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Impacts of Climate Change on Agriculture and Policy Options for Adaptation

The Case of Vietnam

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ABSTRACT

Vietnam is likely to be among the countries hardest hit by climate change, mainly through rising sea levels and changes in rainfall and temperatures. Agriculture can be extensively affected by climate change, and designing effective adaptation strategies will be critical for maintaining food security, rural employment, and foreign exchange earnings. This paper examines these critical issues and thereby makes two contributions to the literature. First, we estimate the impacts of climate change on agricultural and water systems in Vietnam based on crop simulation, hydrological simulation, and river basin models. We then present a yield function approach that models technology advances and policy interventions to improve rice productivity and mitigate the impact of climate change, using a multilevel mixed effects model. This two-pronged approach allows rice yield changes to be linked with both biophysical and socioeconomic conditions. The results indicate that rice production is likely to be severely compromised by climate change. However, investment in rural infrastructure, such as irrigation and road, and human capital can mitigate the negative impacts of climate change. Due to substantial regional variations in impacts and responses, localized policy packages will be key for effective mitigation. Government policies targeting ethnic-minority and poor communities will be especially important components of climate change adaptation strategies.

Keywords: climate change, productivity, Vietnam, rice

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1. INTRODUCTION

Vietnam is among the countries that will be worst affected by the impacts of climate change (Dasgupta et al. 2007). Changes in climate can have serious implications for economic development, especially in the agricultural sector, due to its direct exposure to and dependence on weather and other natural conditions. Studies for the Southeast Asian region show that climate change could lower agricultural productivity by 15–26 percent in Thailand, 2–15 percent in Vietnam, 12–23 percent in the Philippines, and 6–18 percent in Indonesia (Zhai and Zhuang 2009). Nguyen, Vu, and Nguyen (2008) found that the Mekong River Delta and the coastal areas in the north of the central region are most vulnerable to the impact of global warming in Vietnam due to rising sea levels. The authors estimate that the average temperature will increase by 2.5 degrees Celsius by 2070, and sea levels are expected to rise up to 33 centimeters by 2050. It is estimated that about 20–30 percent of the Mekong River Delta will be affected by 2100, and some areas will be salinated (World Bank 2007). The changing climate could be especially damaging for rice cultivation due to substantial modifications in land and water resources. Hydroclimatic disasters such as typhoons, floods, and droughts, which could become more severe and more frequent as the climate changes, would also affect rice production substantially in the country.

Paddy rice (referred as rice in this paper for simplification) has played an important role in food security, rural employment, and foreign exchange in Vietnam. It accounts for more than three-quarters of the country's total annual harvested agricultural area and employs about two-thirds of the rural labor force,[1] thus making a significant contribution to rural livelihoods (Vu and Glewwe 2009; Nguyen 2006). Rice cultivation was at least one source of income (in many cases the major or only source) for more than three-fourths of poor households and for about 48 percent of nonpoor households. A net rice importer in the 1980s, Vietnam has now become the second-largest rice exporter in the world (FAO 2010). Rice yields have increased at a rate of 2.3 percent annually and have been the main driver of output growth over the past two decades.

Even without climate change, the rice sector in Vietnam faces severe challenges in keeping up with population and income growth. Land under rice cultivation has been decreasing and is expected to decrease further in the future. The total rice growing area declined by 6 percent in 2000–2007, mostly due to rapid industrialization and urbanization. According to the Resolution on ensuring National Food Security of Vietnam (GOV, 2009), the total area under rice production is projected to drop by nearly 10 percent by 2030, to 3.8 million hectares. While current rice yields in Vietnam are still high compared to those in other Southeast Asian countries, yields have been stagnating in recent years (FAO 2010). Climate change impacts and declining agricultural productivity could compound the risk of food insecurity in Vietnam. Because the scope of expanding arable land to increase production is limited, and land area may shrink due to climate change, productivity-led growth is the only feasible option to improve rice supply in the long run. Increasing rice productivity will ensure food security, help the country maintain a stable source of export revenues, support rural employment, and generate higher household incomes.

This paper examines these critical issues and thereby makes two contributions to the literature on food security and climate change. We first assess the impacts of climate change on agricultural and water systems in Vietnam based on crop simulation, hydrological simulation, and river basin models. We then present a yield function approach to model technology advances and policy interventions to improve rice productivity and mitigate the impact of climate change, using a multilevel mixed effects model. Section 2 presents the methodologies of the two-pronged approach, linking rice yield changes with both biophysical and socioeconomic conditions. Section 3 presents the empirical results of the projections of the impacts of climate change on rice production and the policy interventions for adaptation. Section 4 concludes by discussing policy implications derived from this study.

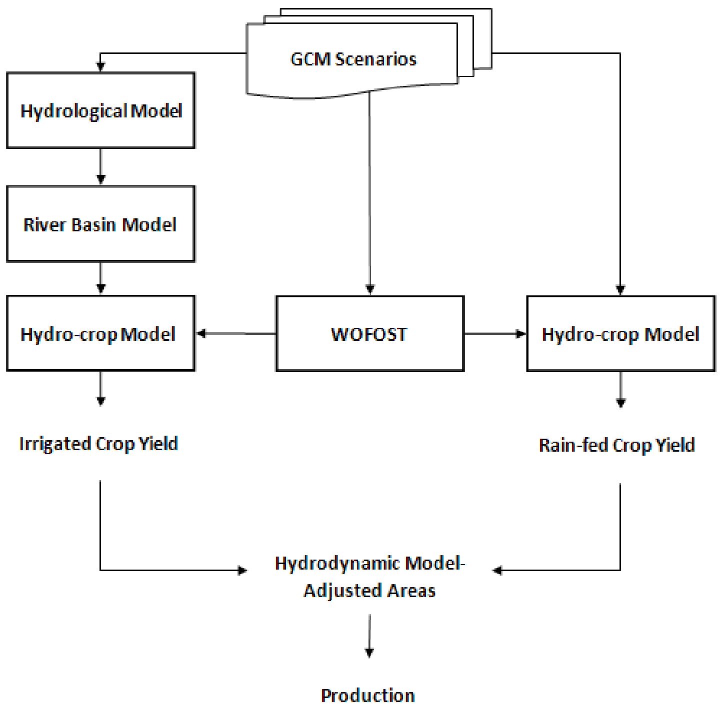
[1] Agriculture is the main employer of rural labor force. The share of labor force devoted to agricultural production ranges from 50.4 percent in the South Central Coast region to above 70 percent in the Central Highland and the northern mountainous regions (Nguyen, Yu and Breisinger 2009 and 2010). Authors' estimation based on data from The 2006 Rural, Agricultural and Fishery Census (GSOb).

2. MODELING CLIMATE CHANGE IMPACTS AND HOUSEHOLD PRODUCTION

Biophysical Modeling of Climate Change Impacts

Figure 1 illustrates the linkages among several models used to assess climate change impacts on crop production in Vietnam. The hydrological models, river basin models, and hydro-crop simulation models are jointly employed to estimate yields of rainfed and irrigated crops. Hydrodynamic models are applied in river deltas to evaluate sea-level rise effects on inundation and salinity intrusion that affect the availability of cropland, especially rice land area.

Figure 1. Integrated modeling framework for climate change impact assessment



Source: Authors' creation.
Note: GCM stans for "general circulation models" that simulate the general circulation of atmosphere and ocean on the globe. WOFOST is a crop growth simulation model developed at the Netherlands and the name stands for "World Food Studies".

Hydrological models simulate the rainfall-runoff process, estimating evapotranspiration and runoff based on weather input for the Red River, the Dongnai River, and the Mekong River basins. River basin models are built for the Red River and Dongnai River basins to integrate river basin hydrology, water demand, water infrastructure, and water institutions and policy into a holistic framework. The Dongnai River basin largely overlaps with the South East agroecological zone. The Red River basin largely overlaps with the North West, the North East, and the Red River Delta agroecological zones.[2] For

[2] Vietnam has relatively complicated terrain, characterized by numerous mountains, many rivers, and a long and meandering coastline. About 28 percent of the total land area of the country is agricultural land, and plains cover about 25 percent of the country's total land area. Vietnam is divided into eight agroecological zones. Figure A1 in the appendix shows the boundaries of these agroecological zones. The northern part of the country is mostly mountainous, with the South China Sea on the south and plains in the middle. This region includes the North West (NW), North East (NE), and Red River Delta (RRD) agroecological zones. The coast areas of the Red River Delta have an elevation of 1 to 2 meters. Elevation of the center area ranges from 2 to 4 meters, with extensive rice and vegetable fields. The central part of Vietnam is sloping and narrow. There are small plains along the coastline and narrow and deep valleys between sloping mountainsides. This part includes the North Central Coast (NCC),

irrigated crops in these zones, a simplified approach is used to estimate climate change impacts on crop yield, following Eastham et al. (2008).

The WOFOST model (Van Diepen et al. 1989; Boogaard et al. 1998) and the empirical hydro-crop model (Thurlow et al. 2008) are used jointly to analyze the impacts of changes in rainfall and temperature on crop yields. WOFOST simulated potential yields under baseline and climate change scenarios. Relative potential yield changes due to climate change are thus determined by a semi-empirical hydro-crop model that simulates crop yield responses to water deficit under rainfed and irrigated conditions. For irrigated conditions, the hydro-crop model takes applied irrigation water from the river basin models. For rainfed conditions, rainfall and soil moisture are the water input for crop evapotranspiration.

To reflect the influencing domain of each of the 25 weather stations in the country used in this study, we divided each agroecological zone into several Thiessen polygons, according to the coordinates of the weather stations within each zone. Crop simulations are performed at the polygons and aggregate up to the agroecological zones. The model simulated potential yields for spring rice and summer rice at three time periods related to climate change projections, which are the baseline period, 2030, and 2050.

In addition to changes in rainfall and temperature, Vietnam is particularly vulnerable to rising sea levels, another important manifestation of climate change, due to the long coastline and low-lying river deltas. Rising sea levels have been observed along the Vietnamese coasts, with a trend comparable to the global rise in sea levels (Vietnam, MONRE 2009). Increased flood inundation and salinity intrusion under rising sea levels will result in cropland shrinking in the most fertile river deltas, jeopardizing rice production in the country. Hydrodynamic modeling with fine spatial and temporal resolutions allows quantitative analysis of inundation and salinity intrusion effects under rising sea levels in a river delta. Based on the hydrodynamic simulation results for the Mekong River Delta (Dung Do Duc, Southern Institute of Water Resources Planning [SIWRP], Vietnam, personal communication, 2009), we reanalyze and estimate increased inundation areas with a water depth over 0.5 meter in the wet season and increased areas affected by salinity intrusion with concentrations higher than 4 grams per liter.

Choice of Climate Change Scenarios

We used the 1978–2007 period as the baseline period for climate change impact and adaptation assessment, based on data availability and closeness to the 1971–2000 baseline period recommended by the Intergovernmental Panel on Climate Change (IPCC-TGCIA 2007). Two future periods, 2016–2045 and 2036–2065, are chosen for climate change scenarios. These two future periods centering at 2030 and 2050 are hereafter referred to as 2030 and 2050, respectively. The “delta” approach is used to derive average monthly changes in precipitation and temperature between the baseline period and the two future periods as recommended by IPCC (IPCC-TGCIA 2007). The derived mean monthly changes are then imposed onto observed meteorological data from weather stations across the country over the baseline period to construct climate change scenarios. For precipitation, we calculate relative changes from the baseline to the future periods in a global climate model (GCM) projection. For temperature, we calculate changes in absolute values.

Based on Zhu and Trinh (2010), we chose the IPSL-CM4 climate projection (hereafter called IPSL) from the Institut Pierre Simon Laplace as the dry climate scenario and the GISS-ER climate projection (hereafter called GISS) from the Goddard Institute for Space Studies as the wet scenario to bracket a wide range of climate condition changes projected by GCMs. The historical climatology of 1971–2000 is roughly in the middle of the projections, implying that there is a nearly equal opportunity

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South Central Coast (SCC), and Central Highlands (CHL) agroecological zones. About 80 percent of the North Central Coast zone is mountains and hills. The Central Highlands is a vast mountainous region with many highlands. The southern part has much more even and flat topography. The South East (SE) zone includes two regions with elevations of 25 to 50 meters and 50 to 200 meters, respectively. The Mekong Delta River (MRD) zone is a vast flat area with an elevation of around 2 meters. Some regions of this delta have elevations lower than the average sea surface level; therefore, in this area about a million hectares are covered by flood water for two to four months per year.

for the climate to become dryer or wetter by 2050. In this study, we also include Vietnam's official climate change projection by the Ministry of Natural Resources and Environment (MONRE) in the form of seasonal changes in rainfall and temperature (Vietnam, MONRE 2009). Thus, the selected climate change scenarios include IPSL, GISS, and MONRE for the 2030 and 2050 projection periods. All the three climate scenarios are based on the A2 emission scenarios from the IPCC scenario family. The A2 emission scenario in general represents a future world with regional-oriented growth-focused policy (IPCC-TGCIA, 2000).

Household-level Production Analysis and Data

To estimate the response of farmers to a changing climate, we estimate a yield function and examine how farmers could increase yields through intensified input use and improved public provisions. The common factors typically used in empirical production analysis include irrigation, research investment, extension services, access to capital and credit, agroclimatic conditions, and rural infrastructure. Sadoulet and de Janvry (2003) provide excellent reviews of the methods and empirical studies used in explaining the dynamics of supply in agriculture.

We choose a typical Cobb-Douglas functional form to represent the production relation between output and inputs. The advantages of using the Cobb-Douglas function are many. First, there is an exact dual relationship between the Cobb-Douglas production and profit functions (Sadoulet and de Janvry 2003). Second, the estimated coefficient of an input from a linearized Cobb-Douglas function is the direct elasticity of the input. The following Cobb-Douglas yield function is chosen to represent the production technology of Vietnamese farmers:

(1)

where crop yield *y* is a function of inputs *x*, including labor, fertilizer, and irrigation applied per unit of land;   includes other fixed and quasi-fixed inputs that are exogenous, such as household head characteristics, as well as infrastructure and government policies;   and   are coefficients to be estimated; and A is a constant. Please note that some of the *Z* variables are not logged because they are dichotomous.

Vietnam's General Statistics Office (GSO) conducts the Vietnam Household Living Standards Surveys (VHLSS) biennially, and this study uses the surveys conducted in 2004 and 2006. VHLSS commune and household selection is based on a two-stage sampling strategy with probability proportional to size separately within each stratum of province and rural/urban domain. Both surveys include information on household crop production and village-level information on access to community and social services (for example, transportation, electricity, markets, schools, and health facilities).

Table 1 lists variables used in the yield function estimation, including inputs and outputs, together with quasi-fixed inputs and supply shifters. These variables are selected based on production theory and previous studies on the determinants of productivity and government investment as summarized by Fan, Yu, and Saurkar (2008). Fan, Hong, and Long's (2004) also found some factors contributing to Vietnamese agriculture, including labor, fertilizer, irrigation, education, road, and agricultural research. Output is expressed as rice yield. Inputs include both traditional inputs (labor) and modern inputs (fertilizer and irrigation) per unit of land. The household head characteristics include gender, age, educational grade, and ethnicity. Because fertilizer quantity is not available at the household level for VHLSS 2004, costs of inputs are used instead. Other quasi-fixed inputs and technology shifters include household head characteristics (age, gender, educational level, and ethnic group), commune infrastructure indicators (electricity and transportation), social service provision (education and health), government intervention (technical support for crops), and community indicators (commune rice and irrigation). A dummy variable of whether the commune is defined as poor by the government is included to reflect the level of general commune development. We introduce two irrigation variables due to the nature of irrigation spending. Usually government invests in the construction and maintenance of canals and dams for public use, and this part is captured by the share of irrigated annual crop area at the commune level. However, farmers must pay for the irrigation to their own plots, and this is captured by the household-level private irrigation expenditure variable.

Table 1. Descriptive statistics of VHLSS 2004 and 2006

Variable	Definition	2004		2006	
		Mean	Std. Dev.	Mean	Std. Dev.
Household rice production					
riceareashare	Area share of rice in annual crops (%)	76.5	24.2	83.1	20.4
area	Rice planted area (ha)	0.7	1.0	1.4	2.5
output	Rice harvest quantity (ton)	3.4	5.3	6.7	13.3
yield	Yield (tons per ha)	4.67	1.3	4.79	1.2
palabor	Total labor per hectare (man-days)	751	657	487	504
laborhire	Share of hired labor (%)	4.2	10.2	4.2	10.8
usefer	Use fertilizer (yes=1)	0.97	0.18	0.97	0.17
useirr	Use irrigation (yes=1)	0.72	0.45	0.71	0.45
pachfer	Chemical fertilizer expenditure (millions VDN per ha)	1.3	0.7	1	0.6
pairr	Irrigation expenditure (millions VDN per ha)	0.3	0.3	0.2	0.2
paN	Nitrogen fertilizer use (kg per ha)			98.3	82.9
paP	Phosphate fertilizer use (kg per ha)			84.2	125
paK	Potassium fertilizer use (kg per ha)			33.8	47.4
paNPK	NPK fertilizer use (kg per ha)			96.5	139.6
patotfer	Total chemical fertilizer use (kg per ha)			324	224.2
soldshare	Share of sold rice in total harvest (%)	24.9	29.6	25.8	30.5
riceonly	Household growing only rice (yes=1)	0.13	0.3	0.2	0.4
hhsize	Household size	4.6	1.7	4.5	1.7
Household head characteristics					
male	Male (yes=1)	0.83	0.4	0.83	0.4
age	Age	47.9	13.5	48	13
grade	Highest school grade finished	6.6	3.5	6.7	3.5
minority	Being minority (yes=1)	0.23	0.4	0.24	0.4
Commune characteristics					
irrshare	Share of annual crop land under irrigation (%)	69.7	33.6	71.2	33.1
electricity	Power supply in commune (yes=1)	0.97	0.2	0.99	0.1
diststop	Distance to nearest road or waterway (km)	3.0	5.6	3.2	7.7
distmkt	Distance to nearest market (km)	3.7	9.6	3.8	10.4
distprim	Distance to nearest primary school (km)	0.7	1.1	0.8	1.2
distagext	Distance to nearest agricultural extension center (km)	11.1	11.1	10.9	10.7
poor	Being a poor commune (yes=1)	0.22	0.4	0.21	0.4

Source: Authors' calculation based on VHLSS 2004 and 2006.

Descriptive statistics of the variables are included in Table 1. Despite the country's rapid economic transformation, rice still dominates in Vietnamese crop cultivation, as rice accounts for more than three-quarters of the annual harvested area. The majority of the producers in the rice-based farming system of Vietnam are smallholders who typically operate on a small area of paddy field (0.7 hectare in 2004 and 1.4 hectares in 2006). This suggests that focusing on increases in farm productivity offers the single most important pathway out of poverty. Average rice yield is stagnant at 4.7 tons per hectare, which is consistent with the trend reported by Nguyen, Yu, and Breisinger (2009 and 2010). The majority of agricultural labor working in paddy fields is household members, and hired labor accounts for only about 4.2 percent of total labor in rice production. Adoption of modern inputs is high in Vietnam, where 97 percent of rice producers opt to use chemical fertilizers and more than 70 percent of households irrigate their rice fields. On average a household consumed 354 kilograms of chemical fertilizer per hectare in 2006, mainly nitrogen and phosphate fertilizers. Market participation is not very high, with only about a quarter of harvested rice entering commercial channels; this underscores the importance of rice in Vietnamese rural households' nutritional conditions and food security. Although the share of rice sold on the market is about 25–26 percent, about 44 percent of Vietnamese households were net sellers in 2006 (Vu and Glewwe 2008). About 13–20 percent of households become specialized in rice cultivation by growing only rice in their annual crop fields. The average household size is approximately 4.5 persons.

More than 80 percent of the surveyed households were male headed. On average the household head is 48 years old and has finished 6 grades in school (based on a 12-grade system). Less than one-quarter of rice-farming households are headed by a member of an ethnic minority. Overall, access to infrastructure and public services improved marginally between the two survey rounds. At the commune level, the share of annual cropland under irrigation increased by 1.5 percentage points in two years. Almost all households have electricity (97–99 percent). The average distance to the nearest transportation, market, and primary school increased slightly between the two surveys. Farmers also experienced a small increase in technical support from agricultural extension agencies. About 22 percent of rice-producing communes in the sample are defined as poor by the government.

We will now develop some hypotheses about the relationships between rice yield and independent variables. Based on economic theory, higher rice yields are observed under intensified production process characterized by higher input usage (labor, fertilizer, and irrigation). The quality of the labor force is reflected by household head literacy, and a literate farmer should be able to quickly adopt new technology and produce more efficiently. More ethnic-minority households are rice farmers and net sellers (81.1 percent and 62.4 percent, respectively) than are ethnic-majority families (47.4 percent and 40.5 percent). However, ethnic-minority households tend to have persistent disadvantages in poverty reduction and hence ethnic-minority families are expected to be less productive than their Kinh counterparts (ADB 2006). Access to transportation and markets increases productivity by increasing the availability of inputs, reducing input prices due to lower transport costs, and increasing income due to greater opportunities for sales or higher prices. Because infrastructure access is measured as the distance to infrastructure and social services, the expected signs of these variables are negative. We expect the availability of crop extension services to increase rice productivity, and the coefficient of the distance to an agricultural extension agent should be negative as well. Other infrastructure variables such as electricity availability are supposed to boost yield through machinery usage. We expect the coefficients of being a poor commune to be negative to reflect low productivity.

3. IMPACTS OF CLIMATE CHANGE

Changes in Temperature and Precipitation and Impacts on Yields and Sea Levels

For the three climate change scenarios in 2030 and 2050, average annual temperature increases in all agroecological zones (Table 2). In general, temperature increases in 2050 are greater than those in 2030. For the IPSL and the MONRE scenarios, temperature increases in the four northern agroecological zones are greater than those in the four southern agroecological zones. For the GISS scenario, the South East and the Mekong River Delta have the least temperature increases in the country.

Table 2. Average annual temperature increase in degrees by agroecological zone

Agroecological Zone	IPSL-2030	IPSL-2050	GISS-2030	GISS-2050	MONRE-2030	MONRE-2050
North West	1.18	2.22	0.91	1.39	0.80	1.33
North East	1.18	2.22	0.89	1.41	0.73	1.28
Red River Delta	1.19	2.21	0.87	1.42	0.70	1.28
North Central Coast	1.14	2.02	0.85	1.41	0.85	1.55
South Central Coast	0.86	1.61	0.99	1.62	0.53	0.93
Central Highlands	0.84	1.57	0.94	1.55	0.50	0.85
South East	0.81	1.49	0.78	1.30	0.63	1.03
Mekong River Delta	0.84	1.54	0.78	1.31	0.62	1.02

Source: Authors’ calculations.

Precipitation changes are shown in Table 3. Generally, IPSL shows reduced precipitation but GISS and MONRE have increased precipitation across all agroecological zones. The magnitude of the precipitation increase is higher in 2050 than in 2030 for both GISS and MONRE, with greater precipitation increases reported by GISS. IPSL has a more complex picture of precipitation changes. For all agroecological zones except for the South Central Coast, precipitation declines more in 2030 than in 2050. This indicates that changes in precipitation under global warming can be more complex than temperature changes, and at a regional scale it is not necessarily always the case that precipitation will monotonically increase or monotonically decrease at the decadal temporal scale.

Table 3. Average percentage changes in annual precipitation by agroecological zones

Agroecological Zone	IPSL-2030	IPSL-2050	GISS-2030	GISS-2050	MONRE-2030	MONRE-2050
North West	-16.5	-12.7	9.8	19.4	1.7	2.8
North East	-16.5	-11.8	10.5	13.5	1.8	3.0
Red River Delta	-14.2	-9.2	8.6	10.1	2.1	3.5
North Central Coast	-11.9	-7.0	7.6	10.0	2.2	3.6
South Central Coast	-7.8	-9.7	5.2	5.7	1.6	2.8
Central Highlands	-11.0	-5.6	4.3	6.0	0.1	0.0
South East	-10.7	-5.0	5.1	6.3	0.7	1.3
Mekong River Delta	-10.5	-6.3	5.2	6.3	0.9	1.5

Source: Authors’ calculations.

In addition to average annual changes, seasonal changes are important, in particular for temperature. Zhu and Trinh (2010) compare mean monthly precipitation under the historical climate condition with the monthly precipitation predicted by the IPSL, GISS, and MONRE climate change scenarios in 2050. The IPSL scenario suggests substantially lower precipitation than in the historical climate, particularly in the north. In northern Vietnam, precipitation decline occurs mostly in the spring and early summer, implying increased irrigation requirements for crop cultivation. Precipitation reduction in the south occurs mostly in the rainy season. The GISS scenario has a significant precipitation increase in the rainy season in the north, with flooding implications, and a precipitation decline in the dry season in the south. The MONRE scenario is a moderate scenario, falling between the IPSL and GISS scenarios.

Crop Productivity Impacts

Significant rice yield decline is observed in all scenarios, ranging from 4.2 percent in MONRE-2030 to 12.5 percent in IPSL-2030. The impact is especially large in the Central Highlands and the northern zones, highlighting the enlarged gaps in food supply in these regions. Although the impact of climate change is relatively moderate in the major rice-producing region of the Mekong River Delta, the average rice yield is projected to drop by 1.4–8.3 percent by 2030.

Sea Level Rise Impacts

This study assumes sea level will rise 17 centimeters by 2030 and 30 centimeters by 2050, based on the official climate change and rising sea level scenario (Vietnam, MONRE 2009). Figure A.2 in the appendix shows the flood inundation situation in the Mekong River Delta with a 30-centimeter rise in the sea level. Equipped with current hydraulic structures, the area inundated with water deeper than 0.5 meter would increase by 276,000 hectares in the rainy season (Table 4). In the dry season, areas affected by salinity intrusion with a concentration greater than 4 grams per liter would increase by 420,000 hectares. If we assume that about 70 percent of the affected areas are paddy rice area, 193,000 hectares of paddy rice area could be lost due to inundation, and 294,000 hectares could be lost due to salinity intrusion by 2050. This loss of rice area will lead to a rice production decline of about 2.7 million metric tons per year (based on 2007 rice yields), 0.9 million tons in rainy season due to inundation and 1.8 million tons in dry season due to salinity intrusion. This is an equivalent of about 13 percent of the 2007 total rice harvest in the Mekong River Delta. Similar analysis was also conducted for the Dongnai River basin near Ho Chi Minh City, but the impacts were found to be far less significant, as shown in Table 4.

Table 4. Loss of rice area and production in 2050 due to flood inundation and salinity intrusion caused by rising sea levels, in the Mekong River Delta and lower Dongnai River basin

River Basin	Mekong River Delta		Lower Dongnai River Basin	
Season	Rainy Season	Dry Season	Rainy Season	Dry Season
Causes	Inundation	Salinity Intrusion	Inundation	Salinity Intrusion
Affected area (thousand hectares)	276	420	22	N/A
Affected rice area (thousand hectares)	193	294	10.7	N/A
Yield (tons/hectare)	4.59	6.02	4.37	N/A
Production loss (million tons)	0.89	1.77	0.05	N/A
Production loss (percentage)	5.2	8.0	2.5	N/A

Source: Authors' calculations.

Note: Yields are from GSOa (2007) harvested paddy yield by seasons and regions. We don't include expected yield growth over time in this calculation. Therefore, the production losses tend to be underestimated.

Assessing Policy Options for Productivity Improvement

Given the strong impacts of climate change on rice production, we need to find ways to increase yields to ensure sustainable development. To estimate the role of different inputs and government policy options in rice production and climate change adaptation, the Cobb-Douglas yield function in equation (1) is estimated using a multilevel mixed effects linear model. A linear mixed model is characterized as a model containing both fixed and random effects. These effects are a generalization of linear regression allowing for the inclusion of random deviations other than those associated with the overall error term. The fixed effects are analogous to standard ordinary least squares (OLS) regression coefficients and are estimated directly. The random effects are not directly estimated but are summarized according to their estimated variance components (McCulloch, Searle, and Neuhaus 2008). The mixed effects linear model is applied to the panel data of VHLSS 2004 and 2006 with multiple levels of random effects: strata, commune (nested within strata), and yearly random variations at all levels. The restricted maximum likelihood (REML) is applied based on the distributional assumptions of the model.

An endogeneity problem may exist in the estimation when unobserved productive inputs are functions of observed inputs (Doraszelski and Jaumandreu 2009). Multilevel random effects are able to tackle the endogeneity problem at commune, strata, and year levels. Felipe, Hasan, and McCombie (2008) suggest that the endogeneity bias may occur if the inputs are measured in terms of value, due to poor approximation to an account identity. We run a separate mixed effects model using fertilizer consumption quantity in VHLSS 2006 to avoid price-induced endogeneity. In this study, both village and household head characteristics are exogenous to farmers' production decisions. In addition, zonal dummies are used to capture unobserved exogenous effects that are fixed at the zonal level as suggested by Mundlak (1961). Mixed effects model results for Vietnam and for each agroecological zone are reported in Table 5. The near-zero significance level of the likelihood ratio (LR) test favors the mixed effects model over the fixed effects model, indicating that the former is a better representation of the production relation.

Because production and inputs are measured in their logarithmic forms, all the estimated parameters are the elasticities of these inputs (if the inputs are continuous). According to van Garderen and Shah (2002), assuming the parameter of the dummy explanatory variable is *b* and the error term is normally distributed, we can derive the percentage effect of the dummy variable on the dependent variable as − , where is the unbiased estimator of *b* and the exact minimum variance of , , is approximated as $\tilde{V}(\hat{p}) = 100^2 \exp\{2\hat{b}\}\left[\exp\{-\hat{V}(\hat{b})\} - \exp\{-2\hat{V}(\hat{b})\}\right]$.

Intensification of the production process brings higher yields, as expected. Yield elasticities with respect to household labor and hired labor are 0.011 and 0.003, respectively, highlighting the important role of home labor. Chemical fertilizer application has a sizable impact on paddy yield, and an additional 1 percent fertilizer use (proxied by fertilizer expenditure) could increase the yield by 0.065 percent. Irrigation expenditure for paddy field significantly increases production with an elasticity of 0.021 (the combined effects of household and commune irrigation). The household's participation in the market also contributes to a higher yield. Households selling 30 percent of their rice output report a 6.5 percent average yield advantage compared with households selling 25.8 percent of their rice output. Rice yields are remarkably lower among minority-headed households, where the average yield is 6.5 percent lower than that among Kinh-headed households. Increased rice production can help rural ethnic-minority households boost income, escape poverty, and improve food security (Nguyen 2006).

Among the infrastructure variables, the electrification rate and the distance to a market both have significant effects of the expected signs. A 1 percent increase in the electrification rate increases output by 4 percent. The huge coefficients of electricity indicate the positive link between infrastructure and agricultural productivity, as the Vietnamese government constantly allocates around 10 percent of total investment in electricity (GSOa, various years). Investment in transportation is an effective way to improve yields. If the distance to the nearest market is shortened by 10 percent (0.4 kilometer), rice yield can be elevated by 0.02 percent (1 kilogram per hectare). Agriculture exhibits disappointing trends in poor communes, where the average rice yield is 7.8 percent lower than the average yield of nonpoor communes.

Table 5. Mixed model estimations of yield function

dep. var. lnyield	Vietnam	RRD	NE	NW	NCC	SCC	CHL	SE	MRD
Household rice production									
lnpahomelabor	0.011	0.000	0.017	0.078	0.015	0.020	0.031	0.009	0.019
	(0.002)***	(0.002)	(0.005)***	(0.018)***	(0.006)**	(0.006)***	(0.015)**	(0.011)	(0.005)***
lnpahirelabor	0.003	0.002	0.002	0.006	0.003	0.002	0.006	0.002	0.008
	(0.001)***	(0.001)***	(0.001)	(0.003)*	(0.001)**	(0.002)	(0.004)	(0.004)	(0.003)***
lnpachfer	0.065	0.044	0.052	0.052	0.096	0.042	0.065	0.053	0.110
	(0.002)***	(0.006)***	(0.006)***	(0.006)***	(0.008)***	(0.009)***	(0.009)***	(0.012)***	(0.011)***
lnpairr	0.019	0.010	0.010	0.020	0.022	0.026	0.028	0.018	0.023
	(0.002)***	(0.003)***	(0.003)***	(0.008)***	(0.004)***	(0.005)***	(0.009)***	(0.009)*	(0.004)***
lnsoldshare	0.004	0.001	0.001	0.003	0.006	0.006	0.001	0.018	0.022
	(0.001)***	(0.001)**	(0.001)	(0.003)	(0.001)***	(0.001)***	(0.004)	(0.004)***	(0.002)***
riceonly	0.000	-0.008	0.008	-0.137	-0.028	0.014	0.003	0.030	-0.002
	(0.007)	(0.007)	(0.030)	(0.123)	(0.025)	(0.019)	(0.140)	(0.038)	(0.015)
Household head characteristics									
male	0.013	0.011	0.036	-0.049	0.005	-0.011	0.075	-0.013	0.021
	(0.006)**	(0.007)	(0.013)***	(0.045)	(0.016)	(0.017)	(0.049)	(0.046)	(0.018)
age	0.000	-0.000	0.000	0.000	-0.000	0.001	0.001	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
grade	0.003	0.001	0.003	0.008	0.001	0.010	0.005	0.010	0.001
	(0.001)***	(0.001)	(0.002)	(0.004)**	(0.002)	(0.003)***	(0.006)	(0.006)*	(0.002)
minority	-0.067	-0.078	-0.046	-0.016	-0.029	-0.149	-0.109	-0.181	-0.027
	(0.011)***	(0.033)**	(0.015)***	(0.061)	(0.034)	(0.061)**	(0.058)*	(0.061)***	(0.032)
Commune characteristics									
lnirrshare	0.002	-0.002	0.011	-0.009	0.006	-0.001	-0.003	0.005	0.005
	(0.001)	(0.001)	(0.004)***	(0.009)	(0.002)***	(0.004)	(0.008)	(0.006)	(0.004)
electricity	0.040		0.051	0.082	-0.047		-0.006		0.019
	(0.023)*		(0.038)	(0.046)*	(0.070)		(0.139)		(0.180)
lndiststop	-0.000	-0.002	-0.002	0.000	-0.000	0.003	0.009	-0.002	-0.002
	(0.001)	(0.001)*	(0.001)	(0.005)	(0.002)	(0.002)	(0.005)*	(0.005)	(0.002)
lndistmkt	-0.002	-0.001	-0.002	0.002	-0.001	-0.001	-0.019	-0.001	-0.005
	(0.001)***	(0.001)	(0.002)	(0.005)	(0.002)	(0.003)	(0.008)**	(0.005)	(0.002)**
lndistprim	0.001	0.001	0.001	-0.002	0.002	0.006	0.001	0.004	0.005
	(0.001)	(0.001)	(0.002)	(0.004)	(0.002)	(0.003)**	(0.006)	(0.006)	(0.003)*
lndistagext	0.000	0.001	0.001	-0.000	0.002	0.005	0.004	-0.007	0.000
	(0.001)	(0.002)	(0.002)	(0.006)	(0.002)	(0.004)	(0.009)	(0.007)	(0.004)
poor	-0.081	-0.095	0.051	-0.196	-0.075	-0.340	-0.249	0.019	-0.012
	(0.012)***	(0.028)***	(0.024)**	(0.057)***	(0.030)**	(0.065)***	(0.059)***	(0.054)	(0.035)

Table 5. Continued

dep. var. lnyield	Vietnam	RRD	NE	NW	NCC	SCC	CHL	SE	MRD
irrpoor	0.003	0.003	-0.008	0.007	-0.011	0.040	0.017	-0.011	-0.002
	(0.002)	(0.005)	(0.005)	(0.011)	(0.004)**	(0.012)***	(0.011)	(0.010)	(0.006)
year	0.025	0.021	0.019	0.016	0.053	0.027	-0.005	0.004	0.032
	(0.002)***	(0.003)***	(0.004)***	(0.010)	(0.006)***	(0.007)***	(0.016)	(0.015)	(0.007)***
Constant	-48.106	-40.684	-36.762	-30.209	-104.130	-52.040	11.950	-6.715	-63.195
	(4.160)***	(5.402)***	(8.620)***	(20.288)	(11.450)***	(13.262)***	(32.040)	(31.064)	(13.484)***
LR-test p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Observations	9124	2538	1728	644	1278	861	438	339	1298
No. of groups	66	11	13	4	6	6	5	8	13

Source: Authors' calculation based on VHLSS 2004 and 2006.

Note: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. See Table 1 for a description of the variables.

The estimates for the rice yield function fluctuate by year and agroecological zone. On average, the rice yield increased by 1.3 percent per year between 2004 and 2006, after adjusting for the nested-level error structure. There are also considerable disparities in regional rice production patterns. Yield responds to additional labor in all zones, with the exception of the more industrialized South East. The impacts of modern technology on rice productivity can be universally observed. The elasticity of rice yield with respect to chemical fertilizer ranges from 0.042 in the South Central Coast to 0.110 in the Mekong River Delta. When household irrigation expense increases by 1 percent, average rice yield increases 0.1 percent in the Red River Delta and 0.023 percent in the Mekong River Delta. In five zones, market participation is an effective way to encourage rice farmers to raise their yield.

The educational level of the household head is found to improve rice yield in the North West, South Central Coast, and South East. Most ethnic minorities live in the mountainous regions, concentrated in the poor regions of the North East, the North West, and the Central Highlands. They depend on agricultural incomes to a far greater extent than do their ethnic-majority counterparts. Average rice yields among minority-headed households are considerably lower than those among Kinh-headed households. The yield difference between ethnic groups is more pronounced in the south: minority-headed households' rice yields are found to be 14 and 17 percent lower in the South Central Coast and South East. Minority households in the north also report lower yields than Kinh households, but the difference is of a smaller magnitude; 7.6 and 4.5 percent yield disadvantages are observed in the Red River Delta and North East. The results have confirmed Swinkels and Turk's conclusion (2006) that development among ethnic minorities through increased agricultural production and productivity (including rice) is essential to raise incomes and thus reduce both regional and ethnic differences in poverty and welfare.

The effects of commune characteristics vary substantially. For example, if the share of irrigated crop area increases from 60 to 66 percent (a 10 percent increase) in the North East, average rice yield can be increased by 4.7 kilograms per hectare. If the electrification rate can be improved from 83 to 90 percent in the North West, the average yield could go up by 39 kilograms per hectare, assuming all other factors remain the same. Investment in transportation is shown to improve yields in almost every zone, suggesting that the government's infrastructure-construction priority is paying off (GSOa, various years). The coefficients of education are positive in the South Central Coast and Mekong River Delta, probably because most schools are in the commune or within a short distance. The positive coefficient of distance to transportation is caused by a cluster of households reporting high yields (more than 7 tons per hectare) but located far away from any transportation (30 kilometers away).

Poor communes generally report lower rice yields, except in the North East. The greatest yield loss occurs in the South Central Coast, Central Highlands, and North West, where rice yields average 17 percent lower in the poor communes. To evaluate the impact of irrigation on poverty, we introduced an interaction term between being a poor commune and the commune irrigation variable. The interaction is significant in the Central Coast zones. If both public and private irrigation measurements were increased by 1 percent, the average yield would be 0.017 percent higher for a household located in a poor commune in the North Central Coast (0.022 private irrigation + 0.006 public irrigation – 0.011 poor commune interaction). Similarly, irrigation investment in poor communes in the South Central Coast could raise yields by 0.066 percent (0.026 private irrigation + 0.04 poor commune interaction).

The multilevel mixed effects regression results for rice yield based on detailed fertilizer consumption quantity are summarized in Table 6. The coefficients are similar to those of the results based on fertilizer expense, suggesting that our results are not substantially biased from endogeneity caused by using value instead of quantity. At the household level, production intensification pays off, as the coefficients for labor, fertilizer, and irrigation are all positive and significant. Different types of fertilizer deliver different results. For instance, a 1 percent increase in nitrogen fertilizer use could boost yield by 0.011 percent, while a 1 percent increase in potassium could increase yield by only 0.002 percent. Irrigation expenditure improves rice yield with an elasticity of 0.021. Average rice yield is higher among households participating in the market due to further integration with the market. The education of the household head helps the household produce rice more efficiently. If the household head were to finish one more year in school, the average rice yield could rise by 0.2 percent. Serious yield differences are detected between ethnic groups, and average rice yield is 6 percent lower for ethnic-minority households.

Table 6. Yield response with respect to fertilizer quantity in 2006

dep. var. lnyield	Vietnam	RRD	NE	NW	NCC	SCC	CHL	SE	MRD
Household rice production									
lnpahomelabor	0.014	-0.001	0.048	0.102	0.016	0.033	0.068	0.007	0.029
	(0.003)***	(0.002)	(0.009)***	(0.022)***	(0.011)	(0.008)***	(0.027)**	(0.018)	(0.007)***
lnpahirelabor	0.002	0.002	0.001	0.003	0.000	0.001	0.001	0.015	0.010
	(0.001)***	(0.001)**	(0.002)	(0.004)	(0.002)	(0.002)	(0.006)	(0.007)**	(0.004)**
lnpaN	0.011	-0.000	0.011	0.018	0.028	-0.000	0.014	0.007	0.003
	(0.001)***	(0.002)	(0.003)***	(0.004)***	(0.005)***	(0.004)	(0.007)**	(0.006)	(0.004)
lnpaP	0.004	-0.001	0.002	0.015	0.002	-0.001	0.015	0.006	0.005
	(0.001)***	(0.001)	(0.001)	(0.003)***	(0.002)	(0.002)	(0.007)**	(0.005)	(0.002)**
lnpaK	0.002	0.001	0.001	0.003	-0.001	0.004	0.008	0.003	0.002
	(0.001)**	(0.001)	(0.001)	(0.004)	(0.002)	(0.002)	(0.007)	(0.006)	(0.002)
lnpaNPK	0.005	-0.000	0.002	0.014	0.003	0.010	0.009	0.007	0.001
	(0.001)***	(0.001)	(0.001)*	(0.003)***	(0.002)	(0.003)***	(0.005)*	(0.006)	(0.003)
lnpairr	0.021	0.010	0.014	0.008	0.029	0.028	0.036	0.028	0.017
	(0.002)***	(0.004)***	(0.004)***	(0.010)	(0.006)***	(0.006)***	(0.015)**	(0.014)**	(0.007)**
lnsoldshare	0.004	0.002	0.001	0.000	0.006	0.006	-0.004	0.020	0.031
	(0.001)***	(0.001)***	(0.001)	(0.003)	(0.002)***	(0.002)***	(0.006)	(0.006)***	(0.004)***
riceonly	0.000	-0.011	0.036	0.008	-0.009	0.007	0.473	0.075	-0.019
	(0.009)	(0.008)	(0.033)	(0.121)	(0.036)	(0.022)	(0.290)	(0.054)	(0.022)
Household head characteristics									
male	0.005	0.010	0.013	-0.083	0.000	-0.013	0.044	0.001	0.032
	(0.008)	(0.008)	(0.016)	(0.047)*	(0.023)	(0.021)	(0.071)	(0.069)	(0.026)
age	-0.000	-0.001	-0.000	-0.001	0.001	0.000	-0.000	-0.000	0.000
	(0.000)	(0.000)**	(0.000)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)
grade	0.002	-0.000	0.004	0.008	0.004	0.007	-0.012	0.012	0.004
	(0.001)**	(0.001)	(0.002)*	(0.004)*	(0.003)	(0.003)**	(0.009)	(0.009)	(0.004)
minority	-0.062	0.039	-0.026	-0.051	-0.013	-0.337	-0.175	-0.111	-0.055
	(0.016)***	(0.050)	(0.019)	(0.086)	(0.054)	(0.073)***	(0.089)**	(0.094)	(0.049)
Commune characteristics									
lnirrshare	0.005	-0.002	0.004	0.000	0.015	0.004	0.003	-0.003	0.010
	(0.002)**	(0.002)	(0.006)	(0.016)	(0.004)***	(0.006)	(0.016)	(0.011)	(0.008)

Table 6. Continued

dep. var. lnyield	Vietnam	RRD	NE	NW	NCC	SCC	CHL	SE	MRD
electricity	0.232		0.176	0.175	-0.029				
	(0.050)***		(0.079)**	(0.069)**	(0.206)				
lndiststop	-0.001	-0.002	-0.000	0.007	-0.003	0.001	0.018	-0.007	-0.005
	(0.001)	(0.001)*	(0.002)	(0.006)	(0.004)	(0.004)	(0.010)*	(0.008)	(0.004)
lndistmkt	-0.003	0.002	-0.002	0.007	-0.000	-0.002	-0.017	-0.003	-0.006
	(0.002)**	(0.002)	(0.002)	(0.009)	(0.004)	(0.004)	(0.014)	(0.008)	(0.004)
lndistprim	0.002	0.000	0.004	0.001	-0.004	0.001	0.008	-0.005	0.003
	(0.002)	(0.002)	(0.002)**	(0.007)	(0.004)	(0.005)	(0.013)	(0.011)	(0.004)
lndistagext	-0.001	0.006	0.001	-0.009	-0.005	0.008	0.002	-0.006	-0.002
	(0.002)	(0.002)**	(0.003)	(0.009)	(0.004)	(0.006)	(0.015)	(0.011)	(0.008)
poor	-0.131	-0.286	0.000	-0.257	-0.040	-0.286	-0.371	-0.060	0.052
	(0.020)***	(0.053)***	(0.035)	(0.077)***	(0.045)	(0.087)***	(0.100)***	(0.093)	(0.079)
irrpoor	0.007	0.045	0.003	0.006	-0.020	0.041	0.016	0.029	-0.023
	(0.004)*	(0.011)***	(0.008)	(0.018)	(0.008)**	(0.018)**	(0.024)	(0.020)	(0.016)
Constant	1.097	1.713	1.027	0.866	1.288	1.380	1.577	1.315	1.252
	(0.074)***	(0.041)***	(0.111)***	(0.203)***	(0.221)***	(0.084)***	(0.233)***	(0.195)***	(0.101)***
LR-test p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000
Observations	4525	1254	877	315	652	434	211	153	629
Number of groups	64	11	11	4	6	6	5	8	13

Source: Authors' calculation based on VHLSS 2006.
Note: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. See Table 1 for a description of the variables.

Improved infrastructure brings out the yield potential among rice farmers. Investment in irrigation facilities at the commune level will boost rice yield. Combining households' own irrigation investment and commune irrigation facilities, the elasticity of irrigation reaches 0.026. Although the electrification rate is quite high in Vietnam, providing electricity to the remaining remote communes could increase yield by a substantial 26 percent. As shown by many studies, investment in transportation is a sure way to improve agricultural productivity. The results suggest that the average rice yield is 1.14 kilograms per hectare higher if the distance to market is shortened by 0.4 kilometer. More attention should be paid to poor communes, where the average household yield is 12.3 percent lower than that of better-off communes. Irrigation investment in poor communes carries an addition bonus, as the elasticity of irrigation could increase by an extra 0.007.

Regional patterns highlight the tremendous biophysical and economic variations across regions, demonstrating that fertilizer application must be tailored to local biophysical conditions for optimal results. Rice is responsive to nitrogen fertilizer in the three northern and Central Highlands zones. The coefficient of nitrogen fertilizer is negative but insignificant in the Red River Delta, and this phenomenon can be attributed to the existing high consumption level of chemical fertilizer (average annual nitrogen fertilizer usage in the Red River Delta is 20 kilograms higher than the national average). Phosphate and combined fertilizer also produce different results in each agroecological zone. For example, phosphate can be effective in the Mekong River Delta zone but not in the North East zone, and vice versa. It is important to notice that in the major rice-producing Mekong River Delta, rice yield is responsive to labor and phosphate fertilizer. The coefficient of education is positive and significant, highlighting the importance of improving labor quality. Minority households are worse off in the South Central Coast and Central Highlands zones, after taking other household characteristics into consideration. At the commune level, most coefficients of infrastructure and social service provision are statistically insignificant, except for in the Red River Delta and the northern zones.

As in the results for fertilizer value, lower rice yields are reported for poor communes, but the difference is of a larger magnitude. Poor communes exhibit alarmingly lower rice yields: in the Red River Delta, North West, and South Central Coast, the average yield of a poor commune is 23–25 percent lower than that of a nonpoor commune. The poor/nonpoor difference is more manifest in the Central Highland, where the average rice yield in a nonpoor commune can be 31 percent higher than that of a poor commune. The interaction term is significant in the Red River Delta and Central Coast zones. If both public and private irrigation measurements were increased by 1 percent, the impact of irrigation would be smaller in the Central Coast zones, suggesting that investment in other aspects of the economy such as infrastructure and social services should be planned together to enhance the effects of irrigation. The effects of irrigation in the Red River Delta are mixed: elasticities of irrigation are 0.01 for nonpoor communes and 0.055 for poor communes.

In summary, the yield function approach identified irrigation as one of the most important means to improve rice productivity and adapt to climate change. Substantial regional variations are observed, requiring localized policy packages to achieve food security and income generation.

Assessing Policy Options for Climate Change Adaptation

Despite the alarming drop in potential crop yield caused by climate change, the results of the foregoing analysis suggest several actions that Vietnam could take to adapt to climate change. The top panel of Table 7 summarizes the impacts from the climate change scenarios, measured as adjusted percentage changes in rice yield, under different climate change scenarios in eight agroecological zones. The estimated yield changes in Table 7 does not consider the so-called "carbon fertilization", a yield-boosting effects of higher atmospheric CO_2 concentration, because of the significant uncertainties associated with carbon fertilization effects (Long et al. 2006; Zhu and Trinh, 2010). The lower panel reports possible yield improvements under various policies targeting climate change adaptation objectives. Ideally, an optimal portfolio of adaptation measures should minimize the cost of adaptation while also minimizing the net adverse impacts of climate change, thus contributing to both food security and climate change resilience. In reality, adaptation measures must often be selected from a limited number of options due to resource constraints. We focus on the impact of policy scenarios in this study and do not consider the cost of achieving these policy goals, which could be substantial in some cases. Because the yield function is in the logarithm form, yield changes caused by different policies are additive, allowing flexible combinations of policies.

Table 7. Rice yield change under climate change and adaptation scenarios

	Vietnam	RRD	NE	NW	NCC	SCC	CHL	SE	MRD
Climate change scenarios									
IPSL-2030	-18.4	-26.6	-14.7	-18.1	-15.1	-26.7	0.6	-8.3	-12.5
IPSL-2050	-19.1	-26.8	-16.2	-24.6	-18.2	-28.4	2.9	-8.1	-13.4
GISS-2030	-6.9	-21.4	-19.9	-15.6	-4.7	-17.6	1.6	-1.4	-7.8
GISS-2050	-14.5	-26.7	-22.0	-22.2	-12.0	-23.9	0.0	-4.3	-11.7
MONRE-2030	-4.3	-2.0	-2.2	-3.3	-3.0	-4.3	-4.7	-5.0	-4.2
MONRE-2050	-7.5	-3.0	-4.9	-8.4	-5.7	-7.5	-5.9	-7.3	-6.8
Climate change adaptation scenarios									
Increase household irrigation expenditure by 100%	1.0	1.4		2.9	2.8	3.6	2.8	1.7	2.1
Place all communes' cropland under irrigation				0.9					0.2
Place all poor communes' cropland under irrigation				0.9					0.2
		1.3	3.2	2.8	1.0	2.3			1.6
Increase household nitrogen fertilizer consumption by 100%		0.2	2.9		1.0	2.4		0.5	0.9
Increase household phosphate fertilizer consumption by 100%		0.2	1.4		1.0	0.9			0.7
Increase household potassium fertilizer consumption by 100%	4.4	5.2	5.2	9.6	4.2	6.5	5.3	11.0	6.5
Increase household fertilizer expenditure by 100%									
Improve labor quality by 1 grade of education		0.4	0.8		0.7				0.2
Implement policy targeting improving minority productivity					2.4	10.4			1.4
Provide electricity to every household		0.4	3.6						0.5
Shorten distance to transportation or market by 1 km	0.1					0.4			0.1
Implement policy targeting poor communes	10.7		23.1	5.8	13.4	31.0			10.2

Source: Authors' calculations.
Note: The climate change adaptation scenarios are based on yield functions. Only coefficients that are statistically significant are reported.

Irrigation expansion helps agriculture cope with current variability in climate and can assist in adaptation to future climate change. Central Vietnam has the greatest potential for expansion in irrigated area, as irrigation has reached its potential in the Mekong River Delta (Kirby and Mainuddin 2009). Although some future modest expansion of irrigated area is possible, improved productivity from existing irrigated lands is essential to meet the bulk of the increased demand for food driven by population and income growth (ACIAR 1999). If household irrigation intensity doubles (expressed as expenditure, assuming a constant water price), average yield could increase by 3.6 percent in the Central Highlands, followed by the Central Coast and South East zones. The impact of irrigation expansion is modest in the delta zones.

Agricultural intensification is another approach to boost rice yield. Average rice yield could increase by 6.5 percent in the country if fertilizer expenditure doubles, with the highest yield increases in the Mekong River Delta (11 percent) and North Central Coast (9.6 percent). Investment in education could enhance both labor productivity and efficiency (Fan, Yu, and Saurkar 2008). If average schooling time were extended by one year, average rice yield could grow by 0.2 percent in Vietnam. The yield increase could be higher in the northern region and South Central Coast. Improvements in rural infrastructure can help increase rice output. The positive effect of electricity is more visible in the less remote mountainous North West (3.6 percent). A modest yield advantage is reported if access to transportation and markets is improved.

It is worth noting that government policies designed to target less-developed regions and vulnerable populations have proven an effective measure to augment rice yield. Taking the Central Highlands as an example, policy targeting the poor communes in the region could boost rice yield by 31 percent. Rice yield among ethnic-minority households could increase by an additional 10.4 percent if policies were designed to improve market access, labor quality, and market access for ethnic minorities.

4. CONCLUSIONS AND DISCUSSION

Rice production in Vietnam faces severe challenges from climate change. There are synergies between climate change study and crop production analysis that can improve our understanding of long-term food security in Vietnam. This analysis integrates rice yield response to inputs, technical change, and policy interventions with impact assessment of climate change on agricultural and water systems. By combining both socioeconomic and environmental conditions in the analysis of rice production, this study takes a holistic approach to the issues of food security, agricultural productivity, and climate change.

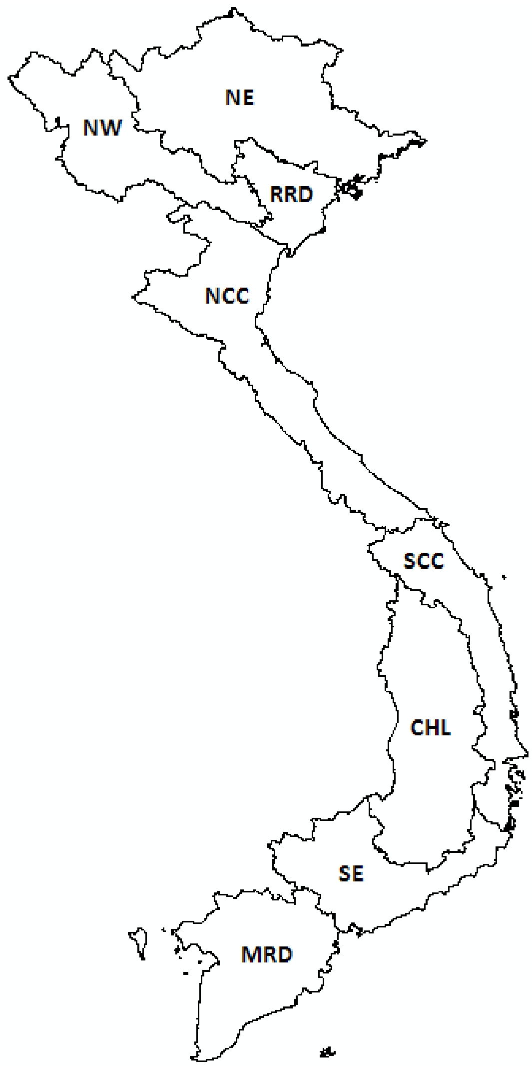
The paper finds that annual rice production may be reduced by 2.7 million tons by 2050 under climate change. However, proper agronomical practice and investment in rural infrastructure and human capital can mitigate the negative impact of climate change and help farmers adapt. There is still great scope to increase crop yields by improving rural infrastructure and social services, including education and irrigation. The empirical results provide evidence for future policy formulation to ensure a steady food supply through improved productivity and integrating climate change into long-term strategic planning. One approach is through improved rural infrastructure and crop intensification, as captured by the yield response model. Labor quality and market participation also contribute to crop productivity advances. The results indicate that government policy targeting ethnic-minority and poor communes is an effective instrument to promote productivity and climate change resilience.

However, the promotion of modern technology and crop diversification should be tailored to local conditions. Because production factors are most efficiently used when other required factors are at their optimum, chemical fertilizers should be balanced to the crop's needs in both the time and space dimensions, considering location-specific ecological conditions, in order to produce the highest returns on the inputs and the largest mitigation of climate change. Crop yield reductions under climate change vary widely across agroecological zones. The yield decline is estimated to be 4.3–8.3 percent by 2050 in the Mekong River Delta, and more severe (a 7.5–19.1 percent decline) in the Red River Delta. The Central Highlands tends to have the greatest crop yield decline under both dry and wet climate change scenarios. Given the substantial regional variations in crop production, localized policy packages are more effective in promoting adaptation to climate change and achieving food security. The impact of public investment could be enhanced significantly if spatial variations were taken into consideration in the policy planning and implementation stages. These outcomes are in line with results from studies in many developing countries indicating that investments in rural roads yield high returns in terms of poverty reduction by improving rural access to key services (Fan 2008). Previous research by Fan, Hong and Long (2004) suggests that investment in road yields high returns in every zone in Vietnam, while education investment produces larger impacts in the South East and delta zones. The Central Highlands stands out for its remarkable potential for improving agricultural productivity though intensification, as well as its high responsiveness to government policies targeting poor communes and ethnic minorities. However, challenging geographic conditions, poor infrastructure and market access may prevent local producers from benefiting from the latest technology.

There are other adaptation options not captured in this study, including investment in agricultural research and development (R&D). The recent stagnant growth in rice productivity underscores the urgent need for substantial investment in agricultural R&D and the wide adoption of high input responsive, high-yield varieties, which are known to be the most important source of income and output growth (Minot, Baulch, and Epprecht 2006; Nin Pratt, Yu, and Fan 2009). Past experience has indicated that government investment in agricultural R&D has the highest return in agricultural production and poverty reduction, far above education, road, and irrigation. The economic return is estimated to be 12.22 Dongs for every one Dong used for agricultural R&D in Vietnam (Fan, Hong, and Long 2004). In preparation for future climate change, it is important to invest in agricultural R&D in order to supply farmers with more drought- and flood-tolerant crop varieties and highly efficient production practices that are more resilient in adverse soil and weather conditions.

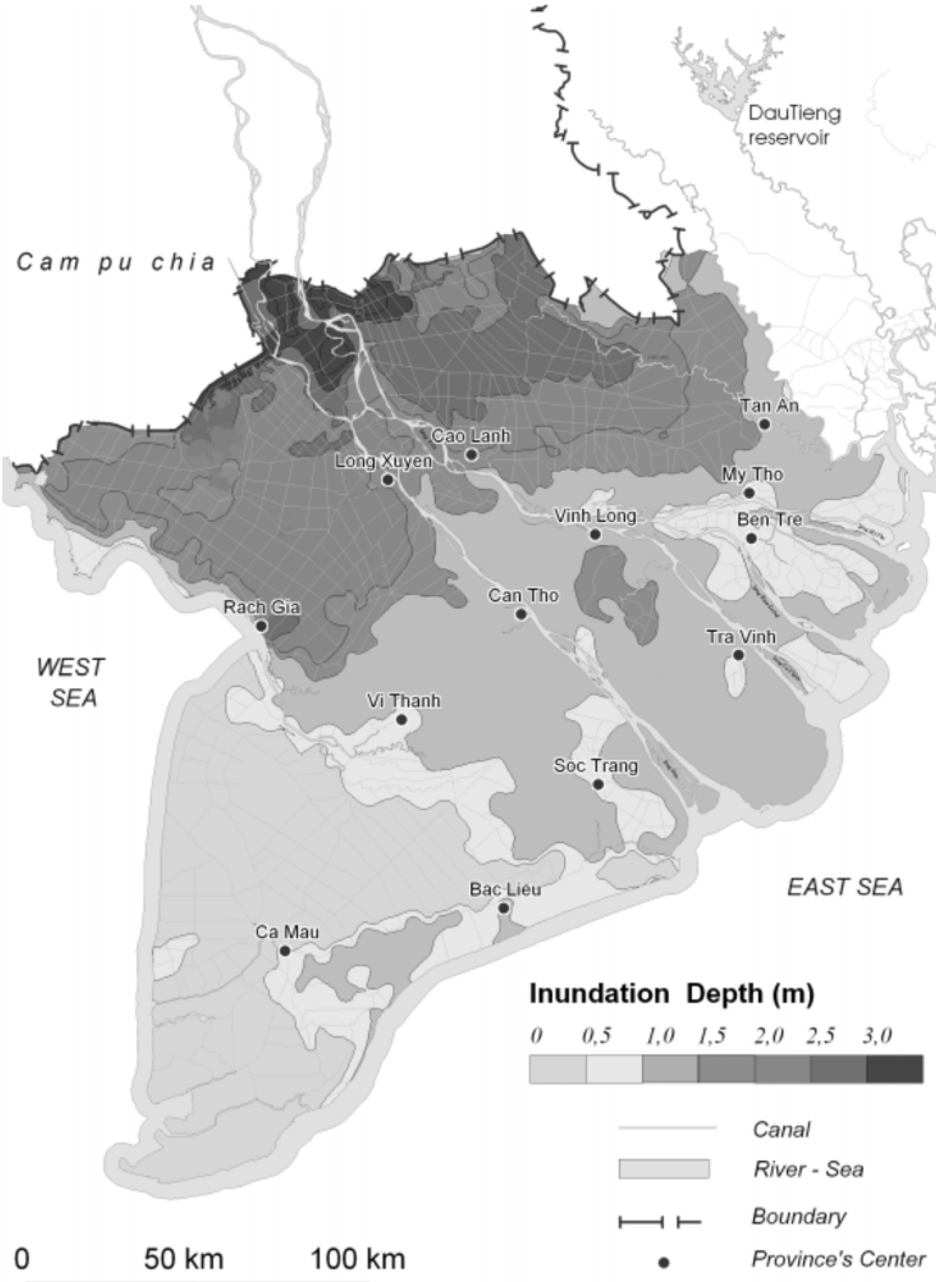
APPENDIX: SUPPLEMENTARY MAPS

Figure A.1. Agro-ecological zones of Vietnam



Source: Authors' creation.

Figure A.2. Flood inundation under 30 cm sea level rise and current hydraulic structures in the Mekong Delta



Source: Southern Institute for Water Resources Planning.

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