called the relevance assumption which states that the instrument has a sufficiently strong association with the treatment variable $\mathrm{E_i}$, and the other is the exogeneity assumption requiring that the IV is not correlated with the disturbance term ε_i in equation (1).

While finding a valid instrument that satisfies the assumptions stated above is challenging, our choice of IV approach is motivated by Mathenge, Smale, & Olwande (2014) who use the "cumulative adoption rate" as an instrument for the endogenous treatment variable on the choice of hybrid maize seed use. In our research, to examine the impact of the endogenous treatment variable, which is the access to agricultural extension services, the use of cumulative access rate as the IV can be similarly defended, with cumulative access rate here defined as the proportion of households which have access to agricultural extension services in each village. The selection of cumulative access rate as the IV is based on the proposition that the village-level share of households accessing a given type of extension services is likely correlated with the individual households' decision to get the services. More specifically, the probability that a household has access to the extension services increases with more neighbouring households receiving the same services. Although this association needs to be statistically tested, the intuition is that the crucial relevance assumption of IV is thus satisfied. Moreover, the fact that other households' decision to access extension services appears to be uncorrelated with factors that determine adoption of aromatic rice by one specific household, the exogeneity assumption of choosing the share of households accessing the extension services within villages as an IV is defensible.

V. RESULTS AND DISCUSSION

5.1 Descriptive Statistics

Table 2 provides the summary statistics and pairwise correlations of all variables employed in our regression analyses from a sample of 13,326 households in the CIAS 2019 data. The first two columns of the table report the means and standard deviations. In terms of access to agricultural information through various sources, a majority of households acquire information through peers. Specifically, about 27% of the households obtain agricultural information through friends or acquaintances. The second most common source of information is the government, with approximately 11% of households receiving agricultural information from this source. However, a lower proportion of households have access to agricultural information through groups and traders, accounting for around 3% and 6% of the sample, respectively. These descriptive statistics also reveal that a relatively large proportion of the households in the sample cultivate aromatic rice, accounting for approximately 14% of the total households.

The degree of association between each variable and every other variable is shown in Columns 3-17. Notably, there is a positive correlation between the adoption of aromatic rice varieties and each of the different agricultural extension information variables, including access to agricultural information from the government, peers, groups, and traders. Moreover, there is also a positive correlation between our proposed instruments – the cumulative access to agricultural information from the four sources at the village level – and the household-level access to agricultural information from those sources. These initial findings are consistent with the extensive literature on agricultural technology adoption and social learning (Mathenge et al., 2014; Rogers, 2003).

5.2 Econometric Results

Table 3, Panel A presents the regression results showing the association between the cumulative access rates of agricultural information from different sources (instrumental variables) and the adoption of information at the household level. Columns 1-4 present the results for different sources of information including government, peers, groups and traders. Results show that the cumulative access rate of agricultural information from all sources at the village level has a significant positive association with the adoption of information from the same entity at the household level. For example, in Column 1 the coefficient on the cumulative access from the government is 0.055 which is strongly significant at the 1% level. This indicates that an increase in the cumulative access rate of agricultural information from the government at the village level is associated with an increase in the adoption of information from the same entity at the household level. In other words, households that have had greater exposure to government-provided agricultural information are more likely to adopt this information.

In Column 2, the association between cumulative access from peers and the adoption of information from peers is also positive and strongly significant, highlighting the important role of peer-to-peer information sharing as an effective method of disseminating agricultural information which may encourage the adoption of new technologies. Results in Column 3 similarly suggest that an increase in the cumulative access rate of agricultural information from groups is associated with an increase in the adoption of information from groups at the household level. This provides support for the hypothesis that groups such as farmer groups or cooperatives can be effective in sharing agricultural information. Finally, results in Column 4 indicate that traders can be an important source of agricultural information for farmers. In the context of Cambodia, as in many other developing Asian countries, smallholder farmers often have direct contacts with traders who not only provide access to agricultural inputs such as seeds and fertilizers but also serve as sources of information about market prices, availability of inputs, good management practices, anticipated productivity gains, and other agricultural information.

Considering the importance of the information shared by these four different sources - government, peers, group and traders, the question that we address next is whether these relationships contribute to the adoption of agricultural technologies such as the adoption of aromatic rice. As we have previously discussed, understanding the relationship between access to agricultural information and the adoption of improved farm technologies is of policy relevance as policy makers can design effective policy interventions to improve agricultural outcomes. In addition, the adoption of new and improved technologies can help farmers to achieve higher crop yields, thereby improving food security, increasing incomes and contributing to poverty reduction (Ali & Abdulai, 2010; Babu, Gajanan, & Sanyal, 2014; Mathenge et al., 2014).

In Table 3 Panel B, we present the results of the regression analysis which investigates the relationship between access to agricultural information and the adoption of aromatic rice using cumulative rates of adoption of agricultural information as instruments. The results in Columns 1-4 show the coefficients on access to agricultural information from the four sources, namely government, peers, groups and traders. In Column 1, the coefficient on the source of agricultural information from the government is positive but not statistically significant, suggesting that access to information provided directly by government may not be an influential driving force behind the adoption of aromatic rice by farmers. This is consistent with empirical results by Schreinemachers et al. (2017) which reported that government extension services did not have significant linkages with farmers' adoption of good practices with pesticides in Cambodia. Additionally, the qualitative study by Chhim, Theng, & Nou (2013) reinforces our empirical results in the sense that the authors highlighted how the perceived inadequacy of extension service information and advice on improved farm technologies such as new varieties, fertilizer and pesticides compels farmers to depend on other sources of information and knowledge, including their peers and traders.

In Column 2, the coefficient on the source of agricultural information from peers is positive and statistically significant at the 1% level, indicating that obtaining information from peers is strongly associated with higher rates of adoption of aromatic rice. In Table 3, Column 2 we estimate the average marginal effect of having access to agricultural information from peers and find that on average households that receive agricultural information from their peers are about 18 percentage points more likely to adopt aromatic rice variety in their production compared to households that do not. This result further suggests that farmers may be more likely to trust their peers who have experience with growing aromatic rice and are willing to share their knowledge about this new technology. This finding can be explained by the concept of social learning, whereby farmers learn from others about the use and profitability of improved farm technologies. As shown in many other low-income countries, in Cambodia farmers may become more receptive to the applicability of a new technology and have greater confidence in its profitability based on the experiences of their neighbors (Conley & Udry, 2010; Matuschke & Qaim, 2008).

The coefficient for obtaining agricultural information from group presented in Column 3 is not statistically significant, suggesting that information from a group (such as a farmer association or cooperative) may not have a significant impact on the adoption of aromatic rice. It is possible that groups may not have the necessary expertise or knowledge about growing aromatic rice. However, the coefficient for information from traders reported in Column 4 is positive and strongly significant, indicating that obtaining agricultural information from traders is a crucial channel for promoting the adoption of aromatic rice among farmers. Farmers may rely on traders as an important source of information on which varieties of aromatic rice are in demand or have a higher market value. As such, farmers may be more inclined to trust and act upon the information provided by traders who have a vested interest in the success of their crops and can benefit from the farmers' increased adoption of aromatic rice. The crucial role of traders in increasing farmers' awareness and knowledge of improved agricultural practices such as aromatic rice adoption is supported by the previous studies such as Kassie et al. (2013); Schreinemachers et al. (2017) and Chhim, Theng, & Nou (2013).

Some of the coefficients on our included control variables also present interesting findings, one of which is the coefficient for agricultural training. The coefficient for agricultural training is positive and statistically significant at the 1% level for all models, suggesting that farmers who have received agricultural training are more likely to adopt aromatic rice than those who have not. This finding highlights the importance of providing training and education to farmers to improve their understanding and knowledge of agricultural practices including aromatic rice growing techniques. The coefficient on female is also positive and statistically significant at the 1% level for all models, suggesting that female-headed households are more likely to adopt aromatic rice than male-headed households. This finding could be due to factors such as women's greater involvement in agricultural activities or their greater willingness to adopt new rice technologies compared to men. Another variable is the positive and statistically significant coefficient on planted area. This indicates that farmers who have larger planted areas are more likely to adopt aromatic rice than those with smaller ones. It is also implied that access to land could play a crucial role in the adoption of new technologies. One possible explanation for this could be that farmers who have larger farms more likely to have more resources which allow them to invest in new technologies and experiment with different crop varieties. Additionally, larger farms can benefit from economies of scale, which means they could try out new technologies and implement innovative agricultural practices more easily.

VI. CONCLUSION

Using the Cambodia Inter-Censal Agriculture Survey (CIAS) 2019, this study analyses whether the access to agricultural information through various sources has a causal impact on the adoption of agricultural technologies, with a focus on aromatic rice varieties. Our results suggest that obtaining agricultural information from peers and traders is significantly associated with a higher likelihood of farmers adopting aromatic rice. This highlights the importance of peers and traders for promoting the adoption of new technologies among farmers. Farmers may perceive information from peers and traders as relevant, reliable and up-to-date, and use this information to make decisions about whether to invest in new technologies. Since the decision is assumed to be based on farm profitability, traders in particular may have specific knowledge about whether a particular technology is worthy of investment. In that sense, both farmers and traders may also have a vested interest in the success of the investment (the farmer seeking higher productivity, and the trader seeking reputational benefits and future seed sales), increasing confidence in the information shared via this channel. Moreover, strong social ties between farmers and peers also appear to help facilitate the exchange of information in a credible and legitimate manner.

In contrast, our findings suggest that government sources of information did not play a significant role in influencing farmers to adopt new agricultural technologies, nor did access to information from groups (e.g., farmers associations). These results are consistent with some previous literature, with the evidence indicating that formal institutional channels including both government and groups may be less effective at communicating agricultural information to farmers as compared to more informal channels via peers and traders. This could be due to various reasons, such as the lack of networking relationships and trust between farmers and government or groups diminishing the perceived credibility of the information provided.

Overall, this study emphasizes the significant role of social connections in promoting the adoption of innovative agricultural practices in Cambodia. The findings not only support hypotheses drawn from social learning theory, but also have practical implications for policymakers. It is essential for policymakers to recognize the importance of peers and traders in facilitating the exchange of agricultural information and building trust among farmers. Further, strategies aimed at promoting the adoption of new agricultural technologies should prioritize leveraging and perhaps strengthening social networks and relationships among farmers and other actors in the agricultural value chain. Given the limited resources of the government, promoting agricultural extension information dissemination through relatively lower cost informal sources (i.e., peers and traders) might be a feasible policy option. Such measures could lead to better outcomes for the agricultural sector in Cambodia, increasing productivity and incomes for farmers while also contributing to food security and poverty reduction in the country.

We wish to address three research questions in future work. The first is to examine welfare gains (or losses) aromatic rice adopters might obtain under different socioeconomic and environmental conditions. Although our descriptive statistics points to potential benefits associated with aromatic rice, we have insufficient information to disentangle potential causal associations between aromatic rice adoption and household incomes or other welfare gains. Second, it is of policy relevance to understand more about the possible heterogeneity of welfare gains (or losses) by socio-economic characteristics of adopters (e.g., gender, geographical location, income). Third, we might need to understand better the gains (or losses) from a costs-benefits framework, allowing the adopters and policymakers to identify whether pushing for aromatic rice adoption is worth the time, efforts and resources.

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IX. FIGURES AND TABLES

Table 1: Differences of characteristics between aromatic and non-aromatic growers

	Non-aromatic (1)	Aromatic (2)	Diff. (1-2)
Female-headed household	0.223	0.222	0.001
	(0.416)	(0.416)	(0.956)
Age	48.605	48.253	0.352
	(11.544)	(11.457)	(0.215)
Marital status of household head (married)	0.864	0.883	-0.018**
	(0.343)	(0.322)	(0.026)
Household size	3.976	4.083	-0.108**
	(1.660)	(1.600)	(0.008)
Planted area (ha)	2.143	3.607	-1.464***
	(6.104)	(6.948)	(0.000)
Agricultural training	0.164	0.254	-0.090***
	(0.370)	(0.435)	(0.000)
Planted area with irrigation (ha)	0.720	1.575	-0.855***
	(2.942)	(3.942)	(0.000)
Planted area with fertilizer (ha)	1.686	3.288	-1.602***
	(5.534)	(6.879)	(0.000)
Planted area with pesticides (ha)	1.556	2.748	-1.191***
	(4.820)	(6.661)	(0.000)
Sales in last 12 months (log, KHR0’000)	2.755	4.254	-1.499***
	(3.017)	(2.945)	(0.000)
Sales / planted area in last 12 months (log, KHR0’000)	2.594	3.59	-0.997***
	(2.705)	(2.406)	(0.000)

Note: Standard deviations of the mean are in parentheses; p-values of the t-test are in brackets.
Source: Authors’ calculations.

Table 2: Descriptive statistics and pairwise correlations

Variable	**Mean**	**SD**	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) Aromatic	0.144	0.352	1.00														
(2) Info from govt.	0.113	0.317	0.06	1.00													
(3) Info from peers	0.265	0.441	0.02	0.17	1.00												
(4) Info from group	0.030	0.171	-0.01	0.15	0.12	1.00											
(5) Info from trader	0.063	0.242	0.04	0.24	0.05	0.07	1.00										
(6) Agri. training	0.177	0.381	0.08	0.22	0.05	0.15	0.27	1.00									
(7) Female	0.223	0.416	0.00	-0.02	-0.03	0.00	-0.01	-0.04	1.00								
(8) Age	48.554	11.532	-0.01	0.01	-0.01	0.00	-0.01	0.04	0.12	1.00							
(9) Married	0.867	0.340	0.02	0.01	0.02	0.01	0.01	0.04	-0.57	-0.22	1.00						
(10) Household size	3.991	1.652	0.02	0.00	-0.01	-0.01	0.02	0.06	-0.15	-0.01	0.15	1.00					
(11) Planted area (ha)	2.355	6.254	0.08	0.04	0.06	0.03	0.04	0.11	-0.08	0.00	0.07	0.05	1.00				
(12) CA[a] from govt.	10.917	6.820	0.03	0.22	0.09	0.04	0.10	0.08	0.04	0.00	-0.02	-0.03	0.02	1.00			
(13) CA from peers	25.374	11.489	0.13	0.09	0.26	0.03	0.09	0.10	-0.01	0.00	0.01	-0.03	0.11	0.37	1.00		
(14) CA from group	2.848	3.105	0.10	0.04	0.03	0.19	-0.01	0.04	0.00	0.00	0.01	-0.02	0.05	0.16	0.15	1.00	
(15) CA from trader	5.974	5.921	0.06	0.09	0.08	-0.01	0.25	0.13	0.01	-0.07	0.01	0.02	0.08	0.40	0.34	-0.04	1.00

[a]cumulative access

Table 3: Access to agricultural information and aromatic rice adoption

Panel A				
Dependent variable	**(1) Information from government**	**(2) Information from peers**	**(3) Information from group**	**(4) Information from traders**
Cumulative access from government	0.055***			
	(0.002)			
Cumulative access from peers		0.031***		
		(0.001)		
Cumulative access from group			0.105***	
			(0.005)	
Cumulative access from traders				0.048***
				(0.002)
Agricultural training	0.732***	0.064**	0.735***	0.915***
	(0.036)	(0.033)	(0.053)	(0.041)
Female	-0.158***	-0.073**	0.056	-0.020
	(0.048)	(0.037)	(0.074)	(0.056)
Age of household head	0.001	-0.001	-0.002	-0.002
	(0.001)	(0.001)	(0.002)	(0.002)
Married	-0.084	0.008	0.052	-0.056
	(0.059)	(0.046)	(0.096)	(0.072)
Household size	-0.013	-0.014*	-0.031*	0.004
	(0.010)	(0.008)	(0.016)	(0.012)
Plated area (in log)	0.047***	0.049***	0.016	0.027*
	(0.012)	(0.010)	(0.018)	(0.016)
Panel B				
Dependent variable	**Aromatic rice adoption (all models)**			
Information from government	0.012			
	(0.128)			
Information from peers		0.738***		
		(0.073)		
Information from group			0.118	
			(0.150)	
Information from traders				0.426***
				(0.155)
Agricultural training	0.208***	0.161***	0.200***	0.139***
	(0.043)	(0.035)	(0.036)	(0.042)
Female	0.145***	0.154***	0.146***	0.141***
	(0.041)	(0.040)	(0.041)	(0.041)
Age of household head	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Married	0.040	0.038	0.039	0.040
	(0.053)	(0.051)	(0.053)	(0.052)
Household size	-0.006	0.000	-0.006	-0.005
	(0.008)	(0.008)	(0.008)	(0.008)
Plated area (in log)	0.231***	0.195***	0.230***	0.226***
	(0.011)	(0.012)	(0.011)	(0.011)

We estimate seemingly unrelated bivariate probit models for the binary outcome (aromatic rice adoption) and the endogenous variables (information source) which are also binary. The instruments include cumulative access to information from government, peers, group and traders at village level. Each cell shows the coefficient for each regressor. Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table 4: Average marginal effects of access to information on aromatic rice adoption

Variable	Marginal effect
Information from government	0.003
	(0.029)
Information from peers	0.176***
	(0.018)
Information from group	0.027
	(0.035)
Information from traders	0.099***
	(0.036)

Standard errors in parentheses are computed using Delta-method.
*** p<0.01, ** p<0.05, * p<0.1