Rural Adaptation to Climate Change: New Findings and Existing Knowledge

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ABSTRACT

This paper discusses the results of new research at the farm level regarding farmers' responses to climate change. These results are placed in the context of existing literature. The topics include the benefits of adaptation, the forms of adaptation, and the drivers of adaptation such as land tenure, water allocation systems, the operation of labor markets, and the extent of social capital. Moreover, this paper examines farmers' responses to market signals as they consider adaptation options and the connections of these options with infrastructure quality. It also reviews policy options that support adaptation.

Keywords: agriculture, climate change, adaptation

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INTRODUCTION

Climate change is a new source of pressure for adaptation in farming systems (Cooper et al. 2008; Thornton and Herrero 2015; Huang and Sim 2017), especially since the number of extreme weather events such as droughts, floods, and severe storms (Easterling et al. 2000) is increasing (Adger et al. 2003). Consequently, welfare effects are likely to be significant (Howden et al. 2007), and farmers in developing countries are potentially more vulnerable (Adger et al. 2003). There are different channels through which the agriculture sector can adapt to these events at the market and household levels.

Trade can mitigate the effects of extreme weather events on local markets by increasing access to farm produce from less affected regions. Extreme weather events elsewhere may create new market opportunities for local producers. Therefore, opening markets to trade is an important means of

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adaptation because inter-regional adjustments in production and consumption can buffer the severe effects of climate change (Reilly and Hohmann 1993).

At the farm household level, adaptation is a key strategy that can reduce the severe effects of climate change on agriculture and food production (Alam, Alam, and Mushtaq 2017). The risks associated with extreme weather events are highly uncertain, and the ways by which farmers respond to these risks differ significantly from the daily farming practices they commonly employ to respond to seasonal climate fluctuations (Adger et al. 2003). Traditional adaptation practices, which are based on methods that have proven successful in the past, are continually being tested and refined. However, there is no store of knowledge and learned experience for coping with infrequent and diverse extreme weather events. Therefore, understanding farmers' adaptation strategies and decision-making processes is important in designing policy interventions to ameliorate and prevent the adverse effects of extreme weather events on farming.

In considering existing and new policy measures that can potentially improve rural adaptation to climate change, it is also useful to account for the perceptions farmers have about the effects of climate change, the conditions governing their access to land and water, and the supporting physical and social infrastructure available to them.

This paper draws on a technical report based on research performed in the Australian Centre for International Agricultural Research (ACIAR) project titled "Assessing Farmer Responses to Climate Change—Adjustment Policy Options" (ADP/2011/039) (Huang, Wang, et al. 2020). A key objective of the project was to supplement and complement the existing literature, which has taken a macroeconomic perspective on the effects of climate change on agriculture, by taking a focus on China and Vietnam and by adding an understanding of their microeconomic effects. The project involved using surveys of individual and farm-level decision-making in response to climate change events. This paper combines the results of this research with other results in the literature. Presenting the context of the work carried out in the ACIAR project, Huang et al. (2020) reviewed the structural changes in the agriculture sector in China and Vietnam (see also Huang and Yang 2017; World Bank Group 2016). This paper begins with a review of the documented and potential benefits of climate change adaptation. Subsequent sections discuss the forms of adaptation, farmers' information and perceptions, other drivers of adaptation, market signals, and infrastructure. Policy options are then presented.

EFFECTS OF CLIMATE CHANGE AND POTENTIAL BENEFITS OF ADAPTATION

This section reviews the effects of climate change and the potential benefits of adaptation. The key result is that the scope for adaptation to offset the effects of climate change is significant.

Channels of Effects

The literature relating to the effects of climate change on agriculture has grown significantly in the last few decades. Generally, early studies assessed such effects using simulation techniques that were built on theories from the physical and social sciences (e.g., Adams et al. 1990; Kane, Reilly, and Tobey 1992). A substantial body of research, as reviewed in Adams et al. (1990), has addressed the possible physical effects of climate change on agriculture, focusing on changes in crop and livestock yields and the associated economic consequences.

Among all agricultural subsectors, most of the literature focus on crop production and the potential effects of climate change on crop production. According to Hulme (1996), climate change can physically affect crops in four ways:

1. Changes in temperature and precipitation will alter the distribution of agroecological zones. The resulting changes of multiple environmental factors that lie within each zone will further affect crop production.

2. Higher levels of carbon dioxide (CO_2) can positively affect crop production by increasing water-use efficiency and photosynthesis rates. (However, Zhu et al. [2018] pointed out that the additional food grown in this environment may be less nutritious.)
3. Water run-off is affected by climate conditions. This directly affects crop yields.
4. Climate variability, especially the increased frequency of extreme weather events such as droughts and floods, can result in unpredictable damage to crops.

Lobell and Burke (2008) reported that the effects of climate change on agriculture are uncertain because the relative importance of temperature and precipitation varies, leading to the mixed net impact of climate change on crop production. This was confirmed by numerous studies on the effects of climate change in China (e.g., Smit and Cai 1996; You et al. 2009; Zhai, Lin, and Byambadorj 2009; Yin et al. 2016).

National, Regional, and Sectoral Studies

Multiple climate impact assessments have been performed using data from China, usually at either the national or the regional level. Tang et al. (2000) applied alternative general circulation models to evaluate the potential impacts of global climate change on China's agriculture. Liu et al. (2004) used county-level data on agricultural net revenue to assess the economic impacts of climate change and found that the overall effect can be positive. Wang, Huang, and Rozelle (2010) referred to scenarios in which rice yields in China can decline anywhere between 9 percent and 13 percent in the 2020s, without considering a CO_2 fertilization effect. Examining the climate–agriculture linkage from a water-use perspective, Tao et al. (2003) found that changes in the water demands of south and north China were divergent (i.e., demand will decrease in the south but increase in the north) and will consequently have different impacts on crop yields. Zhai, Lin, and Byambadorj (2009) used a general equilibrium model to estimate the effect of climate change on China's agriculture and concluded that the overall impact will be moderate at the macroeconomic level.

From a regional perspective, Chavas et al. (2009) investigated the long-term effects of climate change on agricultural productivity in eastern China. Employing simulation techniques, they concluded that maize and winter wheat will benefit significantly in the North China Plain, while potato yields can suffer in southwest China. Assessing the impacts of climate change on cropping systems in northeast China, Yin et al. (2016) concluded that there can be production benefits from the expansion of the crop-growing season, but the damage caused by pests, diseases, and weeds can also become more severe.

Many researchers have focused on the effects of climate change on one or several specific types of crops. These include You et al. (2009) who studied wheat productivity in China, Yao et al. (2007) and Xiong et al. (2009) who studied rice yields, and Xiong et al. (2010) who studied cereals. Other researchers have also investigated the use of key crop production inputs such as water, in conjunction with crop yield impact assessments, including Wu, Jin, and Zhao (2010) and Xiong et al. (2010). As Hulme (1996) predicted, the mechanisms linking climate change and agriculture are numerous and can result in mixed findings, as shown by these studies.

Wang, Huang, and Yan (2013) used a comprehensive water-simulation model to analyze the effects of climate change on agriculture in 10 river basins in China under three different climate scenarios. In some scenarios, water shortages in the north, particularly in the Liahe and Haibe river basins, will become more acute; in the south, water balances will improve. They also found that despite the greater influence on water balances in the north, the effects of climate change on total crop production will be moderate if farmers can relocate water among crops and adjust irrigated and rainfed land use.

There is a scarcity of literature on the effects of climate change in Vietnam. Examining scenarios of the effects of climate change on land use in the country, Rutten et al. (2014) found that 47 percent of paddy area was at risk of flooding and the flood-prone areas were concentrated in the Mekong River Delta. The World Bank (2010) reviewed the effects of climate change on agriculture in Vietnam, including the impacts of changes in temperature, changes in rainfall, and rising sea levels. The review also covered hydroclimatic risks such as river flooding, storms, salinity intrusion, and sea inundation, which are important in the Mekong River Delta; as well as flash floods and droughts, which are less important. In the scenarios considered, the World Bank (2010) estimated that rice yields can fall by 6.3 percent to 12 percent in the Mekong River Delta by 2050, without considering a CO_2 fertilization effect. Additionally, Booth et al. (1999) considered the possible effects of climate change on forest species.

Farm-level Studies

Wang et al. (2014) considered the impact of climate change on net crop revenue in north and south China. Analyzing data from 753 national meteorological stations and socioeconomic data from 8,405 farms across 28 provinces in China, they concluded that, on average, a rise in temperature will reduce farm crop revenue in both north and south China. Increasing temperatures, while beneficial to irrigated farms, will have adverse effects on rainfed farms. Moreover, with climate change, farms in the north will be more vulnerable to temperature and precipitation variations than those in the south.

Huang, Wang, and Wang (2015) used data from a survey of 1,653 rice farmers to examine the effects of climate change on farm practices that had been adopted to cope with extreme weather events, and their consequences. They found that floods and droughts reduced yields and increased the risk of reduced rice yields significantly. They also found that farmers who had adapted their farming practices had reduced those risks and increased yields significantly. They concluded that there was scope for scaling up cost-effective farm adaptation practices and provision of public services related to natural disasters.

Huang et al. (2018) estimated the potential benefits of long-run adaptation using a panel of household survey data from a large sample in rural China. Using various model settings and climate change scenarios, they determined that long-run adaptation can mitigate one-third to one-half of the damage caused by climate warming on crop profits by the end of the 21st century. A similar result was found using the same method in the USA and Vietnam, where long-run adaptation was estimated to mitigate one-third and one-half of the damage, respectively.

Using panel data of rice farmers in Vietnam, Dang et al. (2020) examined the short-run impacts of farmers' adaptation practices on rice yields. They found that adopting adaptation measures can reduce yield loss caused by disasters. They also found that farmers with direct access to early-warning information about climate and to technical support were more likely to apply adaptation measures.

The following sections review the different forms of adaptation employed by farmers and the drivers of their use. The focus is on decision-making at the household level.

FORMS OF ADAPTATION

In the face of climate extremes, farmers have adopted numerous adaptation strategies in different agroecological conditions. These include, but are not limited to, irrigation technology advancement (Wu, Jin, and Zhao 2010; Xiong et al. 2010); variety choice (Tao and Zhang 2010); cultivation-timing changes, soil-tillage practices, crop protection (Yin et al. 2016); and input changes (You et al. 2009), such as the use of plastic film for soil cover (Yin et al. 2016).

Forms of adaptation can be categorized based on the level of the decision maker involved, while specific measures can be further categorized into engineering and non-engineering (Table 1). Examples of engineering and non-engineering

Table 1. Types of adaptation

Level of Decision Maker	Category 1	Category 2	Activity
Farm household	Engineering	Investment	Well, pump, greenhouse, water cellar, pond
		Maintenance	Well, pump, greenhouse, water cellar, pond
	Non-engineering	Water-saving technology	Border irrigation, furrow irrigation, level field, surface pipe, sprinkler, drip, plastic film, less tillage, residual retention, intermittent irrigation, drought-resistant crop varieties
		Farm management	Change the following: variety, sowing and harvest date, reseeding, fixing and cleaning, irrigation time and volume, other inputs
		Risk management	Adjust planting structure, agricultural insurance
		Off-farm	Employment, migration, investment
Rural community	Engineering	Investment	Reservoir, irrigation–drainage system, dam, pond, well, pump and underground pipe
		Maintenance	Reservoir, irrigation–drainage system, dam, pond, well, pump and underground pipe
	Non-engineering	Risk management	Disaster-resistant activity, agricultural insurance
		Capacity improvement	Disaster-prevention training, water-user association, other farmers' association
Government	Engineering	Investment	Reservoir, irrigation–drainage system, dam
		Maintenance	Reservoir, dam
	Non-engineering	Risk management	Provide the following: disaster-warning service, disaster-response knowledge, funding support, technical support, emergency-warning system, emergency-response plan, rules and regulations for disaster, amended water price policy
		Capacity improvement	Disaster-prevention training

Source: Authors

measures are investments in irrigation and new methods of farm management, respectively.

Presenting farmers' choice of adaptation methods for drought in six provinces in China, Chen, Wang, and Huang (2014) found that among the farm households, 76 percent predominantly used only non-engineering adaptation measures, 14 percent used no adaptation measures, 10 percent used both types of measures, and none used only engineering measures. The most popular non-engineering measures were changing production inputs and adjusting crop planting and/or harvesting times. Other common responses were to irrigate more frequently, to change crop varieties, and to buy crop insurance. Interestingly, the use of engineering measures was low. Among the engineering measures that the farm households used, the most popular were related to water management: investing in wells, building new dams, purchasing pumps, investing in surface pipes and sprinklers, and maintaining channels. Furthermore, Chen, Wang, and Huang (2014) observed that when policy support was available, farm households were more likely to adopt both engineering and non-engineering measures. Policy support included early-warning technology and technical, financial, and physical support. However, only 5 percent of farm households received this type of support. Farm households with indicators of higher levels of social connections were also more likely to adopt both types of responses.

Climate change is widely recognized, but the role of government support in adaptation is much less understood. Xu and Findlay (2019) modeled the decision to adapt as a three-stage process, with each stage dependent on whether (1) the farmer needs adaptation, (2) there are constraints that prevent adaptation, and (3) such constraints can be removed through government support. They determined that government support was associated with an increase of 24.4 percent in the probability that adaptation measures will be adopted. This positive change is much larger than the estimates in other recent studies and suggests that government support is more effective among farmers with adaptation constraints that they can address. Therefore, there is value in correctly identifying each subgroup to optimize the expected policy impacts.

In Vietnam, the adoption of engineering measures has been more widespread and has mainly consisted of modifications to irrigation systems. The non-engineering measures that most Vietnamese farmers use include changing sowing and harvesting dates, rice varieties, and crops. The farmers carry out these adaptation measures as coping mechanisms during disasters and as precautionary measures in normal years.

Dang, et al. (2021) studied farmers' responses to drought and to salinity intrusion in the Mekong Delta in 2010–2016. Using data from a panel sample of 340 farm households in the Ben Tre and Tra Vinh provinces, they learned that more traditional adaptation practices were adopted in the years when serious disasters occurred and government support, along with other household characteristics, influenced those adaptation practices. Based on data for 2011, 2015, and 2016 from a sample of 390 rice-producing households in the same provinces, Dang, et al. (2017) found that the more serious the disaster was, the more likely the adaptation measures of farmers and local governments will reinforce one another. However, they also found that policy changes tended to lag behind the quicker shifts in climate conditions and farmer adaptation measures.

The main focus from this point on in this paper is the adoption of non-engineering measures and the drivers of the decision to adapt. This section will review farmers' use of information about climate change and their perceptions of it. The literature from many parts of the world has consistently shown that farmers' perceptions affect their choice of adaptation strategies (Juana, Kahaka, and Okurut 2013; Asante et al. 2017; Ayanlade, Radeny, and Morton 2017). A recent study in China also confirmed that perceptions are a key factor affecting farmers' actual adaptation behavior (Sjögersten et al. 2013). This follows the reasoning that human actions are based on perceptions formed from the quality and relevance of available information and the ability to access and assess that information. That ability is facilitated by social networks, education, and experience. Particularly, information about climate and early warning about droughts and floods are important in promoting better adaptation responses among farmers. Similarly, information about the availability of post-event services, assistance, and support are vital in alleviating hardship.

Empirically, it has been observed that overall perceptions are affected by factors such as the farmers' age, education, and access to information (Debela et al. 2015). Moreover, it has been documented that risk perceptions are affected by adaptive capacity at the farm level and sensitivity to climate change (Safi, Smith, and Liu 2012).

In their study of early-warning information and farmers' perceptions of and adaptation to drought in China, Hou, Huang, and Wang (2015) used household survey data from nine provinces and found that over half of the farmers perceived that the droughts had become more severe in the last 10 years. Early warnings of drought had also altered their perceptions and affected their adaptation choices. Moreover, farmers who perceived an increase in the severity of droughts were more likely to adapt by adopting water-saving technologies. Looking specifically at the influence of social networks and farm assets on farmers' perceptions of climate change, Hou, Huang, and Wang (2017) determined that only 18 percent of farmers accurately perceived the actual increases in annual mean temperatures over the past 10 years. However, they found that social networks improved perceptions, and farmers with larger land holdings had more accurate perceptions of climate change.

China-based studies on access to information stresses the value of early-warning systems. Generally, this is because (1) farmers are 20 percent more likely to perceive an increase in the severity of droughts when early-warning information is provided; and (2) 8 percent more farmers are expected to adopt the use of surface pipes to respond to droughts if early-warning information is provided.

Weather information has the features of a public service. Hence, its provision is unlikely to be adequately funded privately and there is a case for state funding. Dang and Nguyen (2016) found that the provision of formal information with government support played an important role in improving farmers' perceptions of local climate variability. As they pointed out, when considering a policy to raise awareness of climate change, the potential of the policy to be applied widely should be taken into account.

The North China Plain is an ecologically vulnerable region frequently affected by droughts. In a study of farmer responses to droughts in that region using data from large-scale village and farm surveys in five provinces, Wang et al. (2015) found that wheat farmers adapted better to droughts when provided with early-warning information and policy support. Their adaptation measures included adjusting seeding and harvesting dates and enhancing irrigation intensity. Similarly, in their study of the effect of information provision and policy support on 2,157 plots of 695 households drawn from 66 villages in three provinces in Vietnam, Dang and Nguyen (2016) found a significant improvement in adaptation responses because of early-warning information. Government support included financial, technical, and in-kind measures.

DRIVERS OF ADAPTATION

This section discusses a series of drivers of adaptation, including household characteristics, land tenure arrangements, water allocation systems, labor market features, and the extent of social capital.

Household characteristics have long been considered possible factors affecting adaptation to climate change. Commonly identified characteristics include education level, sex, age, and wealth status (e.g., Deressa et al. 2009), and the influence of these factors can be further manifested through perception formation (Juana, Kahaka, and Okurut 2013; Asante et al. 2017; Ayanlade, Radeny, and Morton 2017).

Huang et al. (2014) focused on farmers' use of crop diversification to adapt to floods and droughts. Analyzing data from a large-scale household survey in nine provinces of China, they determined that crop diversification was used to adapt to extreme weather events. Adaptation was more significant if they experienced the event in the previous year. They also found that the use of crop diversification varied depending on the farmer's age and sex. Younger farmers were more likely to plant more types of crops. Female farmers were more likely to diversify than males. Interestingly, farmers with less education were more likely to manage risk by diversifying. The authors noted that these farmers may have had difficulty in responding using other measures. Farmers with larger farms were more likely to diversify. The authors concluded that the value of support (which might be technical or financial) for adjustments varies between types of farmers and suggested that older farmers and those with smaller farms may benefit from more attention.

However, results vary in terms of the importance of various household characteristics. For example, Thennakoon et al. (2020) did not find statistically significant evidence that age, education, or wealth affected the use of adaptation in the form of changes in a variety of management practices. Reviewing the determinants of changes in irrigation practices in response to extreme drought events, Wang et al. (2019) learned that a response was more likely when the household head was male because changes in irrigation practices require more coordination among households and that heads are mostly male. The effects of age and, interestingly, education were negative in these results, but the effects of landholding per head and a location in a plains area were positive.

Capital intensity and farm size matter. Huang et al. (2018) examined the adaptive capacity of farmers and identified factors influencing their ability to derive long-term benefits from adapting to climate change. Household-level capital intensity (production capital per hectare) had a significant positive effect on farmers' adaptive capacity. Furthermore, beyond a certain level, increases in farm size led to increases in adaptive capacity. Age had a significant negative effect in adaptive capacity.

These results reinforce the value of focusing on indicators of risk categories for farmers such as smaller farm size, older age, location other than a plains area, and lesser wealth.

Land Tenure

Land tenure has widely been considered a factor affecting agricultural technology adoption, including climate change adaptation procedures (Soule, Tegene, and Wiebe 2000; Place and Otsuka 2002; Gebremedhin and Swinton 2003; Deininger and Jin 2006; Abdulai, Owusu and Goetz 2011; Oostendorp and Zaal 2012). The nature of farmers' rights to land and water critically influences farmers' adaptation to climate change by shaping farming practices. More sustainable and profitable practices depend on longer-term investments to maintain and improve the quality of soil and the manner in which it is used. These investments are facilitated by land tenure arrangements that assure farmers who make such investments that they will be able to reap longer-term benefits. Many successful climate change adaptation measures depend on the presence of such longer-term investments.

The ACIAR project ascertained that clearly defined property rights also had a positive impact on management practices. According to Thennakoon et al. (2020), rice farmers in the Guangdong province of China who had contracted land were more likely to implement successful adaptation measures to extreme weather events than farmers who rented land from the collective or from other farmers.

Water Allocation Systems

Well-defined rights for water use encourage longer-term investments in conservation and efficient use of water. Rights to the available supply of water and the ability to trade those rights are important in encouraging water flow to the most profitable uses. This especially applies at times when, or in areas where, water is scarce, and the available supply needs to be allocated to numerous uses.

Urbanization in China has an effect on agricultural use of water and crop production. Yan, Wang, and Huang (2015) estimated that an increase of 1 percent in urbanization will result in a decrease of 0.47 percent in the share of water used for agriculture. The decrease in the use of water for the irrigation of crops such as rice and wheat is associated with declines in yields and production and with an increase in reliance on rainfed production. To minimize such declines, the authors highlighted the need for institutional and policy innovations, such as clarifying water rights and pricing mechanisms, to encourage the use of water-saving techniques and technologies for both agricultural and urban uses of water.

Labor Markets

Off-farm labor markets provide farmers a means of adaptation to climate change. In response to the negative productivity shocks to agricultural output caused by climate change, farmers can mitigate the damage to their overall welfare by seeking off-farm employment. However, the mitigating effect of such labor reallocation depends on the property rights of farmland and the availability of off-farm work. This was illustrated by Huang, Zhao, et al. (2020) who found that farmers with off-farm working opportunities who did not have property rights to farmland benefited most from labor reallocation.

Social Capital

Social capital refers to the norms and networks that enable people to act collectively. Family, friends, and associates represent an important collective asset that helps people deal with poverty and vulnerability, resolve disputes, and take advantage of new opportunities (Woolcock and Narayan 2000).

An important area for discussion is the influence of policies and social capital on farmers' decisions to adopt adaptation measures against droughts. Using a large-scale household and village survey in six provinces across China, Chen, Wang, and Huang (2014) found that a higher level of social capital in a household was associated with better adaptive capacity against droughts. Moreover, the ability to adapt was influenced by the characteristics of households and local communities. Dang (2016) had similar results on the influence of farm household characteristics, local infrastructure, and government support on adaptive capacity in Vietnam. These results were from a study of the adaptation behavior of Vietnamese rice farmers based on a large-scale survey of 623 rice farmers affected by climate change in the Mekong River Delta and South Central Coast regions.

MARKET SIGNALS

The price of agricultural products is another major factor influencing farmers' behavior. When climate change reduces supply, prices typically rise, inducing an increase in output in the new supply conditions. However, farmers' responses to price changes may also vary in the context of climate change. It is typically found that farmers' responses are not strong in the short-run because, as might be expected, periods of extreme weather limit their capacity to respond (Yang and Huang 2019; Huang and Yang 2019). Moreover, the elasticities of farmers' responses will be underestimated by models that do not allow for the longer-run lagged adjustment in supply.

A further consideration with respect to the price signals is the extent of market integration. A weather event that shocks supply may have the initial effect of raising prices. However, when local markets are integrated with the rest of the country or the rest of the world, the price impact will be reduced when goods are imported from other regions. The impact on consumers in that case is reduced, but a greater impact is borne by local producers. Incentives to increase local production are also reduced. This reduced-incentive effect is less significant when the weather events are more widespread.

Examining these effects, Huang et al. (2017) applied the empirically estimated price elasticities of major crops in both the normal and extreme weather event years from the ACIAR project. Simulating the impacts of extreme weather events using an integrated model of CAPSiM (a partial "captive simulation" equilibrium model in agriculture for China) and a general equilibrium model (global trade analysis program), they established that without considering the lower supply elasticities of many commodities in the crop sector when encountering extreme weather events, the impacts of climate variations on production, consumption, and trade are underestimated. The impacts also varied depending on the degree of trade liberalization assumed. A more open economy in the agriculture sector minimized the effects of extreme weather events on consumption and price through imports.

INFRASTRUCTURE

Community infrastructure supporting agriculture includes roads and waterways that facilitate the transport of farm produce to markets, local community centers, schools and shops, and information about weather and market prices. The nature and quality of such physical and social infrastructure significantly influence farmers and farming practices, especially during extreme weather events.

Household and community assets affect farmers' drought adaptation measures in China. Using data from a household survey in three provinces, Wang, Huang, and Wang (2014) found that both asset types affect adaptive behavior. Household social capital and wealth, community networks, and access to government anti-drought services facilitated farmers' adoption of adaptation measures that resulted in higher crop yields. Moreover, there can be a degree of substitution between irrigation infrastructure and other adaptation measures.

In Vietnam, Dang et al. (2020) used data from a survey of 340 households undertaken in 2011, 2015, and 2016 to examine farmers' adaptation to droughts. They found that farmers who had access to government services were more likely to adjust farm practices to offset weather hazards, and farmers who participated in agricultural production training were more likely to apply offsetting measures. The adaptation measures employed had significantly increased rice yields and reduced yield variability.

Where suitable water resources are available, farm-specific infrastructure such as irrigation systems can be developed or enhanced to further facilitate the expansion of intensive water-dependent farming, such as rice paddies in drought-prone regions. For example, Wang, Huang, et al. (2018) used a field survey to study the adaptation responses of rice farmers in their use of water. They learned that villages with irrigation infrastructure had a significant increase in yields and reduction to the risks of declines in rice production. Based on a field survey of five provinces in the North China Plain, Wang, Yang, et al. (2018) reported that, when faced with a severe drought, farmers changed their management practices to mitigate its effects by increasing irrigation frequency and by increasing the efficiency of irrigation by using surface pipes. Similarly, they reported a significant increase in yields and reduction to the risks of declines in rice production.

ADAPTATION AND POLICY OPTIONS

Forms of adaptation are either autonomous and can be undertaken by farmers individually or planned, require collective action, and undertaken by local communities and governments. The latter include investments in infrastructure and other forms of social support. As noted earlier, adaptation measures can either involve elements of engineering or as be non-engineering types such as those listed in Table 1 under risk management and capacity improvement. Table 1 also shows that most engineering adaptation measures require action by local communities or governments. Many non-engineering adaptation measures are in the hands of farmers and involve changes in farm management.

The ACIAR project focused on farmers' decision-making and the expectation that farmers are more likely to make decisions that can positively improve adaptation to climate change, when those decisions are complemented by planned government measures. The importance of complementarities can be overlooked if undue emphasis is placed on individual measures. Ease of implementation also matters. For each type of adaptation, implementation can be relatively easy or difficult. Similarly, the impact of implementation can be relatively low or high. Policies that identify and administer adaptation measures that are easy to implement and have a significant positive impact should be prioritized.

Generally, the ease of implementation will depend on local conditions. For example, the ease of implementation of various water-related measures will depend on the extent and quality of the irrigation infrastructure, which varies by catchment, that farmers share. Similarly, the ability to make investments will depend on the availability of credit, the financial viability of the particular measure, and the credit-worthiness of the borrower. Furthermore, in the results reported above, the security of property rights affects not only longer-term investments in land improvement and on-farm irrigation work, but also the willingness of farmers to adopt improved management measures.

Planning and institutional measures affect the impact of the measures adopted. Specifically, there are synergies between planned adaptation activities at the community level, which can, through better incentives, stimulate adaptive responses. For example, good information systems will support farmers in making more efficient decisions. Likewise, water pricing provides farmers with incentives to make use water more efficiently, as well as a benchmark for evaluating investments in local capture and storage of water. Removing restrictions on labor mobility will allow farmers to make efficient choices with respect to remaining in on-farm work, seeking off-farm work, or relocating to urban areas permanently.

One of the challenges is that these packages of planned and institutional measures are in the hands of various levels of government and as such, the degree of coordination required to implement them is critical (Nguyen et al. 2020). Another challenge is that governments often have incentives to adopt particular types of measures. Visible initiatives, such as large-scale engineering measures like sea walls, may be more visible to their constituencies, despite a lack of return on investment, compared to others that are less visible in those terms, such as water markets.

CONCLUSION

Climate change influences farming not only through changes in temperature and precipitation, but also through the frequency of extreme weather events such as droughts, floods, and severe storms.

The traditional adaptation methods farmers employ to respond to variations in seasonal conditions, such as changing the use of farm inputs and altering seeding and harvesting times, will continue to be applicable to coping with climate change. Facilitating the adoption and improving the efficiency of such adaptation practices should be part of any policy response to climate change. Facilitation and improvement must include a thorough review of (1) farmers' property rights to land and water to encourage longer-term investments and to enable profitable adjustments to their use in farming; (2) physical infrastructure, such as roads and waterways, to ensure their continued relevance and maintenance; (3) social infrastructure, such as systems for the extension of knowledge about weather; and (4) knowledge about farming techniques and technologies.

Farmers' adaptive capacity varies considerably. Farmers who are older, have lower incomes and smaller farms, and live in mountainous areas are more prone to the adverse effects of climate change. It is critical to focus on the welfare of these farmers because they are less likely to adapt autonomously and more likely to experience reduced incomes. They should have greater access to social capital and to early-warning and other information systems.

A strategy that applies across all levels of government is valuable. More frequent extreme weather events such as droughts, floods, and severe storms will increase the incidence of episodic poverty among farmers and farming-dependent communities. Responses should include policies to increase the resilience of farming systems and the adaptive capacities of farmers. These policies must be developed in the context of structural land-use changes that have occurred because of urbanization and the diversion of water supplies from agricultural to urban uses. Local, regional, and national governments should all be involved in designing these strategies.

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