Three Essays on Agricultural Decision-making in Changing Environments

by

Justin D. McKinley
B.Sc. Environmental Economics and Policy
M.Sc. International Masters in Rural Development
M.Sc. Agricultural Economics

A thesis submitted for the degree of *Doctor of Philosophy* at
Monash University in July 2020
Department of Economics
Monash Business School
Monash University
Clayton, VIC 3800

Copyright notice

Abstract

This thesis looks at agricultural decision-making in changing environments in three separate essays. The environments in which smallholder producers in Southeast Asia do business is changing rapidly. Increased incomes in the region change consumer demand and provide opportunities in new markets, especially livestock, for agricultural households. Producers also face several new and unique challenges associated with climate change. They must adapt their behaviours and farming practices to optimise outcomes in their new realities, dealing with stress brought on by climate change. Understanding agricultural decision-making is more important now than ever, as the environments that producers operate in is changing faster than ever. In this thesis, we will look at agricultural decisions as they relate to climate change adaptation and mitigation, as well as why some producers enter new export markets while others do not. The first two essays are related to agricultural decisions for producers experiencing climate change. The third essay then looks at the characteristics of the agent to see if there are differences in the decision-makers, using the context of cattle producers in Laos entering the novel export market for cattle.

Essay one looks at the role of Vietnamese rice producers in helping the government meet its greenhouse gas mitigation commitments to the Paris Climate Accord. In this essay, we look at factors that influence rice farmers' irrigation choices, specifically, whether or not they use alternate wetting and drying (AWD), an irrigation technique that reduces water consumption by one-third and greenhouse gas emissions by nearly one-half. We find that farmers' expectations of AWD, such as effect on yield or input costs, change the likelihood of them using AWD. Additionally, they are less likely to use AWD if they reported that they receive an irrigation subsidy.

Essay two focuses on climate change adaptation decisions made by agricultural households in Vietnam. We investigate how autonomous adaptions vary by individuals, depending on which climatic stresses they are responding to and what impacts they observe as a result of the stress. We find that individuals vary autonomous adaptations

depending on which climatic stresses they are responding too as well as by the impacts of the stress. We also show that the types of stress experienced by individuals are largely heterogeneous across provinces.

In essay three, we explore the idea that there are cognitive differences between individuals who engage in entrepreneurial activities and those who do not, using the concept of executive functions from cognitive psychology. In this study, we look at the case of cattle producers in Lao PDR, who either raise cattle for the export market (entrepreneurs) or savings (traditional producers). We conclude that individuals who participate in entrepreneurial activity are better at planning, impulse control, and attention. Few differences exist between the two groups beyond the differences in executive functions. All three essays have implications for future policies and furthering our collective understanding of decision-making by agricultural producers in changing environments.

Declaration

This thesis is an original work of my research and contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

Signature: [redacted]

Print Name: Justin McKinley

Date: 03/07/2020

Acknowledgements

At the closing of my Ph.D. journey, I find myself reflecting on the last few years of my life with a wide range of emotions. The strongest of which is immense gratitude for everyone who helped me on this journey. My thanks begin with my supervisor, Jeffrey LaFrance, for accepting me into the program, mentoring me along the way, and entertaining me with countless stories. I am also grateful to my co-supervisors, Paulo Santos and Michael Ward, for their steadfast support over the past few years. Without the support of my supervisors, my thesis would not have been possible. More generally, I want to thank Monash University and the Department of Economics for the opportunity to study here, and for providing a welcoming and supportive environment to do so.

My gratitude also extends to my classmates. I couldn’t have made it through the program without all of you. I will not try to list names, as I will undoubtedly forget someone, so rather, I will only say, you know who you are. Learning together made the process easier and much more enjoyable than what it would have been trying to do it on my own. Additionally, thanks to all of you who listened and provided comments on my work. Our talks helped me to focus my discussions and conduct better research. And lastly, thank you for your friendship. As an international student living far from home, having good friends that I can depend on nearby has meant a lot to me.

I would also like to thank Wayne Geerling and all my economics students. One of my most important discoveries during my time at Monash is my love of teaching. Wayne was an excellent teacher and mentor during my time in the program. Through Wayne’s leadership, and the patience of my students, I have grown in confidence and capability as a teacher and I hope to have the opportunity to pursue this passion more in the future.

Finally, I want to thank my family and loved ones. We've all made sacrifices along the way for me to complete my PhD. Whether it be the absence of each other's company or listening to me lament during the hardest times. For this, I am grateful. But I am most grateful to my partner, Marie. Thank you for giving me the strength to carry on when I couldn't find it myself. Of everyone who helped me along the way, no one did so more than you.

To Bart, thank you for your final gift.

Table of Contents

Introduction *1*

Chapter 1: How Expectations, Information, and Subsidies Influence Farmers' Use of Alternate Wetting and Drying in Vietnam's River Deltas *5*

1.1 Introduction **6**

1.2. Literature Review **8**

1.2.1. Rice cultivation and GHG emissions **8**

1.2.2 Alternate wetting and drying **9**

1.2.3. Irrigation in Vietnam **12**

1.2. Materials and Methods **13**

1.3. Results and discussion **19**

1.3.1. Conditional Logit Model **19**

1.3.2. Cost and Return **22**

1.4. Conclusions **26**

1.5. References **28**

1.6. Appendices **32**

Chapter 2: Climate Change Adaptation Strategies Vary with Climate Change Stress: Evidence from Three Regions of Vietnam *37*

2.1. Introduction **38**

2.2. Methods and Data **42**

2.2.1. Data collection **42**

2.2.2. Data description **44**

2.2.3. Multivariate probit estimation **45**

2.3. Results and Discussion **51**

2.3.1. Household model **51**

2.3.2. Agricultural Adaptations **56**

2.3.3 Climate Change Stresses **60**

2.4 Conclusions **62**

2.5. References **64**

2.6. Appendices **67**

Chapter 3: Becoming an Entrepreneur: Cognitive Function and the Transition to the Market ***72***

3.1. Introduction **73**

3.2. The Behaviour of an Entrepreneur **74**

3.3. Context and Data **78**

3.4. Explaining entrepreneurship **85**

3.5. Conclusions **88**

3.6. Acknowledgments **89**

3.7. References **91**

3.8. Appendices **97**

Conclusions ***106***

How Expectations, Information, and Subsidies Influence Farmers' Use of Alternate Wetting and Drying in Vietnam's River Deltas **106**

Climate Change Adaptation Strategies Vary with Climate Change Stress: Evidence from Three Regions of Vietnam **108**

Becoming an Entrepreneur: Cognitive Function and the Transition to the Market **109**

Introduction

Decision-making in the presence of scarcity is paramount in economic theory. Utility, production, and consumption theory all depend on the agent's choices. Agricultural decisions are no different. Producers are continually making decisions to maximise their utility. The environments that these producers operate in is constantly changing. Now and in the future, producers must adapt to the new threats, constraints, and opportunities brought on by external factors such as globalisation and climate change. In this thesis, we present three examples of agricultural decisions in changing environments within the context of smallholder producers in Southeast Asia.

The first chapter of this thesis focusses on the role of rice farmers in Vietnam's climate change mitigation strategy. At the Paris Climate Agreement in 2015, Vietnam committed to an eight percent reduction in greenhouse gas (GHG) emissions by 2030. These reductions will come in part from the agricultural sector and specifically rice production. One promising GHG mitigating technology used in rice production is Alternate Wetting and Drying (AWD), which can reduce GHG emission by as much as 48%. This study aims to understand the factors that influence a farmers' decision to use AWD, economic, or otherwise. We do so by using primary data collected in Vietnam's Mekong River Delta and Red River Delta to compare yield, cost, and returns of farmers who currently use AWD to farmers who use the conventional production method of continuously flooded (CF) rice. McFadden's conditional logit model is used to model factors that may influence the farmers' decision to use AWD or not. Variables used in the model include expectations of farm inputs (e.g., will water use increase or decrease with AWD use?) and yield for AWD use, sources of agricultural information, and irrigation subsidy perceptions. Our study is the first of its kind to use expectations as an explanatory variable for the outcome, namely, expectations of AWD as a determinant of AWD use. Results indicate that the respondents' expectations of AWD use, where respondents receive agricultural information, and whether or not they perceive that they receive a subsidy for irrigation are all significant factors in whether or not they use AWD.

The second chapter looks at the autonomous adaptations to climate change used by rice-producing households in Vietnam, with a specific focus on how individual responses change, depending on which climate change stress that individuals report as the driver of their adaption. Vietnam faces several adverse climate change stresses such as increases in temperature, drought, flooding, saltwater intrusion, and sea-level rise. Past research on climate change adaptation in Vietnam has highlighted that climate change stresses and challenges faced by populations vary across the country. In this study, we are interested to know if autonomous responses also vary, depending on which stress individuals are responding to. To answer this question, we use primary-collected data of 1,306 individuals from the Mekong River Delta, Central Vietnam, and the Red River Delta. Adaptation choices of these individuals are analysed at two levels: the household-level and the agricultural-level. We estimate multivariate probit models by Genz-Geweke-Hajivassiliou-Keane (GGHK) simulated maximum likelihood methods. Our results show that climate change adaptations vary depending on which stresses individuals are responding to. At the household level, droughts and floods have the strongest effect on climate change adaptation. However, adaptations at the agricultural level depend more on the impacts of the stress and less so on the climate change stress itself. Understanding what climate change stresses are already eliciting a response, and what adaptations are being used by individuals, is invaluable for designing successful climate change policies. This understanding can also help policymakers identify where gaps exist in individual climate change adaptations and fill these gaps with a public response.

Finally, in the third chapter, we change our focus to the characteristics of the agent. Specifically, we look at entrepreneurs, a group of individuals known for their willingness to move into new markets sooner than other individuals. The increased recognition that the capacity to innovate may be central to economic growth raises the question of what is different about entrepreneurs. We explore the hypothesis that entrepreneurs may differ from non-entrepreneurs in their capacity to process information and act on it, which we measure using the concept of executive functions. Using data from a sample of cattle producers in a transition economy, we show that cognitive heterogeneity is remarkably different between those who are willing to transition from the traditional use of cattle as a savings mechanism and explore the new opportunities created by increased market integration with export markets. Most notably, entrepreneurs are better at impulse control, attention, and planning. These results do not seem driven by selection into cattle production. We argue that, given the evidence that executive functions are malleable, these results may have important implications for entrepreneurship training.

Chapter 1: How Expectations, Information, and Subsidies Influence Farmers' Use of Alternate Wetting and Drying in Vietnam's River Deltas

This chapter contains collaborative work with Bjoern Ole Sander (International Rice Research Institute – Vietnam Country Office, Hanoi, Vietnam), Vuduong Quynh (Institute for Agricultural Environment, Hanoi, Vietnam), Mai Van Trinh (Institute for Agricultural Environment, Hanoi, Vietnam), Jeffrey T. LaFrance (Monash University, Department of Economics, Melbourne, Australia)

1.1 Introduction

Ratifying the Paris Agreement resulting from the 21st Conference of Parties, the Vietnamese Government committed to as much as a 28% percent reduction of greenhouse gas (GHG) emissions by 2030 with international support, as compared to the estimated business as usual scenario for the country (Government of Viet Nam 2015). (Government of Viet Nam 2015)Agriculture plays a pivotal role in Vietnam achieving its stated GHG reductions because agriculture is the second-largest annual GHG-emitting sector in Vietnam behind the energy sector, representing 23% of total annual GHG emissions in Vietnam (USAID 2016). More than 50% of agricultural GHG emissions come from rice (*Oryza sativa L.*) cultivation, which represents 54% of all GHG emissions from the agricultural sector in Vietnam (USAID 2016). Because of the importance of the agricultural sector in total annual GHG emissions in Vietnam, the country's nationally determined contribution specifically targets reductions coming from the agricultural sector, and specifically, technologies to reduce GHG emissions in the agricultural sector (Government of Viet Nam 2015).

There are already suitable technologies/practices available to reduce GHG emissions from rice production, but the uptake in Vietnam has remained low, and the factors influencing the use of these technologies/practices are not well understood. One GHG-abating practice well-suited to Vietnam and of particular importance to our investigation is alternate wetting and drying (AWD). AWD is a water management practice that can reduce GHG emissions by as much as 48% (Sander et al. 2015), but few farmers practice AWD in Vietnam. Given the gaps in knowledge, we evaluate farmers' choices to use AWD or not, with a specific focus on perceptions of AWD, sources of agricultural information, and whether or not a farmer perceives receiving an irrigation subsidy. Furthermore, concerning perceptions of AWD, we compare farmer perceptions of AWD with on-farm costs and returns to determine if perceptions of AWD match the economic reality of AWD. We answer these research questions using a McFadden condition logit model, analysing irrigation practice decisions for farmers in Vietnam. We use primary data for 225 households, collected from the Red River Delta in the north of Vietnam and the Mekong

River Delta in the south of Vietnam. We first analyse data for the whole sample, and then, data is analysed by river delta to determine how factors may vary across locations.

Results indicate that expectations do matter for farmers' decisions to use AWD or not. Farmers who believed that AWD use would increase the number of weeds in their fields were less likely to use AWD in the pooled sample covering both deltas. This result held in the Mekong River Delta, but not in the Red River Delta. Farmers in the Mekong River Delta were also more likely to use AWD if they believed that they would use less water when using AWD. Farmers in the Red River Delta were more likely to use AWD if they believed it would increase their yield and also if they believed it made planning a crop calendar easier.

Information also mattered for farmers' decisions to use AWD or not. Farmers in the pooled sample who reported receiving agricultural information from media sources such as the TV or radio and farmers who received information from agricultural companies were less likely to use AWD. Conversely, farmers who received information from local staff, NGOs, or their neighbours were all more likely to use AWD. All these results hold when looking at the Mekong River Delta, but only receiving agricultural information from an NGO made farmers more likely to use AWD in the Red River Delta.

Farmers who reported receipt of an irrigation subsidy were less likely to use AWD. We find this result to be accurate for the pooled sample and the Red River Delta, but not for the Mekong Delta. Reduced water consumption is the primary economic incentive of AWD, so this result is not surprising. Lessening incentives will no doubt lead to lower demand for the practice.

Finally, the expectations of AWD that were significant factors in farmers' decisions to use AWD or not were often the reality of the cost and return analysis for the farms. Believing that AWD use would increase the number of weeds in the field was found to be true in reality; AWD farmers paid more for weeding. The expectation that AWD use increases rice yield held by farmers in the Red River Delta translated to reality in the cost and return results, with AWD farmers reporting higher yields. However, for farmers in the Mekong River Delta, the belief that using AWD would decrease water use is not reflected as the reality observed by farmers in the cost and return results. However, farmers' responses to receiving an irrigation subsidy may influence this result; farmers who said they received a subsidy paid significantly less for irrigation than farmers who said they did not receive a subsidy.

The model used in this study is not novel but rather tested and reliable. The application of the model in this setting, however, is novel. This is the first study of its kind to apply McFadden's model with perceptions and expectations to determine the use of new agricultural technologies/practices. Perceptions and expectations have not been previously used as predictors in the use of new agricultural technologies/practices, and certainly not for AWD.

1.2. Literature Review

1.2.1. Rice cultivation and GHG emissions

Rice (*Oryza sativa L.*) cultivation represents 54% of all GHG emissions from the agricultural sector in Vietnam (USAID 2016). Globally, rice has the highest carbon footprint of any of the major cereal crops, producing 3.8 Mg carbon dioxide equivalent (CO2e) per hectare per season, as compared to 0.7 Mg CO2e per hectare per season for wheat and 1.4 Mg CO2e per hectare per season for maize (Linquist et al. 2012; Mosier et al. 2006). The primary reason for this difference is that cultivated, continuously-flooded wetland rice emits significant quantities of methane gasses during production (Smith et al. 2008) and methane gas has a conservative Global Warming Potential (GWP) 25 times higher than carbon dioxide (CO2) (Aulakh et al. 2001; Wassmann et al. 2000). More recent estimates from the IPCC (2013) state that methane GWP is 28 times higher than CO2. Rice paddies are estimated to be responsible for between 10-14% of global anthropogenic methane emissions annually (IPCC 2007), and approximately 70% of total methane emissions are anthropogenic (El-Fadel and Massoud 2001).

Flooding a rice paddy with water cuts off the supply of oxygen from the atmosphere to the soil, resulting in anaerobic fermentation of organic matter in the soil and, consequently, in the production of Methane (Ferry 1992). Methane emissions occur in rice paddies because of the production and oxidation of methane by methanogenic and methanotrophic bacteria, respectively (Win et al. 2012). Methane is produced in the soil by the bacteria and then enters the root system of the rice plants, passing through the gas vascular system of the plants to the atmosphere (Alam and Jia 2012). Methane fluxes in rice production are affected by several factors, such as the chemical and physical properties of soil, fertiliser use (inorganic and organic), air and soil temperatures, composition and activity of soil microorganisms, the physiological characteristics of the rice cultivars, crop residue management, and water management practices (Bodelier et al. 2000). While rice paddies do provide the ideal anoxic freshwater environments for methane production (Archer 2007), we should recognise that irrigated lowland rice is not only a significant emitter of methane gas but also one of the most promising targets for methane gas mitigation (Wassmann et al. 2000).

1.2.2 Alternate wetting and drying

Lowland rice is often grown in continuously flooded conditions in which the paddy is submerged in water from transplant until approximately two weeks before harvest. Alternatively, rice can be grown under a management practice known as AWD. AWD is a water management technique that follows periods of saturation with periods of aeration. One method of allowing the water level in the paddy to fall to approximately 15 cm below the surface of the soil before irrigating again ensures the roots constant access to water and is called ‘safe AWD’ (Belder et al. 2004; Bouman et al. 2007; Bouman and Tuong 2001). Water management techniques like AWD (multiple aerations) or midseason drainage (MSD) (single aeration), are the easiest way to mitigate methane emissions from lowland rice production (Bronson et al. 1997; Cai et al. 1997; Sanchis et al. 2012; Wassmann et al. 2000; Yagi et al. 1996). In fact, single aeration, such as MSD and multiple aerations, such as AWD irrigation schedules, reduce methane emissions by at least 40% (Wassmann et al. 2000). The lesser of the two mitigation options, MSD, reduces methane emissions by 40%, while AWD, classified under the UNFCCC' multiple aeration' category, reduces methane emissions by 48% (Sander et al. 2015).

The literature has not provided any conclusive evidence on the effect of AWD on rice yield. Some studies have found that, compared to continuous flooding (CF), AWD reduces yield (Bouman and Tuong 2001; Eriksen et al. 1985), others found that AWD had a similar yield to CF rice (Cabangon et al. 2004; Chapagain and Yamaji 2010; Palis and Hossain 2004), and others still found that AWD had a higher yield than CF rice (Belder et al. 2004; Ceesay et al. 2006; Zhang et al. 2009). Increased yields from AWD could be the result of increased nutrient uptake by rice plants under AWD conditions (Yang et al. 2004). Sander et al. (2015) reported that while AWD is not likely to have an impact on yield, there is some anecdotal evidence to support increased yield as a result of AWD use. Some possible explanations for increased yield from AWD use are: (1) lodging-resistant culms (stems and stalks), (2) increased tillering, (3) reduced pests and diseases, and (4) better soil conditions at harvest (Sander et al. 2015). Nalley et al. (2015) reported that yield loss varied depending on the 'type' of AWD. As AWD treatments became more restrictive and used less water, yield declined relative to the higher levels for CF (Nalley et al. 2015). Carrijo et al. (2017) conducted an extensive meta-analysis of 56 different studies comparing yields between AWD and CF. The results of their meta-analysis showed that AWD reduced yield by 5.4% on average (Carrijo et al. 2017). However, the study also found that when water levels were only allowed to drop 15 cm below the surface before watering again, known as 'safe AWD,' then there were no yield penalties (Carrijo et al. 2017). Similar results were found by (Bouman et al. 2007).

One potential drawback to AWD is that the practice can increase the cost of weed management through increased manual weeding and increased herbicide expenditure (Kürschner and Henschel 2010; Rahman 2015). However, in some rice production systems, these increased costs can be offset by the reduced costs of irrigation associated with AWD. Reductions in water use can be the primary cost savings in rice production either directly through water fees or indirectly through fuel costs to run irrigation pumps

(Alam et al. 2009; Karim M.R; Alam M.M.; Ladha and Islam M.S.; Islam 2014; Kürschner and Henschel 2010). However, depending on the irrigation scheme, pump owners do not always pass on the economic savings of reduced water use to other farmers, so to facilitate the increased uptake of AWD would require a new agreement between farmers and pump owners where these pecuniary benefits are shared (Rahman 2015). Additionally, AWD can reduce water consumption by up to 35% with no yield penalty (Lampayan et al. 2015).

Various studies have reported that the total production costs of CF rice in Vietnam are between $1,091/ha[1] to $1,184/ha and the total production costs of AWD rice in Vietnam are between $1,046/ha to $1,222/ha (Alam et al. 2009; Basak 2011; Karim M.R; Alam M.M.; Ladha and Islam M.S.; Islam 2014; Nargis et al. 2009). Previous studies have shown overall irrigation cost savings for AWD farmers as compared to CF farmers ranged from $23/ha to $42/ha (Alam et al. 2009; Karim, M.R; Alam, M.M.; Ladha and Islam, M.S.; Islam 2014; Kürschner and Henschel 2010). A study from Vietnam reported that farmers who participated in AWD had 30% lower irrigation costs than farmers who used CF (Quicho 2013).

While AWD is one of the most promising GHG reducing technologies (Richards and Sander 2014), showing high abatement potential for rice production in Vietnam (Escobar Carbonari et al. 2019), the adoption rate of AWD strongly depends on incentives. Monetary incentives are limited to areas where water savings link directly to reduced costs (Sander et al. 2015). Increased uptake of AWD can be accommodated by the use of meter-based or volumetric-consumption based water rates, rather than other commonly used pricing schemes such as area-based or season-based (Tsusaka et al. 2015). Volumetric-consumption pricing would create a proper incentive structure for collection action towards water savings, in contrast to the area- and season-based pricing schemes, which have a zero marginal cost of using water (Tsusaka et al. 2015).

---

[1] All dollar values ($) in this study are reported in US dollars

1.2.3. Irrigation in Vietnam

Irrigation systems and government support schemes vary across the two deltas of interest in this study. As per protocol 143/2003 from the Vietnamese Government, introduced in 2003 and revised in 2012, the Government shall provide support to local irrigation companies through the Department of Agriculture and Rural Development (Government of Vietnam 2012). The Government provides different levels of support depending on which type of irrigation system farmers are using - pumped irrigation, gravity-fed irrigation, or a mix of the two types of irrigation. At the time of this study, the support provided by the Government was approximately $72.38/ha/season and $46.39/ha/season for pumped irrigation in the Red River and Mekong River Deltas, respectively; $50.38/ha/season and $32.19/ha/season for gravity-fed irrigation in the Red River and Mekong River Deltas, respectively; and $61.52/ha/season and $36.23/ha/season for mixed irrigation in the Red River and Mekong River Deltas, respectively (MARD 2014).

Both the abovementioned deltas in Vietnam have a series of canals to transfer water from rivers to farmers' fields. Canals are classified with numerical values based on their proximity to the river. Meaning, canal ones connect directly to the rivers, canal twos are offshoots of canal ones, and canal threes are offshoots of canal twos. In total, Vietnam has 36,394 kilometres of level one canals, 57,508 kilometres of level two canals, and 141,149 kilometres of level three canals (MARD 2014). Nearly half of the country's total length of canals are in the Mekong River Delta. In total, there are more than 15,000 kilometres of level one canals, 27,000 kilometres of level two canals, and 50,000 kilometres of level three canals in the Mekong River Delta (Trung and Dũng 2015).

Through MARD, the Government covers the cost of maintaining level one and level two canals (e.g., dredging) and pays the associated costs of moving water from rivers to canal levels one and two. The payment scheme to move the water from the canals into the farmers' fields varies by location. Generally, farmers pay a fee to an organised group, such as an agricultural cooperative, water-use organisation, irrigation management board, or private pumping station, to move the irrigation water from the canals to their fields. In some cases, the fee paid to these organisations bundles irrigation costs (e.g., pumping and canal repairs) with other services such as pest and disease monitoring. The cost of this fee is negotiated between farmers and the irrigation providers each season and depends on several factors, like elevation changes in the pumping area and the number of additional services organisations provide with irrigation.

Farmers in the Mekong River Delta and farmers from the Red River Delta both receive the same benefits from the Department of Agriculture and Rural Development to move irrigation water to level one and level two canals. Also, both deltas receive government support for canal maintenance, such as dredging. However, in the Mekong River Delta, the entire budget is used in canal maintenance and the transfer of water from the rivers to level one and two canals. In the Red River Delta, there is enough money remaining after canal maintenance and moving irrigation water into the canals to provide additional support, ranging from approximately $28-$40/ha/season, and paid to the local organisation (e.g., cooperative) responsible for moving the irrigation water from the canal to the farmers' fields (IAE 2017). This additional support lowers the price paid for irrigation by the farmer and thus reduces the primary economic incentive of AWD use, monetary savings from reduced water use.

1.2. Materials and Methods

The International Rice Research Institute collected the primary, cross-sectional data used in this study with their local partner in Vietnam, the Institute for Agricultural Environment. Geographical selections of respondents were based on a priori of knowledge of rice-producing river deltas, where at least some of the population used AWD. Once communes were selected, enumerators worked with local cooperative leaders to select farmers using a stratified random sampling procedure for AWD and CF farmers, based on the irrigation technique used in the previous season. The study area covers the two main rice-producing river deltas in Vietnam, the Mekong River Delta, and the Red River Delta. A total of 225 farmers, 45 from each province, were interviewed in An Giang, Hai Duong, Kien Giang, Soc Trang, and Thai Binh Provinces (Figure 1.1). We collected household data on the primary variables of interest – perceptions of AWD, agricultural information sources, and perception of receiving a water subsidy, as well as socioeconomic control variables such as technology awareness, self-reported risk preference, and socioeconomic variables including farm costs, revenues, and productivity.

Figure 1.1: Location of study: interviews conducted in shaded provinces

We investigate factors that influence a smallholder farmer's decision whether or not to use AWD, using conditional logit analysis, first developed by McFadden (1973).[2]

[2] More precise theoretical information on McFadden's conditional logit can be found in: (Maddala, 1983; McFadden, 1978, 1974, 1973; McFadden and Train, 2000; Train, 2003)

Understanding human choice behaviour has been a long-running interest in the field of economics. However, understanding this is a complicated task primarily based on observed behaviour. Part of the difficulty, as noted by McFadden (1973), is that the econometrician cannot observe or control all the factors that may influence behaviour. Additionally, the process of observation itself influences the decision-maker. This lack of control makes it necessary to make statistical inferences from individual choice behaviour sampled from a population of individuals. For this study, our population of interest is smallholder rice producers in Vietnam.

In a conditional logit model, each individual, i, receives some perceived level of utility from each choice alternative, j. This perceived utility of farmers, U, is the sum of two elements, one deterministic and one random. Conditional logit models often take the following form:

$$U_{ij} = X_{ij} + e_{ij}, \tag{1.1}$$

where the utility, U_{ij}, is the sum of the deterministic element, X_{ij}, and the random element, e_{ij}. The deterministic element is typically modeled as a function of individual attributes of the decision-makers as well as attributes of the choice alternative. The random element is assumed to have the following standard type I extreme value distribution:

$$f(e_{ij}) = \exp[-e_{ij} - \exp(-e_{ij})]. \tag{1.2}$$

We also assume that individuals will act rationally in such a way that they seek to maximise their utility. As such, each individual, i, will select a choice alternative, j, that maximises their perceived utility, U_{ij}. The probability that individual i will select choice alternative j is:

$$\pi_{ij} = \Pr(Y_i = j) = \Pr[\max(U_{i1}, \dots, U_{iJ}) = U_{ij}] \tag{1.3}$$

Following Maddala (1983 p.60-61), equation 1.3 can be expressed as a conditional logit model:

$$\pi_{ij} = \frac{\exp(X_{ij})}{\sum \exp(X_{ij})}. \quad (1.4)$$

However, because the smallholder rice producers in this study only have two choice alternatives, the problem can be solved using a standard logistic regression model. The logistic model is used to estimate the deterministic element, X_{ij}, from equation 1.1. Attributes observed about the individuals and choice alternatives make up X_{ij}. In this model, the choice alternatives can be considered as a set with two elements, $j = \{AWD, CF\}$. For the logistic regression model to accurately predict the choice alternative of each individual, it must be that:

$$X_{i,AWD} + e_{i,CF} \geq X_{i,CF} + e_{i,AWD}, \quad (1.5)$$

for all farmers who use AWD and:

$$X_{i,CF} + e_{i,AWD} > X_{i,AWD} + e_{i,CF}, \quad (1.6)$$

for all farmers who continuously flood their paddies.

We use a logistic regression model to estimate the farmers' decisions to practice AWD or not. The model follows the standard logistic regression model in the form:

$$Y_i = F\left(\beta_0 + \sum_{k=1}^{n} \beta_k X_{ik}\right) + \mu_i, \quad (1.7)$$

where Y_i is the choice outcome of a farmer using AWD and takes the value:

$$Y_i = \begin{cases} 1: Farmer\ practices\ AWD \\ 0: Farmer\ does\ not\ practice\ AWD. \end{cases} \quad (1.8)$$

F denotes the use of a standard logistic distribution function, X_i is a vector of k independent variables (description of variables in Appendix 1.1), and μ_i is the error term for each individual i. Generally, the regressors in this model are attributes of the individual respondents or the objects of choice. We only include attributes in the model that we expect to have an impact on the outcome of the decision-maker. Summary statistics for the regressors are in Table 1.1.

Table 1.1. Summary statistics of logit regressors by outcome variable

Variable	AWD (n=100) Mean	AWD (n=100) Std. Dev.	CF (n=125) Mean	CF (n=125) Std. Dev.	Difference AWD-CF
Primary school or less	0.150	(0.359)	0.224	(0.419)	-0.074*
HH income from farming (%)	78.69	(27.37)	70.93	(28.67)	7.759**
Technology awareness	0.320	(0.973)	-0.256	(0.950)	0.576***
Self-reported risk preference	3.660	(0.879)	3.232	(0.985)	0.428***
AWD water use expectation	2.040	(0.634)	2.184	(0.652)	-0.144**
AWD fertiliser expectation	2.430	(0.714)	2.592	(0.763)	-0.162*
AWD pest expectation	2.480	(0.745)	2.584	(0.774)	-0.104
AWD weed expectation	2.610	(0.931)	3.096	(0.884)	-0.486***
AWD weather loss expectation	2.770	(0.664)	2.824	(0.597)	-0.054
AWD costs expectation	2.320	(0.679)	2.528	(0.809)	-0.208**
AWD lodging expectation	1.970	(0.643)	2.144	(0.692)	-0.174**
AWD harvest expectation	3.500	(1.142)	3.568	(1.095)	-0.068
AWD soil quality expectation	3.590	(0.698)	3.528	(0.799)	0.062
AWD yield expectation	3.920	(0.614)	3.752	(0.656)	0.168**
AWD calendar expectations	3.650	(0.716)	3.696	(0.710)	-0.046
Ag info TV/radio	0.800	(0.402)	0.800	(0.402)	0.000
Ag info local staff	0.880	(0.327)	0.768	(0.424)	0.112**
Ag info company	0.390	(0.490)	0.392	(0.490)	-0.002
Ag info NGO	0.430	(0.498)	0.056	(0.231)	0.374***
Ag info neighbour	0.520	(0.502)	0.488	(0.502)	0.032
Perceived water subsidy	0.150	(0.359)	0.344	(0.477)	-0.194***

Note: '***','**', and'*' are significant t-test differences at the 1%, 5%, and 10% level, respectively

1.3. Results and discussion

1.3.1. Conditional Logit Model

Results of the conditional logit analysis as well as the marginal effects $(\Delta Y/\Delta X)$, taken at the means can be seen in Table 1.2. By taking the marginal effects at the mean, the model reports the change in the percent likelihood of using AWD for a one-unit change in the independent variables for the average value of each independent variable. Table 1.2 reports the independent variables that are likely to influence farmers' individual choices on whether to use AWD, following McFadden's conditional logit model. The logit models shown in Table 1.2 predicted the outcome correctly 79.11% of the time for the pooled sample, 82.22% of the time for the Mekong River Delta, and 91.11% of the time for the Red River Delta, as seen in Appendices 1.2 –12.4.

Table 1.2. Results of the conditional logit model marginal effects

	Pooled Sample		Mekong River		Red River	
Variable	$\Delta Y/\Delta X^{‡}$	Std. Err.	$\Delta Y/\Delta X^{‡}$	Std. Err.	$\Delta Y/\Delta X^{‡}$	Std. Err.
Primary school or less	-0.016	0.069	0.013	0.076	0.024	0.208
Farm income (%)	0.002**	0.001	0.001	0.001	0.004***	0.002
Technology awareness	0.100***	0.029	0.130***	0.045	0.107*	0.056
Self-reported risk	0.083***	0.028	0.136***	0.035	-0.035	0.045
AWD water use expectation	-0.036	0.038	-0.096**	0.046	0.091	0.075
AWD fertiliser expectation	-0.032	0.032	0.014	0.040	-0.060	0.055
AWD pest expectation	0.007	0.029	0.005	0.034	0.003	0.061
AWD weed expectation	-0.076**	0.030	-0.118**	0.049	-0.062	0.040
AWD weather loss expectation	0.048	0.030	0.053	0.046	0.041	0.031
AWD costs expectation	-0.018	0.032	-0.051	0.046	-0.001	0.036
AWD lodging expectation	-0.044	0.031	-0.001	0.046	-0.080	0.054
AWD harvest expectation	-0.027	0.026	-0.024	0.033	0.030	0.048
AWD soil quality expectation	-0.014	0.033	0.077	0.048	-0.049	0.040
AWD yield expectation	0.045	0.032	-0.019	0.040	0.110*	0.057
AWD calendar expectations	-0.018	0.030	-0.040	0.041	-0.089**	0.043
Ag info TV/radio	-0.143**	0.073	-0.319***	0.098	0.050	0.117
Ag info local staff	0.196**	0.078	0.200**	0.093	-0.143	0.210
Ag info company	-0.107*	0.064	-0.139	0.086	-0.112	0.139
Ag info NGO	0.352***	0.071	0.301***	0.096	0.400**	0.163
Ag info neighbour	0.124**	0.056	0.151*	0.082	0.067	0.089
Perceived subsidy	-0.205***	0.062	-0.075	0.086	-0.210**	0.087

Note: '***','**', and'*' are significant at the 1%, 5%, and 10% level, respectively
‡: Marginal effects taken at the means of all variables

Respondents were asked a series of Likert scale questions about their expectations of AWD to determine if these expectations influenced their choice to use the practice. Questions were asked about some less-known potential advantages of AWD, such as reduced lodging, some better-known advantages such as reduced irrigation water use, as well as some better-known disadvantages of AWD such as increased number of weeds in the field. A Farmer’s expectation of the number of weeds in the field was the only significant factor in the pooled sample; farmers who believed AWD would increase the number of weeds in the field were less likely to use AWD. This result held in the Mekong River Delta but not in the Red River Delta. A farmer’s expectation of yield differences from using AWD was also a significant factor in the Red River Delta, albeit only at the ten percent level of significance. Farmers who believed that AWD would increase their yield were more likely to use AWD. There is not strong evidence in the literature that AWD increases yield, but there is strong evidence that AWD reduces water consumption. The expectation of water use from using AWD was a significant factor in the Mekong Delta. Famers who were more likely to use AWD if they believed that it would reduce water consumption. This result is a significant finding because reduced water consumption, and therefore, reduced irrigation cost is the primary economic incentive for farmers to use AWD.

Whether or not farmers perceive that they receive an irrigation subsidy or not could be mitigating the economic incentive realised by reduced water consumption. Results for the pooled sample indicate that farmers are 20% less likely to use AWD if they perceive that they receive an irrigation subsidy. This result only holds in the Red River Delta, and the magnitude of the effect increases to 21%. This outcome is intriguing because, as previously described in the literature review section, a farmer from the Mekong River Delta receives the same subsidy amount as any other farmer from that delta, and a farmer from the Red River Delta receives the same subsidy amount as any other farmer from that delta. However, following this subsidy scheme, farmers located nearer to the irrigation canals effectively pay a lower price for irrigation than those living further away. For example, one commune in the Red River Delta, Ngu Phuc, is located near the river Song Van Uc and only pays $15.03/ha for irrigation compared to the average price of $38.61/ha paid by the other farmers in the Red River Delta. These farmers in Ngu Phuc do not have the same economic incentives to reduce water consumption through AWD use and, therefore, do not use the practice. The current irrigation subsidy scheme is reducing incentives for some farmers to use AWD.

Sources of agricultural information, which were measured using a series of binary (yes, no) questions, was also found to affect farmers' decisions whether or not to use AWD. Results for the pooled sample in table 1.2 show that receiving agricultural information from TV/radio and private agricultural companies both reduced the likelihood of using AWD by 14.3% and 10.7%, respectively. Conversely, receiving agricultural information from local staff (e.g., local extension officers), NGOs, or a neighbour increased the participants' likelihood to use AWD by 19.6%, 25.2%, and 12.4%, respectively. All of these results held in the Mekong River Delta, with some variations in the magnitude of the effect and the significance level. However, the effect of information sources on AWD use was less important in the Red River Delta, where only receiving information from an NGO had a positive and significant effect. Farmers in the Red River Delta are less responsive to information sources than farmers in the Mekong River Delta.

Other control variables used in the model also had a significant effect on AWD use. Farmers in the Red River Delta and the pooled sample were more likely to use AWD as the share of agricultural income as an overall percentage of household income increased. Additionally, farmers in the Mekong River Delta and the pooled sample were more likely to use AWD if they were aware of a higher number of climate-smart technologies/practices, as well as if they considered themselves to be more risk-loving than their neighbours.

1.3.2. Cost and Return

To understand if the expectations of AWD from the previous section are the reality seen by farmers, a cost and return analysis was conducted, which covered income, costs, and yield for farmers. The results of this analysis are shown in Table 1.3 for the pooled sample, as well as by river delta. We disaggregate costs by each production process and include the costs of materials, machines, fuel, and labour. Income and costs were converted to USD from VND using the local exchange rate at the time of the survey. Results are divided by the farmers who use AWD and those farmers who use the traditional practice, CF.

Table 1.3. Cost and return by AWD usage.

	Pooled Sample			Mekong River Delta			Red River Delta		
	AWD	CF	Diff.ᶧ	AWD	CF	Diff. ᶧ	AWD	CF	Diff. ᶧ
Yield (kg/ha)	6,498.11	6,044.61	453.5***	7,040.451	6,498.291	542.16***	5,684.60	5,364.08	320.52**
	(946.41)	(1,037.84)		(668.48)	(858.31)		(682.91)	(908.62)	
Rice price (USD/kg)	0.30	0.30	0.00	0.27	0.27	0.00	0.35	0.34	0.01**
	(0.05)	(0.06)		(0.02)	(0.03)		(0.05)	(0.06)	
Gross income	1,907.02	1,749.14	157.88***	1,864.45	1,717.89	146.55***	1,970.89	1,796.00	174.89***
	(234.32)	(245.89)		(218.61)	(247.93)		(245.16)	(237.58)	
Cost-land prep	135.23	131.4	3.83	100.34	71.59	28.75***	187.55	221.12	-33.57**
	(85.85)	(93.76)		(64.76)	(38.49)		(87.67)	(79.51)	
Cost-planting	96.19	94.19	2.00	104.41	98.82	5.59	83.86	87.23	-3.37
	(61.46)	(59.1)		(39.21)	(36.38)		(83.69)	(82.20)	
Cost-fertiliser	201.47	200.73	0.74	178.59	177.11	1.49	235.79	236.17	-0.38
	(83.14)	(74.01)		(55.19)	(52.69)		(104.51)	(86.79)	
Cost-weeding	20.93	13.67	7.26***	26.28	18.24	8.03***	12.92	6.81	6.11***
	(18.83)	(10.71)		(22.23)	(11.20)		(6.52)	(4.58)	
Cost-pest control	38.25	31.19	7.06**	37.39	35.88	1.51	39.53	24.16	15.37**
	(32.67)	(29.65)		(23.45)	(35.35)		(43.29)	(15.93)	
Cost-irrigation	34.88	37.33	-2.45	43.99	44.99	-1.00	21.21	24.73	-3.52
	(29.97)	(29.01)		(34.74)	(30.16)		(11.57)	(18.44)	
Cost-harvest	117.13	114.05	3.08	83.18	91.18	-7.99***	168.06	148.37	19.69**
	(52.02)	(38.95)		(13.52)	(11.41)		(46.46)	(40.49)	
Cost-post harvest	3.04	4.57	-1.53	0.08	0.09	-0.01	7.50	11.28	-3.78*
	(8.03)	(10.45)		(0.45)	(0.76)		(11.38)	(14.11)	
Total costs	647.12	627.13	19.99	574.27	537.90	36.37**	756.41	759.87	-3.46
	(195.2)	(175.98)		(150.14)	(92.90)		(205.42)	(187.07)	
Net income	1,259.90	1,122.01	137.89***	1,290.18	1,180.00	110.18***	1,214.48	1,036.13	178.35***
	(284.94)	(300.41)		(241.11)	(263.19)		(338.58)	(332.20)	

Note: '***',' **', and'*' are significant at the 1%, 5%, and 10% level, respectively

ᶧ: Difference is AWD – CF and all significance tests determined using t-test

Values in parentheses are standard errors

All values are reported in USD per hectare unless indicated otherwise

In all cases, for the pooled sample or the individual river deltas, the net income is always higher for farmers who were using AWD. This effect seems to be driven primarily by the increased yields realised by AWD farmers. The literature is divided into the effect of AWD on farmers' yields. As described in the literature review, some studies have found that AWD reduces yield (Bouman and Tuong 2001; Eriksen et al. 1985), others found that AWD increases yield (Belder et al. 2004; Ceesay et al. 2006; Zhang et al. 2009), and others found that there is no effect on yield (Cabangon et al. 2004; Chapagain and Yamaji 2010; Palis and Hossain 2004). In our results, farmers' expectations that AWD increases yields, are consistent with the results of the cost and return section; farmers practicing AWD do have higher yields.

We find the cost of weeding to also be significantly higher in all cases, for the pooled sample or the individual river deltas. Previous studies find similar results of higher weeding costs (Kürschner and Henschel 2010; Rahman 2015). The absence of water during the drying period allows for weed establishment in the paddy, and the constant flooding in CF rice production does not allow for weed establishment. The number of weeds in the field was a significant factor in a farmer's decision to use AWD or not from the previous section.

Farmers' expectations that AWD use increases the costs of weed control, found in the choice model, are warranted. The increased cost of weed control is the most substantial economic disincentive of AWD use, and the farmers we surveyed seem to be well aware of this disincentive. Their expectations of increased weeding costs with AWD use match the economic reality in their fields.

The most significant economic incentive to using AWD, reduced irrigation cost, was not the economic reality seen for the surveyed farmers. In the previous section, the expectation of lower water use while using AWD was a significant factor for farmers in the Mekong River Delta to use the practice. These expectations, however, did not translate into reality as there is no significant difference in the prices paid for irrigation between AWD and CF farmers at any level. However, if irrigation cost is disaggregated for CF farmers by their response to receiving an irrigation subsidy or not, significant differences in the cost paid by CF and AWD farmers emerge (Figure 1.2). CF farmers who reported that they received an irrigation subsidy paid $17.97/ha. This cost is significantly less than AWD farmers who reported that they did not receive a subsidy, $33.17/ha, and other CF farmers who reported that they did not receive a subsidy, $46.81/ha. The fact that there was no difference in the average cost paid for irrigation in Table 1.2 looks to be driven by the perception of an irrigation subsidy. The distributions of irrigation costs seen in Figure 1.2 show that the average cost paid by AWD farmers is approximately centred between the reported irrigation cost for CF farmers. CF farmers who reported that they did receive a subsidy fall below AWD farmer, paying $15.20/ha less, and CF farmers who reported that they did not receive a subsidy fall above AWD farmers, paying $13.64/ha more. Both irrigation costs reported by CF farmers were significantly different from the irrigation cost paid by AWD farmers.

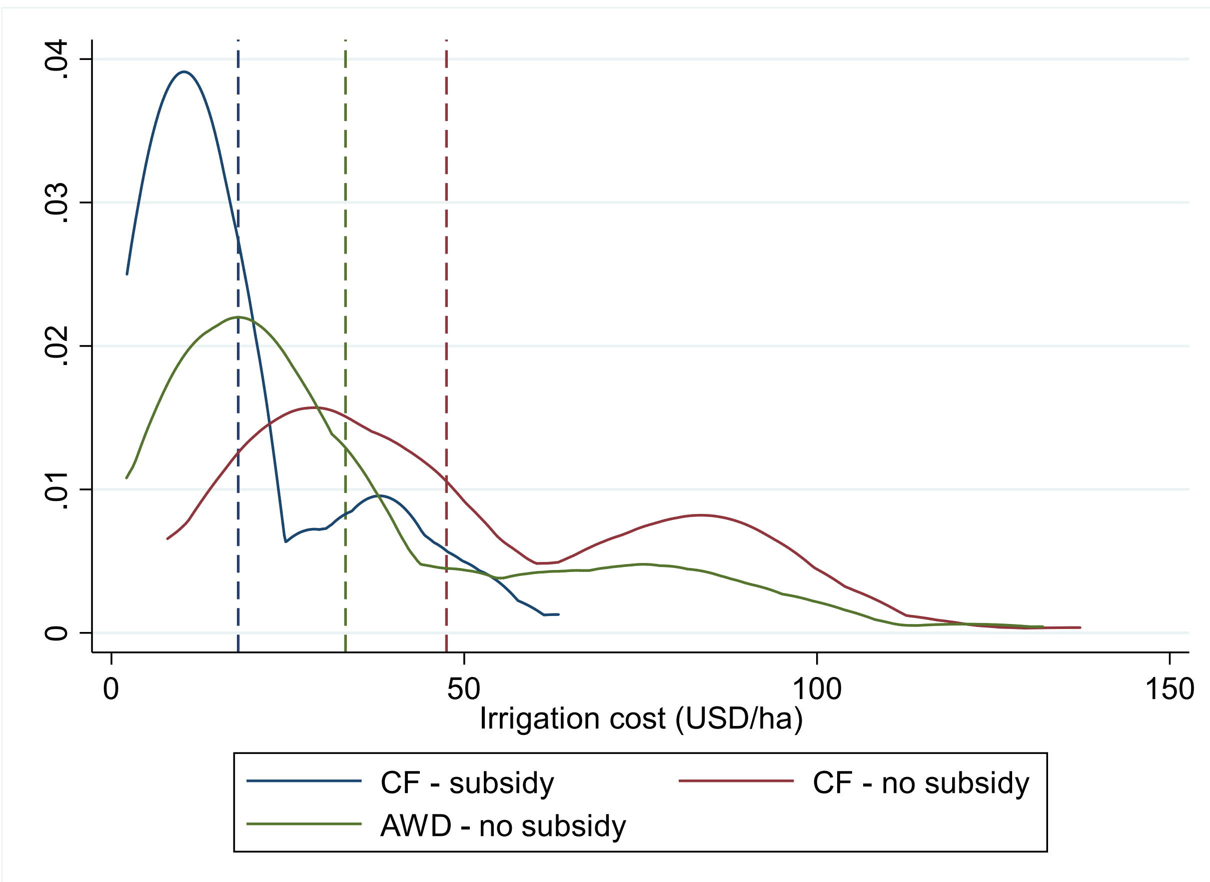

Figure 1.2: Distribution of irrigation costs by perceived subsidy and AWD use

1.4. Conclusions

The study found that the expectations of AWD were important determinants of the use of AWD. In either the pooled sample or when looking at individual river deltas, the expectation of higher yields and lower irrigation cost increased a farmer's likelihood to use AWD while increased weed cost decreased a farmer's likelihood to use AWD. Additionally, yield expectations matched reality for farmers surveyed in this study; we find AWD farmers to have higher yields compared to CF farmers. The same expectations-matching-outcomes were seen for irrigation costs, but only if the perceived subsidies are considered. The cost and return results showed no difference in the costs of irrigation between AWD and CF farmers, but there is a difference between AWD and CF farmers when the perceived subsidies are considered. Lastly, evidence of expectations matching outcomes was seen in farmers' expectations of weeds increasing with AWD use. This expectation decreased the likelihood of that farmer using AWD, and the results of the cost and return analysis showed that AWD farmers did pay more for weed control than CF farmers.

The most significant economic disincentive of AWD, increased weeds, are well understood by farmers in this study. Not only does this affect their use of AWD, but the results of the cost and return analysis show strong support for this expectation being accurate. There is less evidence, however, that the most significant economic incentive of AWD, decreased water use, is well understood. It was only a significant determinant in AWD use for farmers in the Mekong River Delta, and the results of the cost and return show no significant differences in irrigation costs for AWD and CF farmers. However, we show evidence that the benefits of reduced water consumption are offset by the current irrigation subsidy scheme in place. CF farmers who report receiving a subsidy pay significantly less than AWD farmers, and CF farmers who report receiving a subsidy pay significantly more than AWD farmers.

The Vietnamese Government is working towards meeting its stated objectives as it relates to the Paris Climate Agreement and its nationally determined contribution. Rice is a significant contributor to GHG emissions in the agricultural sector of Vietnam and, as such, has substantial potential to contribute to achieving the nationally determined contribution. One of the most promising mechanisms to reduce GHG emissions in rice production is AWD, where nearly 50% of GHG emissions can be abated by following the recommended irrigation procedures. The main economic benefit of AWD is realised through reduced water consumption for irrigation and thus lower irrigation costs. The Government can use its control of irrigation subsidies to influence the price of irrigation for farmers. We observe the effect of this subsidy in our study. If a farmer perceives that they receive an irrigation subsidy, they are less likely to adopt AWD by as much as 21%. This effect is most pronounced in the Red River Delta, where farmers receive support from the Government to move irrigation water from the canals to the fields. In the Mekong River Delta, farmers do not receive this support, and additionally, there is no reported effect of perceived irrigation subsidies.

The Vietnamese Government can use AWD to abate GHG emissions and move closer to achieving their nationally determined contribution without burdening themselves or Vietnamese farmers with additional costs to production. The promotion of AWD can be achieved by changing expectations through proper channels of agricultural information, particularly in the Mekong River Delta, where farmers in this study were more responses to sources of agricultural information. Furthermore, as the perceived water subsidy variable shows, AWD use can be improved by adjusting the incentives around irrigation, specifically in the Red River Delta. A combination of these efforts could help Vietnam mitigate GHG emissions from rice production and move closer to obtaining its nationally determined contribution to the Paris Climate Agreement.

1.5. References

Alam, M.S., Islam, MS, Salam, M., Islam, MA, 2009. Economics of Alternate Wetting and Drying Method of Irrigation: Evidences from Farm Level Study. Agric. 7, 82. https://doi.org/10.3329/agric.v7i1.5258

Alam, M.S., Jia, Z., 2012. Inhibition of methane oxidation by nitrogenous fertilizers in a paddy soil. Front. Microbiol. 3. https://doi.org/10.3389/fmicb.2012.00246

Archer, D., 2007. Global Warming: Understanding the Forecast. Blackwell, Malden, MA.

Aulakh, M.S., Wassmann, R., Rennenberg, H., 2001. Methane emissions from rice fields—quantification, mechanisms, role of management, and mitigation options. Adv. Agron. 70, 193–260. https://doi.org/10.1016/S0065-2113(01)70006-5

Basak, J.K., 2011. Impacts of Increasing Production Costs on Rice Price: Implications for Food Security 1–21.

Belder, P., Bouman, B.A.M., Cabangon, R., Guoan, L., Quilang, E.J.P., Yuanhua, L., Spiertz, J.H.J., Tuong, T.P., 2004. Effect of water-saving irrigation on rice yield and water use in typical lowland conditions in Asia. Agric. Water Manag. 65, 193–210. https://doi.org/10.1016/j.agwat.2003.09.002

Bodelier, P.L., Roslev, P., Henckel, T., Frenzel, P., 2000. Stimulation by ammonium-based fertilizers of methane oxidation in soil around rice roots. Nature 403, 421–424. https://doi.org/10.1038/35000193

Bouman, B.A.M., Lampayan, R.M., Tuong, T.P., 2007. Water Management in Irrigated Rice: Coping with Water Scarcity, International Rice Research Institute. International Rice Research Institute, Los Baños, Philippines.

Bouman, B.A.M., Tuong, T.P., 2001. Field water management to save water and increase its productivity in irrigated lowland rice. Agric. Water Manag. 49, 11–30. https://doi.org/10.1016/S0378-3774(00)00128-1

Bronson, K.F., Neue, H.U., Abao, E.B., Singh, U., Neue, K.F.B.H., Abao, U.S.E.B., 1997. Automated Chamber Measurements of Methane and Nitrous Oxide Flux in a Flooded Rice Soil: I. Residue, Nitrogen, and Water Management. Soil Sci. Soc. Am. J. 61, 981–987. https://doi.org/10.2136/sssaj1997.03615995006100030038x

Cabangon, R.J., Tuong, T.P., Castillo, E.G., Bao, L.X., Lu, G., Wang, G., Cui, Y., Bouman, B.A.M., Li, Y., Chen, C., Wang, J., 2004. Effect of irrigation method and N-fertilizer management on rice yield, water productivity and nutrient-use efficiencies in typical lowland rice conditions in China. Paddy Water Environ. 2, 195–206. https://doi.org/10.1007/s10333-004-0062-3

Cai, Z., Xing, G., Yan, X., Xu, H., Tsuruta, H., Yagi, K., Minami, K., 1997. Methane and nitrous oxide emissions fromrice paddy fields as affected by nitrogen fertilisers and water management. Plant Soil 196, 7–14. https://doi.org/10.1023/A:1004263405020

Carrijo, D.R., Lundy, M.E., Linquist, B.A., 2017. Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis. F. Crop. Res. 203, 173–180. https://doi.org/10.1016/j.fcr.2016.12.002

Ceesay, M., Reid, W.S., Fernandes, E.C.M., Uphoff, N.T., 2006. The effects of repeated soil wetting and drying on lowland rice yield with System of Rice Intensification (SRI) methods. Int. J. Agric. Sustain. 4, 5–14. https://doi.org/10.1080/14735903.2006.9686007

Chapagain, T., Yamaji, E., 2010. The effects of irrigation method, age of seedling and

spacing on crop performance, productivity and water-wise rice production in Japan. Paddy Water Environ. 8, 81–90. https://doi.org/10.1007/s10333-009-0187-5
El-Fadel, M., Massoud, M., 2001. Methane emissions from wastewater management. Environ. Pollut. (Barking, Essex 1987) 114, 177–85. https://doi.org/10.1016/S0269-7491(00)00222-0
Eriksen, A.B., Kjeldby, M., Nilsen, S., 1985. The effect of intermittent flooding on the growth and yield of wetland rice and nitrogen-loss mechanism with surface applied and deep placed urea. Plant Soil 84, 387–401. https://doi.org/10.1007/BF02275476
Escobar Carbonari, D., Grosjean, G., Läderach, P., Dai, N.T., Sander, B.O., McKinley, J., Sebastian, L., Tapasco, J., 2019. Reviewing Vietnam's Nationally Determined Contribution: A New Perspective Using the Marginal Cost of Abatement. Front. Sustain. Food Syst. 3, 14. https://doi.org/10.3389/fsufs.2019.00014
Ferry, J.G., 1992. Biochemistry of Methanogenesis. Crit. Rev. Biochem. Mol. Biol. 27, 473–503. https://doi.org/10.3109/10409239209082570
Government of Viet Nam, 2015. Intended Nationally Determined Contribution of Viet Nam.
Government of Vietnam, 2012. Decree No. 67/2012 / ND-CP of the Government: Amending and supplementing a number of articles of the Government's Decree No. 143/2003 / ND-CP of November 28, 2003, detailing the implementation of a number of Article of the Ordinance on exploitation and pr [WWW Document]. URL http://vanban.chinhphu.vn/portal/page/portal/chinhphu/hethongvanban?class_id=1&mode=detail&document_id=163522 (accessed 5.4.19).
IAE, 2017. Consultation on building a water saving suitability irrigation map and developing a plan for replication of alternate dry and wet rice cultivation in Thai Binh-IRRI-C2016-151. Hanoi, Vietnam.
IPCC, 2007. Climate Change 2007: The Physics Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA.
Karim, M.R; Alam, M.M.;Ladha, J., Islam, M.S.;Islam, M.R., 2014. Effect of different irrigationand tillatge methods on yield and resource use efficiency of Boro rice (Oryza sativa). Bangladesh J. Agril. Res. 39, 151–163.
Kürschner, E., Henschel, C., 2010. Water Saving in Rice Production–Dissemination, Adoption and Short Term Impacts of Alternate Wetting and Drying (AWD) in Bangladesh, Series of the Department of Rural Development 241.
Lampayan, R.M., Rejesus, R.M., Singleton, G.R., Bouman, B.A.M., 2015. Adoption and economics of alternate wetting and drying water management for irrigated lowland rice. F. Crop. Res. 170, 95–108. https://doi.org/10.1016/j.fcr.2014.10.013
Linquist, B., Van Groenigen, K.J., Adviento-Borbe, M.A., Pittelkow, C., Van Kessel, C., 2012. An agronomic assessment of greenhouse gas emissions from major cereal crops. Glob. Chang. Biol. 18, 194–209. https://doi.org/10.1111/j.1365-2486.2011.02502.x
Maddala, G.S., 1983. Limited-dependent and qualitative variables in econometrics. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511810176
MARD, 2014. Củng cố, phát triển thủy lợi nội đồng gắn với xây dựng nông thôn mới. Ha Noi, Vietnam.

McFadden, D., 1978. Modeling the Choice of Residential Location. Transp. Res. Rec. 72–77.

McFadden, D., 1974. The Measurement of Urban Travel Demand. J. Public Econ. 3, 303–328.

McFadden, D., 1973. Conditional logit analysis of qualitative choice behavior. Front. Econom. https://doi.org/10.1108/eb028592

McFadden, D., Train, K., 2000. Mixed MNL models for discrete response. J. Appl. Econom. 15, 447–470. https://doi.org/10.1002/1099-1255(200009/10)15:5<447::AID-JAE570>3.3.CO;2-T

Mosier, A.R., Halvorson, A.D., Reule, C. a, Liu, X.J., 2006. Net global warming potential and greenhouse gas intensity in irrigated cropping systems in northeastern Colorado. J. Environ. Qual. 35, 1584–98. https://doi.org/10.2134/jeq2005.0232

Nalley, L., Linquist, B., Kovacs, K., Anders, M., 2015. The economic viability of alternative wetting and drying irrigation in arkansas rice production. Agron. J. 107, 579–587. https://doi.org/10.2134/agronj14.0468

Nargis, F., Miah, T.H., Khanam, T.S., Sarwer, R.H., 2009. Profitability of Mv Boro Rice Production Under Shallow Tubewell Irrigation System in Some Selected Areas of Tangail District. Progress. Agric. 20, 237–244.

Palis, F.G., Hossain, M., 2004. A farmer participatory approach in the adaptation and adoption of controlled irrigation for saving water: a case study in Canarem, Victoria, Tarlac, Philippines. Philipp. J. Crop Sci. 29, 397–401.

Quicho, E., 2013. Evaluation of the Adoption and Economic Impacts of Alternate Wetting and Drying Technology in Irrigated Rice-Growing Areas in An Giang Province in the Mekong Delta, Southern Vietnam 2007, 90–92. https://doi.org/10.1017/CBO9781107415324.004

Rahman, M.S., 2015. Case Studies on Farmers' Perceptions and Potential of AWD in Two Districts of Bangladesh. Dhaka, Bangladesh.

Richards, M., Sander, B.O., 2014. Alternate wetting and drying in irrigated rice. J. AHIMA 67, suppl 2p; quiz 49–50.

Sanchis, E., Ferrer, M., Torres, A.G., Cambra-López, M., Calvet, S., 2012. Effect of Water and Straw Management Practices on Methane Emissions from Rice Fields: A Review Through a Meta-Analysis. Environ. Eng. Sci. 29, 121015061819000. https://doi.org/10.1089/ees.2012.0006

Sander, B.O., Wassmann, R., Siopongco, D.L.C., 2015. Gas Emissions from Rice and Empirical Evidence, in: Hoanh, C., Smakhtin, V., Johnston, R. (Eds.), Climate Change and Agricultural Water Management in Developing Countries. CABI Publishing, Wellingford, United Kingdom, pp. 193–207.

Smith, P., Nabuurs, G.J., Janssens, I.A., Reis, S., Marland, G., Soussana, J.F., Christensen, T.R., Heath, L., Apps, M., Alexeyev, V., Fang, J., Gattuso, J.P., Guerschman, J.P., Huang, Y., Jobbagy, E., Murdiyarso, D., Ni, J., Nobre, A., Peng, C., Walcroft, A., Wang, S.Q., Pan, Y., Zhou, G.S., 2008. Sectoral approaches to improve regional carbon budgets. Clim. Change 88, 209–249. https://doi.org/10.1007/s10584-007-9378-5

Train, K.E., 2003. Discrete Choice Methods with Simulation. Cambridge Univ. Press 1–388. https://doi.org/10.1017/CBO9780511753930

Trung, T.C., Dũng, T.V., 2015. Phân tích thực trạng và đề xuất giải pháp phát triển tổ

chức dùng nước ở vùng đồng bằng sông cửu long. TẠP CHÍ KHOA HỌC VÀ CÔNG NGHỆ THỦY LỢI SỐ 30, 1–7.
Tsusaka, T.W., Kajisa, K., Pede, V.O., Aoyagi, K., 2015. Neighborhood effects and social behavior: The case of irrigated and rainfed farmers in Bohol, the Philippines. J. Econ. Behav. Organ. 118, 227–246. https://doi.org/10.1016/j.jebo.2015.04.022
USAID, 2016. Greenhouse Gas Emissions in Vietnam. Washington DC. https://doi.org/https://www1.toronto.ca/city_of_toronto/environment_and_energy/key_priorities/files/pdf/ghg-aq-inventory-june2007.pdf
Wassmann, R., Neue, H.U., Lantin, R.S., Makarim, K., Chareonsilp, N., Buendia, L. V, Rennenberg, H., 2000. Characterization of methane emissions from rice fields in Asia. II differences among irrigated, rainfed, and deepwater rice. Nutr. Cycl. Agroecosystems 58, 13–22. https://doi.org/10.1023/A:1009822030832
Win, K.T., Nonaka, R., Win, A.T., Sasada, Y., Toyota, K., Motobayashi, T., Hosomi, M., 2012. Comparison of methanotrophic bacteria, methane oxidation activity, and methane emission in rice fields fertilized with anaerobically digested slurry between a fodder rice and a normal rice variety. Paddy Water Environ. 10, 281–289. https://doi.org/10.1007/s10333-011-0279-x
Yagi, K., Tsuruta, H., Kanda, K.I., Minami, K., 1996. Effect of water management on methane emission from a Japanese rice paddy field: Automated methane monitoring. Global Biogeochem. Cycles 10, 255–267. https://doi.org/10.1029/96GB00517
Yang, C., Yang, L., Yang, Y., Ouyang, Z., 2004. Rice root growth and nutrient uptake as influenced by organic manure in continuously and alternately flooded paddy soils. Agric. Water Manag. 70, 67–81. https://doi.org/10.1016/j.agwat.2004.05.003
Zhang, H., Xue, Y., Wang, Z., Yang, J., Zhang, J., 2009. An alternate wetting and moderate soil drying regime improves root and shoot growth in rice. Crop Sci. 49, 2246–2260. https://doi.org/10.2135/cropsci2009.02.0099

1.6. Appendices

Appendix 1.1: Description of variables used in equation (1.7).

Variable	Description
Primary school or less	Highest education is primary school or less (1=yes)
HH income from farming (%)	Percent of household income from farming
Technology awareness	Normalised number of technologies known
Self-reported risk preference	Normalised Likert - self-reported risk preference
AWD water use expectation	Normalised Likert - AWD water use compared to CF
AWD fertiliser expectation	Normalised Likert - AWD fertiliser use compared to CF
AWD pest expectation	Normalised Likert - AWD loss from pest compared to CF
AWD weed expectation	Normalised Likert - AWD weeds in the field compared to CF
AWD weather loss expectation	Normalised Likert - AWD poor weather yield loss compared to CF
AWD costs expectation	Normalised Likert - AWD production costs compared to CF
AWD lodging expectation	Normalised Likert - AWD lodging compared to CF
AWD harvest expectation	Normalised Likert - AWD ease of harvest compared to CF
AWD soil quality expectation	Normalised Likert - AWD quality of soil compared to CF
AWD yield expectation	Normalised Likert - AWD yield compared to CF
AWD crop cal. expectation	Normalised Likert - AWD ease of planning crop calendar compared to CF
Ag info TV/radio	Receive agricultural information from TV or radio (1=yes)
Ag info local staff	Receive agricultural information from local staff (1=yes)
Ag info company	Receive agricultural information from agricultural company (1=yes)
Ag info NGO	Receive agricultural information from NGO (1=yes)
Ag info neighbour	Receive agricultural information from a neighbour (1=yes)
Perceived water subsidy	Respondent perceives receiving a water subsidy (1=yes)

Appendix 1.2: Hit miss table of conditional logit model – all deltas

Logistic model for awd

Classified	True D	True ~D	Total
+	70	17	87
-	30	108	138
Total	100	125	225

Classified + if predicted Pr(D) >= .5
True D defined as awd != 0

Sensitivity	Pr(+| D)	70.00%
Specificity	Pr(-|~D)	86.40%
Positive predictive value	Pr(D| +)	80.46%
Negative predictive value	Pr(~D| -)	78.26%
False + rate for true ~D	Pr(+|~D)	13.60%
False - rate for true D	Pr(-| D)	30.00%
False + rate for classified +	Pr(~D| +)	19.54%
False - rate for classified -	Pr(D| -)	21.74%
Correctly classified		79.11%

Appendix 1.3: Hit miss table of conditional logit model – Mekong River Delta

Logistic model for awd

Classified	True D	True ~D	Total
+	48	12	60
-	12	63	75
Total	60	75	135

Classified + if predicted Pr(D) >= .5
True D defined as awd != 0

Sensitivity	Pr(+| D)	80.00%
Specificity	Pr(-|~D)	84.00%
Positive predictive value	Pr(D| +)	80.00%
Negative predictive value	Pr(~D| -)	84.00%
False + rate for true ~D	Pr(+|~D)	16.00%
False - rate for true D	Pr(-| D)	20.00%
False + rate for classified +	Pr(~D| +)	20.00%
False - rate for classified -	Pr(D| -)	16.00%
Correctly classified		82.22%

Appendix 1.4: Hit miss table of conditional logit model – Red River Delta

```
Logistic model for awd

              -------- True --------
Classified |         D            ~D  |      Total
-----------+--------------------------+-----------
     +     |        35             3  |         38
     -     |         5            47  |         52
-----------+--------------------------+-----------
   Total   |        40            50  |         90

Classified + if predicted Pr(D) >= .5
True D defined as awd != 0
--------------------------------------------------
Sensitivity                     Pr( +| D)   87.50%
Specificity                     Pr( -|~D)   94.00%
Positive predictive value       Pr( D| +)   92.11%
Negative predictive value       Pr(~D| -)   90.38%
--------------------------------------------------
False + rate for true ~D        Pr( +|~D)    6.00%
False - rate for true D         Pr( -| D)   12.50%
False + rate for classified +   Pr(~D| +)    7.89%
False - rate for classified -   Pr( D| -)    9.62%
--------------------------------------------------
Correctly classified                        91.11%
--------------------------------------------------
```

Chapter 2: Climate Change Adaptation Strategies Vary with Climate Change Stress: Evidence from Three Regions of Vietnam

This chapter contains collaborative work with Jeffrey T. LaFrance (Monash University, Department of Economics, Melbourne, Australia) and Valerien O. Pede (International Rice Research Institute, Los Banos, Philippines.

2.1. Introduction

The overwhelming consensus of experts is that the climate is changing, and humans are responsible (Oreskes 2004, Doran and Zimmerman 2009). Climate change refers to changes in the mean or variability of climate that persists over an extended period, typically of at least a decade, such as global warming (IPCC 2018). Increased global temperatures bring unprecedented risks to vulnerable populations as a result of disrupting natural systems – examples are increases in the frequency and severity of droughts, floods and other extreme weather events; increased global sea-level rise; and biodiversity loss (IPCC 2012, IPCC 2014, Mysiak, Surminski et al. 2016).

Vietnam is especially vulnerable to the effect of climate change because of its geography and population demographics. A report from ADB (2009) concluded that many of the countries of Southeast Asia are especially vulnerable to the impacts of climate change because of their long coastlines, high concentration of human and economic activity in coastal regions, large and growing populations, and importance of agriculture as a source of employment and income. Vietnam's vulnerability is high because of its large cities, coastal regions, and high mountain ranges (Albert, Bronen et al. 2018). Additionally, low-lying river deltas add to its vulnerability and make it one of the most affected countries from adverse climate change stresses, such as flooding, saltwater intrusion, and drought (Dasgupta, Laplante et al. 2007, Dasgupta, Laplante et al. 2011). Rural communities that rely on agriculture are some of the most vulnerable populations to climate change because they often have a vulnerable livelihood, reduced adaptive abilities, and live in high-risk areas (Dung and Sharma 2017). 70% of Vietnam's population lives in rural areas, and around 60% of the rural population relies on agriculture for their incomes (Bergstedt 2015). The effects of climate change are felt disproportionately by poor households because their livelihoods are more dependent on agriculture than wealthier households (Davies, Guenther et al. 2009), and climate change decreases agricultural productivity and food security (Iglesias, Quiroga et al. 2011). For example, temperature increases are expected to decrease crop output (Johnston, Hoanh et al. 2010) and livestock output because of an increased incidence of pests and diseases (IPSONRE

2009). Increased climate variability will most threaten communities that rely on resources because of their increased vulnerabilities and risk exposure; this is especially true in rural development and agricultural sectors (IPCC 2012). Climate change stresses will be felt especially hard by agricultural households. There is evidence that these communities are already feeling these effects. A recent study by Trinh, Rañola Jr et al. (2018), found that farmers in their study are losing 20% of their annual income from agriculture as a result of climate change.

Climate change stresses are expected to increase in Vietnam in the future, with severe consequences. Studies have forecast increasing average temperatures, sea-level rise, changing precipitation, and increasing drought in regions of Vietnam (Cuong 2008, IPCC 2014). IPSONRE (2009) forecast regional climate change, including the three regions covered in our study, the Red River Delta, Central Vietnam, and the Mekong River Delta. Some of these regional forecasts are the same, such as increasing temperature, frequency and intensity of storms, and drought. Other forecasts are variable over regions, Central Vietnam is forecast to have increased rainfall in addition to their seasonal drought, and the Mekong River Delta is forecast to be impacted by increased sea-level rise and salinity intrusion (IPSONRE 2009). Sea-level rise of one meter is anticipated to cause severe impacts to the inhabitants of the Mekong River Delta, Red River Delta, and Ho Chi Minh City (MONRE 2009). In total, between 11% to 25% of the country's population could be directly affected, and GDP losses are estimated to be between 10% to 25% with a one-meter and three-meter increase in sea level, respectively (Dasgupta, Laplante et al. 2007). Declining agricultural production is anticipated because of increasing temperatures (IPSONRE 2009) as well as increasing floods and salinisation (Dung and Sharma 2017).

With the presence of all of these stresses, the Vietnamese government is not sitting idly by. Vietnam, particularly the agricultural and rural development sectors, have developed comprehensive climate change policies with consideration given to adaptation and mitigation (Dung and Sharma 2017). Examples include the creation of the National Climate Change Strategy in 2011, which lays out strategic objectives to be accomplished by 2050, or the creation of the National Committee on Climate Change created in 2012 (McKinley, Adaro et al. 2015)[3]. However, there are opportunities for improvement by bringing in more local stakeholders. Dung and Sharma (2017) note that while the Ministry of Agriculture and Rural Development is ahead in developing policy frameworks for climate change adaptation, current systems do not adequately address the private sector and local community involvement in responses. Similarly, a key informant interview from McKinley, Adaro et al. (2015) finds that policy still follows a top-down approach, with almost no consultation with local communities or organisations. Comprehensive policies with guiding rules to increase the participation of local communities and mechanisms to incentivise them to take part in climate change mitigation and adaptation are essential (Dung and Sharma 2017). Vietnam has several mitigation options available in agriculture (Escobar Carbonari, Grosjean et al. 2019), but regardless of how much mitigation occurs, climate change is already occurring, and adaptation is necessary to overcome these changes (Malik, Qin et al. 2010). Adaptation and mitigation are not alternatives and must both be pursued, but the costs will influence the choice of policies (Mendelsohn 2012).

There are numerous climate change adaptations,[4] falling into different categories and at varying costs. A recent study by Christoplos, Ngoan et al. (2017) finds that Vietnamese farmers' adaptations are increasingly autonomous and less capital intensive. Autonomous adaptations[5] are not conscious adaptations to climatic stimuli, but rather spontaneous responses triggered by changes in natural, market or human systems (IPCC 2018). Autonomous adaptations are widely considered to be reactive and undertaken by private actors rather than governments (Malik, Qin et al. 2010). Individuals only adopt private adaptations when they are efficient, i.e., when the benefits outweigh the costs, because all of the costs and benefits go to the individual who is making the decision

---

[3] See Mckinley, Adaro et al. (2015) and Dung and Sharma (2017) for recent reviews of climate change policies in Vietnam.

[4] Climate change adaptation is commonly defined as an adjustment in natural or human systems in reponse to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities (UNFCCC 2020, IPCC 2018)

[5] See Malik, Qin, and Smith (2010) for a review of autonomous adaptations

(Mendelsohn 2000, Mendelsohn 2012). Autonomous responses are more often short-run adaptations because the impacts are less uncertain, and benefits are more predictable (Stern 2007). Long-run are less common than short-run adaptations because of the uncertainty and more substantial capital investments involved in long-term investments (Stern 2007). Individuals will make efficient adaptations if they have the resources to do so, but unexpected stress can lead to disruptions in livelihoods, resulting in increased vulnerability from reduced access to social, political, and economic resources (Adger 1999). Microfinance has the potential to play a significant role in autonomous adaptations by providing households with access to necessary resources (Malik, Qin et al. 2010). Agrawala and Carraro (2010) note in their review that the nature of microfinance lending, large volume and low-value loans is consistent with the needs for adaptation – providing large volumes of decentralised loans. Their review found that significant overlaps already exist between climate change adaptation and microfinance lending. Hammill, Matthew et al. (2008) argue that microfinance builds resiliency in households by making them less vulnerable to shocks from climatic stresses and more capable of coping with the impacts; as they put it, "the logic here is simple – the more assets and capabilities people have, the less vulnerable they are."

We are not the first researchers interested in how agricultural households are adapting to climate change in Vietnam. There have been numerous studies about varying topics within climate change responses in Vietnam (see: Nguyen, Hoang et al. 2013, Le Dang, Li et al. 2014, Christoplos, Ngoan et al. 2017, McElwee, Nghiem et al. 2017, Trinh, Rañola Jr et al. 2018, Waibel, Pahlisch et al. 2018, Ylipaa, Gabrielsson et al. 2019), including studies that used subsets of the same dataset that we use in our analysis (Mishra and Pede 2017, Duffy, Pede et al. 2020). The intentions of these publications are primarily the same as ours, to provide insights to policymakers in order to strengthen climate change policy in Vietnam. While the previous literature adds to the discussion in a meaningful way, we believe that gaps in knowledge still exist and that we can fill some of these voids. Our study is unique from previous studies in that it covers more regions of Vietnam, while also covering multiple climate change stresses. Additionally, we can identify which stresses elicit specific responses from individuals. The purpose of this study is to investigate how climate change adaptation in rice-producing households of Vietnam vary, depending on the primary climate stresses and resulting impacts observed by individuals.

2.2. Methods and Data

2.2.1. Data collection

Data for this study come from household interviews conducted by the International Rice Research Institute with their local partners in Vietnam; the Institute of Policy and Strategy for Agriculture and Rural Development, and the Vietnam National University of Agriculture as part of the Consultative Group on International Agricultural Research Program on Climate Change, Agriculture, and Food Security. The data collection occurred in three rounds of surveys, with collection occurring in the Mekong River Delta, followed by the Red River Delta, and finally in central Vietnam. These three survey rounds are inclusive of seven provinces of Vietnam, as seen in Figure 2.1. The survey resulted in a total of 1,306 unique respondents, comprised of husbands and wives from 653 rice-producing households. Missing responses for the key choice variables reduced the number of observations used to 1,290 for the household choice model and 1,244 for the agricultural choice model.

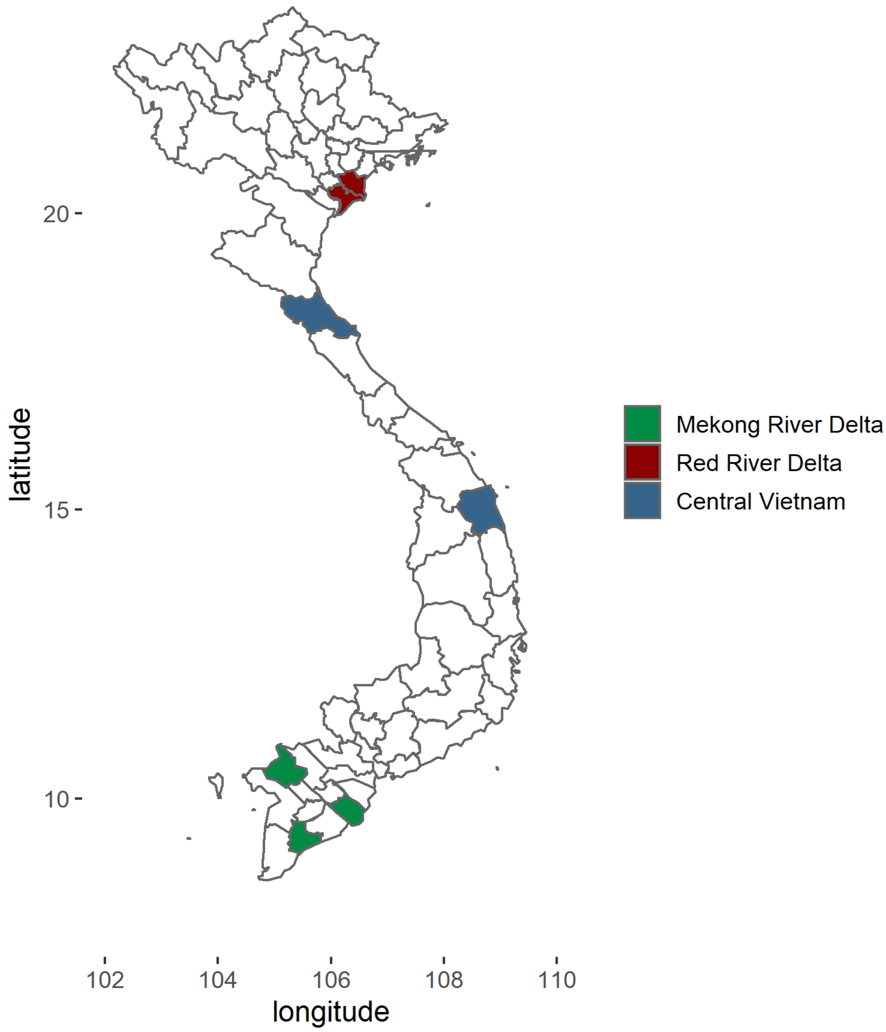

Figure 2.1: Provinces covered by three separate surveys in Vietnam.

Enumerators used a priori knowledge of areas facing different climate change issues to select provinces, districts, communes, and villages for data collection. Once villages were selected, the village head (or similar) provided a list of farmers with at least ten years of rice-farming experience to the enumerators. Survey participants were then selected using a stratified random sampling procedure with equal numbers of respondents from each village.

2.2.2. Data description

We are chiefly interested in how individual responses vary, depending on which climate change stress most affects each respondent and which impacts are brought on by the reported stress. To investigate this problem, we look at two levels of autonomous adaptations. For the household level, we use responses to the question, "What coping strategies do you do in response to the negative impacts of this stress?" and for the agricultural level, we use responses to the question, "What changes in your farming activities did you do during this stress?" We argue for causality in these responses because of the structure of the survey. The questionnaire asks respondents to identify all climate change stresses that are present in their area and then identify the one that most affects them from a list of stresses, previously identified to be present in Vietnam. The definition of these stresses and their material impact on rice production are:

- **Flooding** is extended periods of excessive rainfall, beyond the normal limits for a region. Rice crops exposed to flooding for prolonged periods can fail.
- **Storms** are disturbances in the atmosphere that result in periods of strong winds and heavy rainfall. Heavy winds can destroy rice plants in the paddy through lodging, and sudden rainfall from storms can erode soil and destroy crops.
- **Salinity intrusion** is the movement of seawater inland into freshwater aquifers and rice paddies. When soils become too saline from saltwater intrusion, they are no longer suitable to grow rice.
- **Sea-level rise** is an increase in global sea level, which encroaches into low-lying coastal lands. Suitable agricultural land can be lost to the encroaching sea, or farmers may be forced to invest in expensive infrastructure to protect low-lying coastal lands.
- **Drought** is a shortage of water resulting from an extended period of low rainfall. Periods of drought can increase rice farmers' irrigation costs or even result in total crop failure when irrigation is either not available or too costly.
- **Heat** is extended periods of above-average temperatures. High temperatures, particularly during the flowering period, can cause low yields or total crop failure in rice plants, as a result of spikelet sterility.

All proceeding questions refer to the response for stress that most affects them, including the resulting impacts and autonomous adaptations. Respondents reported which impacts they experienced as a result of the climate change stress by answering a series of binary yes-no questions to signify that the stress caused any of the following impacts –

decreases in rice paddy yield, or increases in rice crop loss (e.g., crop destroyed from lodging), food insecurity, indebtedness, or detrimental health impacts.

We model the causal structure of decision making as follows:

> Perceived climate change stress → resulting impacts/outcomes → reported autonomous adaptations

Because respondents could have multiple reported responses to climate change, we model their choices using a multivariate probit model. To make the use of this model feasible, we clustered the original responses for the household and the agricultural models into aggregate groups. The group aggregates and the corresponding disaggregate responses are in appendix 2.1 and appendix 2.2 for the household and agricultural models, respectively. This step is necessary because multivariate probit models produce 2^n choice regimes, where $n =$ the number of dependent variables jointly modeled. There were 14 possible original options (i.e., dependent variables) for the household model, which results in an unmanageable problem where there are 2^{14} or 16,384 choice regimes.

2.2.3. Multivariate probit estimation

The applications estimate multivariate probit models by Genz-Geweke-Hajivassiliou-Keane (GGHK) simulated maximum likelihood methods. In this study $N = 3$ and a total of $2^3 = 8$ choice regimes, illustrated here for the individual response survey. The statistical model is based on the system of latent variables,

$$y_{ij}^* = \boldsymbol{x}_i'\boldsymbol{\beta}_j + \varepsilon_{ij}, i = 1, \dots, I, j = 1, \dots, N, \boldsymbol{\varepsilon_{ij}} i.i.d. N(0_N, \boldsymbol{R}), \boldsymbol{R} = \begin{bmatrix} 1 & \rho_{12} & \cdots & \rho_{1N} \\ \rho_{12} & 1 & \cdots & \rho_{2N} \\ \vdots & \ddots & \ddots & \vdots \\ \rho_{1N} & \dots & \rho_{N-1,N} & 1 \end{bmatrix}, \quad (2.9)$$

and the associated observable indicator variables,

$$y_{ij} = \begin{cases} 0, \text{iff } y_{ij}^* \leq 0, \text{iff } \varepsilon_{ij} \leq -\boldsymbol{x}_i^{'}\beta_j, \\ 1, \text{iff } y_{ij}^* > 0, \text{iff } \varepsilon_{ij} > -\boldsymbol{x}_i^{'}\beta_j, \end{cases} i = 1, \cdots, I,\ j = 1, \cdots, N. \quad (2.10)$$

The multivariate probit model estimates the probability that each respondent's choices fall in the appropriately associated regime. The probit model estimates the correlation matrix, $\boldsymbol{R}$, and normalised slope coefficients, β_j, as necessary and sufficient conditions for identification.

For $N = 3$, let $\mathcal{R} = \{0,1,2,3,4,5,6,7\}$ be the set of choice regimes and associate each $r \in \mathcal{R}$ as follows with the percent corresponding to each regime in parentheses.

Household model:

$$r_i = \begin{cases} 0, \text{no adaptation}, y_{i1} = y_{i2} = y_{i3} = 0 & (53\%) \\ 1, \text{financial response}, y_{i1} = 1, y_{i2} = y_{i3} = 0 & (9\%) \\ 2, \text{lifestyle adjustment}, y_{i2} = 1, y_{i1} = y_{i3} = 0 & (17\%) \\ 3, \text{outside assistance}, y_{i3} = 1, y_{i1} = y_{i2} = 0 & (2\%) \\ 4, \text{financial response \& lifestyle adjustment}, y_{i1} = y_{i2} = 1, y_{i3} = 0 & (11\%) \\ 5, \text{financial response \& outside assistance}, y_1 = y_3 = 1, y_2 = 0 & (2\%) \\ 6, \text{lifestyle adjustment \& outside assistance}, y_{i1} = 0, y_{i2} = y_{i3} = 1 & (2\%) \\ 7, \text{all 3 adaptations}, y_{i1} = y_{i2} = y_{i3} = 1 & (4\%) \end{cases} \quad (2.11)$$

Agricultural model:

$$r_i = \begin{cases} 0, \text{no change}, y_{i1} = y_{i2} = y_{i3} = 0 & (36\%) \\ 1, \text{rice change}, y_{i1} = 1, y_{i2} = y_{i3} = 0 & (6\%) \\ 2, \text{crop change}, y_{i2} = 1, y_{i1} = y_{i3} = 0 & (35\%) \\ 3, \text{livestock change}, y_{i3} = 1, y_{i1} = y_{i2} = 0 & (1\%) \\ 4, \text{rice change \& crop change}, y_{i1} = y_{i2} = 1, y_{i3} = 0 & (16\%) \\ 5, \text{rice change \& livestock change}, y_1 = y_3 = 1, y_2 = 0 & (0\%) \\ 6, \text{crop change \& livestock change}, y_{i1} = 0, y_{i2} = y_{i3} = 1 & (5\%) \\ 7, \text{all 3 adaptations}, y_{i1} = y_{i2} = y_{i3} = 1 & (3\%) \end{cases} \quad (2.12)$$

The estimation problem is to find values of $(\beta_1, \cdots, \beta_N, \boldsymbol{R})$ to maximise the joint likelihood, or probability, of the survey respondents' falling in the associated reported regimes. The GGHK procedure uses a sequence of recursive change of variables to express the associated probability integrals for compactly for each respondent. First, define the lower triangular Cholesky factorisation of the correlation matrix by $\boldsymbol{R} = \boldsymbol{L}\boldsymbol{L}'$, where $\boldsymbol{L}$ is a lower triangular matrix with strictly positive main diagonal elements, i.e., for the case of $N = 3$,

$$\boldsymbol{L} = \begin{bmatrix} \ell_{11} & 0 & 0 \\ \ell_{21} & \ell_{22} & 0 \\ \ell_{31} & \ell_{32} & \ell_{33} \end{bmatrix},\ \ell_{11}, \ell_{22}, \ell_{33} > 0. \tag{2.13}$$

Second, define the *i.i.d.* standard normal random variables, $\boldsymbol{z}_{ij}\ iid\ N(0_3, \boldsymbol{I}_3)$, by the system of linear equations, $\varepsilon_{ij} = \boldsymbol{L}\boldsymbol{z}_{ij}$, so that $E(\varepsilon_{ij}) = \boldsymbol{L}E(\boldsymbol{z}_{ij}) = 0_3$, and $E(\varepsilon_{ij}\varepsilon_{ij}') = \boldsymbol{L}E(\boldsymbol{z}_{ij}\boldsymbol{z}_{ij}')\boldsymbol{L}' = \boldsymbol{R}, \forall\ i = 1, \cdots, I$. This implies:

$$\varepsilon_{ij} = \sum_{k=1}^{j} \ell_{jk} z_{ik} \leq -\boldsymbol{x}_i'\beta_j, iff\ z_{ij} \leq -\frac{\left(\boldsymbol{x}_i'\beta_j + \sum_{k=1}^{j-1} \ell_{jk} z_k\right)}{\ell_{jj}}\ \ i = 1, \cdots, I,\ \ j = 1, \cdots, N. \tag{2.14}$$

This gives the probability that the i^{th} survey respondent chooses regime $r_i \in \boldsymbol{\mathcal{R}}$ in terms of a recursive set of standard normal integrals, with the limits of integration functions of the lower indexed levels of the standard normal random variates. For example, for $r_i = 0$, we have

$$Pr(r_i = 0) = \int_{-\infty}^{-\frac{\boldsymbol{x}_i'\beta_1}{\ell_{11}}} \left(\int_{-\infty}^{-\frac{(\boldsymbol{x}_i'\beta_2 + \ell_{21} z_1)}{\ell_{22}}} \left(\int_{-\infty}^{-\frac{(\boldsymbol{x}_i'\beta_3 + \ell_{31} z_1 + \ell_{32} z_2)}{\ell_{33}}} \varphi(z_3) dz_3 \right) \varphi(z_2) dz_2 \right) \varphi(z_1) dz_1, \tag{2.15}$$

where $\varphi(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2}$ is the standard normal probability density function (pdf).

The other seven regimes have analogous probability statements with the upper (lower) limits of integration defined by $-\left(\boldsymbol{x}_i^{'}\beta_j + \sum_{k=1}^{j-1} \ell_{jk} z_k\right)/\ell_{jj}$ if $y_{ij} = 0, (1)$, for each $j = 1,2,3$. Define the recursive change of variables from the standard normal distribution to the uniform distribution,

$$u_{ij} = \Phi(z_{ij}) = \int_{-\infty}^{z_{ij}} \varphi(z) dz\,,\ du_{ij} = \varphi(z_{ij}) dz_{ij},\ z_{ij} = \Phi^{-1}(u_{ij}),\ i = 1, \cdots, I,\ j = 1, \cdots, N, \qquad (2.8)$$

where $\Phi(z) = \int_{-\infty}^{z} \frac{1}{\sqrt{2\pi}} e^{-½x^2} dx$ is the cumulative distribution function (cdf) of the standard normal random variable.

If $y_{ij} = 0$, then set the lower limit of integration for u_{ij} to $\underline{U}_{ij} = 0$ and the upper limit of integration for u_{ij} to $\bar{U}_{ij} = \Phi\left(-\frac{\left(\boldsymbol{x}_i^{'}\beta_j + \sum_{k<j} \ell_{jk} \Phi^{-1}(u_{ik})\right)}{\ell_{jj}}\right)$. On the other hand, if $y_{ij} = 1$, then set the lower limit of integration to $\underline{U}_{ij} = \Phi\left(-\frac{\left(\boldsymbol{x}_i^{'}\beta_j + \sum_{k<j} \ell_{jk} \Phi^{-1}(u_{ik})\right)}{\ell_{jj}}\right)$ and the upper limit of integration to be $\bar{U}_{ij} = 1$. In each individual survey response and at every level of integration, dependence of the sequential limits of integration on $\boldsymbol{x}_i$, $[\boldsymbol{\beta_1} \quad \boldsymbol{\beta_2} \quad \boldsymbol{\beta_3}]^{'}, \boldsymbol{L}$, and uniform random variables $[u_{i1} \quad \cdots \quad u_{i,j-1}]^{'}$ is taken into account explicitly to evaluate and update the likelihood function. This method appeals to existing fast and accurate closed-form approximations to the standard normal cdf (e.g., Hastings 1970) and its inverse (e.g., Acklam 2003) to facilitate the calculation of the probabilities.

The individual choice probability, or likelihood function, is given by

$$L_i(\boldsymbol{x}_i, \beta, \boldsymbol{L}) = Pr(r = r_i) = \int_{\underline{U}_{i1}}^{\bar{U}_{i1}} \int_{\underline{U}_{i2}}^{\bar{U}_{i2}} \int_{\underline{U}_{i3}}^{\bar{U}_{i3}} du_3 du_2 du_1. \qquad (2.9)$$

Each joint integral is over a proper subset of the 3-dimensional unit cube, $[0,1] \times [0,1] \times [0,1]$, so that this can be evaluated quickly and precisely with any number of methods. The current industry standard is simulation methods. There is no limit to the number of discrete choices, in principle. However, the curse of dimensionality increases computational time rapidly as the dimension of a problem grows, even with modern computing speeds and power. The full likelihood function for all survey respondents is

$$\prod_{i=1}^{I} L_i(\boldsymbol{x}_i, \beta, \boldsymbol{L}) = \prod_{i=1}^{I} \left(\int_{\underline{U}_{i1}}^{\bar{U}_{i1}} \int_{\underline{U}_{i2}}^{\bar{U}_{i2}} \int_{\underline{U}_{i3}}^{\bar{U}_{i3}} du_3 du_2 du_1 \right). \tag{2.10}$$

The method simulates the likelihood function for each given $(\boldsymbol{x}_i, \beta, \boldsymbol{L})$ to approximate the integrals on the right-hand-side, and searches of the parameters $(\beta, \boldsymbol{L})$ to find the simulated maximum likelihood estimators.

A complete list of independent variables with summary statistics is in Table 2.1., and descriptions of the variables are in Appendix 2.3.

Table 2.1. Summary statistics of independent variables

Variable	Mean	Std. Dev.	Min	Max
Flood stress	0.27	0.44	0.00	1.00
Storm stress	0.17	0.38	0.00	1.00
Salinity stress	0.17	0.38	0.00	1.00
Drought stress	0.16	0.36	0.00	1.00
Heat stress	0.16	0.36	0.00	1.00
Other stress	0.01	0.11	0.00	1.00
No stress	0.07	0.25	0.00	1.00
Low yield	0.70	0.46	0.00	1.00
Crop loss	0.24	0.43	0.00	1.00
Food insecurity	0.05	0.22	0.00	1.00
Increased debt	0.06	0.24	0.00	1.00
Health impact	0.84	0.36	0.00	1.00
No impact	0.14	0.35	0.00	1.00
Male	0.50	0.50	0.00	1.00
Age (years)	51.17	10.91	22.00	86.00
Education (years)	6.62	2.74	0.00	14.00
Farm experience (years)	31.50	11.10	2.00	63.00
Total household size	4.08	1.56	2.00	10.00
Total farm size (ha)	0.99	1.30	0.05	14.30
An Giang Province	0.14	0.34	0.00	1.00
Bac Lieu Province	0.10	0.30	0.00	1.00
Ha Tinh Province	0.17	0.38	0.00	1.00
Nam Dinh Province	0.16	0.37	0.00	1.00
Quang Ngai Province	0.17	0.38	0.00	1.00
Tra Vinh Province	0.09	0.29	0.00	1.00
Thai Binh Province	0.17	0.37	0.00	1.00
Total HH income (million VND)	129.83	144.71	2.25	1,760.00
Ag info – government	0.37	0.48	0.00	1.00
Ag info – radio	0.18	0.38	0.00	1.00
Ag info – television	0.34	0.47	0.00	1.00
Ag info – traditional	0.28	0.45	0.00	1.00
Ag into – neighbour	0.18	0.38	0.00	1.00
Ag info – another farmer	0.17	0.38	0.00	1.00
Weather info – government	0.15	0.36	0.00	1.00
Weather info – radio	0.30	0.46	0.00	1.00
Weather info – television	0.87	0.33	0.00	1.00
Weather info – traditional	0.21	0.41	0.00	1.00
Weather info – neighbour	0.13	0.33	0.00	1.00

2.3. Results and Discussion

2.3.1. Household model

We begin by looking at the autonomous responses to climate change stress at the household level to determine if specific climate change stresses and climate change impacts are eliciting stronger or more varied responses from individuals. The results of the multivariate probit model for household adaptations are available in Table 2.[6]

We find variations in the type of responses and likelihoods of individuals choosing a specific adaptation depending on the stress that most affected them. Flood and drought stresses elicit the strongest responses. Drought is a significant factor in selecting both financial and lifestyle changes. Flood stress is only a significant factor for financial change, but it has the largest coefficient and highest level of significance among all the stresses. Storm and salinity stresses are also significant factors for individuals choosing a financial change, albeit only at the ten percent level of significance. Individuals responded the least to heat stress in their adaptation decisions. Heat stress is only a significant factor for a lifestyle change adaptation, and it reduced the likelihood of an individual choosing that option. Whether or not an individual has an autonomous response varies by the type of stress that most affects them.

---

[6] Some responses at the household level of adaptation were ambiguous. Table 2. includes these ambiguous responses are part of the outside option. An alternative specification that omits ambiguous responses is in Appendix 2.4. Similar results are obtained in both specifications of the model.

A financial response is the most common autonomous adaptation selected as a result of stress. The likelihood of a financial response increased for all stresses, except for drought. Additionally, increased debt as an impact of stress correlates with financial response. This unsurprising result is from individuals borrowing money as an adaptation strategy; the adaptation is worsening the impact. Choosing a lifestyle adjustment was also significantly affected by drought and heat stress. Drought made an individual more likely to make a lifestyle adjustment, and heat made an individual less likely to make a lifestyle adjustment. The response of the individual varies by the type of stress they are experiencing.

Table 2.2. Multivariate probit results, individual coping strategies to climate stress

	(1) Financial Change		(2) Lifestyle Change		(3) Outside Assistance	
	Mean	St. Error	Mean	St. Error	Mean	St. Error
No stress (base)	-	-	-	-	-	-
Flood stress	0.601***	(0.223)	0.004	(0.199)	0.245	(0.288)
Storm stress	0.400*	(0.236)	-0.076	(0.214)	-0.150	(0.289)
Salinity stress	0.394*	(0.222)	0.290	(0.200)	0.081	(0.250)
Drought stress	0.512**	(0.223)	0.354*	(0.200)	0.142	(0.268)
Heat stress	-0.073	(0.235)	-0.401*	(0.211)	-0.438	(0.306)
Low yield	-0.005	(0.132)	-0.027	(0.129)	0.183	(0.169)
Crop loss	0.244**	(0.101)	-0.026	(0.099)	0.265**	(0.126)
Food insecurity	-0.019	(0.207)	-0.186	(0.198)	-0.341	(0.276)
Increased debt	0.514***	(0.180)	0.634***	(0.171)	0.392**	(0.191)
Health impact	-0.198	(0.180)	-0.150	(0.171)	0.308	(0.244)
No impact	0.185	(0.134)	0.077	(0.127)	0.150	(0.165)
Male	-0.270***	(0.086)	0.160*	(0.082)	-0.072	(0.109)
Age (years)	-0.001	(0.008)	-0.008	(0.007)	-0.009	(0.009)
Education (years)	0.003	(0.016)	0.019	(0.016)	0.017	(0.020)
Farm experience (years)	-0.003	(0.007)	0.001	(0.007)	0.008	(0.009)
Total household size	0.066**	(0.029)	0.041	(0.028)	0.045	(0.036)
Total farm size (ha)	0.130**	(0.051)	0.021	(0.048)	0.106	(0.065)
An Giang Province (base)	-	-	-	-	-	-
Bac Lieu Province	0.384*	(0.200)	0.129	(0.198)	1.148***	(0.279)
Ha Tinh Province	-0.485**	(0.191)	-0.087	(0.182)	0.083	(0.295)
Nam Dinh Province	-0.494**	(0.211)	-0.698***	(0.207)	0.769**	(0.302)
Quang Ngai Province	-0.762***	(0.182)	0.022	(0.172)	0.302	(0.258)
Tra Vinh Province	0.159	(0.218)	-0.041	(0.212)	1.399***	(0.298)
Thai Binh Province	-0.401**	(0.199)	-0.449**	(0.193)	0.416	(0.294)
Total HH income (million VND)	-0.001***	(0.000)	-0.000	(0.000)	-0.001*	(0.001)
Ag info – government	-0.032	(0.104)	0.103	(0.098)	0.138	(0.137)
Ag info – radio	0.120	(0.118)	0.538***	(0.113)	-0.138	(0.153)
Ag info – television	-0.158	(0.096)	0.134	(0.091)	0.282**	(0.122)
Ag info – traditional	0.313***	(0.107)	0.562***	(0.101)	0.206	(0.136)
Ag into – neighbour	-0.134	(0.128)	0.109	(0.118)	-0.451***	(0.173)
Ag info – another farmer	0.497***	(0.114)	0.253**	(0.110)	0.228	(0.150)
Weather info – government	-0.078	(0.148)	-0.167	(0.136)	0.200	(0.183)
Weather info – radio	-0.093	(0.098)	0.285***	(0.092)	-0.027	(0.125)
Weather info – television	0.059	(0.147)	-0.166	(0.136)	-0.376**	(0.168)
Weather info – traditional	0.154	(0.122)	0.068	(0.114)	0.098	(0.151)
Weather info – neighbour	-0.349**	(0.145)	0.088	(0.126)	0.044	(0.183)
Constant	-1.107***	(0.380)	-0.711**	(0.353)	-2.258***	(0.488)
ρ_{21}	0.399***	(0.059)				
ρ_{31}	0.457***	(0.076)				
ρ_{32}	0.275***	(0.073)				
Observations	1,290		1,290		1,290	

Note: "***", "**", and "*" are significant at 1%, 5%, and 10% respectively

The effects of the impacts brought on by stress vary by reported adaptation. All three responses significantly correlate with increased debt. Reporting a financial change or receiving outside assistance also significantly correlates with experiencing crop loss.

None of the other impacts were significant factors in selecting household responses, likely because most of the data collected in the survey are agricultural impacts and not general impacts that the household may experience from climate change.

The map in Figure 2.2 provides a spatial representation of where adaptations are happening or not happening in Vietnam. The map shows some apparent differences in how individuals in different provinces are adapting to climate change. Generally, fewer adaptations occurred in the Red River Delta and reported adaptations increased further south in Vietnam. In the Red River Delta, provinces report no change as an adaptation to climate change most frequently, 70% and 71% for Thai Binh and Nam Dinh, respectively. This response is substantially higher than any of the other adaptation options for the region Respondents from the Red River Delta are using fewer autonomous responses than the other regions of the study.

The Mekong River Delta, and especially the coastal provinces, were the most responsive to climate change. Bac Lieu and Tra Vinh reported the highest percentage of respondents who practice financial changes, lifestyle changes and receive outside assistance. An Giang reported similar values for financial and lifestyle changes but reported receiving assistance much less than the coastal provinces of the Mekong River Delta. The results show that even within the same region, adaptation strategies can vary considerably.

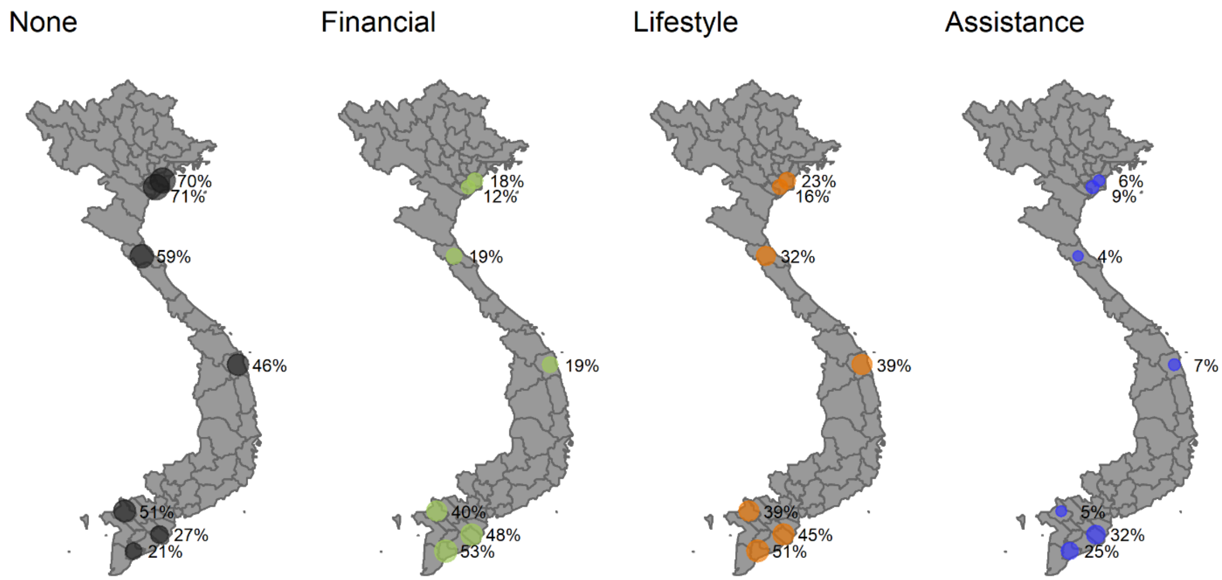

Figure 2.2: Map of percent of respondents practicing household adaptations in each surveyed province.

2.3.2. Agricultural Adaptations

A multivariate probit model is also used to analyse autonomous responses to climate change stress through agricultural adaptations. The results of this multivariate probit model are in Table 2.3.[7] Agricultural adaptations are much less responsive to specific climate change stresses than household responses were in the previous section. Instead, individuals are more responsive to the impacts resulting from stress, rather than which stress caused the impact. Only heat elicits a response at the agricultural level. Individuals who report heat stress are more likely to adapt using a crop change on their farm and less likely to adapt by moving resources into livestock production and away from rice production.

Adaptations vary, depending on which impact of stress individuals are responding to. Individuals change their rice variety when the resulting impact of the stress is either lower yields or increased debt. Low yield also made individuals more likely to make a crop change. Additionally, individuals made a crop change if they experienced crop loss. Individuals who report food insecurity and increased debt, are both more likely to make a livestock change in which they move away from rice production and into raising livestock. Low yields, crop loss, food insecurity, and increased debt all produce climate change adaptations, but the adaptations vary across the range of impacts.

[7] Some responses at the agricultural level of adaptation were ambiguous. Table 2.3. includes these ambiguous responses are part of the outside option. An alternative specification that omits ambiguous responses is in Appendix 3.5. Similar results are obtained in both specifications of the model.

Table 2.3. Multivariate probit results, agricultural adaptations to climate stress

	(1) Rice Change		(2) Crop Change		(3) Livestock Change	
	Mean	St. Error	Mean	St. Error	Mean	St. Error
No stress (base)	-	-	-	-	-	-
Flood stress	0.090	(0.218)	-0.002	(0.191)	-0.253	(0.286)
Storm stress	-0.356	(0.232)	0.056	(0.201)	-0.176	(0.292)
Salinity stress	-0.339	(0.232)	0.073	(0.197)	-0.386	(0.284)
Drought stress	0.028	(0.225)	-0.049	(0.196)	-0.447	(0.286)
Heat stress	-0.045	(0.222)	0.390**	(0.193)	-0.614**	(0.294)
Low yield	0.286*	(0.151)	0.278**	(0.125)	0.252	(0.189)
Crop loss	0.076	(0.107)	0.246**	(0.098)	0.211	(0.136)
Food insecurity	0.207	(0.225)	-0.323	(0.214)	0.857***	(0.240)
Increased debt	0.392*	(0.203)	-0.137	(0.178)	0.530**	(0.247)
Health impact	0.168	(0.188)	-0.219	(0.160)	0.170	(0.255)
No impact	0.186	(0.145)	-0.014	(0.119)	0.163	(0.191)
Male	0.227***	(0.086)	-0.035	(0.078)	0.241**	(0.115)
Age (years)	-0.023***	(0.008)	0.002	(0.007)	-0.013	(0.011)
Education (years)	0.014	(0.018)	0.032**	(0.016)	-0.006	(0.024)
Farm experience (years)	0.015**	(0.008)	-0.003	(0.007)	-0.000	(0.011)
Total household size	-0.017	(0.030)	0.048*	(0.027)	0.118***	(0.037)
Total farm size (ha)	-0.077	(0.057)	0.083*	(0.048)	0.137*	(0.070)
An Giang Province (base)	-	-	-	-	-	-
Bac Lieu Province	-0.364	(0.223)	0.300	(0.190)	0.015	(0.348)
Ha Tinh Province	-0.259	(0.192)	0.206	(0.176)	0.762**	(0.319)
Nam Dinh Province	0.123	(0.204)	0.235	(0.188)	1.259***	(0.329)
Quang Ngai Province	-0.290	(0.186)	0.364**	(0.169)	0.818***	(0.306)
Tra Vinh Province	-0.174	(0.239)	0.281	(0.209)	0.850**	(0.347)
Thai Binh Province	0.197	(0.196)	0.102	(0.181)	1.536***	(0.317)
Total HH income (million VND)	0.000	(0.000)	-0.001**	(0.000)	0.000	(0.001)
Ag info – government	0.203**	(0.102)	0.175*	(0.094)	-0.134	(0.145)
Ag info – radio	0.088	(0.115)	0.032	(0.109)	-0.090	(0.166)
Ag info – television	0.230**	(0.092)	0.041	(0.085)	0.173	(0.125)
Ag info – traditional	0.084	(0.109)	0.211**	(0.102)	0.026	(0.140)
Ag into – neighbour	-0.113	(0.126)	-0.046	(0.117)	-0.110	(0.168)
Ag info – another farmer	0.234**	(0.116)	0.023	(0.107)	-0.102	(0.170)
Weather info – government	0.284**	(0.142)	0.331**	(0.137)	0.084	(0.198)
Weather info – radio	0.143	(0.097)	0.147*	(0.089)	-0.171	(0.140)
Weather info – television	-0.116	(0.148)	0.131	(0.136)	0.001	(0.197)
Weather info – traditional	0.076	(0.116)	0.006	(0.111)	-0.191	(0.161)
Weather info – neighbour	-0.019	(0.138)	-0.386***	(0.124)	-0.023	(0.194)
Constant	-0.600	(0.379)	-0.929***	(0.338)	-2.407***	(0.503)
ρ_{21}	0.389***	(0.056)				
ρ_{31}	0.073	(0.080)				
ρ_{32}	0.663***	(0.093)				
Observations	1,244		1,244		1,244	

Note: "***", "**", and "*" are significant at 1%, 5%, and 10% respectively

Like the previous section, the map in Figure 2.3 provides a spatial representation of where agricultural adaptations are happening, or not happening, in Vietnam. Unlike what we find in the household model, the range of individuals that report taking no action to climate change stress is more homogenous across provinces. Taking no action ranged from 32%

in Nam Dinh to 42% in An Giang. Most individuals in all provinces already use an autonomous response; however, the adaptation they use varies by location. Reporting a crop change adaptation such as diversifying crops, adjusting the cropping pattern, or leaving land fallow, is by far the most commonly cited climate change adaptation. Anywhere from 47-61% of respondents from each province reported making one of the abovementioned changes to their cropping practices.

Responding with a change specific to rice production (i.e., changing rice variety) is the second most commonly cited response. However, there are considerable differences across locations for changing rice varieties. This variation is likely a result of the types of stress present in each of the provinces. The popularity and availability of stress-tolerant rice varieties differ with each of the stresses. The provinces that report changing their rice variety least often are the same provinces that report salinity stress most frequently. While this result may indicate a lack of interest or availability in saline-tolerant varieties at the time of our data collection, a study conducted after our survey by Paik, Le et al. (2020) suggests that salinity-tolerant varieties in the Mekong River Delta are now widely adopted.

Changing from rice to livestock is the least common adaptation selected for all provinces. The rice and crop changes we previously discussed are all short-run adaptations in which inputs to production are varied (Stern 2007). Livestock is a form of capital (Jarvis 1974), and capital adjustments are long-run adaptations that are more difficult for individuals to use because of increased uncertainty (Stern 2007). Individuals from the Red River Delta report livestock investments most commonly, but only 15% of individuals in Thai Binh and 11% of individuals in Nam Dinh report this option. Outside of the Red River Delta, adapting to climate change through livestock is sparsely reported, with all other provinces reporting in the single digits, except for Tra Vinh, where 12% of individuals reported using making a livestock change.

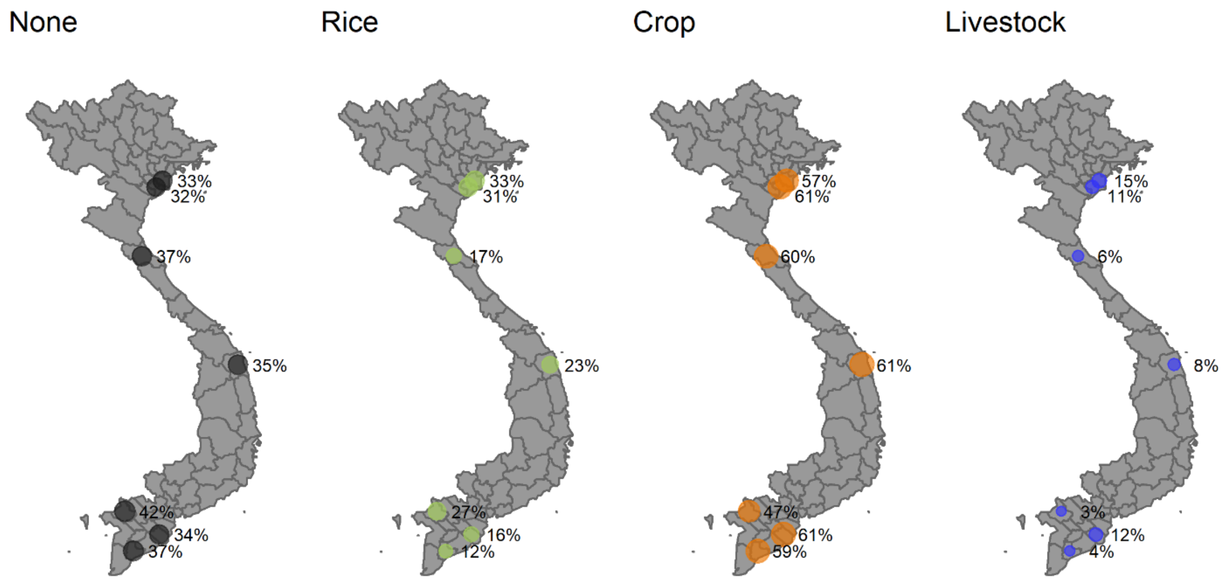

Figure 2.3: Map of percent of respondents practicing agricultural adaptations in each surveyed province

2.3.3 Climate Change Stresses

The provinces surveyed in this study face varied and unique climatic stress. Of those mapped in Figure 2.4, the most notable thing to point out is that hardly any farmers reported that there is no stress present in their areas. Provinces in the Red River Delta had the highest percentage of no-stress-present responses with 10% and 13% for Thai Binh and Nam Dinh, respectively. However, all other provinces only reported between 1% and 2% that there is no stress present in their area. Climate change stresses are observed widely across the entire country.

Some stresses are reported more homogenously across the country, while others impact individual provinces much more than others. Heat stress is reported more uniformly across provinces by anywhere from one-half to three-quarters of respondents in each province. Drought is frequently reported in all provinces as well, although less frequently in the Red River Delta, where only one-quarter of all respondents report its presence. Other surveyed provinces report drought more frequently, between 41% and 89% of the time. Individuals report the remaining stresses more heterogeneously. Respondents commonly cite flooding in Central Vietnam and An Giang Province, but less so in the Red River Delta and the coastal provinces of the Mekong River Delta. They also report storms least frequently in the Mekong River Delta compared to other locations. Finally, salinity and sea-level rise are more common in low-lying coastal regions. For example, An Giang province is comfortably inland, and nobody from this province reported the presence of either sea-level rise or salinity. Some climate change stresses are felt homogenously across Vietnam, but others vary significantly from one province or region to another.

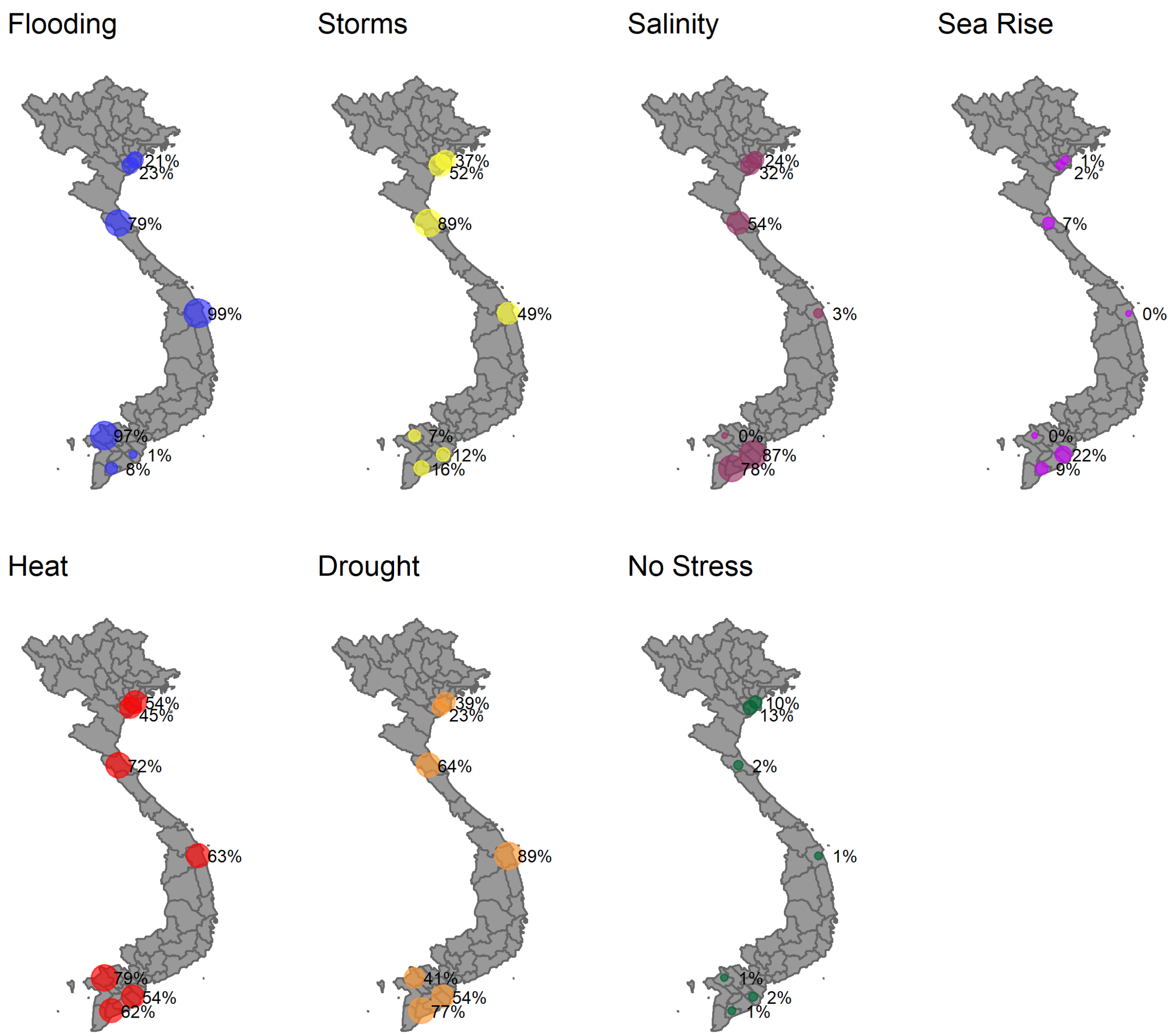

Figure 2.4: Prevalence of climate change stresses, by province

2.4 Conclusions

This article set out to better understand if some climate change stresses or impacts from climate change stress elicited stronger climate change adaptations from individuals. The answer to this question is a resounding yes. At the individual adaptation level, drought, flooding, and to a lesser extent, storms and salinity intrusion, elicited the strongest autonomous adaptations from individuals. The most common autonomous response at the household level is to have a financial adaptation, such as selling assets, borrowing money, or using savings. Households using a financial response may provide an opportunity for microfinance lending in Vietnam as a way to build capacity and reduce vulnerability in households as they adapt to climate change. Autonomous adaptations taken in the private market are generally understood to be efficient. Microfinance is a way for poorer households to access the additional resources necessary to carry out efficient autonomous responses to climate change.

Compared to the household level, sources of climate change stress are less critical for adaptation decisions at the agricultural level. At this level, impacts brought on by climatic stress elicited stronger adaptation responses from individuals than the sources of the stress. Farmers who experienced low yields as a result of stress are more likely to adapt their rice-farming practices through changing the variety of rice that they grow. Our results provide field-level evidence that the sources of stress vary across landscapes in Vietnam. These results show the necessity for location-specific adaptation policies in Vietnam, which have been called for in previous publications.

Furthermore, this study provides policymakers with evidence of which stresses are already causing autonomous adaptations among individuals and the different responses individuals are using. Equally important as climate change action is climate change inaction. We did not find climate change adaptations resulting from specific stresses, such as sea-level rise and saltwater intrusion. This leaves room for a government response to those stresses where private adaptations are presently absent. All the while, the government can financially support private autonomous adaptations, through channels such as microfinance lending. Of course, autonomous adaptations alone are not enough. Rather, it should be seen as a way to help individuals help themselves in the short run, while other planned adaptations and mitigation options are established as part of a comprehensive climate change policy.

2.5. References

ADB (2009). The Economics of Climate Change in Southeast Asia: A regional Review. Manila, Philippines, Asian Development Bank.

Acklam, P. J. (2003). "An algorithm for computing the inverse normal cumulative distribution function." Peter's Page.

Adger, W. N. (1999). "Social vulnerability to climate change and extremes in coastal Vietnam." World development **27**(2): 249-269.

Agrawala, S. and M. Carraro (2010). "Assessing the role of microfinance in fostering adaptation to climate change."

Albert, S., R. Bronen, N. Tooler, J. Leon, D. Yee, J. Ash, D. Boseto and A. Grinham (2018). "Heading for the hills: climate-driven community relocations in the Solomon Islands and Alaska provide insight for a 1.5 C future." Regional environmental change **18**(8): 2261-2272.

Bergstedt, C. (2015). Cultivating gender: meanings of place and work in rural Vietnam, Nias Press.

Christoplos, I., L. D. Ngoan, L. T. H. Sen, N. T. T. Huong and H. Nguyen (2017). "Changing arenas for agricultural climate change adaptation in Vietnam." Development in Practice **27**(2): 132-142.

Cuong, N. (2008). "Viet Nam country report—a regional review on the economics of climate change in Southeast Asia." Report submitted for RETA **6427**.

Dasgupta, S., B. Laplante, C. Meisner, D. Wheeler and J. Yan (2007). The impact of sea level rise on developing countries: a comparative analysis, The World Bank.

Dasgupta, S., B. Laplante, S. Murray and D. Wheeler (2011). "Exposure of developing countries to sea-level rise and storm surges." Climatic Change **106**(4): 567-579.

Davies, M., B. Guenther, J. Leavy, T. Mitchell and T. Tanner (2009). "Climate change adaptation, disaster risk reduction and social protection: complementary roles in agriculture and rural growth?" IDS Working Papers **2009**(320): 01-37.

Doran, P. T. and M. K. Zimmerman (2009). "Examining the scientific consensus on climate change." Eos, Transactions American Geophysical Union **90**(3): 22-23.

Duffy, C., V. Pede, G. Toth, K. Kilcline, C. O'Donoghue, M. Ryan and C. Spillane (2020). "Drivers of household and agricultural adaptation to climate change in Vietnam." Climate and Development: 1-14.

Dung, P. and S. Sharma (2017). Responding to Climate Change in the Agriculture and Rural Development Sector in Vietnam. Redefining Diversity & Dynamics of Natural Resources Management in Asia, Volume 2, Elsevier**:** 13-25.

Escobar Carbonari, D., G. Grosjean, P. Läderach, T. D. Nghia, B. O. Sander, J. McKinley, L. Sebastian and J. Tapasco (2019). "Reviewing Vietnam's Nationally Determined Contribution: A New Perspective Using the Marginal Cost of Abatement." Frontiers in Sustainable Food Systems **3**: 14.

Hammill, A., R. Matthew and E. McCarter (2008). "Microfinance and climate change adaptation."

Hastings, W. K. (1970). "Monte Carlo sampling methods using Markov chains and their applications."

Iglesias, A., S. Quiroga and A. Diz (2011). "Looking into the future of agriculture in a changing climate." European review of agricultural economics **38**(3): 427-447.

IPCC (2012). Managing the risks of extreme events and disasters to advance climate change adaptation–summary for policy makers, World Meteorological Organization Geneva**:** 24.
IPCC (2014). Climate Change 2013: The physical science basis: Working group I contribution to the fifth assessment report of the Intergovernmental Panel on Climate Change, Cambridge University Press.
IPCC (2018). Annex I: Glossary. Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. J. B. R. Matthews.
IPSONRE (2009). Viet Nam Assessment Report on Climate Change (VARCC). Hanoi, Institute of Strategy and Policy on Natural Resources and Environment.
Jarvis, L. S. (1974). "Cattle as capital goods and ranchers as portfolio managers: an application to the Argentine cattle sector." Journal of Political Economy **82**(3): 489-520.
Johnston, R. M., C. T. Hoanh, G. Lacombe, A. D. Noble, V. U. Smakhtin, D. Suhardiman, S. P. Kam and P. S. Choo (2010). Rethinking agriculture in the Greater Mekong Subregion: how to sustainably meet food needs, enhance ecosystem services and cope with climate change.
Le Dang, H., E. Li, I. Nuberg and J. Bruwer (2014). "Understanding farmers' adaptation intention to climate change: A structural equation modelling study in the Mekong Delta, Vietnam." Environmental Science & Policy **41**: 11-22.
Malik, A., X. Qin and S. C. Smith (2010). "Autonomous adaptation to climate change: a literature review." Institute for International Economic Policy Working Paper Series: 1-25.
McElwee, P., T. Nghiem, H. Le and H. Vu (2017). "Flood vulnerability among rural households in the Red River Delta of Vietnam: implications for future climate change risk and adaptation." Natural Hazards **86**(1): 465-492.
Mendelsohn, R. (2000). "Efficient adaptation to climate change." Climatic Change **45**(3-4): 583-600.
Mendelsohn, R. (2012). "The economics of adaptation to climate change in developing countries." Climate Change Economics **3**(02): 1250006.
Mishra, A. K. and V. O. Pede (2017). "Perception of climate change and adaptation strategies in Vietnam." International Journal of Climate Change Strategies and Management.
MONRE (2009). Climate change, sea level rise scenarios for Vietnam, Hanoi Press**:** 34.
Mysiak, J., S. Surminski, A. Thieken, R. Mechler and J. C. Aerts (2016). "Brief communication: Sendai framework for disaster risk reduction–success or warning sign for Paris?" Natural Hazards and Earth System Sciences **16**(10): 2189-2193.
Nguyen, Q., M. H. Hoang, I. Öborn and M. van Noordwijk (2013). "Multipurpose agroforestry as a climate change resiliency option for farmers: an example of local adaptation in Vietnam." Climatic change **117**(1-2): 241-257.
Oreskes, N. (2004). "The scientific consensus on climate change." Science **306**(5702): 1686-1686.

Paik, S., D. T. P. Le, L. T. Nhu and B. F. Mills (2020). "Salt-tolerant rice variety adoption in the Mekong River Delta: Farmer adaptation to sea-level rise." Plos one **15**(3): e0229464.
Stern, N. (2007). The economics of climate change: the Stern review, cambridge University press.
Trinh, T. Q., R. F. Rañola Jr, L. D. Camacho and E. Simelton (2018). "Determinants of farmers' adaptation to climate change in agricultural production in the central region of Vietnam." Land Use Policy **70**: 224-231.
UNFCCC. (2020). "Glossary of climate change acronyms and terms." Retrieved April 3, 2020.
Waibel, H., T. H. Pahlisch and M. Völker (2018). Farmers' perceptions of and adaptations to climate change in Southeast Asia: the case study from Thailand and Vietnam. Climate smart agriculture, Springer, Cham: 137-160.
Ylipaa, J., S. Gabrielsson and A. Jerneck (2019). "Climate Change Adaptation and Gender Inequality: Insights from Rural Vietnam." Sustainability **11**(10): 2805.

2.6. Appendices

Appendix 2.1. Aggregate and disaggregate responses for individual-level adaptations

Aggregate Categories	Disaggregate responses
(1) Do nothing	Nothing
(2) Financial response	Sold land
	Sold livestock
	Sold other assets
	Borrowed money from the bank
	Borrowed money from others
	Postponed payment of loans
	Used savings
(3) Lifestyle adjustment	Reduced consumption
	Worked more
	Took child out of school
(4) Assistance	Received assistance from relatives and friends
	Received assistance from the government
	Received assistance from NGO

Appendix 2.2. Aggregate and disaggregate responses for agricultural-level adaptations

Aggregate Categories	Disaggregate responses
(1) No change	No change
(2) Rice change	Change rice variety
(3) Crop change	Change crop pattern
	Diversify crops
	Leave fallow
(4) Livestock change	Move from rice to livestock

Appendix 2.3: Description of independent variables

Variable	Description
Age	Age of respondent in years
Education	Education of respondent in years
Farm experience	Years of farming experience of the respondent
Total household size	Number of people living in the respondent's household
Total farm size	Total farm size in meters squared
An Giang Province	Respondent is from An Giang Province
Bac Lieu Province	Respondent is from Bac Lieu Province
Ha Tinh Province	Respondent is from Ha Tinh Province
Nam Dinh Province	Respondent is from Nam Dinh Province
Quang Ngai Province	Respondent is from Quang Ngai Province
Tra Vinh Province	Respondent is from Tra Vinh Province
Thai Binh Province	Respondent is from Thai Binh Province
Total HH income	Total household income reported in million Vietnamese Dong
Flood stress	Respondent reports flooding stress as most severe climate change stress
Storm stress	Respondent reports storm stress as most severe climate change stress
Salinity stress	Respondent reports salinity stress as most severe climate change stress
Drought stress	Respondent reports drought stress as most severe climate change stress
Heat stress	Respondent reports heat stress as most severe climate change stress
Other stress	Respondent reports some other stress as most severe climate change stress
No stress	Respondent reports there is no climate change stress
Low yield	Respondent reports low yield as an impact of climate change stress
Crop loss	Respondent reports crop loss as an impact of climate change stress
Food insecurity	Respondent reports food insecurity as an impact of climate change stress
Increased debt	Respondent reports increased debt as an impact of climate change stress
Health impact	Respondent reports worsened health as an impact of climate change stress
No impact	Respondent reports no impact from climate change stress
Ag info - government	Respondent receives agricultural information from the government
Ag info - radio	Respondent receives agricultural information from the radio
Ag info - television	Respondent receives agricultural information from television
Ag info - traditional	Respondent receives agricultural information from traditional knowledge
Ag into - neighbour	Respondent receives agricultural information from their neighbour
Ag info - another farmer	Respondent receives agricultural information from another farmer
Weather info - government	Respondent receives weather information from the government
Weather info - radio	Respondent receives weather information from the radio
Weather info - television	Respondent receives weather information from the television
Weather info - traditional	Respondent receives weather information from traditional knowledge
Weather info - neighbour	Respondent receives weather information from their neighbour

Appendix 2.4. Multivariate probit results, individual adaptations to climate change stress, includes ambiguous responses

	Financial Change (1)		Lifestyle Change (2)		Assistance (3)	
	Mean	St. Error	Mean	St. Error	Mean	St. Error
Flood stress	0.577**	(0.225)	-0.041	(0.201)	0.212	(0.289)
Storm stress	0.379	(0.239)	-0.114	(0.218)	-0.192	(0.291)
Salinity stress	0.386*	(0.224)	0.274	(0.203)	0.057	(0.252)
Drought stress	0.493**	(0.225)	0.318	(0.202)	0.112	(0.269)
Heat stress	-0.100	(0.238)	-0.445**	(0.214)	-0.488	(0.308)
Low yield	-0.040	(0.134)	-0.060	(0.131)	0.155	(0.170)
Crop loss	0.238**	(0.102)	-0.032	(0.099)	0.259**	(0.126)
Food insecurity	-0.021	(0.208)	-0.201	(0.199)	-0.341	(0.278)
Increased debt	0.517***	(0.180)	0.636***	(0.172)	0.391**	(0.191)
Health impact	-0.225	(0.182)	-0.171	(0.172)	0.287	(0.245)
No impact	0.172	(0.135)	0.064	(0.129)	0.139	(0.165)
Male	-0.280***	(0.087)	0.150*	(0.083)	-0.079	(0.110)
Age (years)	-0.001	(0.008)	-0.008	(0.007)	-0.009	(0.009)
Education (years)	0.003	(0.016)	0.019	(0.016)	0.015	(0.021)
Farm experience (years)	-0.003	(0.007)	0.001	(0.007)	0.008	(0.009)
Total household size	0.060**	(0.029)	0.034	(0.028)	0.040	(0.036)
Total farm size (ha)	0.135***	(0.051)	0.025	(0.049)	0.110*	(0.065)
Bac Lieu Province	0.372*	(0.201)	0.113	(0.199)	1.138***	(0.279)
Ha Tinh Province	-0.442**	(0.192)	-0.040	(0.183)	0.119	(0.296)
Nam Dinh Province	-0.432**	(0.213)	-0.638***	(0.209)	0.827***	(0.304)
Quang Ngai Province	-0.745***	(0.182)	0.052	(0.172)	0.315	(0.259)
Tra Vinh Province	0.138	(0.219)	-0.071	(0.213)	1.380***	(0.299)
Thai Binh Province	-0.332*	(0.201)	-0.374*	(0.195)	0.468	(0.295)
Total HH income (million VND)	-0.001***	(0.000)	-0.000	(0.000)	-0.001**	(0.001)
Ag info – government	-0.052	(0.104)	0.084	(0.099)	0.119	(0.137)
Ag info – radio	0.127	(0.120)	0.564***	(0.115)	-0.134	(0.154)
Ag info – television	-0.155	(0.097)	0.133	(0.092)	0.281**	(0.123)
Ag info – traditional	0.307***	(0.108)	0.554***	(0.102)	0.200	(0.136)
Ag into – neighbour	-0.139	(0.128)	0.110	(0.119)	-0.454***	(0.174)
Ag info – another farmer	0.503***	(0.115)	0.258**	(0.110)	0.230	(0.150)
Weather info – government	-0.097	(0.149)	-0.185	(0.136)	0.185	(0.184)
Weather info – radio	-0.091	(0.099)	0.285***	(0.093)	-0.025	(0.126)
Weather info – television	0.054	(0.148)	-0.170	(0.137)	-0.387**	(0.169)
Weather info – traditional	0.149	(0.122)	0.058	(0.114)	0.093	(0.151)
Weather info – neighbour	-0.359**	(0.145)	0.072	(0.127)	0.036	(0.183)
Constant	-1.001***	(0.386)	-0.587	(0.359)	-2.146***	(0.495)
ρ_{21}	0.386***	(0.058)				
ρ_{31}	0.453***	(0.077)				
ρ_{32}	0.264***	(0.073)				
Observations	1,245		1,245		1,245	

Note: "***", "**", and "*" are significant at 1%, 5%, and 10% respectively

Appendix 2.5. Multivariate probit results, agricultural adaptations to climate change stress, includes ambiguous responses

	Rice Change (1)		Crop Change (2)		Livestock Change (3)	
	Mean	St. Error	Mean	St. Error	Mean	St. Error
Flood stress	0.105	(0.220)	0.009	(0.193)	-0.235	(0.288)
Storm stress	-0.349	(0.234)	0.074	(0.204)	-0.159	(0.294)
Salinity stress	-0.352	(0.233)	0.060	(0.199)	-0.395	(0.285)
Drought stress	0.039	(0.227)	-0.036	(0.199)	-0.446	(0.288)
Heat stress	-0.078	(0.224)	0.348*	(0.196)	-0.648**	(0.296)
Low yield	0.293*	(0.151)	0.286**	(0.126)	0.260	(0.190)
Crop loss	0.070	(0.108)	0.244**	(0.099)	0.210	(0.137)
Food insecurity	0.193	(0.225)	-0.345	(0.214)	0.847***	(0.241)
Increased debt	0.394*	(0.203)	-0.142	(0.178)	0.540**	(0.247)
Health impact	0.176	(0.190)	-0.199	(0.162)	0.183	(0.257)
No impact	0.216	(0.146)	0.022	(0.119)	0.188	(0.192)
Male	0.214**	(0.086)	-0.059	(0.078)	0.232**	(0.116)
Age (years)	-0.024***	(0.008)	0.001	(0.007)	-0.014	(0.011)
Education (years)	0.014	(0.018)	0.032**	(0.016)	-0.006	(0.024)
Farm experience (years)	0.016**	(0.008)	-0.002	(0.007)	-0.000	(0.011)
Total household size	-0.015	(0.030)	0.049*	(0.027)	0.120***	(0.037)
Total farm size (ha)	-0.075	(0.057)	0.087*	(0.048)	0.136*	(0.071)
Bac Lieu Province	-0.348	(0.224)	0.318*	(0.190)	0.032	(0.350)
Ha Tinh Province	-0.222	(0.194)	0.248	(0.177)	0.794**	(0.321)
Nam Dinh Province	0.216	(0.207)	0.371*	(0.191)	1.342***	(0.332)
Quang Ngai Province	-0.267	(0.187)	0.394**	(0.169)	0.839***	(0.307)
Tra Vinh Province	-0.156	(0.239)	0.300	(0.210)	0.870**	(0.350)
Thai Binh Province	0.273	(0.199)	0.199	(0.184)	1.614***	(0.321)
Total HH income (million VND)	0.000	(0.000)	-0.001**	(0.000)	0.000	(0.001)
Ag info – government	0.180*	(0.102)	0.146	(0.094)	-0.153	(0.146)
Ag info – radio	0.102	(0.116)	0.050	(0.110)	-0.084	(0.168)
Ag info – television	0.217**	(0.093)	0.024	(0.086)	0.169	(0.126)
Ag info – traditional	0.067	(0.110)	0.193*	(0.103)	0.007	(0.141)
Ag into – neighbour	-0.119	(0.127)	-0.049	(0.118)	-0.120	(0.169)
Ag info – another farmer	0.256**	(0.117)	0.055	(0.109)	-0.078	(0.171)
Weather info – government	0.265*	(0.142)	0.300**	(0.138)	0.068	(0.199)
Weather info – radio	0.138	(0.098)	0.142	(0.090)	-0.179	(0.141)
Weather info – television	-0.110	(0.149)	0.144	(0.137)	0.006	(0.198)
Weather info – traditional	0.061	(0.116)	-0.022	(0.112)	-0.207	(0.162)
Weather info – neighbour	-0.017	(0.138)	-0.385***	(0.125)	-0.021	(0.195)
Constant	-0.637*	(0.382)	-0.974***	(0.340)	-2.436***	(0.506)
ρ_{21}	0.369***	(0.056)				
ρ_{31}	0.055	(0.080)				
ρ_{32}	0.647***	(0.093)				
Observations	1,223		1,223		1,223	

Note: "***", "**", and "*" are significant at 1%, 5%, and 10% respectively

Chapter 3: Becoming an Entrepreneur: Cognitive Function and the Transition to the Market

---

This chapter contains collaborative work with Paulo Santos (Monash University, Department of Economics, Melbourne, Australia), Stefan Meyer (Monash University, Department of Economics, Melbourne, Australia), and Fue Yang (National University of Laos, Department of Agriculture, Vientiane, Laos)

3.1. Introduction

In a now-classic discussion of how to expand the production possibilities frontier that leads to higher productivity and a pathway out of poverty, Schultz (1964) argued that the only viable option was for producers to replace traditional inputs with new ones. The adoption of such innovations would be facilitated by the presence of human capital (Schultz 1961, Becker 1962, Schultz 1962) and would neither be universal nor automatic (Rogers 1962): only some would take advantage of the new disequilibria. Schultz (1990) calls them entrepreneurs. But what is an entrepreneur? And, as in the legendary exchange between Fitzgerald and Hemingway, are they "different from you and me" only because they have more money -- or, on the contrary, differ in ways that are not captured in standard interpretations of the "poor but rational"?

This paper addresses this question in one specific context, the transition to the market in one formerly centralised economy, Lao PDR (hereafter, Laos). The new ways of doing things are not technologies embodied in physical inputs, as we will analyse the decisions and characteristics of producers in a very traditional activity (cattle): the novelty is that some explicitly aim at producing for a relatively new market (export market) rather than its traditional use in a rural economy (savings). We explore the hypothesis that such entrepreneurs may be different because they process information in ways that differ from non-entrepreneurs. We measure those differences using the concept of executive functions.

Executive functions are top-down mental processes that control an individual's attention, dictate their ability to use information or suppress instinctive responses when those responses are not optimal (Miller and Cohen 2001, Espy 2004, Burgess and Simons 2005). Executive functions are crucial in deliberate activity and include fluid intelligence (synonymous with reasoning and problem-solving) and cognitive planning, both of which build from core executive functions, inhibitory control (including attention), working memory, and cognitive flexibility. Diamond (2013), presents a detailed review of executive functions, while Dean, Schilbach et al. (2019) explore their potential importance in explaining poverty persistence, including through innovation, as agents must be able to see themselves in 'other states of the world,' learn about new technologies and predict their potential costs and benefits with some degree of accuracy. [8]

Our analysis shows that producers who take advantage of new markets perform significantly better on different tasks designed to measure their cognitive functioning. Entrepreneurs are more attentive, better at impulse control and planning. As a result, and although they do not change production technology, they behave differently when trading: they are more likely to bargain over prices with traders, with whom they seem to have longer-term relations, while plausibly incurring lower transaction costs. Although we do not offer new theoretical perspectives on how to incorporate executive functions into an economic model, we note the similarities with a much more developed line of work that expands the human capital model to include personality traits (Borghans, Duckworth et al. 2008, Almlund, Duckworth et al. 2011). This similarity guides some of the policy suggestions, with which we conclude.

3.2. The Behaviour of an Entrepreneur

In what is perhaps the earliest known mention of the concept, Richard Cantillon defined the entrepreneur as a person who buys a commodity at a specific price in order to resell at an unknown higher price in the future (Cantillon 1755). Cantillon's characterisation was broadened by Mill (1871), who equated the entrepreneur with a business manager who takes risks. These early definitions were challenged in the early 20th century by Knight (1921) and Schumpeter (1934, 1947). Knight (1921) builds on the distinction between risk (that can be evaluated with known probabilities) and uncertainty (that involves unknown probabilities) to challenge Mill's definition of an entrepreneur arguing that under his definition the entrepreneur would not require any particular skills for success and that it would be inconceivable that higher rents could be earned simply because of willingness to take risks. Schumpeter (1947) developed this critique, claiming that risk-taking was

[8] A summary review of executive functions is also presented in appendix 3.1.

better associated with capitalists and that it was not a distinguishing feature of the entrepreneur. Instead, Schumpeter (1934) considers an entrepreneur a central actor in economic development whose function is to carry out new combinations of innovations.[9]

The generalised adoption of neoclassical economics brought with it the demise of concerns about the nature of the entrepreneur who became, in the words of Baumol and Schilling (2018), the 'invisible man' in economic theory. The reasons for this are two-fold. First, most microeconomic models study static equilibria, and by their innovative nature, entrepreneurs are destroyers of equilibria (Schumpeter 1947). All the while, they seek out arbitrage opportunities that arise from disequilibria and thus move the economy back towards equilibrium (Kirzner 1978). These two combined impacts do not fit stationary models in which innovation is excluded (Baumol and Schilling 2018). The second reason is that entrepreneurs bring invention, which is, by definition, something new that has not been available before, making it a heterogeneous product that hinders optimisation analysis that underlies most microeconomic theory (Baumol and Schilling 2018).

As a result, much attention in economics was directed to the role of market imperfections, in particular in financial markets, in shaping who among otherwise identical individuals becomes capable of innovating (Blanchflower and Oswald 1998). These problems are exacerbated for capital-intensive industries in low- and middle-income countries where financial markets are less developed (Rajan and Zingales 1996). To the extent that behavioural heterogeneity is considered, it mostly focused on the role of risk preferences, reflecting both its history and its importance in economic theory. Perhaps surprisingly, given the attention devoted to this hypothesis, there is still no consensus. Some studies

---

[9] Schumpeter further defines five types of innovations: 1) introducing a new good (or improving an existing good), 2) introducing a new method of production, 3) opening a new market (especially for export), 4) securing a new source of inputs for production, and 5) creating a new type of industrial organisation. The diversity of innovative behavior is also emphasised in a recent review by Ahmad and Seymour (2008), who define entrepreneurs as, *"those persons (business owners) who seek to generate value, through the creation or expansion of economic activity, by identifying and exploiting new products, processes or markets."*

conclude that entrepreneurs are more risk-loving (Stewart and Roth 2007), while other studies conclude that their risk propensity is no different from the rest (Miner and Raju 2004). Domurat and Tyszka (2018) suggest that these different outcomes can result from a variety of sources such as variation in sampling, the definition of entrepreneur used in the study, how risk was measured, and which domain of risk is measured (e.g., financial vs. health). Until now, there is still no conclusive answer on the entrepreneurs' propensity to take risks from empirical research.

To bring back the entrepreneur to its central role in development, Casson (2018) argues that addressing complexities brought on by the reintroduction of the entrepreneur in economic theory may require an economic theory that is inclusive of insights from social sciences beyond economics. Psychology offers a natural starting point, directing us to consider the role of how personality characteristics such as the five-factor model of personality (i.e., the Big Five), achievement motivation, locus of control, risk attitudes, and self-efficacy may distinguish the entrepreneur.[10]

Evidence that any of these characteristics matter to characterise entrepreneurs is mixed. Zhao and Seibert (2006) find some evidence to support that entrepreneurs differ in three of the big five dimensions. Similarly, a meta-analysis from Collins, Hanges et al. (2004) suggests that achievement motivation is a significant factor in choosing entrepreneurship as a career as well as performance as an entrepreneur. A review of studies on locus of control concludes that entrepreneurs demonstrate greater internality than the general population, but achievement motivation has a stronger effect (Rauch and Frese 2007).

While evidence to support a link between entrepreneurship and psychological traits such as achievement motivation and locus of control has been somewhat weak, there is somewhat more support to the hypothesis that self-efficacy plays a more critical role in explaining who becomes an entrepreneur (Domurat and Tyszka 2018) even if this conclusion is not unanimous (Rauch and Frese 2007). The importance of self-efficacy in

---

[10]Definitions of these terms are in Appendix Table 3.A.1.

entrepreneurship may be explained by the individual's belief in their abilities when facing an unknown challenge, such as entering a new market. As such, these results raised the question of which abilities matter most.

Expanding that line of questioning, and closer to our approach, Hartog, Van Praag et al. (2010) link cognitive abilities, such as math and language, and social abilities with the decision to become entrepreneurs (versus a wage earner). They conclude that the skills that mattered differed between the two groups. Wage-earners benefited from language and clerical skills, while entrepreneurs benefited most from mathematical skills as well as other social and technical abilities.[11]

One approach to further explore how distinct abilities shape the decision to become an entrepreneur is to rely on the concept of executive functions. Executive functions are top-down mental processes that control an individual's attention, dictate their ability to use information or suppress instinctive responses when those responses are not optimal (Miller and Cohen 2001, Espy 2004, Burgess and Simons 2005). An increasing number of studies have been influenced by this concept to study, for example, how self-control matters for borrowing and savings (Ashraf, Karlan et al. 2006), consumption (Gruber and Köszegi 2001, Giné, Karlan et al. 2010), as well as productivity (Ariely and Wertenbroch 2002, Kaur, Kremer et al. 2015) or how attention influences technology adoption (Bennear, Tarozzi et al. 2013, Drexler, Fischer et al. 2014, Hanna, Mullainathan et al. 2014). Additional studies find cognitive flexibility to be an important factor in two areas that are particularly relevant to entrepreneurs, innovation and creativity (Jaušovec 1991, Runco and Okuda 1991, Jaušovec 1994, Chi 1997). Other executive functions, such as working memory and cognitive planning, have received much less attention, although their importance is not necessarily negligible.

[11] They also conclude that a balance of these skills is important, providing some support to Lazear's Jack-of-all-trades theory (Lazear 2002, Lazear 2004).

One major limitation of this growing literature is its isolated discussion of each executive function at a time, which seems to go against the very definition of some of these concepts in which executive functions are largely intertwined and build off of each other (Diamond 2013). This limitation may reflect both the fact that, although these studies have used the language of psychology, they have formalised it and understand it differently, as well as a preference for simplicity and, naturally, building a model of self-control rather than a model of all executive functions (including self-control) is more feasible.

This article examines whether executive functions play an important role in a producer's willingness to "try new things" Schumpeter (1947), in this case, take advantage of new market opportunities. We use a unique and rich dataset that includes, in addition to data on production decisions and respondents' demographic characteristics, data on different tasks implemented to measure the main executive functions that we can expect to explain entrepreneurship.

3.3. Context and Data

Our data comes from rural areas in northern Laos. As in other parts of Asia, this is a region that is going through what Delgado, Rosegrant et al. (2001) call the 'livestock revolution,' the global change in agriculture driven by increased demand for livestock products, itself fuelled by population growth, urbanisation, and increased incomes in low-income countries.[12] Given Laos' comparative advantage in ruminant production relative to its neighbours (Stür, Gray et al. 2002) and its proximity to large markets (notably China, Thailand, and Vietnam), producers in this country are well-placed to take advantage of increased demand, making cattle production a growing income opportunity in Laos (Phonvisay, Vanhnalat et al. (2016). Producing cattle is not a new activity in the rural

---

[12] FAOSTAT data supports the conclusion that similar trends are at play in Laos, where bovine (cattle and buffalo) meat production has increased nearly fivefold between 1980 and 2013 (from 9,930 tonnes to 49,371 tonnes). Stür, Gray et al. (2002) state the demand for meat had grown consistently in Laos as well as the rest of Southeast Asia and the trend was likely to continue.

areas of developing countries, and an extensive literature studies its role and importance, noticeably as a saving mechanism (Harding, Warner et al. 2007). Producing cattle for a relatively large and distant foreign market is, however, new.

The data used in this study were collected as part of a household survey in two provinces in northern Laos, Luang Prabang, and Xiangkhuang. In total, 840 households from 72 villages, were interviewed in 2017 and 2018. Data collected in 2017 included the primary variables of interest, the executive functions,[13] as well as other socioeconomic characteristics of the household. Data collected in 2018 included production data for cattle. Village-level data used in this study comes from a separate survey conducted with village leaders. The final sample size for the analysis is 711 unique households; we removed observations because of missing or incomplete executive function measurements.

At the start of the 1990s, the Lao Government and international donors recognised the potential importance of the cattle industry to smallholder farmers in Laos. They worked towards building capacity in the cattle industry through improved extension services, disease surveillance, and animal husbandry techniques (Phonvisay, Vanhnalat et al. 2016). As shown in Figure 3.1, [14] producers responded in a very dynamic way: in 2018, at the time of the survey, approximately 75% of households in our sample produced cattle (against a meagre 17% in 1990). From the period of 1990-2014, the percentage of our sample raising cattle increased gradually ($\approx 1\%$ per annum). There is a noticeable increase during the period 2014 - 2018 when the share of cattle producers increased by approximately 5% per annum. Simultaneously, this increase is accompanied by an increase in the importance of producing for the market, which grew to 39% of producers in 2018 (from a much lower share of 9% in 1990). It seems that not only rural households in our sample increased their wealth in terms of livestock (accompanying the general

[13] Description of tests used to measure executive functions in Appendix Table 3.A.2.

[14] Groups aggregated by their response to question, “What is your primary reason for keeping cattle?” Respondents either raise cattle for market or for savings.

reduction in poverty in the country since the 1990s) but that an increasing fraction of producers see themselves as actively recognising and taking advantage of the new opportunity created by earlier capacity building.

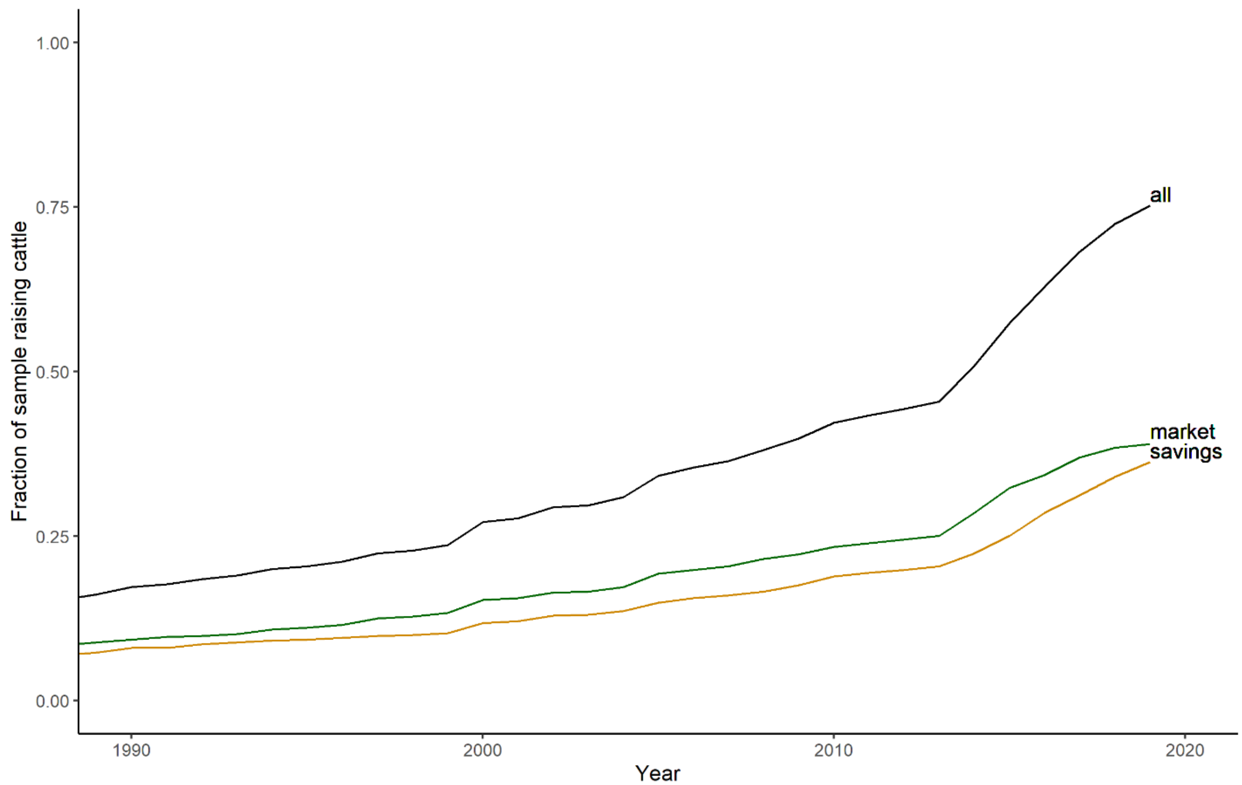

Figure 3.1: Fraction of sample raising cattle
Note: Longitudinal data based on recall of year producer started raising cattle, disaggregated by reason for raising cattle

We can consider three different types of households concerning cattle production, (1) they can raise cattle for the market (hereafter, entrepreneurs),[15] (2) they can raise cattle primarily as a savings mechanism (hereafter, traditional producers), or (3) they do not raise cattle at all. Table 3.1 allows a first discussion of any differences between these three types of households. The first conclusion drawn from Table 3.1 is that entrepreneurs

[15] Entrepreneurs in the context of this study are defined as the cattle producers who take advantage of the new market opportunity of raising cattle specifically for sale at the market. Or as Schumpeter (1947) would say, the producers who, "try new things."

are systematically different from traditional producers and non-producers in *all* executive functions. In all cases, entrepreneurs performed better than other households in the different tasks used to measure their executive functions. In contrast, we do not find a difference in terms of risk aversion and only statistically weak differences in terms of time preferences, with entrepreneurs being less patient than traditional producers. The second conclusion is that we do not find many differences between entrepreneurs and traditional producers in terms of demographic characteristics, wealth (land and assets), or access to labour. Entrepreneurs had slightly larger farm sizes and more access to young female labour than traditional producers, but all other wealth and demographic characteristics were the same.

The information in Table 3.1 also allows us to contrast entrepreneurs with those who do not produce cattle. The extent of these differences is now much larger: not only are non-producers different in terms of their executive functions (usually performing worse than entrepreneurs), but also in several other dimensions. Households that do not raise cattle are more likely to be younger, more likely to be headed by women, generally less wealthy both in terms of assets and privately-owned forest land and have less access to labour. Except for inhibitory control, all the executive functions were significantly different between the entrepreneurs and non-producers. In all cases, the entrepreneurs had better scores than their counterparts.

Table 3.1. Descriptive statistics, by household type.

	(1) Cattle (Market) Entrepreneurs		(2) Cattle (Savings) Traditional		(3) No Cattle Non-producers		Difference	
	Mean	SD	Mean	SD	Mean	SD	(1)-(2)	(1)-(3)
Household Head characteristics								
Cognitive planning	-0.11	1.31	-0.90	1.70	-0.82	1.67	0.79***	0.71***
Fluid intelligence	0.14	0.96	-0.06	1.07	-0.07	0.94	0.20**	0.21**
Inhibitory control‡	-0.07	0.11	-0.09	0.12	-0.08	0.10	0.02**	0.01
Working memory	0.15	0.95	-0.12	0.98	-0.05	1.04	0.27***	0.20**
Cognitive flexibility	0.22	0.89	-0.13	1.04	-0.13	1.04	0.35***	0.35***
Attention‡	0.20	0.84	-0.18	1.08	-0.07	1.11	0.38***	0.27***
Risk aversion	1.79	2.53	1.72	2.50	2.04	2.68	0.08	-0.25
Discount rate	0.17	0.14	0.15	0.13	0.16	0.14	0.02*	0.00
Schooling	5.39	2.85	5.38	2.89	5.49	3.24	0.01	-0.10
Age	47.81	12.31	47.47	12.83	45.39	13.21	0.35	2.42**
Male	0.97	0.16	0.97	0.17	0.94	0.24	0.00	0.03*
Literacy	0.92	0.27	0.90	0.31	0.89	0.31	0.03	0.03
Household characteristics								
Farm size (ha)	3.17	3.20	2.79	2.48	3.03	2.73	0.37*	0.14
Forest size (ha)	0.96	2.15	0.78	1.61	0.47	1.10	0.18	0.50***
Agricultural assets	0.13	1.06	0.11	1.04	-0.28	0.80	0.02	0.41***
Male labour (13-17)	0.38	0.62	0.41	0.63	0.28	0.56	-0.03	0.10**
Female labour (13-17)	0.46	0.68	0.33	0.62	0.39	0.81	0.13**	0.08
Male labour (18-60)	1.72	0.98	1.74	1.00	1.36	0.82	-0.01	0.37***
Female labour (18-60)	1.75	0.96	1.66	0.88	1.52	0.75	0.09	0.23***
Total labour	4.32	1.83	4.14	1.77	3.55	1.74	0.18	0.77***
Dependency ratio	1.01	0.82	0.99	0.82	1.01	0.71	0.02	0.01
N	**290**		**258**		**163**			

Note: '***', '**', and '*' are significant at 1%, 5%, and 10% respectively

‡: We use the symmetric values of inhibitory control and attention so that higher values indicate better performance in the task.

In short, it seems that the decision to produce for the market (i.e., being an entrepreneur) versus for savings (the traditional activity), mostly reflects differences in producers' cognitive functioning. A natural follow up question is whether these two types of producers do things differently, either with respect to production or the way that cattle are marketed.

Production decisions of entrepreneurs and traditional producers are compared in Table 2. Entrepreneurs have larger herds and receive higher revenues from cattle production, but this difference is primarily driven by the number of cattle sold, as we cannot detect any difference in the price they receive for the animals they sell. Entrepreneurs also differ in how they manage herd size, being more likely to breed cows and restock through births, whereas traditional producers are more likely to purchase cattle to increase their herd size, presumably when benefiting from a positive shock to income. What is perhaps surprising is that there are not many other differences in management – entrepreneurs are not more likely to use modern breeding techniques, allocate resources to the production of forage or silage. They are even less likely to use preventative care, such as vaccinating their cattle against foot and mouth disease (a typically non-fatal disease), although they are slightly more likely to use a curative treatment.

Table 3.2. Differences in production technology: entrepreneurs vs. traditional producers

	(1) Cattle (Market) Entrepreneurs		(2) Cattle (Saving) Traditional		Difference
	Mean	SD	Mean	SD	(1)-(2)
Herd Size	10.06	(9.07)	7.62	(6.85)	2.44***
Cattle Purchased (% yes)	0.109	(0.312)	0.239	(0.428)	-0.131***
Number of Cattle Purchased	0.412	(1.47)	0.517	(1.27)	-0.106
Number of cattle Born	2.42	(2.4)	1.95	(1.95)	0.47***
Cattle Sold (% yes)	0.551	(0.498)	0.363	(0.482)	0.188***
Number of Cattle Sold	3.59	(3.3)	2.15	(1.83)	1.44***
Cattle Revenue	15,109.91	(13192.24)	9,951.51	(9858)	5,158.40***
Price per cattle	4,717.62	(2132.28)	4,746.79	(2459.92)	-29.17
Controlled Mating (% yes)	0.041	(0.198)	0.023	(0.151)	0.018
Grow Fodder (% yes)	0.415	(0.494)	0.459	(0.499)	-0.044
Purchase Fodder (% yes)	0.003	(0.058)	0.00	(0.00)	0.003
Grow Silage (% yes)	0.01	(0.101)	0.008	(0.088)	0.002
HS Vaccine (% yes)	0.476	(0.5)	0.456	(0.499)	0.021
Foot and Mouth Vaccine (% yes)	0.293	(0.456)	0.436	(0.497)	-0.144***
Parasite Vaccine (% yes)	0.122	(0.328)	0.127	(0.334)	-0.005
Other Vaccine (% yes)	0.136	(0.343)	0.124	(0.33)	0.013
Use Curative Treatment (% yes)	0.133	(0.34)	0.089	(0.285)	0.044*
Dry Season Free grazing (% yes)	0.776	(0.418)	0.795	(0.404)	-0.02
Wet Season Free grazing (% yes)	0.361	(0.481)	0.402	(0.491)	-0.041
Observations	294		259		

Note: '***', '**', and '*' are significant at 1%, 5%, and 10% respectively

Differences in marketing behaviour between entrepreneurs and traditional producers are presented in Table 3.3. The data shows that, in general, entrepreneurs are more engaged in marketing activities than traditional producers. A higher percentage of entrepreneurs sell their cattle to multiple traders, in village markets. They were also more likely to check the price of cattle before a sale, especially by contacting a trader directly, and also more likely to bargain over the price with traders.

Table 3.3. Differences in marketing practices: entrepreneurs vs. traditional producers

	(1) Cattle (Market) Entrepreneurs		(2) Cattle (Saving) Traditional		Difference
	Mean	SD	Mean	SD	(1)-(2)
Sold to trader (% yes)	0.327	(0.47)	0.224	(0.418)	0.103***
Sold to other traders (% yes)	0.262	(0.026)	0.181	(0.023)	0.081***
Sold cattle inside village (% yes)	0.398	(0.49)	0.293	(0.456)	0.105***
Sold cattle outside village (% yes)	0.088	(0.284)	0.097	(0.296)	-0.009
Checked cattle price before sale (% yes)	0.347	(0.477)	0.29	(0.454)	0.057*
Check cattle price inside village (% yes)	0.2	(0.401)	0.193	(0.395)	0.007
Check cattle price outside village (% yes)	0.058	(0.233)	0.039	(0.193)	0.019
Check cattle price with traders (% yes)	0.153	(0.361)	0.104	(0.306)	0.049**
Don't know how to check price (% yes)	0.054	(0.227)	0.039	(0.193)	0.015
Pre-arrange price with trader (% yes)	0.167	(0.373)	0.143	(0.351)	0.024
Bargain price with trader (% yes)	0.303	(0.46)	0.231	(0.423)	0.072**
Observations	294		259		

Note: '***', '**', and '*' are significant at 1%, 5%, and 10% respectively

3.4. Explaining entrepreneurship

We examine the importance of differences in executive functions in explaining the decision to produce cattle for the market (vs. raising cattle for the traditional purpose of savings). We model this decision using a Heckman selection model for binary outcomes (Heckman 1979, Aakvik, Heckman et al. 2005) that accounts for selection into cattle production. These results, for both selection and outcome, are presented in Table 3.4.[16] We assume that village-level characteristics (that are exogenous to households) such as availability of communal grazing and forests, irrigation infrastructure, and whether the village was affected by the Land and Forest Allocation policy (a land zoning program that restricts the expansion of agricultural land, with the aim of limiting swidden agriculture and protecting forest) will condition the feasibility of cattle production but have no direct influence on the market orientation of the producer. Similarly, the availability of household

[16] See Table 3.A.3. for probit model results not accounting for selection into cattle. The significance levels of some executive functions change when selection accounted for – particularly cognitive flexibility which loses significance from 1% to 10% with Heckman model.

labour by young males, with low opportunity costs outside of raising livestock, is likely to explain the decision to raise cattle but, conditional on overall labour availability, should play no role in explaining entrepreneurship.

Table 3.4. Explaining entrepreneurship

	Raise Cattle		Entrepreneur	
	Mean	SE	Mean	SE
Cognitive Planning	0.046	(0.040)	0.152***	(0.047)
Fluid intelligence	0.084	(0.061)	0.033	(0.057)
Inhibitory control (symmetric)	-0.053	(0.462)	1.097**	(0.466)
Working memory	-0.102	(0.075)	0.097*	(0.057)
Cognitive flexibility	0.089	(0.066)	0.124*	(0.067)
Attention (symmetric)	-0.010	(0.064)	0.180***	(0.059)
Risk aversion	-0.035*	(0.019)	0.017	(0.021)
Discount rate	0.130	(0.356)	0.824**	(0.410)
Schooling	-0.048**	(0.023)	-0.032	(0.024)
Age	-0.000	(0.005)	0.010*	(0.006)
Male	0.542**	(0.253)	-0.180	(0.314)
Literacy	0.211	(0.198)	0.331	(0.221)
Farm size (ha)	-0.035	(0.023)	0.034	(0.026)
Forest size (ha)	0.099**	(0.045)	0.028	(0.032)
Agricultural assets	0.362***	(0.102)	-0.152*	(0.085)
Dependency Ratio	0.143	(0.104)	-0.034	(0.070)
Viengkham district	-0.063	(0.218)	0.060	(0.162)
Kham district	-0.021	(0.271)	-0.126	(0.216)
Phoukhout district	-0.635*	(0.369)	0.141	(0.252)
Dist. to market (km)	-0.005	(0.007)	0.002	(0.006)
Number of ext. visits	0.005	(0.030)	-0.008	(0.023)
Rainy season access	-0.532**	(0.236)	0.284*	(0.158)
District HQ Distance (km)	0.008	(0.006)	0.003	(0.004)
Cattle Experience (years)			-0.003	(0.007)
Total labour			-0.047	(0.037)
Male labour (13-17)	0.240**	(0.111)		
Female labour (13-17)	0.024	(0.102)		
Male labour (18-60)	0.290***	(0.095)		
Female labour (18-60)	0.072	(0.058)		
Mixed village ecosystem	-0.145	(0.200)		
Upland village ecosystem	-0.667***	(0.253)		
Communal grazing (ha)	0.000***	(0.000)		
Communal forest (ha)	-0.000***	(0.000)		
Village irrigation	0.239	(0.212)		
LFA policy	0.440**	(0.175)		
ρ			-0.941**	(0.452)
Constant	-0.006	(0.503)	-0.299	(0.463)
Observations	711		711	

Note: ‘***’, ‘**’, and ‘*’ are significant at 1%, 5%, and 10% respectively. Standard errors are clustered at the village level. We use the symmetric values of inhibitory control and attention so that higher values indicate better performance in the task.

The main conclusion is that better performance in the tasks used to measure the different executive functions significantly increases the likelihood of an individual being an entrepreneur. Compared to traditional producers, entrepreneurs have higher self-control (inhibitory control), including the ability to focus on selective stimuli (attention), and excel at planning (cognitive planning). Additionally, and to a lesser extent, they are also better at storing and manipulating information (working memory) and at learning and quickly adapting to new rules (cognitive flexibility). Somewhat surprisingly, fluid intelligence (which, under the label of cognition, has received most attention by economists) is not a significant factor in explaining producers’ decision to raise cattle for the market. In short, heterogeneity in cognitive abilities seems to matter in distinguishing between entrepreneurs and traditional producers.

Turning our attention to our measures of economic preferences, our results suggest that risk aversion, which has received considerable attention in the entrepreneurship literature, does not play a significant role in explaining entrepreneurship in our study. They also suggest that entrepreneurs are more impatient than traditional producers, who raise cattle as savings for their future selves.

Very few variables are significant in our entrepreneurial model, besides the abovementioned cognitive and behavioural characteristics. We do not find any substantial evidence that location matters for producers’ decisions to enter into the entrepreneurial activity, location fixed effects and other variables are not significant. The only marginally significant location variable in the outcome model is road access to the village during the rainy season. This could affect entrepreneurs' marketing ability, as traders would not have access to their villages during the rainy season. Overall, decisions to enter the entrepreneurial activity are primarily driven by cognitive and behavioural traits of the individual, rather than their demographic and location characteristics.

3.5. Conclusions

In this study, we investigate whether and how entrepreneurs differ from traditional producers, paying particular attention to the importance of heterogeneity with respect to executive functions. We study the decision of cattle producers in northern Laos, who have chosen to take advantage of the new market opportunity of raising cattle to sell at the market (in contrast to the traditional use of cattle as savings).

We find that entrepreneurs are different from non-entrepreneurs in several dimensions. Most notably is that they score higher in many of the executive functions. Entrepreneurs have better impulse control (inhibitory control), including the ability to focus on selective stimuli (attention), and are better at planning (cognitive planning) compared to traditional producers. This result signals apparent differences in the ways that entrepreneurs process information. Furthermore, even though risk-seeking behaviour is often associated with the entrepreneur, we find no evidence to support the link between risk attitudes and the likelihood of being an entrepreneur.

Our results may carry implications for the promotion of entrepreneurial activity. Training entrepreneurship is useful because entrepreneurs play a significant role in the economy (Van Praag and Versloot 2007), and this can be especially true in transition economies such as Laos (McMillan and Woodruff 2002). Entrepreneurship training and support programs have been developed to include psychological skills and attitudes beyond the foundational economic and business knowledge being taught (Domurat and Tyszka 2018). These programs may benefit by extending the psychological skills training to include executive function development. There is evidence that executive functions are malleable and can be improved (Klingberg 2010, Diamond and Lee 2011). With computerised training programs providing promising results for executive function improvement in many studies (Klingberg, Fernell et al. 2005, Holmes, Gathercole et al. 2009, Thorell, Lindqvist et al. 2009, Bergman Nutley, Söderqvist et al. 2011). The incorporation of executive function improvement exercises into entrepreneurship training programs is a logical next step.

3.6. Acknowledgments

Data for this paper was collected as part of the project “Improving food security in the northern uplands of Lao People’s Democratic Republic (PDR): Identifying drivers and overcoming barriers," funded by the Australian Centre for International Agricultural Research (ACIAR) through grant ASEM/2012/073

3.7. References

Aakvik, A., J. J. Heckman and E. J. Vytlacil (2005). "Estimating treatment effects for discrete outcomes when responses to treatment vary: an application to Norwegian vocational rehabilitation programs." Journal of Econometrics **125**(1-2): 15-51.

Ahmad, N. and R. G. Seymour (2008). "Defining entrepreneurial activity: Definitions supporting frameworks for data collection."

Almlund, M., A. L. Duckworth, J. Heckman and T. Kautz (2011). Personality psychology and economics. Handbook of the Economics of Education, Elsevier. **4:** 1-181.

Anderson, M. C. and B. J. Levy (2009). "Suppressing unwanted memories." Current Directions in Psychological Science **18**(4): 189-194.

Ariely, D. and K. Wertenbroch (2002). "Procrastination, deadlines, and performance: Self-control by precommitment." Psychological science **13**(3): 219-224.

Ashraf, N., D. Karlan and W. Yin (2006). "Tying Odysseus to the mast: Evidence from a commitment savings product in the Philippines." The Quarterly Journal of Economics **121**(2): 635-672.

Bandura, A. (1994). Self-efficacy Encyclopedia of human behavior. V. Ramachaudran. New York, Academic Press. **4:** 71-81.

Basner, M. and D. F. Dinges (2011). "Maximizing sensitivity of the psychomotor vigilance test (PVT) to sleep loss." Sleep **34**(5): 581-591.

Baumol, W. J. and M. A. Schilling (2018). Entrepreneurship. The New Palgrave Ditionary of Economics. M. Vernengo, E. P. Caldentey and B. J. R. Jr. London, Palgrave MacMillon**:** 3762-3768.

Becker, G. S. (1962). "Irrational behavior and economic theory." Journal of political economy **70**(1): 1-13.

Bennear, L., A. Tarozzi, A. Pfaff, S. Balasubramanya, K. M. Ahmed and A. Van Geen (2013). "Impact of a randomized controlled trial in arsenic risk communication on household water-source choices in Bangladesh." Journal of environmental economics and management **65**(2): 225-240.

Berg, E. A. (1948). "A simple objective technique for measuring flexibility in thinking." The Journal of general psychology **39**(1): 15-22.

Bergman Nutley, S., S. Söderqvist, S. Bryde, L. B. Thorell, K. Humphreys and T. Klingberg (2011). "Gains in fluid intelligence after training non-verbal reasoning in 4-year-old children: A controlled, randomized study." Developmental science **14**(3): 591-601.

Besner, D. and M. Coltheart (1979). "Ideographic and alphabetic processing in skilled reading of English." Neuropsychologia **17**(5): 467-472.

Blanchflower, D. G. and A. J. Oswald (1998). "What makes an entrepreneur?" Journal of labor Economics **16**(1): 26-60.

Borghans, L., A. L. Duckworth, J. J. Heckman and B. Ter Weel (2008). "The economics and psychology of personality traits." Journal of human Resources **43**(4): 972-1059.

Bourguignon, F., M. Fournier and M. Gurgand (2007). "Selection bias corrections based on the multinomial logit model: Monte Carlo comparisons." Journal of Economic Surveys **21**(1): 174-205.

Broadbent, D. (1958). "Perception and Communication."

Burgess, P. W. and J. S. Simons (2005). "18 Theories of frontal lobe executive function: clinical applications." The effectiveness of rehabilitation for cognitive deficits: 211.

Canas, J., J. Quesada, A. Antolí and I. Fajardo (2003). "Cognitive flexibility and adaptability to environmental changes in dynamic complex problem-solving tasks." Ergonomics **46**(5): 482-501.

Cantillon, R. (1755). Essay on the Nature of Trade in General, Liberty Fund.

Carlin, D., J. Bonerba, M. Phipps, G. Alexander, M. Shapiro and J. Grafman (2000). "Planning impairments in frontal lobe dementia and frontal lobe lesion patients." Neuropsychologia **38**(5): 655-665.

Casson, M. (2018). Entrepreneur. The New Plagrave Dictionary of Economics. M. Vernengo, E. P. Caldenty and B. J. R. Jr. London, Palgrave MacMillon**:** 3758-3762.

Chi, M. T. (1997). Creativity: Shifting across ontological categories flexibly. Creative thought: An investigation of conceptual structures and processes. T. B. Ward, S. M. Smith and J. Vaid. Washington DC, US: American Psychological Association**:** 209-234.

Chun, M. M., J. D. Golomb and N. B. Turk-Browne (2011). "A taxonomy of external and internal attention." Annual review of psychology **62**: 73-101.

Collins, A. and E. Koechlin (2012). "Reasoning, learning, and creativity: frontal lobe function and human decision-making." PLoS biology **10**(3): e1001293.

Collins, C. J., P. J. Hanges and E. A. Locke (2004). "The relationship of achievement motivation to entrepreneurial behavior: A meta-analysis." Human performance **17**(1): 95-117.

Conway, A. R., M. J. Kane and R. W. Engle (2003). "Working memory capacity and its relation to general intelligence." Trends in cognitive sciences **7**(12): 547-552.

Corsi, P. M. (1973). Human memory and the medial temporal region of the brain, ProQuest Information & Learning.

Cowan, N., A. M. AuBuchon, A. L. Gilchrist, T. J. Ricker and J. S. Saults (2011). "Age differences in visual working memory capacity: Not based on encoding limitations." Developmental science **14**(5): 1066-1074.

Cowan, N., J. S. Saults and E. M. Elliott (2002). The search for what is fundamental in the development of working memory. Advances in child development and behavior, Elsevier. **29:** 1-49.

Crone, E. A., C. Wendelken, S. Donohue, L. van Leijenhorst and S. A. Bunge (2006). "Neurocognitive development of the ability to manipulate information in working memory." Proceedings of the National Academy of Sciences **103**(24): 9315-9320.

Davidson, M. C., D. Amso, L. C. Anderson and A. Diamond (2006). "Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching." Neuropsychologia **44**(11): 2037-2078.

Dean, E. B., F. Schilbach and H. Schofield (2017). "Poverty and Cognitive Function."

Dean, E. B., F. Schilbach and H. Schofield (2019). Poverty and Cognitive Function. The Economics of Poverty Traps. C. B. Barrett, M. R. Carter and J.-P. Chavas. Chicago, IL, University of Chicago Press**:** 57.

Delgado, C., M. Rosegrant, H. Steinfeld, S. Ehui and C. Courbois (2001). "Livestock to 2020: The next food revolution." Outlook on Agriculture **30**(1): 27-29.

Diamond, A. (2013). "Executive functions." Annual review of psychology **64**: 135-168.

Diamond, A. and K. Lee (2011). "Interventions shown to aid executive function development in children 4 to 12 years old." Science **333**(6045): 959-964.
Domurat, A. and T. Tyszka (2018). "18 Entrepreneurial Activity." CENTRE FOR DECISION RESEARCH, UNIVERSITY OF LEEDS, UK: 287.
Drexler, A., G. Fischer and A. Schoar (2014). "Keeping it simple: Financial literacy and rules of thumb." American Economic Journal: Applied Economics **6**(2): 1-31.
Duncan, J., A. Parr, A. Woolgar, R. Thompson, P. Bright, S. Cox, S. Bishop and I. Nimmo-Smith (2008). "Goal neglect and Spearman's g: competing parts of a complex task." Journal of Experimental Psychology: General **137**(1): 131.
Espy, K. A. (2004). "Using developmental, cognitive, and neuroscience approaches to understand executive control in young children." Developmental Neuropsychology **26**(1): 379-384.
Ferrer, E., B. A. Shaywitz, J. M. Holahan, K. Marchione and S. E. Shaywitz (2010). "Uncoupling of reading and IQ over time: Empirical evidence for a definition of dyslexia." Psychological science **21**(1): 93-101.
Friedman, N. P., A. Miyake, R. P. Corley, S. E. Young, J. C. DeFries and J. K. Hewitt (2006). "Not all executive functions are related to intelligence." Psychological science **17**(2): 172-179.
Garon, N., S. E. Bryson and I. M. Smith (2008). "Executive function in preschoolers: a review using an integrative framework." Psychological bulletin **134**(1): 31.
Giné, X., D. Karlan and J. Zinman (2010). "Put your money where your butt is: a commitment contract for smoking cessation." American Economic Journal: Applied Economics **2**(4): 213-235.
Gruber, J. and B. Köszegi (2001). "Is addiction “rational”? Theory and evidence." The Quarterly Journal of Economics **116**(4): 1261-1303.
Hanna, R., S. Mullainathan and J. Schwartzstein (2014). "Learning through noticing: Theory and evidence from a field experiment." The Quarterly Journal of Economics **129**(3): 1311-1353.
Harding, M., R. Warner and D. Kennedy (2007). Livestock health and vaccines in Cambodia and Laos - Project final report. Canberra, ACIAR.
Hartog, J., M. Van Praag and J. Van Der Sluis (2010). "If you are so smart, why aren't you an entrepreneur? Returns to cognitive and social ability: Entrepreneurs versus employees." Journal of Economics & Management Strategy **19**(4): 947-989.
Heckman, J. J. (1979). "Sample selection bias as a specification error." Econometrica: Journal of the econometric society: 153-161.
Henik, A. and J. Tzelgov (1982). "Is three greater than five: The relation between physical and semantic size in comparison tasks." Memory & cognition **10**(4): 389-395.
Holmes, J., S. E. Gathercole and D. L. Dunning (2009). "Adaptive training leads to sustained enhancement of poor working memory in children." Developmental science **12**(4): F9-F15.
Horn, J. L. and R. B. Cattell (1966). "Refinement and test of the theory of fluid and crystallized general intelligences." Journal of educational psychology **57**(5): 253.
Jaušovec, N. (1991). "Flexible strategy use: A characteristic of gifted problem solving." Creativity Research Journal **4**(4): 349-366.
Jaušovec, N. (1994). Flexible thinking: An explanation for individual differences in ability, Hampton Press.

Kane, M. J. and R. W. Engle (2002). "The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective." Psychonomic bulletin & review **9**(4): 637-671.

Kaur, S., M. Kremer and S. Mullainathan (2015). "Self-control at work." Journal of Political Economy **123**(6): 1227-1277.

Kirzner, I. M. (1978). "Competition and Entrepreneurship." University of Chicago Press Economics Books.

Klingberg, T. (2010). "Training and plasticity of working memory." Trends in cognitive sciences **14**(7): 317-324.

Klingberg, T., E. Fernell, P. J. Olesen, M. Johnson, P. Gustafsson, K. Dahlström, C. G. Gillberg, H. Forssberg and H. Westerberg (2005). "Computerized training of working memory in children with ADHD-a randomized, controlled trial." Journal of the American Academy of Child & Adolescent Psychiatry **44**(2): 177-186.

Knight, F. (1921). "Risk, Uncertainty and Profit."

Kotovsky, K., J. R. Hayes and H. A. Simon (1985). "Why are some problems hard? Evidence from Tower of Hanoi." Cognitive psychology **17**(2): 248-294.

Lazear, E. P. (2002). Entrepreneurship. Cambridge, Mass, National Bureau of Economic Research. **NBER Working Paper Series 9109**.

Lazear, E. P. (2004). "Balanced skills and entrepreneurship." American Economic Review **94**(2): 208-211.

Lehto, J. E., P. Juujärvi, L. Kooistra and L. Pulkkinen (2003). "Dimensions of executive functioning: Evidence from children." British Journal of Developmental Psychology **21**(1): 59-80.

Luciana, M., H. M. Conklin, C. J. Hooper and R. S. Yarger (2005). "The development of nonverbal working memory and executive control processes in adolescents." Child development **76**(3): 697-712.

Lunt, L., J. Bramham, R. G. Morris, P. R. Bullock, R. P. Selway, K. Xenitidis and A. S. David (2012). "Prefrontal cortex dysfunction and 'jumping to conclusions': bias or deficit?" Journal of Neuropsychology **6**(1): 65-78.

Mackworth, N. H. (1948). "The breakdown of vigilance during prolonged visual search." Quarterly Journal of Experimental Psychology **1**(1): 6-21.

Martin, M. M. and C. M. Anderson (1998). "The cognitive flexibility scale: Three validity studies." Communication Reports **11**(1): 1-9.

Martin, M. M. and R. B. Rubin (1995). "A new measure of cognitive flexibility." Psychological reports **76**(2): 623-626.

McMillan, J. and C. Woodruff (2002). "The central role of entrepreneurs in transition economies." Journal of economic Perspectives **16**(3): 153-170.

Mill, J. S. (1871). Principles of political economy: with some of their applications to social philosophy, London: Longmans, Green, Reader and Dyer.

Miller, E. K. and J. D. Cohen (2001). "An integrative theory of prefrontal cortex function." Annual review of neuroscience **24**(1): 167-202.

Miner, J. B. and N. S. Raju (2004). "Risk propensity differences between managers and entrepreneurs and between low-and high-growth entrepreneurs: A reply in a more conservative vein."

Miyake, A., N. P. Friedman, M. J. Emerson, A. H. Witzki, A. Howerter and T. D. Wager (2000). "The unity and diversity of executive functions and their contributions to

complex “frontal lobe” tasks: A latent variable analysis." Cognitive psychology **41**(1): 49-100.
Moffitt, T. E., L. Arseneault, D. Belsky, N. Dickson, R. J. Hancox, H. Harrington, R. Houts, R. Poulton, B. W. Roberts and S. Ross (2011). "A gradient of childhood self-control predicts health, wealth, and public safety." Proceedings of the National Academy of Sciences **108**(7): 2693-2698.
Pashler, H. E. and S. Sutherland (1998). The psychology of attention, MIT press Cambridge, MA.
Phonvisay, A., B. Vanhnalat and P. Sinavong (2016). Pro-poor Policy Analysis on Cattle Productivity and Industry in Lao PDR. Vientiane, Laos, Food and Agriculture Organization: 1-101.
Posner, M. I. and G. J. DiGirolamo (1998). "Executive Attention: Conflict, Target Detection, and Cognitive Control."
Rajan, R. G. and L. Zingales (1996). Financial dependence and growth, National bureau of economic research.
Rauch, A. and M. Frese (2007). "Let's put the person back into entrepreneurship research: A meta-analysis on the relationship between business owners' personality traits, business creation, and success." European Journal of work and organizational psychology **16**(4): 353-385.
Raven, J. (2000). "The Raven's progressive matrices: change and stability over culture and time." Cognitive psychology **41**(1): 1-48.
Raven, J. C. (1936). "Mental tests used in genetic studies: The performance of related individuals on tests mainly educative and mainly reproductive." Unpublished master’s thesis, University of London.
Roca, M., A. Parr, R. Thompson, A. Woolgar, T. Torralva, N. Antoun, F. Manes and J. Duncan (2009). "Executive function and fluid intelligence after frontal lobe lesions." Brain **133**(1): 234-247.
Rogers, D. O. I. E. M. (1962). diffusion of innovations everett m rogers, New York: Free Press of Glencoe.
Rotter, J. B. (1966). "Generalized expectancies for internal versus external control of reinforcement." Psychological monographs: General and applied **80**(1): 1.
Runco, M. A. and S. M. Okuda (1991). "The instructional enhancement of the flexibility and originality scores of divergent thinking tests." Applied Cognitive Psychology **5**(5): 435-441.
Schiller, J. (2006). Rice in Laos, Int. Rice Res. Inst.
Schultz, T. W. (1961). "Investment in human capital." The American economic review **51**(1): 1-17.
Schultz, T. W. (1962). "Reflections on investment in man." Journal of political economy **70**(5, Part 2): 1-8.
Schultz, T. W. (1964). "Transforming traditional agriculture." Transforming traditional agriculture.
Schumpeter, J. (1934). The theory of economic development, Springer.
Schumpeter, J. A. (1947). "The creative response in economic history." The journal of economic history **7**(2): 149-159.

Stewart, W. H. and P. L. Roth (2007). "A meta-analysis of achievement motivation differences between entrepreneurs and managers." Journal of small business management **45**(4): 401-421.
Stroop, J. R. (1935). "Studies of interference in serial verbal reactions." Journal of experimental psychology **18**(6): 643.
Stür, W., D. Gray and G. Bastin (2002). "Review of the livestock sector in the Lao People's Democratic Republic."
Tchanturia, K., H. Davies, M. Roberts, A. Harrison, M. Nakazato, U. Schmidt, J. Treasure and R. Morris (2012). "Poor cognitive flexibility in eating disorders: examining the evidence using the Wisconsin Card Sorting Task." PloS one **7**(1): e28331.
Theeuwes, J. (1991). "Exogenous and endogenous control of attention: The effect of visual onsets and offsets." Perception & psychophysics **49**(1): 83-90.
Theeuwes, J. (2010). "Top–down and bottom–up control of visual selection." Acta psychologica **135**(2): 77-99.
Thorell, L. B., S. Lindqvist, S. Bergman Nutley, G. Bohlin and T. Klingberg (2009). "Training and transfer effects of executive functions in preschool children." Developmental science **12**(1): 106-113.
Van Praag, C. M. and P. H. Versloot (2007). "What is the value of entrepreneurship? A review of recent research." Small business economics **29**(4): 351-382.
Zhao, H. and S. E. Seibert (2006). "The big five personality dimensions and entrepreneurial status: A meta-analytical review." Journal of applied psychology **91**(2): 259.

3.8. Appendices

Appendix 3.1. Descriptions of executive functions

Inhibitory control is the ability to control one's behaviour, attention, emotions, or thought. Inhibitory control allows people to choose how to react rather than reacting instinctively to internal predisposition or external temptation (Diamond 2013). In earlier literature, inhibitory control was disaggregated into two separate parts: interference control and response inhibition. The first part allows us to ignore distracting stimuli that have the potential to distract from one's goal. [17] The second aspect of inhibitory control, response inhibition, does not involve restricting attention to stimuli but instead restricting behaviour or responses. Moffitt, Arseneault et al. (2011) conducted a long-term study that followed 1,000 children of similar backgrounds into adulthood. The study argued that inhibitory control, measured when individuals were children, had predictive power on outcomes throughout the individuals' lives, even after controlling for environmental factors. Children who displayed more inhibitory control from ages 3 to 11 were more likely as teenagers to stay in school and less likely to use drugs (Moffitt, Arseneault et al. 2011). Children who displayed higher inhibitory control went on to have better mental health, better physical health (e.g., lower body weight, lower blood pressure), higher incomes, lower crime rates, and were found to be happier as adults (Moffitt, Arseneault et al. 2011).

Attention works closely with inhibitory control. Attention is defined as the ability to focus attention on a specific piece of information by engaging in a selection process in which

---

[17] The first aspect of inhibitory control, interference control, can be further thought of as internal and external inhibition. Internally, unwanted memories and thoughts can be ignored and even forgotten, this is known as cognitive inhibition (Anderson and Levy 2009). Externally, attention can shift suddenly to external stimuli such as a loud noise. This involuntary attention to external stimuli is driven by the properties of the stimuli themselves (Theeuwes 1991). When an individual chooses to ignore these external stimuli and focus on their goals it is most often referred to as selective or focused attention (a.k.a. active attention, attentional control, attentional inhibition, endogenous attention, executive attention, goal-driven attention, top-down attention, volitional attention, or voluntary attention) (Posner and DiGirolamo 1998, Theeuwes 2010).

an individual continues to process stimuli from this source (Dean, Schilbach et al. 2017). Attention can be both internal and external (Chun, Golomb et al. 2011). Some positive examples would include focusing attention on internal stimuli for a task one wished to complete and focusing attention on external stimuli that can help you complete this task, (e.g., reading about an econometric model). Attention has received much attention from economists and psychologists because of its relevance in decision-making (Pashler and Sutherland 1998). Attention is simply selecting information to be processed; however, attention is limited, and one's ability to efficiently select information to be processed can be depleted (Broadbent 1958).

Working memory involves holding and manipulating information in mind that isn't currently present (Baddeley & Hitch, 1994; Smith & Jonides, 1999). Working memory differs from short-term memory in that short-term memory only involves holding information without any manipulation of the information (Diamond 2013). The development pattern of working memory is very similar to the abovementioned effect of age on inhibitory control. Children develop the ability to hold information in mind quite early, with infants and young children being able to hold one or two things in mind for a sustained period (Adele Diamond, 1995; Nelson, Sheffield, Chevalier, Clark, & Espy, 2013). However, the ability to hold many things in mind and manipulate information in mind develops much more slowly and comes later in life for individuals after a long developmental process (Cowan, Saults et al. 2002, Luciana, Conklin et al. 2005, Crone, Wendelken et al. 2006, Davidson, Amso et al. 2006, Cowan, AuBuchon et al. 2011). Finally, much like inhibitory control, working memory declines as a natural part of the aging process (Fiore, Borella, Mammarella, & De Beni, 2012; Fournet et al., 2012).

Cognitive flexibility is defined as the ability to adapt to changing circumstances (Friedman, Miyake et al. 2006), involving switching between rules, tasks, or mental sets (Lezak et al., 2004) and allowing an individual to change their view or see things from multiple perspectives.[18] Cognitive flexibility builds on the working memory, and inhibitory control develops much later in individuals (Davidson, Amso et al. 2006, Garon, Bryson et al. 2008). Martin and Rubin (1995) and Martin and Anderson (1998) suggest that cognitive flexibility is composed of three steps: individual's awareness that alternatives exist to the current situation, followed by a willingness to be adapt to alternatives and, finally, the decision to modify their behaviour or switch their beliefs for the current situation.

Fluid intelligence refers to an individual's ability to solve novel problems of which they have no prior experience (Horn and Cattell 1966).[19] It can further be thought of as the ability to solve problems, reason, and to see spatial relationships among items (Ferrer, Shaywitz et al. 2010). Previous studies have found high fluid intelligence, as measured by Raven's progressive matrices (Raven 1936, Raven 2000) to be highly correlated with other independently measured executive functions (Kane and Engle 2002, Conway, Kane et al. 2003, Duncan, Parr et al. 2008, Roca, Parr et al. 2009).

Cognitive planning, also known as sequencing, is the ability to create a strategy of steps (in sequence) to achieve intended goals (Dean, Schilbach et al. 2019). To plan well, individuals must consider multiple hypothetical steps to reach their desired outcome and then select from the multiple options the one that will most efficiently help them reach their desired goal (Carlin, Bonerba et al. 2000).

Executive functions are largely interdependent, as seen in figure 3.A.1. Working memory relies upon inhibitory control, and inhibitory control relies upon working memory. Cognitive flexibility relies upon both working memory and inhibitory control, and the higher-level executive functions rely upon working memory, inhibitory control, and cognitive flexibility.

---

[18] Cognitive flexibility is also referred to as mental flexibility, cognitive shifting, set shifting, or task/attention switching (Canas, Quesada et al. 2003, Tchanturia, Davies et al. 2012).

[19] Together with crystalised intelligence, formed by learned skills, subjects, etc, fluid intelligence form general intelligence

Interventions focused on any one specific executive function will likely have spillover effects into some of the other executive functions.

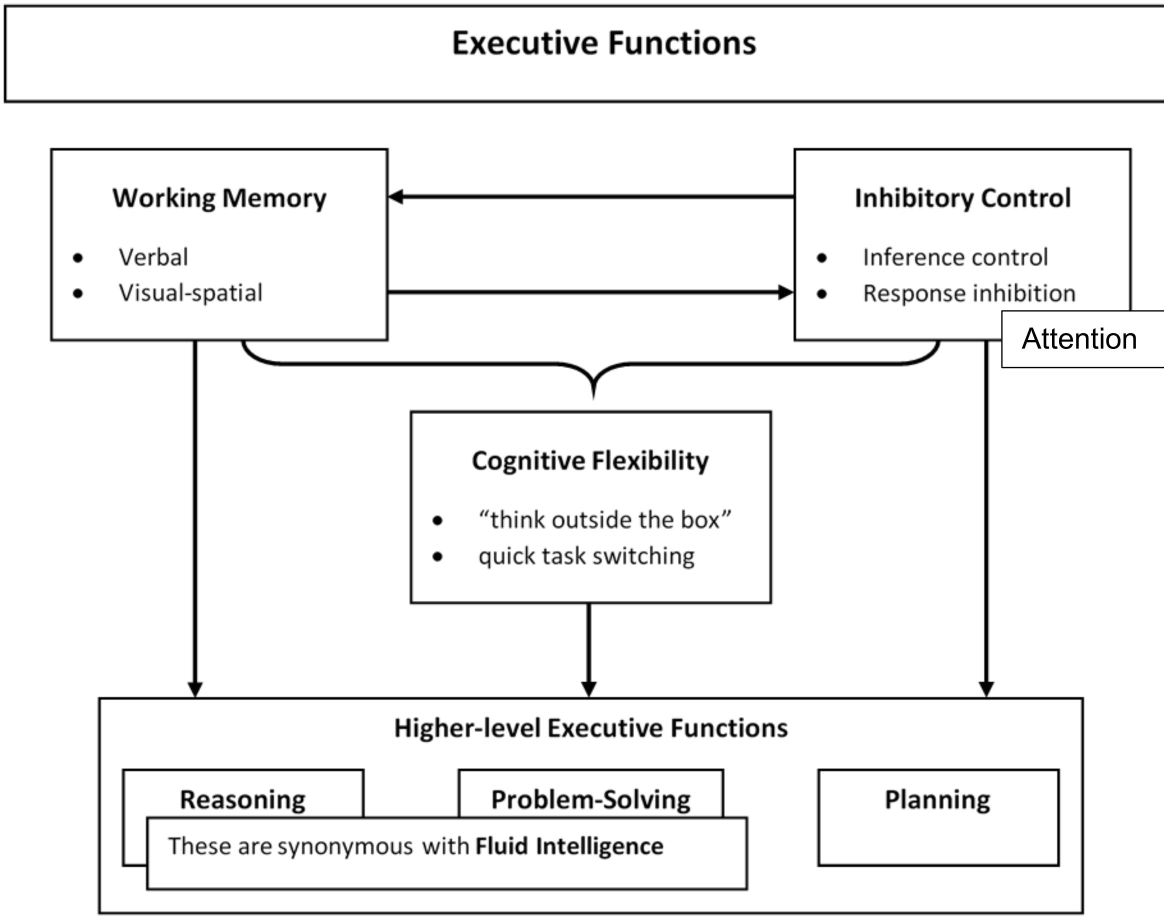

Figure 3.A.1. Simplified interrelationship of executive functions (adapted from Diamond (2013).

Different executive functions are likely to enter an agent's utility function primarily as changes to an agent's preferences as well as their feasible sets. By not acting impulsively and being able to focus on the task at hand using inhibitory control, an agent's feasible set should be larger. Inhibitory control allows an agent to be more productive with their time. Inhibitory control will also enter an agent's time preference as it is crucial in delaying gratification and choosing a better option tomorrow over a lesser option today.

Working memory may also change the feasible sets of agents. The ability to mentally store and manipulate information for sustained periods of time can make agents more efficient and productive. An example in agriculture could be an agent performing mental math to determine how much fertiliser to use on a given plot of land. Too little and the crop won't meet its full potential, too much and the excess fertiliser is of no use to the productivity of the plant and is therefore inefficient use of the fertiliser.

Cognitive flexibility is likely to change an agent's preferences as well as feasible sets. Cognitive flexibility is vital in seeing things from multiple perspectives or changing views. This ability is essential when, for example, an agent is considering adopting new technologies. Being able to see themselves in as Dean, Schilbach et al. (2019) say, 'other states of the world' can essentially make it less costly for an agent to make changes because higher levels of cognitive flexibility allow an agent to learn new rules quickly. Higher levels of cognitive flexibility also make task/attention switching easier, which could allow agents to engage in multiple and more diverse productive activities. This would allow for different feasible sets as well as different preferences for the agent.

Cognitive planning is a higher-level executive function and is likely to change feasible sets for an agent. Agents with higher levels of cognitive planning ability are better at considering multiple hypothetical options that will help them reach the desired goal. This ability to better plan in order to reach a more desirable outcome should loosen constraints and extend an agent's feasible sets.

The final higher-level executive function is fluid intelligence. Agents with higher levels of fluid intelligence have a higher ability to solve new problems without any prior experience with them. Similar to cognitive flexibility, this executive function can enter an agent's utility function through preferences as it is less costly for agents with higher levels of fluid intelligence to learn new things. This may also translate into more diverse productive activities among the agent, changing their feasible sets.

Table 3.A.1. Definitions of personality characteristics

Characteristic	Definition	References
Five-factor model of personality (i.e., the Big Five)	1. *Openness to experience* – the degree to which a person needs intellectual stimulation, change, and variety. 2. *Conscientiousness* – The degree to which a person is willing to comply with conventional rules, norms, and standards. 3. *Extraversion* – The degree to which a person needs attention and social interaction. 4. *Agreeableness* – The degree to which a person needs pleasant and harmonious relations with others. 5. *Neuroticism (Emotional Stability)* – The degree to which a person experiences the world as threatening and beyond their control.	(Borghans, Duckworth et al. 2008)
*Achievement motivatio*n	An individual's desire to do well at an activity in order to achieve a sense of accomplishment	(Borghans, Duckworth et al. 2008)
Locus of control	The extent to which people believe that they can control outcomes in their lives. Individuals with a more internal locus of control believe that their actions directly affect outcomes. Conversely, individuals with a more external locus of control believe that outcomes are beyond their control and are dependent on external circumstances	(Rotter 1966)
Self-efficacy	One's belief in their ability to succeed in a task. Self-efficacy can ebb and flow throughout one's life – a series of failures can reduce self-efficacy, and a series of successes can increase self-efficacy	(Bandura 1994)

Table 3.A.2. Measuring executive functions

Executive Function	Measurement task	Description	References
Inhibitory control	Numerical Stroop task	Measured using the numerical Stroop task, which is the same as the original Stroop task, in that individuals are asked to override their automatic responses in favor of more controlled responses. Respondents compare two numbers of different sizes in either congruent pairs (e.g., 6 2) or incongruent pairs (e.g., 6 2), and their response times are measured for either physical or size judgments. Larger inhibition scores → lower inhibitory control.	(Stroop 1935) (Besner and Coltheart 1979) (Henik and Tzelgov 1982)
Attention	Psychomotor Vigilance Task	Vigilance task measured using the app from *Psych Lab 101*. Respondents are asked to tap on the screen when a white box appears in the target area and to not respond when the white box appears outside of the target area. 100 trials were run, 20 of which had targets. The average response time of the vigilance test was recorded as the measurement of attention. Larger attention scores → lower attention.	(Basner and Dinges 2011)
Working memory	Backward Corsi block test	Measured using the app *Visuospatial Memory Test*. Respondents are required to remember a sequence of numbers in the app and then manipulate the sequence and report it in backward order from which it was originally presented to measure their working memory. Larger working memory scores → higher working memory capacity	(Corsi 1973)
Attention	Psychomotor Vigilance Task	Measured using the Psychomotor Vigilance Task (Mackworth 1948) For these tasks, individuals are asked to respond to a stimulus for an extended period of time. In this specific application, individuals were asked to look at a screen and tap when a dot appears in the top half of a target area but not when it appears in the bottom half. Scores are determined by response time; lower scores equate to better performance.	(Mackworth 1948)
Cognitive flexibility	Berg card sorting task	Individuals are asked to sort playing cards according to different categories such as colour, number, and shape. They do not know the correct sorting criteria and must infer the correct criteria through trial and error. The rules for correct sorting automatically change during the game, and the individuals once again need to infer the correct criteria. Individuals with higher levels of flexibility are better able to adapt to the new rules and thus have fewer sorting errors. Larger flexibility scores → higher cognitive flexibility	(Berg 1948)
Cognitive planning	Tower of Hanoi	Measured by requiring participants to move a series of differently sized discs from a pole on the left side to another pole on the right side, following a series of rules. The fewer moves it takes an individual to accomplish the task, the higher their ability in cognitive planning. Larger planning scores → higher levels of cognitive planning	(Kotovsky, Hayes et al. 1985)
Fluid intelligence	Raven progressive matrices	Measured using a series of progressively harder 3x3 matrix puzzles that must be solved by correctly selecting the missing piece of each puzzle. This tests the logical reasoning and the individual's ability to solve new problems without any prior knowledge. Larger fluid intelligence scores → higher level of fluid intelligence	(Raven 1936) (Raven 2000)

Table 3.A.3. Explaining entrepreneurship probit model – no selection

	Entrepreneur	
	Mean	SE
Cognitive Planning	0.161***	(0.033)
Fluid intelligence	0.069	(0.050)
Inhibitory control (symmetric)	0.925**	(0.466)
Working memory	0.053	(0.055)
Cognitive flexibility	0.163***	(0.060)
Attention (symmetric)	0.193***	(0.059)
Risk aversion	-0.007	(0.019)
Discount rate	0.815**	(0.330)
Schooling	-0.041**	(0.020)
Age	-0.000	(0.005)
Male	0.122	(0.284)
Literacy	0.364*	(0.195)
Farm size (ha)	0.017	(0.021)
Forest size (ha)	0.071**	(0.028)
Agricultural assets	0.003	(0.076)
Dependency Ratio	0.013	(0.065)
Viengkham district	0.056	(0.156)
Kham district	0.004	(0.177)
Phoukhout district	-0.180	(0.243)
Dist. to market (km)	-0.004	(0.006)
Number of ext. visits	-0.010	(0.015)
Rainy season access	0.042	(0.151)
District HQ Distance (km)	0.007*	(0.004)
Cattle Experience (years)	0.022***	(0.008)
Total labour	0.031	(0.034)
Constant	-1.045**	(0.438)
Observations	711	

Note: '***', '**', and '*' are significant at 1%, 5%, and 10% respectively. Standard errors are clustered at the village level. We use the symmetric values of inhibitory control and attention so that higher values indicate better performance in the task.

Conclusions

This thesis looked at the importance of agricultural decision-making in changing environments, in the context of smallholder producers in Southeast Asia. As a result of globalisation and climate change, smallholder producers face unprecedented change, both in terms of frequency and magnitude. Understanding how producers adapt to these new environments is increasingly important now and into the future. The three essays of this thesis all looked at different challenges facing smallholder producers in Southeast Asia, and what factors are important in their decision-making.

How Expectations, Information, and Subsidies Influence Farmers' Use of Alternate Wetting and Drying in Vietnam's River Deltas

In chapter 1, we find that expectations of alternate wetting and drying (AWD) were important determinants in deciding to use AWD. This result is accurate for the pooled sample of all locations as well as when analysing the data by river delta. The expectation of higher yields, decreased weed costs, and lower irrigation cost increased a farmer's likelihood to use AWD. We also find that when comparing the results of the logit model to the reported costs and returns, expectations match reality for yield, weeds in the paddy, and irrigation (when controlling for subsidy). The cost and return analysis revealed that AWD farmers had higher yields, higher weeding costs, and lower irrigation costs when compared to continuously flooded (CF) farmers who do not receive an irrigation subsidy.

Information about AWD plays an important role in producers' irrigation decisions. However, the producers do not seem to be receiving as much information as necessary when making these decisions. The most substantial disincentive of AWD, increased weeds in the paddy, is well understood by producers, but there is less evidence that the most considerable incentive, decreased irrigation use, is understood. The expectation that using AWD reduces water use is only a significant factor in producers' decisions to use the practice in the Mekong River Delta, and the results of the cost and return analysis show no significant differences in irrigation costs between the two groups of producers. However, we show that the benefits of reduced water use are offset by the current irrigation subsidy scheme in place for our producers. CF farmers who report receiving a subsidy pay significantly less than AWD farmers, and CF farmers who report receiving a subsidy pay significantly more than AWD farmers.

AWD has a significant role to play as the Vietnamese Government works towards meeting its stated objectives as it relates to the Paris Climate Agreement and its nationally determined contribution. Rice is responsible for nearly half of all GHG emissions in the agricultural sector of Vietnam and, as such, has substantial potential to contribute to achieving the nationally determined contribution. One of the most promising mechanisms to reduce GHG emissions in rice production is AWD, which abates nearly 50% of all GHG emissions. The main economic benefit of AWD is realised through reduced water consumption for irrigation and thus lower irrigation costs. As such, the government can use its control of irrigation subsidies to allow this incentive to be realised by farmers. We observe the effect of this subsidy in our study. If a farmer perceives that they receive an irrigation subsidy, they are less likely to use AWD by as much as 21%. This effect is most pronounced in the Red River Delta, where farmers receive support from the government to move irrigation water from the canals to the fields. In the Mekong River Delta, farmers do not receive this additional support, and thus, there is no reported effect of perceived irrigation subsidies.

The Vietnamese Government can use AWD to abate GHG emissions and move closer to achieving their nationally determined contribution without burdening themselves or Vietnamese farmers with additional costs to production. The promotion of AWD can be achieved by changing expectations through proper channels of agricultural information, particularly in the Mekong River Delta, where farmers in this study were more responses to sources of agricultural information. Furthermore, as the perceived water subsidy variable shows, AWD use can be improved by adjusting the incentives around irrigation, especially in the Red River Delta. A combination of these efforts could help Vietnam mitigate GHG emissions from rice production and move closer to obtaining its nationally determined contribution to the Paris Climate Agreement.

Climate Change Adaptation Strategies Vary with Climate Change Stress: Evidence from Three Regions of Vietnam

In chapter two, we investigate the climate change adaptation decisions of rice-producing households in Vietnam, investigating household and agricultural adaptations separately. The purpose of this chapter was to understand if some climate change stresses or impacts from climate change stress elicited stronger climate change adaptations from individuals. We find evidence that at the household adaptation level, drought, flooding, and to a lesser extent, storms and salinity intrusion, elicited the strongest autonomous adaptations from individuals. The most common autonomous response at the household level is to have a financial adaptation, such as selling assets, borrowing money, or using savings. The popularity of households using a financial response may provide an opportunity for microfinance lending in Vietnam to build capacity and reduce vulnerability in households as they adapt to climate change. Autonomous adaptations taken in the private market are generally understood to be efficient, and microfinance is a way for poorer households to access the additional resources necessary to carry out efficient autonomous responses to climate change.

Agricultural responses depended less on specific climate change stresses and more so on the impacts brought on my any stress. Low yields, crop loss, increased food insecurity, and increased debt all changed the probabilities of individuals taking specific agricultural responses. Our results also provide field-level evidence that the sources of stress vary across landscapes in Vietnam. These results support the necessity for location-specific adaptation policies in Vietnam called for in previous publications.

Chapter two provides policymakers with evidence of which stresses are already causing autonomous adaptations to occur among individuals and which responses they are using. Climate change inaction is as important as climate change action. Specific stresses, such as sea-level rise and saltwater intrusion, did not elicit strong adaptations from individuals. This void leaves room for a government response to the stresses where private adaptations are presently absent. While addressing the gaps in private adaptations that require significant public support, the government can provide short-term support for individual autonomous adaptations. Microfinance lending is a viable option to support private autonomous adaptations. However, autonomous adaptations alone are not sufficient. Instead, it should be a way to help individuals help themselves in the short run, while other planned adaptations and mitigation options are established as part of a comprehensive climate change policy.

Becoming an Entrepreneur: Cognitive Function and the Transition to the Market

In the final chapter, we change our focus from external factors influencing producers' decisions and focus on the characteristics of the decision-maker themselves. Specifically, we investigate if individuals' scores on cognitive tests can determine their decision to become an entrepreneur. We study this decision in the context of cattle producers in northern Laos, who have chosen to take advantage of the new market opportunity of raising cattle to sell at the market (in contrast to the traditional use of cattle as savings).

In this chapter, we find that entrepreneurs are different from non-entrepreneurs in several dimensions. The largest differences are that they score higher in many of the executive functions. Entrepreneurs have better impulse control (inhibitory control), including the ability to focus on selective stimuli (attention), and are better at planning (cognitive planning) compared to traditional producers. The differences in executive functions signal differences in the way that entrepreneurs process information in decision making.

The results of chapter three may have important implications on how entrepreneurship is trained. Entrepreneurship training programs are beneficial because of the importance of entrepreneurs in economic development. These programs have included psychological skills and attitude development training in more recent times in addition to the standard foundational business and economics training. There is evidence that executive functions are malleable with targeted training. Because of this, progressive entrepreneurship training programs can benefit from the inclusion of executive function training.

In the three chapters of this thesis, we demonstrate the importance of using economics to model decision making for agricultural producers. With new and ever-changing environments, modelling decisions will continue to be an important contribution from the field of economics to agricultural producers. Better understanding producers' decisions are useful in drafting effective policy and developing successful programs to help producers adapt to their changing environments.

****