# Chapter 1 Introduction

The purpose of this study is to investigate farmer households' adaptive responses, their preference patterns for climate change adaptation and the determinants of their adaptive responses. This knowledge is of great interest for designing climate change adaptation schemes. In this study, different farmer segments are assumed to have different preferences for numerous adaptive measures. Household-specific (e.g. income, farm size, household size) and site-specific characteristics (e.g. irrigation access, topography) are assumed to influence farmer preferences through their segment-membership probabilities, with preferences being relatively homogeneous within finite segments but significantly varying between these segments. According to Sagebiel (2011), the finiteness of segments ensures their significance for policy design. Collecting information on site-specific and household-specific characteristics is vital for the latent class modelling (LCM), but the collection should be based on *a priori* knowledge of possible sources of heterogeneity (Boxall & Adamowicz, 2002) to ensure efficient use of resources required for data collection.

This study starts by identifying potential impacts resulting from climate change and variability on agricultural production, with a focus on natural rubber production. The scope of this study covers impacts at both the aggregate (provincial) and farm level. Quantitative analyses of climate impacts on rubber production are limited to latex yield; other performance measures, like growth of rubber trees and latex quality, are not considered. The study continues by identifying interactions among farmers' perception of climate change and vulnerability, and their vulnerability and adaptation to those impacts. The roles and relative importance of these three components in the study area is also assessed.

This study identifies the adaptive measures available to rubber farmers and the common attributes of these measures. Several analytical models, based on heterogeneity of farmers' preferences for adaptive attributes, are used to identify the propensity of different farmer segments to adopt particular adaptive responses. Based on site-specific and household-specific characteristics, the study differentiates one farmer segment from another. Model results include relationships between segment-level adaptive responses and segment-level common characteristics. Hence, this study contributes to the literature on heterogeneous preferences at both the individual and the community level. The final emphasis in this study is on ways to deal with the negative impacts of climate change on natural rubber production in Southeast Vietnam through solutions to adapt and cope with changes in the timing, magnitude and variability of climate events. Adaptation would in turn help improve rubber production and reduce household vulnerability.

## 1.1 Climate Change and Adaptation

Climate change is affecting agricultural systems throughout the world. Climate change refers not only to increasing trends in expected values, but also increasing variability and higher incidence of extreme weather events. Such effects are expected to increase through time at rates that depend on actions to mitigate greenhouse gas emissions (Khan & Roberts, 2013).

Tropical Asian countries are particularly vulnerable to climate change because of their dependence on agriculture coupled with high population densities and exposure to climate change. Understanding of climate change as well as its potential impacts on agricultural production and social life is still limited, especially for poor farmers and rural communities whose livelihoods depend on natural conditions. Losses of crop yield and damage to dwellings and assets after extreme weather events are other consequences of climate change that affect these communities. The tropical climate is suitable for traditional rubber cultivation, and weather patterns within these areas stimulate the growth and latex yield of rubber trees (Fox & Castella, 2013). However, in recent years, leading nations in natural-rubber production are suffering from losses of latex yield and damage to trees due to climate change and variability (RRII, 2010). Although climate change is a global phenomenon (Tazeze et al., 2012), "adaptation might be conceptualised as a site-specific phenomenon to better target adaptive policies" (Comoé & Siegrist, 2015, p. 196). Perception of changing climate and weather patterns and compatible decisions to deal with them are becoming urgent for farmers, local governments and other stakeholders.

According to Tazeze et al. (2012) and Comoé and Siegrist (2015), different agro-ecological settings have different influences on farmer households' adaptive responses, because agro-ecological settings capture heterogeneity in ecological features (Silvestri et al., 2012; Tambo & Abdoulaye, 2012). Farmer households' adaptive responses are formulated more by their perceptions of climate change and its impacts than by the prevailing climatic conditions (Adger et al., 2009; Mertz et al., 2009). Farmers' perception of climate change is a precondition for their adaptation (Hansen et al., 2004; Thomas et al., 2007). In particular, their perception of climate impacts on their livelihoods is likely to influence the probability of their adopting adaptive measures (Adger et al., 2009; Esham & Garforth, 2013). Therefore, an understanding of farmer perception, vulnerability and adaptation to climate change at the local context is necessary in practice.

## 1.2 Significance of the Rubber Industry

Rubber trees have an important strategic role, particularly in Southeast Asian economies, by providing foreign exchange earnings, environmental services and livelihoods for farmers (Barlow & Muharminto, 1982; Diaby et al., 2011; Samarappuli & Wijesuriya, 2009). According to the

AGROINFO (2013), Vietnam, Thailand, Malaysia, Indonesia and India have the largest potential for natural rubber production in the world. Vietnam, Thailand, Malaysia and Indonesia are the largest rubber cultivating nations in Southeast Asia as a whole.

Rubber trees are considered a type of dual ecologically sustainable crop (Samarappuli & Wijesuriya, 2009). Their main direct output is liquid latex that runs from cuttings on bark, but timber is also an important output. Southeast Asian economies benefit from the export of these outputs. Rubber timber has become a profitable industry mainly in Malaysia, Thailand, India and Vietnam. Therefore, farmers cultivate rubber trees for the purpose of producing both latex and timber (Munasinghe & Rodrigo, 2006; Venkatachalam et al., 2013). Timber is harvested when trees become unproductive or die after a long period of tapping, but latex is the main output and the reason farmers plant rubber trees. This study focuses only on latex production, as timber is a secondary output with relative low present value at the time of planting.

Natural rubber production provides environmental services, because rubber trees have the capacity to sequester considerable quantities of carbon dioxide from the atmosphere (RRII, 2010; Samarappuli & Wijesuriya, 2009; Venkatachalam et al., 2013). Rubber plantations are good sinks[1] for atmospheric carbon dioxide and have the potential to contribute significant quantities of carbon biomass[2] to the soil carbon pool[3] (RRII, 2010). One hectare of rubber trees can sequester about 596 tonnes of carbon over 33 years, equivalent to about 903 tonnes of biomass. Compared with most other forest species, rubber plantations conserve soil moisture more effectively. They use water more efficiently under low soil moisture conditions (Samarappuli & Wijesuriya, 2009). Because of all these attributes, rubber is considered "a self-sustaining environmentally acceptable ecosystem" that may help diminish extreme climate effects (RRII, 2010; Samarappuli & Wijesuriya, 2009).

The rubber industry is socially significant, because it provides employment opportunities in both the production and processing sectors (including latex and timber) (RRII, 2010). Rubber trees also serve as a canopy for cash crops in agroforestry systems, which decreases the negative effects of intense sunlight and precipitation on cash crops and soil (RRII, 2010; Samarappuli & Wijesuriya, 2009). Rubber trees have a long period of immaturity (about 5–10 years) followed by a long period of

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[1] Sinks refer to any process, activity or mechanism that removes a greenhouse gas or aerosol, as well as their precursor from the atmosphere (IPCC, 2007).

[2] Biomass, which is usually expressed as dry weight, refers to the total mass of living organisms in a given area or of a given species (IPCC, 2007).

[3] Soil carbon pool refers to the relevant carbon in the soil. It includes various forms of soil organic carbon (humus), soil inorganic carbon and charcoal (Lal et al., 2001).

maturity (about 15–25 years). Over their rotation length they provide monthly income for 20 to 30 years.

## 1.3 Research Context

In 2009, the Prime Minister of Vietnam issued Decision No. 750/QD-TTg, approving the plans to further develop rubber production. Vietnam set an aim to ensure a planted rubber area of 800 000 ha by 2015, latex production of 1.1 million tonnes, export value of 1.8 billion USD, and processing capacity of 360 000 tonnes. The Vietnam rubber industry would remain at least at 800 000 ha until 2020 with latex production of 1.2 million tonnes and export value of 2 billion USD. Southeast Vietnam and the Central Highlands were planned to be stabilised at planted rubber areas of 390 000 ha (representing 49 per cent of the total agricultural area) and 280 000 ha (35 per cent), respectively. However, during the period of 2009–2013 the planted rubber area of the whole country exceeded 800 000 ha and reached 955 000 ha in 2013. Southeast Vietnam exceeded the area approved, some provinces developed rubber cultivation quickly after the approval of the plan. The spontaneous expansion has exceeded the master plan. Meanwhile, the industry has faced the severe challenges of climate change and market uncertainty, especially in recent years.

Rubber tree growth and development depend on local features, resource availability and technical applicability. Local features including edaphic, climate status and land topography identify whether a rubber cultivation area is considered a traditional or non-traditional rubber area (NTRA). Barriers to entering the rubber industry include the substantial investment required, high irrigation-water demand and the lateness of the first harvest. Technical management standards are available, which require rubber farmers to be able to apply them. The MARD, RRIV and VRG have responsibility for issuing and updating technical standards (e.g., preparing sites, planting, nursing rubber trees, harvesting latex). These standards additionally specify appropriate growing regions in terms of climatic, edaphic conditions and land topography. Farm households are empowered to select their farming activities. In this study climate variables are considered as negative externalities that need to be further assessed regarding their actual impacts on natural rubber production.

Southeast Vietnam, considered as the capital of “white gold” – rubber latex, has a natural area of 23 605 km$^2$, occupying seven per cent of the country. This region features mainly *ferralsols* (red basalt) and *acrisols*. Climatic and edaphic conditions in this region are unique and have advantages for large-scale rubber development. In Southeast Vietnam, rubber trees are an important strategic plant that provides high earnings for rubber farmers and contributes to poverty reduction. However, rubber trees are affected negatively by climate change and variability in general, which require rubber farmers to adapt (RRII, 2010). Understanding the adaptation strategies available is crucial to help farmers face climate change (Adger et al., 2003; Charles & Rashid, 2007), by reducing effects of its negative impacts and dealing with socio-economic uncertainties (Kandlikar & Risbey, 2000; Lasco et al., 2011; Osbahr et al., 2006; RRII, 2010).

Reports of local governments in the study area usually agree that climate change impacts on natural rubber production are mostly negative and their consequences are uncertain. As mitigation efforts have stalled, efforts to adapt to climate change are becoming more important. For most poor farmers adaptation is the most urgent choice (Lasco et al., 2011); therefore, assessment of the farm-level adoption of adaptation strategies is crucial to provide information for formulating policies (Charles & Rashid, 2007; Smit et al., 2001). This study focuses on practical needs at the farm level to help rubber farmers successfully adapt. Bradshaw et al. (2004), Kandlikar and Risbey (2000) state that the focus of farm-level assessment should include a micro-level analysis of decision-making processes that farmers have undertaken. The objective of the micro-level analysis in this study is to explore how rubber farmers in Southeast Vietnam make decisions regarding their choice of adaptation strategies. This has significance in designing micro policies to facilitate farmers' adaptation to climate change. Many studies at the farm level have contributed to the success of policies (Ongley, 1996), because the impacts of climate change and variability are most profound at the farm level (Sarker, 2012).

Technologies and cultivation practices have been developed over time to improve latex yield and technical efficiency and offset losses caused by the negative effects of climate change on rubber plantations. These solutions have been adopted in some regions, but not everywhere (Barlow & Muharminto, 1982). These different adoption patterns of farmers depend on the attributes of the technologies, the socio-economic conditions of the respondents (Birol et al., 2007; Falck-Zepeda et al., 2011) and their agro-ecological setting (Comoé & Siegrist, 2015; Tazeze et al., 2012). This study identifies a range of adaptive measures being practised at the farm level in the study area and their key attributes.

The heterogeneity of farmer preferences in their adoption of adaptation strategies is an important research question of relevance in Southeast Vietnam, where natural rubber production is prevalent and important. The implications of research findings for farmers, local governments and other stakeholders that produce the majority of natural rubber output in Southeast Vietnam is the particular focus of the study. Previous existing research contributes to this study in terms of foundational knowledge, research aspects and useful methodologies. Many previous results have indicated the determinants that increase or decrease consumer preferences among desirable attributes (Birol et al., 2007; Falck-Zepeda et al., 2011). In this study a structured questionnaire was used to determine the relationship between farmer preferences for adaptive measures and a set of explanatory variables regarding institutional, socio-economic, demographic, agro-environment, farming and geographic factors at the site and farm level.

## 1.4 Research Objectives, Scope and Questions

### 1.4.1 Research Objectives and Scope

The primary objectives of this study are to identify:

(1) farmers' vulnerability to climate change.

(2) their perception of climate change and its effect on perennial crop performance in terms of quality and yield[4].

(3) their adaptation at the farm level in the face of anticipated climate change.

(4) determinants of adaptive responses of different farmer segments when choosing adaptive measures to climate change or when formulating their preferences for adaptive measures.

(5) appropriate policies based on segment-specific responses so that policy-makers can track the efficacy of these policies.

This study conducts a case in point of the small-scale rubber sector in Southeast Vietnam through a structured questionnaire. The study was designed to answers ten research questions as listed below.

### 1.4.2 Research Questions

Ten research questions were formulated to address aspects of climate change adaptation.

(1) What are the potential impacts of climate change on rubber tree growth, latex yield and quality?

(2) Is there evidence of climate change and climate variability in Southeast Vietnam?

(3) Are there negative or positive relationships between climate variables and latex yields? If so, which climate variables affect latex yield most severely?

(4) How vulnerable are rubber farmer households to climate change?

(5) How do rubber farmers perceive climate change and its effects?

(6) Is there any adaptive deficit to climate change?

(7) What attributes underlie adaptive measures?

(8) Why do rubber farmers choose some adaptive measures but not others?

(9) What determinants affect the adaptive responses of farmer segments to climate change?

(10) What policy recommendations should be introduced to help farmer households adapt to climate change?

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[4] There are two kinds of yield of perennial crops. Yield in productive area is a ratio of harvested production to total productive area. In this study, harvested yield is a ratio of harvested production to total harvested area. Harvested area is equal to the area of productive age minus non-harvested area (DS, 2012).

This study uses a definition of adaptive deficit in the study of Lasco et al. (2011); that is, adaptive deficit refers to farmers who are assumed to be not utilising any adaptive measure to climate change and variability.

### 1.4.3 Definitions

The following terms are used throughout the thesis:

*Adaptive responses* refer to farmers' behaviour as they face tradeoffs in their preferences for adaptive measures. An adaptive response consists of a set of adaptive measures adopted by a farmer based on their specific attributes.

*Adaptive measures* refer to technologies, processes or practices that may be applied to reduce negative effects or impacts caused by climate change and climate variability; for example, rain guard technologies, water-evaporation minimisation processes, latex tapping practices, etc.

*Adaptive attributes* refer to the underlying characteristics of adaptive measures to which farmers respond when they make decisions. These attributes include cost, time, productivity, etc.

*Adaptation strategies* refer to the long-term process followed by farmers to reduce the negative effects or impacts of climate change and climate variability. Strategies are implemented through adaptive responses, which in turn depend on farmers' preferences for adaptive measures.

## 1.5 Significance and Contributions of the Study

The significance of this study is in three areas (i) the five research objectives are based on significant needs in research on adaptation in the agricultural context as identified in previous studies; (ii) the methods of analysis and data collection represent a significant resource to achieve the objectives of this study and to contribute to future studies; and (iii) the findings of this study fit into, and add to, the existing literature on climate change adaptation at the farm level.

The interactions of perception of, vulnerability to, and adaptation to climate change are important to grasp and these factors should not be considered separately in research on adaptation in the agricultural context. Farmer vulnerability to climate change and climate variability involves multi-dimensional considerations. Empirical analysis of actual and expected impacts of both climate change and variability on agricultural production, especially crop performance, is an important contribution for farmers, policy-makers and other stakeholders to more accurately perceive their vulnerability. Their perception of climate change, climate variability, adverse impacts and vulnerability is a prerequisite for adaptive responses to climate change and coping with its impacts of climate. Empirical analysis of farmer households' strategies for: adaptation and coping; determinants affecting their decisions when choosing adaptive measures; and constraints to their adaptation is a prerequisite for successful policy design. The efficacy of policies is enhanced when they are rooted in the practical needs of homogeneous farmer communities. Understanding these interactions and their components is thus of practical significance.

Similar studies of farm level agriculture have applied numerous methods of analysis, but the diversity of methods makes it difficult to compare results. This study applies solid quantitative methods of analysis based on empirical econometric models to address the research objectives. Using available and collected data in provinces in Vietnam, this study applies systematically a range of empirical econometric models and appropriate tests. To my knowledge, the combination of such models and tests has not been comprehensively undertaken in previous studies because of their complexity of application and the need for primary data. The promising techniques herein provide reliable statistical results that are more easily interpretable than more traditional methods for the audience of interest, such as local policy-makers. For example, the parameters of multinomial logit models (MNL) are normally not directly interpretable (Alauddin & Sarker, 2014). Local officials, therefore, may experience difficulties understanding results from such models. The empirical approach used here contributes to formulating quantitative analyses of farmer households' adaptation strategies and in designing appropriate micro policies that help farmer households adapt to climate change.

In developing countries, it is essential to support farmers and farm households in coping with both climate change and its associated variability that constrain their future livelihood opportunities (Kurukulasuriya & Rosenthal, 2003). According to Yu et al. (2013), if Vietnamese farmers in general are supported to respond appropriately to climate change, Vietnam is likely not only to be successful in further reducing poverty, but also provide a template for other similar regions for adapting to climate change. This study addresses this need for the small-scale rubber sector in Vietnam. Small-scale rubber farming represents 40–50 per cent of natural rubber production in Vietnam[5]. This sector is highly vulnerable to market uncertainties (Viswanathan, 2008; Wijesuriya et al., 2007) and requires special attention when formulating adaptation strategies (Wijesuriya & Dissanayake, 2009). If rubber cultivation development is properly implemented, it will facilitate the MDG of poverty alleviation and environmental sustainability. This development requires a better

[5] Production of agricultural crops is an indicator reflecting the total primary products of a certain agricultural crop or group of crops harvested in an agricultural year by a production unit or a region (DS, 2012).

understanding of rubber growers' perception of and adaptation to climate change, with particular focus on small-scale rubber farmer households. The use of resources in this small-scale rubber sector is also expected to be inefficient due to poor awareness and low adoption in terms of technical recommendations of rubber planting and producing (Mesike et al., 2009; Wijesuriya & Dissanayake, 2009).

This study uses a case study in Southeast Vietnam to demonstrate that such a comprehensive approach can contribute significantly to knowledge of and the existing literature on climate change adaptation. This study also contributes to the literature on heterogeneous preferences for adaptive measures at both the individual and the community level. The analysis highlights the importance of research on heterogeneous preferences (Birol et al., 2007; Falck-Zepeda et al., 2011). In particular, this study contributes to knowledge in the use of the LCM (the stated choice experiment method) in a farming context. This clustering approach helps stakeholders to understand adaptive motivations of farmer segments rather than individual rubber farmers, thereby giving more scope for policy contributions. Policy responses can focus on such finite segments, making it easier to track their efficacy in practice.

This study also provides background for further research on cost-benefit analysis and/or cost-effectiveness analysis of available adaptive measures in Southeast Vietnam, since it is able to identify farm-level preferred adaptive measures, yield-quality losses without adaptation, as well as expected yield-quality improvements with adaptation. Cost-effectiveness analysis is a special case of cost-benefit analysis in which all social costs of a portfolio of projects are compared with given policy goals. The policy goals in this case represent social benefits, and all other impacts are measured as social costs (IPCC, 2007). Cost-benefit analysis places monetary values on all costs and benefits associated with a given action. Costs and benefits are compared in terms of their absolute difference and/or their relative ratio, as indicators of how efficient a given investment is, as seen from the society's point of view (IPCC, 2007). According to Lal et al. (2001), costs include monetary values to implement adaptive measures. Benefits include avoided damages or the accrued benefits when adoption and implementation of adaptive measures occur. Charles and Rashid (2007) recommend that the problem of global climate change should have a standard economic approach involving cost and benefit estimation and outlining the strengths and weaknesses of avoiding future climate change. Benefits from preventing climate change should be compared to costs of avoiding damage. These costs could be estimated through changes in factor inputs such as labor, capital and technology. According to Mizina et al. (1999), adaptive measures should be assessed in terms of their cost efficiency rather than benefit-cost ratios. For example, less costly adaptive measures are more likely to be adopted (Charles & Rashid, 2007). Therefore, this study is of general interest in practice and of significance to current knowledge and existing literature on this subject.

## 1.6 Outline of the Study

The study consists of ten chapters:

***Chapter 1: Introduction***

This chapter provides background information on climate change, climate variability, their negative impacts and adaptive responses in agricultural production. This background information forms the basis for considering the rubber industry and challenges it faces, resulting from climate change. The role of the rubber industry in Vietnam and the world, the necessary conditions for industry development, and climate impacts on natural rubber production are highlighted. This chapter formulates the purpose of the study through several primary objectives. It concentrates on the main research questions regarding adaptive measures that rubber growers adopt, adaptive attributes that they prefer, and reasons for their preferences. The scope of the study is limited to the case study of the small-scale rubber sector in Southeast Vietnam, so that the study can provide detailed findings through comprehensive considerations of climate change adaptation at the farm level. Finally, the chapter explains the significance and contributions of the study.

***Chapter 2: Literature Review***

This chapter identifies information gaps and provides theoretical and practical bases for the conduct of this study. It presents definitions involved in climate change and variability, and it reviews how to measure them and their impacts on natural rubber production. It also presents definitions of perception of climate change and variability, vulnerability, adaptation and adaptive capacity at the farm level. Hence, it helps in the understanding of the interactions among perception, vulnerability and adaptation in the situation of interest. This chapter focuses particularly on previous analyses of preference heterogeneity among adaptive measures, and provides the basis for addressing objectives such as identifying (i) the determinants of choices of different farmer segments when selecting adaptive measures or when formulating response preferences and (ii) appropriate policies interacting segment-specific adaptive responses.

***Chapter 3: Overview of the Rubber Industry***

This chapter presents an overview of the rubber industry. The history of natural rubber development and its role in socio-economic development and environmental sustainability in the world and in Vietnam is outlined. Some similar features of neighbouring countries in natural rubber production are also discussed. The chapter focuses particularly on institutional contexts, agro-environments, socio-economic conditions, demographic characteristics and farm characteristics in the study area. These factors underlie the understanding of the profile of the small-scale rubber sector in Southeast Vietnam as outlined in Chapter 6. Emphases of these factors in the profile of the small-scale rubber sector are particularly related to determinants affecting the preference heterogeneity among rubber farmer segments for adaptive measures. The study area and farm sample were selected based on considerations outlined in the chapter.

***Chapter 4: Method of Analysis and Data***

This chapter sets up an analytical framework for the primary objectives of the study and the relationship of these objectives against the related research questions. The information gaps are filled by identifying the requirements of data and the appropriate quantitative methods for analysis. This chapter describes systematically methods of analysis, econometric models and compatible tests used to analyse the two kinds of data: (i) cross-sectional time series of climate and latex yield (secondary data) and (ii) survey data of site-specific characteristics, household-specific characteristics and adaptive responses of rubber farm households (primary data drawn from a structured questionnaire).

***Chapter 5: Climate Change, Climate Variability and Climate Effects on Latex Yield: Evidence Using Cross-Sectional Time Series Data***

This chapter considers the status of climate and latex yield using cross-sectional time series data within the three provinces studied. It addresses evidence related to the magnitude of the climate impacts on latex yield at the aggregate (provincial) level. National, regional and provincial data of latex yields do not show changes in the proportion of rubber clones. Because of the lack of clonal data, the analysis in this chapter focuses only on change and variability of average latex yields in the study area. This chapter uses descriptive statistics, statistical comparisons, trend analysis, simple and multiple linear regression analysis and a range of compatible tests to obtain research findings.

***Chapter 6: Profile of Small-Scale Rubber Sector in Southeast Vietnam: Evidence Using the Survey Data***

This chapter presents numerous important findings from preliminary analyses of the survey data to create a profile of the small-scale rubber sector in Southeast Vietnam. Variables considered include latex yields, institutional contexts, socio-economic conditions, agro-environments, demographic characteristics, farm characteristics, vulnerability and perception of climate change and variability. This farm-level study shows how farm households in the three provinces deal with negative climate impacts on natural rubber production. Although the study area is suited to rubber production, in terms of climatic conditions, edaphic conditions, land topography, institutions, local socio-economic conditions and rubber industry prospects; nonetheless, climate change and variability affect incomes via yield losses. This chapter discribes farmer perceptions of changing climatic conditions and the associated vulnerability. Analyses in this chapter are compared with analyses of the secondary data presented in chapters 3 and 5. This allows for the testing of whether findings using different sources of information are consistent. This chapter uses descriptive statistics, statistical comparisons, correlational analysis and a range of compatible tests to obtain research findings.

***Chapter 7: Adaptation Strategies of Farmers and Constraints to Adaptation at the Farm Level in Southeast Vietnam***

This chapter uses the survey data to identify the adaptive measures that rubber growers adopt, and the adaptive attributes that they prefer. Adaptive measures and attributes were identified in advance through the literature review and consultation with local stakeholders and rubber farmers. Information on rubber farmers' evaluation of adaptive attributes through stated preferences as well as constraints to adaptation was collected through surveys. This chapter uses descriptive statistics, statistical comparisons and a range of compatible tests to obtain research findings.

***Chapter 8: Heterogeneous Preferences for Adaptive Measures at Farmer-Segment Level and Adaptation Determinants: Econometric Analyses Using the Survey Data***

Farmer preferences for adaptive measures are considered heterogeneous. This chapter uses the survey data to identify different adaptive responses of farmer segments and reasons for their preferences for adaptive measures. Reliability analysis and factor analysis were used to obtain these research findings. This chapter also analyses relationships between site-specific characteristics, household-specific characteristics presented in Chapter 6 and their adaptation strategies in Chapter 7. The main findings of this chapter show that three different farm segments have different preferences for four adaptive response types of *resources*, *biology*, *efficiency* and *early returns*. Rubber farm households belonging to the three segments were identified by their segment-specific preferences, site-specific and household-specific characteristics. The latent class econometric analysis was used to obtain these results. This chapter uses descriptive statistics, statistical comparisons and compatible tests to analyse differences in targeted farmer segments. Segment-level analysis of heterogeneous preferences for adaptive measures provides (i) segment-specific preferences; (ii) site-specific and household-specific characteristics; and (iii) the determinants of their adaptive responses if present, which can contribute to design of adaptive policies.

***Chapter 9: Policy Implications of Climate Change Adaptation for the Small-Scale Rubber Sector in Southeast Vietnam***

All practical findings obtained in relation to climate change, climate variability, their actual impacts on latex yield, farmer households' choices of adaptive measures, their adaptive preferences, and the determinants of their adaptive responses provide useful information for aligning micro policy responses. Policy responses focus on (i) controlling the precipitation effects on latex yield, because there is a statistically significant positive linear relationship between increases in total annual precipitation and increases in latex yield; (ii) enhancing farmers' perception of climate change and its negative effects; (iii) reducing farmer households' income vulnerability (improving latex yield); and (iv) addressing practical needs of adaptation (improving adaptive capacity). A section on policy implications is divided into groups of policy responses to equip local policy-makers with the information and the decision tools required. Such an approach contributes to successful adaptation at the farm level. Lessons and empirical experiences from Southeast Vietnam can be applied to other localities and other crops.

***Chapter 10: Summary and Conclusions***

This chapter lists the ten important research questions that arise from the research objectives: (i) potential impacts of climate change on the performance of rubber trees to the impacts reported in the existing literature; (ii) occurrence of climate change and climate variability in the study area; (iii) relationships between climate variables and latex yields; (iv) farmer households' vulnerability to climate change; (v) their perception of climate change and the associated vulnerability; (vi) their adaptive responses among adaptive measures; (vii) underlying attributes for adaptive measures; (viii) heterogeneity of adaptive responses among adaptive measures; (ix) determinants of the adaptive responses of farmer segments; and (x) policy implications helping farmer households adapt to climate change.

In summary, this study addresses a gap in farming systems research in developing countries regarding the comprehensive assessment of climate change adaptation at the farm level. This assessment regarding natural rubber production is particularly useful for local policy-makers, farmers and other stakeholders who face climate impacts on their management roles and livelihoods. The ultimate purpose of this study is to promote adaptation of smallholders in natural rubber cultivation and production for several reasons. As a valuable perennial[6] crop, rubber trees help stabilise the household livelihood. Rubber trees play a vital role in uplifting local economies and in securing land ownership. Thereby, the environment would be protected and rubber trees thus would remain an ideal plant for smallholders (Rodrigo et al., 2009). The economic benefits which rubber growers obtain from high production and attractive prices will spillover to rubber workers and the rubber industry (Nugawela, 2008b).

[6] Perennial plants are those growing and giving products in many years, including perennial industrial plants (tea, coffee, rubber etc.), fruit plants (orange, lemon etc.) and perennial medical plants (cinnamon etc.) (DS, 2012).

# Chapter 2 Literature Review

## 2.1 Introduction

As efforts to combat climate change through international policies have stalled, efforts to adapt are becoming more urgent for agricultural producers, including those involved in natural rubber production. Adaptation to climate change is discussed in terms of perception, vulnerability and adaptive capacity. Understanding these three components is the key to improving adaptation at the farm level and overcoming constraints. According to Le et al. (2014b, p. 545), "if farmers are provided, in their views, with the support they do not really need, then such inappropriate support would not be the solution, but might rather exacerbate the situation. A similar problem could also occur if officers' perceptions of barriers do not reflect farmers' actual constraints". This appears to be a gap that requires all farmers, local policy-makers and other stakeholders to be equipped with the most applicably comprehensive consideration of climate change adaptation. The comprehension is associated with correct perception, appropriate actions, satisfied needs of adoption, and close association across farmers, local policy-makers and other stakeholders who face climate impacts directly on their management roles and livelihoods. Technically, the comprehension addresses graspable information, easily applicable methods of analysis and available analytical instruments.

This chapter presents a review of the literature on adaptation to climate change and relevant issues in agriculture, particularly in natural rubber production. This review covers theoretical and practical aspects of climate change, climate variability, climate-related hazards, negative impacts, vulnerability, perception, adaptation and adaptive capacity of farmers as well as factors affecting their adaptive responses. The basis of the review is to establish an analytical framework and then formulate a comprehensive consideration of climate change adaptation at the farm level. The pathways of the primary research objectives are shown in this chapter, meeting these objectives depends on the availability of data and the methods of analysis in Chapter 4 in order to answer the relevant research questions. This chapter also helps answer the first question of the expected climate impacts on rubber tree performance in terms of growth, latex yield and quality based on evidence from the literature.

As explained in Chapter 1, the broad definition of climate change includes not only changes in the trends (means) of climate variables but also in their variability (variances). When necessary, this study distinguishes between these two aspects of climate change. Change refers to trends in the mean values of the relevant factors (climate and latex yield) over time. Variability refers to the spread of these values around their mean values. These differences are explained by Thornton et al. (2014), who emphasise the importance of considering both types of changes..

## 2.2 Climate Change and Climate Variability

Climate is often defined as 'average weather' in a narrow sense, or as the state of the climate system in a wider sense (Baede et al., 2001). Climate status considers climate change and climate variability, both of which are important in the study of adaptation in the agricultural context (Lal et al., 2001; Lasco et al., 2011; Reidsma et al., 2009; Sarker, 2012). Reidsma et al. (2009) discriminate between climate change and climate variability in assessing their effects on agricultural production. Effects are assessed in terms of form and scale, as well as spatial and temporal dimensions. Impacts of climate variability are usually specified locally, but impacts of climate change are usually specified regionally. These terms are sometimes used inconsistently in daily communications and are usually cited as climate change, because their definitions and mutual relationships are confused. The study of Le et al. (2014b), for example, uses climate variability as a consistent definition. Climate change is causing the severity and frequency of extreme weather events to increase, which are the features of climate variability (Sarker, 2012). Only sectors that can adjust quickly to climate variability can adapt to climate change, since negative impacts of climate variability are likely to be less severe than those of climate change. Communities are generally more adaptable to gradual changes in given average climatic conditions, but less adaptable in the sudden and dramatic presence of inter-annual variations and extremes (Kurukulasuriya & Rosenthal, 2003). A clear distinction between climate change and climate variability is important in formulating policy responses in developing countries (Alderwish & Al-Eryani, 1999; Alexandrov, 1999; Murdiyarso, 2000). The definitions of climate change and climate variability to be used throughout this study are presented below.

### 2.2.1 Climate Change

Climate change refers to changes in the state of climate variables over a long time period and is defined as an overall shift in climatic conditions (Reidsma et al., 2009). Climate change is measured as long-term changes in average temperature and average precipitation (Kurukulasuriya & Rosenthal, 2003).

### 2.2.2 Climate Variability

According to Baede et al. (2001), climate variability refers to a variation in the mean status of climate variables over temporal and spatial scales. Climate variability reflects short-term variations, as well as frequency of extreme weather events (Kurukulasuriya & Rosenthal, 2003).

This study uses the definitions of climate change and climate variability of Baede et al. (2001) and Reidsma et al. (2009). Accordingly, it analyses climate change through trends of climate variables over time and it analyses climate variability through trends in standard deviations of climate variables across provinces over time. Trends of temperature and precipitation are analysed using secondary time series data. Sarker (2012) also used secondary time series data in some provinces of Bangladesh to measure trends of maximum, average and minimum temperatures, and to measure trends of total precipitation using monthly figures, annual figures and five-year moving averages.

### 2.2.3 Climate-Related Hazards

According to Lal et al. (2001), Southeast Asia is characterised by a tropical-monsoon climate regime with high constant precipitation and heavily leached soils. Annual mean warming in Asia is forecast to be about 3°C in 2050s and about 5°C in 2080s as a result of increased atmospheric concentration of greenhouse gases. Global warming is associated with a decrease in water resources (surface and ground) and an increase in evapotranspiration rates (Charles & Rashid, 2007). Threats of water security themselves are extreme (Alauddin & Sarker, 2014). However, Giorgi et al. (2001) predict that the warming in Southeast Asia may be less than the mean of global warming. The impacts of climate change and variability have been predicted and are occurring, but their magnitude and progress in Southeast Asia are extremely complex to grasp (Yusuf & Francisco, 2009).

Yusuf and Francisco (2009) identified climate-related hazards in Southeast Asia; however, they only focused on the five common hazards of tropical cyclones, droughts, floods, landslides and sea level rise[7]. McElwee (2010) indicates that these threats to Southeast Asia could become increasingly unpredictable over coming years. Vietnam is both one of the most vulnerable nations in the world by the effects of climate change, and one of the top fifteen nations in the world severely imperiled by natural hazards like drought and storms (McElwee, 2010). Vietnam is also in the top five nations in East Asia predicted to be the seriously affected by sea level rise (Dasgupta et al., 2009).

Agricultural production is a critical contributor to climate change (IPCC, 2007) and also has direct exposure to climate change and weather patterns (Howden et al., 2007; Liu et al., 2007; Tubiello & Rosenzweig, 2008; World Bank, 2007; Yu et al., 2013). Especially in tropical countries, climate change affects agricultural productivity and water resources, thereby economic growth, household incomes and the primary livelihood for most rural people (Ben et al., 2002; Breisinger et al., 2011; Cruz et al., 2007; Dasgupta et al., 2009; Devadoss & Isik, 2006; Kandlikar & Risbey, 2000; Kurukulasuriya & Rosenthal, 2003; Lasco et al., 2011; McElwee, 2010; Mendelsohn, 2000; Thurlow et al., 2009; Yu et al., 2013; Yusuf & Francisco, 2009). Hence, livelihood opportunities in the agricultural sector are becoming more susceptible, which constrains poverty reduction efforts in these countries (Ben et al., 2002; Kurukulasuriya & Rosenthal, 2003).

[7] Sea level rise refers to an increase in mean levels of the ocean (Lal et al., 2001).

Agricultural conditions in Vietnam are dominated by the Asian tropical-monsoon climate regime (Lal et al., 2001). Precipitation is more uniform in the central and southern regions of Vietnam, but it has been more erratic in recent years. Low precipitation and high temperatures cause droughts, while short-lived and intense precipitation events cause floods. Generally, such situations have negative effects on agricultural production (Yu et al., 2013). For example, it has been predicted that climate change in the Southeast Asian region can reduce agricultural productivity by 15–26 per cent in Thailand, 12–23 per cent in the Philippines, 6–18 per cent in Indonesia and 2–15 per cent in Vietnam (Zhai & Zhuang, 2009).

Droughts in recent years in Vietnam have affected most regions of the country, but have been mainly concentrated in the central and southern regions. Recent droughts also have lasted longer compared with droughts in the past. Heavy rains have caused more serious and frequent floods in the central and southern regions of Vietnam. The intensity and unpredictability of localised precipitation has risen and caused serious floods. The number of typhoons hitting Vietnam has reduced during the past four decades, but their magnitude has become more intense and they have tended to track southwards. Based on the regional climate models[8], the seasons of storms are likely to be extended and have unusual occurrences (McElwee, 2010). El Niño and La Niña are extreme climate events[9] that have become more intense during the past fifty years, causing natural disasters that have become more severe and frequent (Thanh et al., 2004; Yu et al., 2013). Most of natural disasters in Vietnam are related to weather and climate variation (Thanh et al., 2004). Damage to crops and dwellings after natural disasters have put many Vietnamese rural areas into poverty, and there are enormous threats to people whose livelihoods depend on natural resources (Dasgupta et al., 2009). Livelihood consists of capabilities, assets (in terms of material and social resources) and activities needed for a means of living. A livelihood is sustainable if it can cope with and recover from natural stress and shocks, while maintaining or enhancing its capabilities and assets (Chambers & Conway, 1992). Sustainable livelihood of households is related to their access to five groups of capital assets: natural capital, human capital, physical capital, financial capital and social capital (Bebbington, 1999; Viswanathan, 2008).

[8] Regional scale is defined as a range of 104–107 km$^2$. Sub-continental scale is from 107 km$^2$, and local scale is less than 104 km$^2$ (Giorgi et al., 2001).

[9] An extreme climate event is considered to be an average of a number of extreme weather events over a certain period of time, where the average itself is extreme (e.g. mean precipitation over a season) (Baede et al., 2001).

## 2.3 Potential Impacts of Climate Change and Variability

### 2.3.1 Impacts on Agricultural Production

There are two kinds of climate impacts on agricultural production. Potential climate impacts are those that could occur without adoption of adaptive measures, whereas actual impacts occur after adoption of adaptive measures. There are two assumptions in considering actual impacts of climate change in the short-term. Firstly, it is assumed that there is no new technological advance employed to diminish the impacts of climate change or, if there is one, it is not immediately effective. Secondly, it is assumed that adaptive capacity remains stable. Technological advance, adaptive capacity or any socio-economic variables can change over time, and their changes can impact on the magnitude of the vulnerability that farmers face. Thus, actual impacts of climate change on farmers can also differ.

Lasco et al. (2011) point out that it is important to understand clearly the actual detrimental impacts of climate change and variability on agricultural production, in order to reduce such impacts as well as enhancing the resilience of farmers. Resilience refers to the amount of change that natural and human systems may experience without varying the state of the systems (Ahmad et al., 2001). Reidsma et al. (2009) and Lasco et al. (2011) discuss the projection of actual impacts of climate change at the farm and regional levels. The projection requires a consideration of impacts of climate change, climate variability, institutional contexts, agro-environments, socio-economic conditions, demographic characteristics, farm characteristics and crop yields. These influence the vulnerability, perception and adaptive capacity at the farm level.

Some climate impacts can be adverse or favourable. For instance, higher carbon dioxide concentrations and higher temperatures are likely to cause pest and disease outbreaks. Higher carbon dioxide concentrations are also expected to have positive impacts on plants, because there is greater water-use efficiency and a higher rate of photosynthesis (Kurukulasuriya & Rosenthal, 2003). In some cases, in the presence of floods, farmers take advantage of soil nutrient supplements via sediments (Yu et al., 2013). However, in tropical regions mostly negative climate impacts are expected (Mendelsohn, 2000). There are four types of risks in the agricultural sector (Kurukulasuriya & Rosenthal, 2003):

(1) production risks due to weather variation and crop diseases and pests,
(2) ecological risks from climate change, pollution and natural resource management,
(3) market risks from variation of input and output prices, and
(4) regulatory or institutional risks due to government intervention in agriculture.

These risk types need to be distinguished in choosing research orientations and policy implications. As can be seen in Chapter 1, this study focuses on the scope of production and ecological risks.

### 2.3.2 Impacts on Natural Rubber Production

Most of the research on the relationships between climate variables and rubber farming activities were derived from Sri Lankan journal articles, since the literature on rubber tree-based farming systems research was concentrated in this region (Rodrigo & Balasooriya, 2009). There are no available studies in English on rubber tree-based farming systems in Vietnam. Much of the emphasis in the Vietnamese literature has been on the adaptation of poor rice farmers, while this study focuses on thriving regions in Southeast Vietnam with better-off farmers. A thriving region may capture unique features in agricultural production, because the poverty status of a community may have an adverse correlation with agricultural productivity through constraining its access to necessary resources (Yu et al., 2013). According to Rao et al. (1998), the relationship between latex yield and climate variables in any of the rubber growing regions had not been reported. Some studies on this relationship commonly conducted field experiments at small-scale rubber plantations, with uniform genetic materials and similar agro-management conditions. There are similar features of the rubber development history and rubber farming systems amongst rubber growing nations in Southeast Asia (these are described in detail in Chapter 3), so findings from these nations are useful for this study.

There are various climate-related hazards affecting natural rubber production, depending on temporal and spatial dimensions. The temporal dimension refers to hazards in the long term and the short term and includes actual and potential impacts. The spatial dimension refers to hazards in regional or local scope. This study focuses on hazards resulting from changes in temperature and precipitation over time on latex yield, because distribution of precipitation, temperature, sunshine and humidity are the main factors contributing to yield variability in different agro-ecological settings (Rao et al., 1998).

Climate change interferes with biological processes of rubber trees. It has negative impacts in terms of tree growth, latex quality and yield through various direct and indirect mechanisms over which growers have no control (Purnamasari et al., 2002; RRII, 2010; Venkatachalam et al., 2013). Mechanisms interfering with biological processes indirectly include climate change reducing available resources, increasing riskiness of adaptive efforts and constraining returns on rubber production investment. Almost all of the traditional rubber growing areas in the world suffer from climate extremes. Warmer and drier climate in these areas is expected in coming years, which may significantly diminish the supply of natural rubber (RRII, 2010). According to Kurukulasuriya and Rosenthal (2003) and Priyadarshan (2003), changes in temperature and precipitation patterns would result in changes in soil moisture, soil texture, soil drainage and water availability for irrigation that subsequently affects latex yield.

Potential impacts of climate change on rubber tree growth and latex yield are complex and difficult to anticipate. The intensity of climate change will vary across the traditional rubber growing areas in the world, and it is difficult to anticipate exactly how these changes will occur in the future (IPCC, 1996b; RRII, 2010). This is why adaptation that improves the resilience of farming systems and households is essential for coping with climate change in tropical countries.

The RRII (2010) found heterogeneous effects of maximum, average and minimum temperatures on latex yield and tree growth in some rubber growing areas in India. There is evidence that latex yield is affected by climate variables such as total precipitation received, temperature (Lobell et al., 2007), the frequency and duration of rainy events (Purnamasari et al., 2002). Reidsma et al. (2009) suggest that variation in temperature (i.e. difference between daily maximum and minimum temperatures) has considerable effects on crop yield, while other researchers suggest that a change in mean temperature would have more effect on crop yield. Results from the studies of Rao et al. (1998) and Raj et al. (2005) show that maximum temperature has the most significant impact on dry rubber latex yield[10] (DRC).

Tapping[11] usually occurs in the early morning, while the temperature is low, to ensure obtaining latex flows strongly enough from rubber trees. The latex flow rate is high in the early morning resulting in a high latex yield, so an increase in minimum temperature could affect latex quality and yield at tapping (Nugawela, 2008b; RRII, 2010). DRC of different clones is affected differently by minimum temperature (Priyadarshan, 2003). Rubber tree diseases are considered to be a serious problem, especially as rubber trees are usually farmed as a monoculture. Higher temperature would increase incidences of pests and diseases on crops, but lower temperature could affect photosynthesis of young rubber trees and thereby reduce their growth (RRII, 2010).

Precipitation affects rubber trees at all stages of their growth, and low precipitation is a key constraint in widespread rubber cultivation in drier areas[12] where are considered a NTRA. Lower precipitation could decrease areas under irrigation (RRII, 2010). High precipitation also causes losses of latex yield directly because of washout by rainwater. According to Purnamasari et al. (2002), an increase in precipitation could have an increased effect in variability of latex yield. In wet seasons, rubber farmers are usually concerned about delays and losses of latex yield and production in tapping. For example, rainy weather limits the number of tapping days, while tapping days

[10] Dry rubber latex yield in grams of latex coagulating in collecting cups is measured per tree per tapping.

[11] Tapping is a cutting action that helps latex flow off rubber trees due to a pressure imbalance between the inside and the outside of cut bark.

[12] Since demand for natural rubber and rubber wood products had increased, there had been widespread rubber cultivation in drier areas of Sri Lanka (RRII, 2010).

influence latex yield and production. Thus, rubber farmers have to adapt to the rainy weather in order to ensure enough tapping days (Barlow & Muharminto, 1982; Nugawela, 2008a). “It has become a common practice for the rubber growers to complain, each year that they are unable to harvest their rubber to full potential due to the interference of rain on tapping” (Nugawela, 2008a, p. 42).

In wet seasons, precipitation is unevenly distributed among provinces in Vietnam, and rain events usually last several days. The commencement of wet seasons varies and can occur too early or too late. Some severe events can occur in wet seasons, such as storms, tornadoes, flash floods, heavy wind and rain. Importantly, in recent years, storms and tropical depression bands originating from the East Sea have significantly affected Southeast Vietnam more frequently. Their severity levels depend on magnitude, direction and position of storms and tropical depression bands (VNCHMF, 2013). Such severe events can impact on rubber trees’ biophysical characteristics and rubber farmers’ socio-economic conditions. Precipitation and temperature distributions are related to variability in latex yield (Purnamasari et al., 2002). The fact remains that there is a stratum of heterogeneous effects of climate variables on the performance of rubber trees, but irrigation water and soil moisture appear to significantly affect the performance of rubber trees.

### 2.3.3 Measuring Climate Impacts

Measuring climate impacts is to define and evaluate detrimental and beneficial impacts of climate change on natural and human systems (Lal et al., 2001). Some studies have used linear regressions to measure climate impacts on latex yield and DRC, and have employed time series data of climate variables and yields from field experiments (Rao et al., 1998). They have considered climate variables (e.g., precipitation, temperature, sunshine duration, pan evaporation, vapour pressure deficit) as predictors which affect latex yield and DRC. To my knowledge, there have been no similar studies using aggregate level data. The reason is that aggregate level data of latex yield and DRC are of heterogeneity of genetic materials and farming practices (Rao et al., 1998).

## 2.4 Vulnerability to Climate Change and Variability

### 2.4.1 Rationale for Assessing Vulnerability

Vulnerability measures a person’s ability to adapt to external natural shocks on their livelihood. Also, vulnerability indicates the degree to which natural and human systems are susceptible to, or unable to cope with, adverse effects of climate change and extremes (Lal et al., 2001).

Lal et al. (2001) assessed vulnerability to climate change in the Asian region; and the degree of vulnerability among regions in Southeast Asia was modelled by Yusuf and Francisco (2009). This information could be useful for stakeholders including farmers, decision-makers and researchers defining priorities and adaptation strategies in Southeast Asia to address climate change. Lasco et al. (2011) identified farmer vulnerability levels to impacts. They argue that assessing vulnerability is crucial in research on adaptation, because adaptation strategies would differ depending on the vulnerability profiles of a region or a community (Lal et al., 2001).

### 2.4.2 Measuring Vulnerability

Yusuf and Francisco (2009) utilised a mapping instrument to produce a master map that showed degrees of climate-related vulnerability in Southeast Asia. Vulnerability may be identified as a function of three indicators including exposure, sensitivity and adaptive capacity. Yusuf and Francisco (2009) quote these three definitions as follows: (i) Exposure refers to the nature and intensity to which natural and human systems are exposed to during climate change and variability; (iii) Sensitivity refers to the degree to which natural and human systems are affected, either adversely or beneficially, by climate variables. The effect may be direct from a change in crop yield in response to a change in the mean or variation of temperature or indirect from other damage caused by an increase in frequency of extremes; (iii) Adaptive capacity (adaptability) refers to the ability of natural and human systems to adjust to the consequences of climate change, climate variability and extremes in order to moderate potential damage, as well as taking advantage of opportunities. Also, it indicates all capabilities, resources and institutions of a nation or a region to implement effective adaptive measures (IPCC, 2007).

Yusuf and Francisco (2009) obtain a general indicator of climate-related vulnerability by averaging these three standardised indicators. In relation to vulnerability levels, Burton et al. (2000) reveal that natural and human systems with the greatest sensitivity and the least adaptability to climate change may be the most vulnerable. According to Yusuf and Francisco (2009), the method of identifying the most vulnerable nations is through an identification of the most vulnerable areas[13] within these nations. They collected available data at the sub-national level (state, provincial and district units) for seven Southeast Asian nations (including Vietnam, Thailand, Indonesia, Malaysia, Laos PDR, Cambodia and the Philippines). As shown in Figure 2.1.B, most regions of Vietnam, Thailand, Malaysia and Indonesia had the lowest vulnerability level to the five external natural shocks (these are presented in Section 2.2.3).

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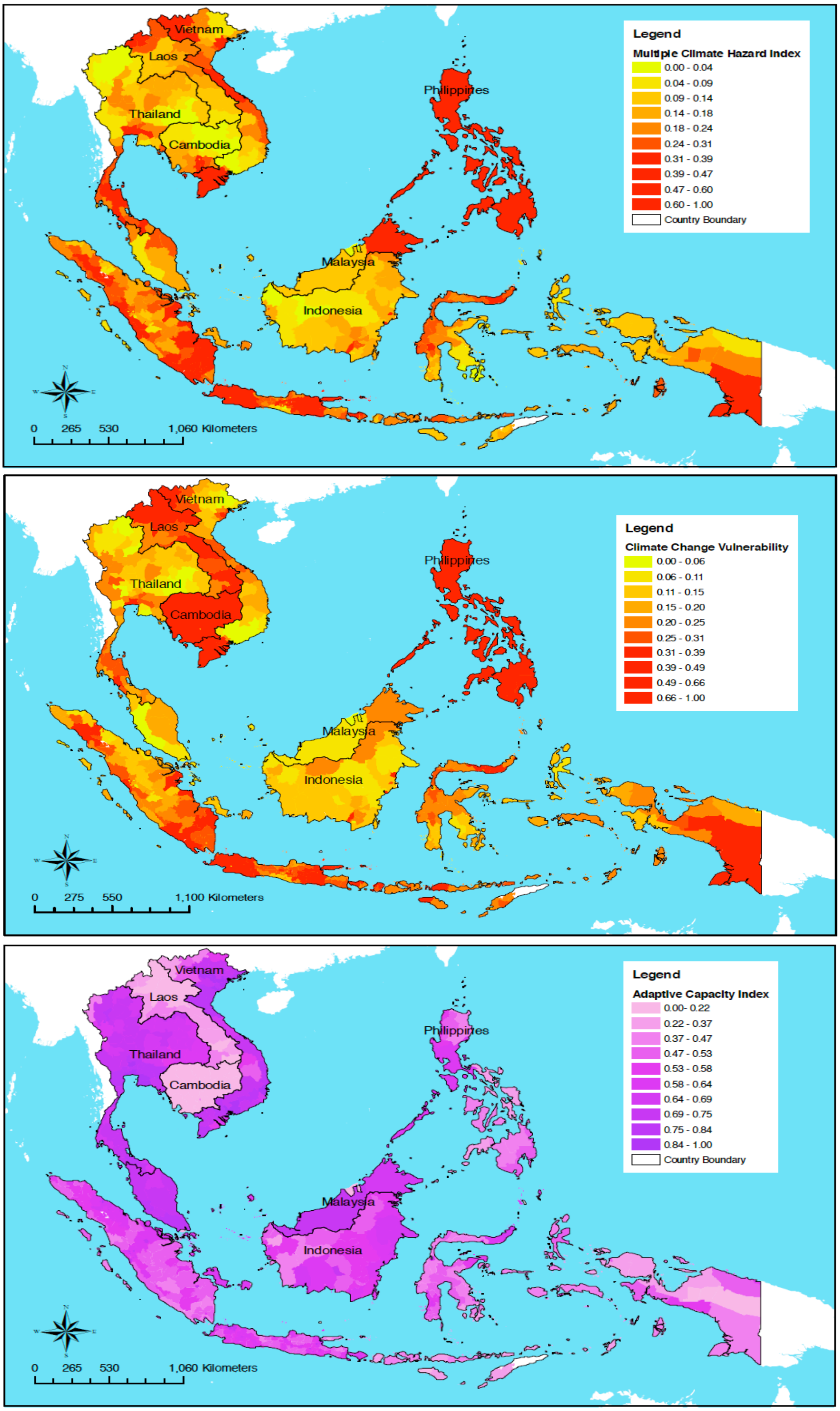
[13] This assessment was conducted at 530 sub-national areas including 341 districts of Indonesia, 19 provinces of Cambodia, 17 provinces of Laos PDR, 14 states of Malaysia, 14 provinces of the Philippines, 72 provinces of Thailand, and most (53/64) provinces of Vietnam.




A

B

C

**Figure 2.1: Map of adaptive capacity in Southeast Asia**

*Source: Yusuf and Francisco (2009)*

Climate variables cause three types of vulnerability: income, poverty and inequality (Yusuf & Francisco, 2009). Income vulnerability represents farmers' losses of on-farm income caused by climate variables through decreasing crop yields or other causes such as decreasing output prices and increasing production costs. Vulnerability to poverty represents farmers' insecurity of livelihood. For instance, if farmers' main source of income is rubber trees, when this crop fails they do not have another source of income to fall back on. Vulnerability of inequality represents farmers' ability to access resources in the presence of external natural shocks. All three types of vulnerability make cultivation and livelihood more difficult for farmers.

Osbahr et al. (2006) stated that there had been qualitative assessments of vulnerability, but socio-economic effects had been inadequately studied. There have been some studies of vulnerability of farmers in developing nations who face climate change and variability. Nonetheless, most of them concentrate on cash crops such as rice and cassava in regions that have the highest sensitivity and vulnerability. Therefore, an approach of income vulnerability fits quantitative assessments of vulnerability.

There are other factors affecting vulnerability to climate change; such as high population density and high exposure (Yusuf & Francisco, 2009). Socio-economic conditions and institutional contexts of a region could influence its vulnerability to extreme weather events faced by farmers (Smit et al., 2000). Vulnerability may vary over time, since the variables of exposure, sensitivity and adaptive capacity are not fixed. They can be assumed to be similar in the short-term, but they can be different in the long-term. To capture farmer vulnerability in the short-term, the variables of exposure, sensitivity and adaptive capacity must be assumed to be constant (Yusuf & Francisco, 2009). Assessing vulnerability to climate change is limited when there is a failure to distinguish between potential and actual impacts (Ahmad et al., 2001).

## 2.5 Perception of Climate Change and Variability

### 2.5.1 Role of Perception of Climate Change and Variability

The role of perception of climate change and variability is crucial in coping with climate change (Maddison, 2007; McElwee, 2010; Meinke et al., 2009; Reidsma et al., 2009; Smit et al., 2000; Wijesuriya et al., 2011; Yusuf & Francisco, 2009). According to Le et al. (2014b), studies on farmer perception of climate change and constraints to adaptation in Southeast Asian countries remain significant. Maddison (2007) states that actual adaptation to climate change follows a two-stage process: (i) perceiving that climate change is occurring, and (ii) choosing whether or not to take adaptive measures. Therefore, both perception and adaptation must be considered in adaptation research. Relationships among climate change, climate variability, climate-related hazards, exposure, sensitivity, vulnerability, adaptive capacity, crop management and crop yield are particularly complex and differ between regions. A comprehensive understanding of these relationships would be required in assessing the impacts of climate change and variability on agricultural production (Lal et al., 2001).

Many researchers have provided evidence on the importance of perception. According to McElwee (2010), adaptation to climate change is influenced by individual perception of climate change. It is crucial for farmers in affected areas to adapt to extreme weather events, but this requires farmers to clearly perceive what potential impacts of these events might be. According to Raymond and Spoehr (2013), heterogeneity in the understanding of climate change impacts on farmers' adaptive types. Meinke et al. (2009) indicate that negative effects of climate change and variability have not led to proper adaptive measures yet, since there is a lack of experiential knowledge. However, adaptation is sometimes only undertaken by people who can perceive climate change (Maddison, 2007). Farmers' adaptive actions might be more efficient if the farmers could improve their awareness of adaptive processes (Smit et al., 2000). According to Reidsma et al. (2009), recognition of hazard exposure is a significant factor for appropriate adaptation, since this could stimulate adaptive responses. Farmer perception of climate change may affect their cultivation efficiency, because better perception of climate change can help farmers choose proper adaptive measures. According to Yohe and Neumann (1997), farmers could act rationally with perfect information or given uncertainty in some cases. Charles and Rashid (2007) observe that, although a person may not have a comprehensive perception of climate change, he could still take appropriate adaptive actions by randomly adjusting to maximise profits.

### 2.5.2 Measuring Perception

According to McElwee (2010), the perception of climate change relates to changes in daily weather status and their negative impacts on crop yield. He measured farmers' perceptions of changes in local weather patterns in Ben Tre and Can Tho provinces (Vietnam). Local people were asked about their common perception of climate change in the past, present and future. He concluded that their perception of climate change and its causes varied significantly among individuals over time, but most of them concurred that the weather status was becoming less easy to anticipate and more prone to severe events. For example, the length of droughts had increased; the intensity of precipitation had increased; and the unpredictability of wet seasons had increased. The seasons were occurring earlier than in the past. The interviewees expressed concern over the weather status, including high temperature, early rains, floods, typhoons and saltwater intrusion. Those respondents' statements of local prevailing meteorological variables were then compared to historical records of climate at the hydro-meteorological stations.

### 2.5.3 Barriers to Perception

There are threats that limit farmer perception of climate change and variability. Awareness of these concepts and ways to respond to their impacts are limited, especially in developing nations (Nelson et al., 2010).

Imperfect awareness among decision-makers of local and regional impacts reflects limited national capacities in climate monitoring, climate forecasting and coordinating in the formulation of policy responses. The available information on, and public awareness of the impacts of climate change, particularly in Asia, are insufficient. Insufficient information also makes it more difficult to improve public awareness of the climate impacts, which can hinder effective adaptation (Lal et al., 2001).

In practice, the awareness of a few experts and local officials to climate change showed limitations because of the lack of information, methods, instruments and empirical experience in order to cope with it. Indigenous knowledge could help local people face natural disasters, but such knowledge may become less effective due to the severity of climate extremes that are beyond human control (McElwee, 2010). Climate phenomena that are out of local experience mean that people are likely to require basic knowledge to cope with climate change. Knowledge seems inadequate, regarding whether or not natural disasters could occur more often and be stronger, or where they may occur (IPCC, 1996b). From this point of view, the threats of climate change become much more severe if farmers do not improve their awareness and do not prepare for adaptive actions in the coming years.

## 2.6 Adaptation to Climate Change and Variability

### 2.6.1 Role of Adaptation to Climate Change and Variability

Adaptation has potential to help farmers, particularly poor farmers, overcome the threats of climate change (Lasco et al., 2011; Osbahr et al., 2006; RRII, 2010), reduce the negative impacts of climate change, protect their livelihoods and enhance any potential advantages that climate change may bring (Gandure et al., 2013; Ishaya & Abaje, 2008; Mertz et al., 2009; Thomas et al., 2007; Wheeler et al., 2013). According to the IPCC (2007), adaptation refers to measures and initiatives to diminish the vulnerability of natural and human systems to actual or potential impacts of climate change. Adaptation also refers to adjustments or interventions over time (e.g. season to year or decades to centuries), which manages the losses or takes advantage of the opportunities caused by climate change (Ahmad et al., 2001; Penny, 2008).

### 2.6.2 Adaptive Types to Climate Change and Variability

Ideally, a comprehensive strategy to cope with climate change and variability includes both adaptation and mitigation (Lasco et al., 2011). According to Harris and Roach (2007), two types of solutions can be used to minimise the negative impacts of climate change: preventive measures to mitigate the impacts and adaptive measures to deal with consequences of the impacts.

Harmer and Rahman (2014) reviewed the literature on farm-level climate change adaptations in developing countries, focusing on farmers' perceptions and their adaptations. They found difficulties in discrimination between risk mitigation strategies (coping strategies or livelihood strategies) and adaptation strategies to climate change by their temporal and spatial dimensions. For example, farmers can concern more about crop prices than climate change so that their adaptations are driven by profit considerations or other livelihood reasons. Harmer and Rahman (2014, p. 818) quote that "climate change is rarely the solo or primary motivator for adaptive actions". This study tries to separate farmers with climate motivators for adaptive actions out of pooled farmers. This effort can be addressed by analysing farmers' choice behaviours among adaptive measures. Also, Harmer and Rahman (2014) found difficulties in discrimination between adaptation strategies to climate change and these to climate variability. In addition, the link between farmers' perceptions of climate change and their adaptations is difficult to grasp. This is an approachable gap that needs to be obtained in this study.

Lasco et al. (2011) state that there are six adaptive types: reactive (ex-post[14]) and anticipatory (ex-ante[15]) adaptation depending on timing; autonomous[16] and planned[17] adaptation depending on organisation or administration; and private and public adaptation depending on scope. Ex-post or ex-ante adaptive measures have strengths and weaknesses (Kurukulasuriya & Rosenthal, 2003). Ex-post adaptive measures depend on available resources such as manpower, institutional capacity, finance

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14 Reactive (or autonomous) adaptive measures to be made in response to consequences of climate impacts are called "ex-post". In this case, decision makers are able to perceive what is coming. Reactive adaptation is implemented after experiencing climate impacts (Kurukulasuriya & Rosenthal, 2003).

15 Adaptive measures to be made in anticipation of a coming change are called "ex-ante" or "planed". In this case, decision makers are able to predict what have occurred. Anticipatory adaptation is proactive and taken before full perception of climate impacts (Kurukulasuriya & Rosenthal, 2003).

16 Autonomous adaptation is a response to climate variability irrespective of external intervention in its performance. For instance, as a farmer changes his cultivation schedule to adapt to variation of precipitation, he does not pay more attention to what local authorities may intervene.

17 Planned adaptation involves institutions and policies enhancing adaptability through new opportunities, advanced technologies and infrastructure. For example, governments order researchers to develop and introduce some drought-tolerant clones as long-term adaptive solutions.

and technology (Ausubel, 1991). Ex-ante adaptive measures apply to capital-intensive sectors such as coastal or forest protection, and it is recognised that they decrease long-term vulnerability regardless of ex-post adaptive measures (Fankhauser et al., 1999). However, this type of adaptation requires precautions to be taken against possible future events. If climate variability is sudden or dramatic, the investment in capital-intensive sectors becomes less attractive (Kurukulasuriya & Rosenthal, 2003).

According to Kurukulasuriya and Rosenthal (2003) and Reidsma et al. (2009), there are additional adaptive types, including short-term and long-term adaptations depending on duration and adaptive timing. Short-term adaptation usually deals with severe weather events and requires rubber farmers to cope urgently, because such events can occur unpredictably. Long-term adaptation usually deals with changes in mean temperature, precipitation and sea level rise, requiring rubber farmers to have adaptation strategies to diminish the impacts of climate change and variability. Adaptive options include not only complex actions of governments or international bodies, but also the simple actions taken by individuals (McElwee, 2010). For instance, most respondents in the study of McElwee (2010) in Vietnam had not changed their cultivation techniques (complex actions) in the last five years, but a few residents grew trees or dug water pools (simple actions) to improve their farming conditions in response to climate change. However, simple adaptations that suit moderate climate change may not be very effective with more severe climate change (Howden et al., 2007). Effective adaptive options require a comprehensive scrutiny of public awareness and vulnerability (Lal et al., 2001). Additionally, because of priorities in resource allocation, the efforts of governments and communities are likely to focus on regions that have the highest sensitivity and vulnerability (Lasco et al., 2011; Osbahr et al., 2006). While richer nations may be able to afford to adapt to negative impacts of climate change, poorer ones alone seem unable to afford preventive actions (Harris & Roach, 2007).

In some cases, private adaptation is likely to be enough to diminish climate-related risks, but in general private adaptation to climate change is seldom enough. Some measures may be taken at the individual or farm level, others require collective action and government intervention (Charles & Rashid, 2007). In the case of Indian agriculture, private adaptation was estimated to reduce the potential damage from climate change by about 15–25 per cent (Ahmad et al., 2001). McElwee (2010) measured collective adaptive actions in some Vietnamese communities and studied farm households' individual adaptive actions. Most collective action consumed time from households rather than money. This means that the financial costs of collective actions are not high, but people need to dedicate time to them. It is important to have some idea of the adaptive costs experienced by different regions. In many regions the benefits of strong and early action far outweigh economic benefits of no action (Harris & Roach, 2007).

Harmer and Rahman (2014) divide common adaptation strategies into six adaptive types: (i) financial adaptations, (ii) labour adaptations, (iii) technology-based strategies, (iv) land-based strategies, (v) cultural strategies and (vi) support from available resources. Although every adaptive type has specific identities, some of them have overlaps. Birol et al. (2007) and Dung (2007) indicate that adaptive responses should be dynamic, meaning that no one solution will be appropriate all the time. A change in technologies and socio-economic conditions of farmers influences farmer preferences among adaptive measures. Charles and Rashid (2007) and Reidsma et al. (2009) observed that impacts of climate change, climate variability, institutional contexts, socio-economic conditions, agro-environments, demographic characteristics, farm characteristics, crop yields and family income could affect adaptive types at the farm level. Therefore, policy responses should be intentionally updated.

According to Charles and Rashid (2007) and Lasco et al. (2011), adaptive measures should be conducted as complementary strategies and should not be used in isolation. Many adaptation strategies for climate change that have been undertaken in developing nations have usually focused on long-term scenarios. They tend to have less direct relevance to farmers. Nonetheless, adaptation in the short-term may result in inadaptability in the long-term. Thus, a long-term (planned) adaptation for farming performance is necessary. Adaptation to climate change and variability needs different sets of policy responses (Kurukulasuriya & Rosenthal, 2003).

### 2.6.3 Measuring Adaptation

Measuring adaptation consists of applying indexes and using them to evaluate availability, economic feasibility and applicability of adaptive measures (Lal et al., 2001). Osbahr et al. (2006) presented qualitative assessments of adaptability of rice and cassava farmers in developing nations. Lasco et al. (2011) analysed the adaptive deficit of farmers to identify the climate-risk they faced through the following key steps:

(i) Assess the climate-related hazards that farmers face.
(ii) Analyse farmer vulnerability due to climate impacts.
(iii) Assess the strengths and weaknesses of local adaptive actions.
(iv) Assess the effectiveness of each adaptive option with respect to its cost-benefit ratios or cost efficiency.
(v) Determine if an adaptive deficit exists.

### 2.6.4 Adaptive Capacity

Previous studies usually examine the adaptive capacity of communities, and they use an indicator of adaptive capacity that is constructed as a function of socio-economics, infrastructural conditions and technological status (Figure 2.2). For instance, Yusuf and Francisco (2009) measured the adaptive capacity of communities in Southeast Asia. Following the RRII (2010), some studies used mapping tools to show adaptive capacity of rubber cultivation over different areas. The information was integrated in a map that showed portions of rubber plantations in different locations, and categorised them into three degrees of related adaptability to precipitation variability including low, moderate and high adaptability. Osbahr et al. (2006) assessed qualitatively adaptability of rice and cassava farmers in developing nations. However, these studies usually considered adaptive capacity of communities to particular outcome variables of climate.

Figure 2.1.C shows the relatively high adaptive capacity of Southeast Asian nations, excepting Laos PDR and the Philippines. Yusuf and Francisco (2009) consider the technological status with respect to electricity coverage (the percentage of households accessing electricity) and irrigation coverage (the percentage of irrigated agricultural land). The infrastructural conditions are with respect to road density (the number of km of road per $km^2$) and communication (the number of fixed phone lines per capita). Three component indicators of socio-economic factors consist of the human development index (HDI), the poverty incidence and income inequality. HDI is constructed from standard of living, longevity and education level.

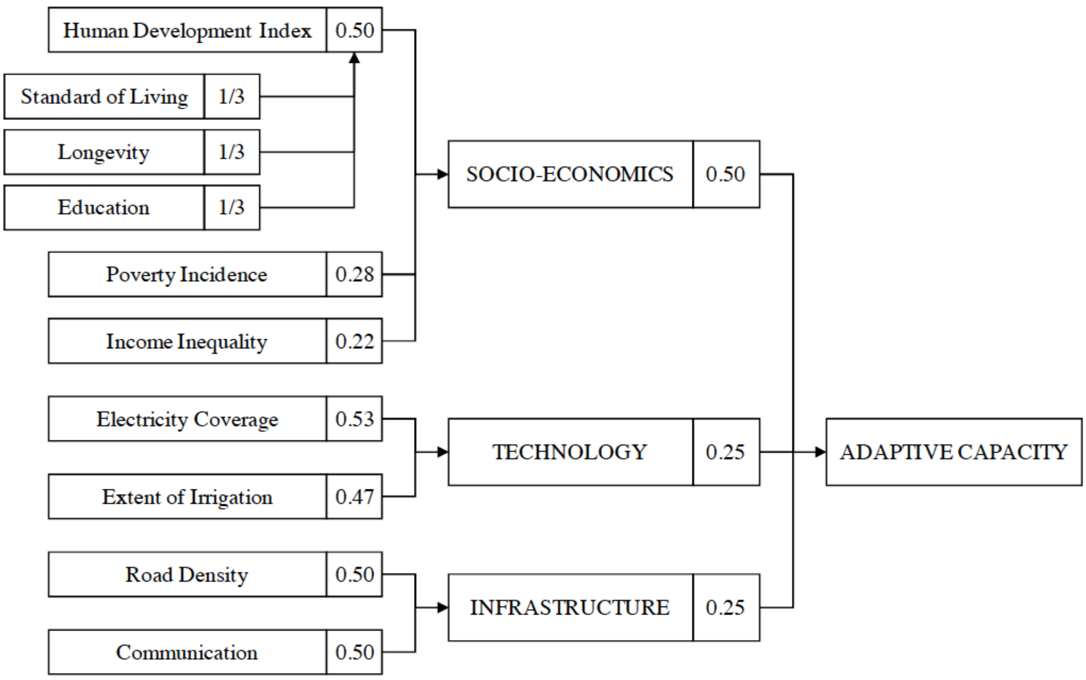


**Figure 2.2: Construction of an adaptive capacity index**

Numbers in the boxes are weights of each component indicator

*Source: Yusuf and Francisco (2009)*

According to Yusuf and Francisco (2009), adaptive capacity plays a primary role in changing the spatial pattern of vulnerability. In the case of Cambodia, low adaptive capacity is in the most vulnerable regions, irrespective of their low exposure to climate-related hazards. In the case of the eastern coast of Vietnam, this region is susceptible to tropical cyclones, but it has a high adaptive capacity, as control for tropical cyclones has been prioritised to moderate the damage they cause.

On the other hand, high adaptive capacity in populated areas such as Bangkok (Thailand) and Jakarta (Indonesia) does not mean that exposure to climate change would be moderate. High adaptive capacity is sometimes insufficient to moderate extreme vulnerability, because the combination of high population density and high exposure contributes to an increase in vulnerability for severe weather events (Yusuf & Francisco, 2009). Natural and human systems that have a high adaptive capacity seem to be more resilient to negative effects of climate change, so the systems' resilience is tightly connected to their adaptability (Lasco et al., 2011; Smit et al., 2000).

### 2.6.5 Barriers to Adaptation

Barriers (constraints) refer to any obstacle in reaching a goal (such as adapting or mitigating to potential impacts of climate change and variability), which can be overcome or attenuated by a policy or a measure (IPCC, 2007). Barriers to adaptation may limit farmers' ability to make essential adjustments to their farming practices in order to adapt to climate change (Alauddin & Sarker, 2014). There is a range of barriers affecting adaptive capacity, in which poor farmers are especially vulnerable. They include resource limitation (Lasco et al., 2011; Osbahr et al., 2006); imperfect perception of climate change by the community (Lal et al., 2001; Nelson et al., 2010); insufficient information; frequent presence of extreme weather events; and lack of impact-assessment methodologies for socio-economic, environmental and climate change scenarios[18] (Lal et al., 2001; Lasco et al., 2011).

Maddison (2007) points out barriers to adaptation at the farm level including access to extension services, access to meteorological advice, education level, farm size, market rationing of key agricultural inputs, institutional context, land-use type[19] and asset ownership. The relative importance of these factors might differ depending on regional and national features, and these features contribute to adoption ability. However, adaptation strategies at the farm level, such as

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[18] Climate scenario represents a plausible and simplified future climate to investigate potential impacts of climate change, and often serves as an input to impact models. A scenario of climate change differentiates between a climate scenario and the current climate (Baede et al., 2001).

[19] Land-use refers to socio-economic purposes for type of managed land; for example, pasture, prawn farm and conservation. Changes in land-use as, for example, when forest is converted to agricultural land (IPCC, 2007).

diversification of income and livelihood switching from farm to non-farm activities, may increase adaptive capacity to severe weather events (Adger et al., 2003; Charles & Rashid, 2007).

Adaptive barriers operating at the farm level can be classified into ecological, technical, socio-economic, institutional and political aspects (IPCC, 1996a; Kurukulasuriya & Rosenthal, 2003; Maddison, 2007; Smit et al., 1999).

## 2.7 Determinants of Farmers' Adaptive Responses among Adaptive Measures

The determinants of farmers' adaptive responses have been studied in different agricultural contexts and different crop farming systems. There is evidence that farming decisions on adaptation to climate change are influenced by several factors. The study of Alauddin and Sarker (2014) in Bangladesh found that the determinants of rice farmers' adaptive responses among adaptive measures fall into three categories: household-specific characteristics, institutional factors and social capital. These factors can be grouped into adaptive capacity (considering institutional contexts, agro-environments, socio-economic conditions, demographic and farm characteristics), perception of and vulnerability to climate change. All these factors are likely to be crucial in enabling the agricultural sector to adapt to climate change (IPCC, 1996a; Kurukulasuriya & Rosenthal, 2003; Smit et al., 1999; Wibawa et al., 2006).

Lancaster (1966) developed a consumer choice model by assuming that consumers derive their satisfaction not only from the goods themselves, but also from attributes the goods give. In other words, consumers choose goods and services based on their attributes. The consumer choice model has an econometric basis from random utility models, which are employed to integrate their behaviors with economic valuations into stated choice experiments. In this model the utility of a choice combines a deterministic component and an error component. The error component means that predictions cannot be made with certainty. Therefore, choices made will depend on the probability that the utility of a choice is higher than that of other choices (Birol et al., 2007). Based on the consumer choice model, previous adaptation studies have found heterogeneous preferences among respondents.

Models for assessing determinants affecting farmers' decisions when choosing adaptive measures assume that adoption of each adaptive option is related to a number of factors above and particular attributes of each option itself (Birol et al., 2007; Charles & Rashid, 2007; Falck-Zepeda et al., 2011; Mendelsohn & Seo, 2007). Climatic conditions also influence farmers' behaviour in dealing with climate change. High annual average temperature, low annual average precipitation and water shortages increase the probability of a farmer responding to climate change and to efficient use of scarce water resources (Charles & Rashid, 2007).

Various empirical models have been used for studies on determinants affecting heterogeneous preferences, including the LCM, MNL and MNP (Alauddin & Sarker, 2014; Birol et al., 2007; Charles & Rashid, 2007; Falck-Zepeda et al., 2011; Kurukulasuriya & Mendelsohn, 2007a). Latent class econometric analysis, based on the consumer choice model developed by Lancaster (1966), has potential to explain mechanisms of adaptive behaviour in agriculture. Some studies have applied the LCM to explain logical mechanisms through which determinants affect farmers' choices of hypothesised products like GM banana or GM maize. According to Falck-Zepeda et al. (2011), there are several different models which could be used to estimate preference heterogeneity: the covariance heterogeneity model, the random parameters logit (RPL) model and the LCM. The RPL is called the mixed logit model. However, the covariance heterogeneity model and the RPL identify sources of heterogeneity at the individual level. According to Boxall and Adamowicz (2002), these two models are not suited to explain sources of segment-level heterogeneity. Investigating the segment level would be more closely aligned to the needs of policy-making compared to analysis of individual farmers. Although the MNL is used more common than the MNP (Alauddin & Sarker, 2014), neither model solves for factors that are directly unobserved and directly unmeasured. There are factors affecting different adaptive choices that are directly unobserved and directly unmeasured (Charles & Rashid, 2007). However, the LCM can overcome this gap and is popularly applied in the agricultural context (Birol et al., 2007; Falck-Zepeda et al., 2011). Some advantages of the LCM compared with other models are summarised for more detailed in Section 4.3.4.3.

Falck-Zepeda et al. (2011) used the LCM to investigate consumer preferences for GM banana in Uganda. They found that consumer preferences were heterogeneous. Consumer preferences were investigated in terms of banana attributes such as bunch size, biotechnological types and producer's benefit. Birol et al. (2007) also used the LCM to investigate Mexican farmer preferences for GM maize in Mexico. They found that farmer preferences were heterogeneous. Their preferences were investigated in terms of three attributes of biodiversity: crop species richness, maize variety richness and maize breeds. Birol et al. (2007) used the principal factor extraction method to identify the determinants affecting Mexican farmer preferences.

The LCM was used in these two studies to identify simultaneously sample segments that had homogenous preferences for some attributes, as well as specific characteristics of respondents affecting their preferences. Birol et al. (2007) considered the farmers' characteristics including household-specific socio-economic and demographic information, site-specific socio-economic information, produce information, as well as their attitude and perception regarding GM maize.

Kurukulasuriya and Mendelsohn (2007a) employed the MNL to analyse crop choices that were considered to be adaptive measures. The MNP was employed to analyse determinants that influenced choices of adaptive measures. The MNP accounts simultaneously for the influence of explanatory variables on each adaptive measure, while allowing unobserved and unmeasured factors (error terms) to be freely correlated (Golob & Regan, 2002). Charles and Rashid (2007) used descriptive statistics, the LCM and the MNP to estimate determinants affecting Southern African farmers' decisions on adapting to climate change. The results showed the determinants affecting the farm-level adaptive options and the constraints that needed to be considered by Southern African Governments to intervene through policy instruments.

This chapter presented a literature review on a range of the definitions used in research on adaptation to climate change. It paid great attention to climate change, climate variability, climate impacts, vulnerability, perception and adaptation in agriculture. Apart from quantitative methods to measure these factors, it focused econometric models to estimate site-specific and farm-specific determinants affecting farmers' choice behaviours among adaptive measures as well as attributes of adaptive measures increasing their utility. The knowledge of these domains is a comprehensive consideration of adaptation research, thereby it assists local policy-makers in design of adaptation policies for crop farming systems.

## 2.8 Conclusion

This chapter provided the basis to design an analytical framework for a case study of interest. The analytical framework in Chapter 4 is based on theories and hypotheses drawn from this chapter. It helps identify inputs and outputs of the study as well as possible interrelationships between them. This chapter in part answered the first question that there is a series of heterogeneous effects of climate variables on the performance of rubber trees, but irrigation water and soil moisture remain significant to the performance of rubber trees.

Sections 2.2 and 2.3 are the basis to analysing climate change and variability in the study area. They are also the basis to estimate actual impacts of expected climate variables on latex yield presented in Chapter 5. Sections 2.4 and 2.5 are the basis to analysing farmers' vulnerability and their perception of climate change and variability in the local context. These outcomes are presented in Chapter 6. Section 2.6 is the basis to analysing adaptation and adaptive constraints to climate change and variability at the farm level. These outcomes are presented in Chapter 7. Section 2.7 is the basis to analysing determinants affecting their decisions when choosing adaptive measures at the farm level. These outcomes are presented in Chapter 8. The next chapter presents an overview of rubber-based farming as a basis for designing the case study.

# Chapter 3 Overview of the Rubber Industry

## 3.1 Introduction

This chapter presents an overview of the rubber industry and its future prospects. It focuses on understanding the vulnerability and the adaptive progress of the industry, especially site-specific socio-economic and agro-ecological characteristics which can affect farmer perception, vulnerability and adaptability in the study area. This chapter finds similar features among natural rubber growing nations in Southeast Asia, so that adaptive experiences and solutions in these countries could be applied in this study.

## 3.2 Overview of the World Rubber Industry

*Hevea* rubber has been a beneficial commodity in the world for over 100 years. *Hevea brasiliensis* is one of ten species of *Hevea* and is one of the main sources of commercial natural rubber production. *Hevea brasiliensis* was brought to tropical Asia in the 1800s from the upper Amazon region of Brazil to establish commercial rubber plantations. *Hevea brasiliensis* has properties that have made it the most preferred plant in Southeast Asia. It supplies white or yellow latex with 30–40 per cent higher yield than other species. Further improvements are obtained using clones, which combine high yields and other desirable attributes (Venkatachalam et al., 2013).

Rubber trees have become a development instrument and a good way to fight deforestation and soil erosion, critical problems in tropical countries. Rubber trees also reduce human pressure on natural forests by supplying an excellent timber (Diaby et al., 2011).

According to the RRII (2010), most rubber trees are grown in Southeast and South Asian developing nations and in some areas of South America and Africa. The Asian share of natural rubber production in the world has remained above 90 per cent, with Southeast and South Asian nations contributing about 77 per cent and 10 per cent of global natural rubber production respectively in 2009. However, the relative shares between regions have changed considerably over recent decades.

Viswanathan (2008) found a common background of rubber cultivation in tropical Asian countries. Rubber cultivation-based agriculture emerged as an estate-based system in the early 1900s, under the patronage of Western colonialism. After national reunifications in the region, the structure of this system was quickly transformed. Five pioneering countries in commercial rubber cultivation development including Thailand, Malaysia, India, Indonesia and Vietnam, transformed from the estate-based system into the small-scale rubber sector. Socio-economic, political and institutional contexts in each country had impacted strongly on this transformation. As a result, the small-scale rubber sector occupied almost 90 per cent of natural rubber production in Thailand, while it was 89 per cent in India and Malaysia, 83 per cent in Indonesia[20] (Viswanathan, 2008) and only 40–50 per cent in Vietnam[21] (AGROINFO, 2013). Some countries like China that depend on imported natural rubber paid more attention to the development of large-scale rubber cultivation (Fox & Castella, 2013). Recently, efforts have been made to increase the number of rubber clones that can be planted in any soil type around the world (Venkatachalam et al., 2013); however, their latex yield can be very different due to agro-environmental constraints like weather, soil and diseases (Diaby et al., 2011).

**Table 3.1: Global natural and synthetic rubber production, 2000–2013**

| **Year** | **Natural rubber** (.000 tonnes) | **Synthetic rubber** (.000 tonnes) | **Total rubber production** (.000 tonnes) | **Share of natural rubber** (%) |
|---|---|---|---|---|
| 2000 | 6762 | 10 870 | 17 632 | 38.35% |
| 2001 | 7332 | 10 483 | 17 815 | 41.16% |
| 2002 | 7326 | 10 877 | 18 203 | 40.25% |
| 2003 | 8006 | 11 338 | 19 344 | 41.39% |
| 2004 | 8744 | 11 977 | 20 721 | 42.20% |
| 2005 | 8907 | 12 073 | 20 980 | 42.45% |
| 2006 | 9827 | 12 612 | 22 439 | 43.79% |
| 2007 | 9890 | 13 347 | 23 237 | 42.56% |
| 2008 | 10 128 | 12 711 | 22 839 | 44.35% |
| 2009 | 9690 | 12 385 | 22 075 | 43.90% |
| 2010 | 10 399 | 14 082 | 24 481 | 42.48% |
| 2011 | 10 974 | 15 115 | 26 089 | 42.06% |
| 2012 | 11 410 | - | - | - |
| 2013 | 11 770 | - | - | - |

“-”: unavailable data

*Source: The AGROINFO (2013)*

Global natural rubber production reached 11.41 million tonnes in 2012. The annual average increase during the period 2000–2012 is about 4 per cent (Table 3.1 and Figure 3.1). Average latex yield among producers in the world reached 1441 kg/ha (Figure 3.2). Global natural rubber consumption

[20] These figures refer to the year 2004.

[21] These figures refer to the year 2012.

in 2012 is estimated at about 10.95 million tonnes, with the annual average increase during the period 2000–2012 of about 3 per cent (Table 3.2 and Figure 3.1). Global natural rubber exports have decreased since 2010, after increasing during the period 2003–2009 (Figure 3.1) (AGROINFO, 2013). An important factor affecting the decrease in natural rubber exports was market instability and the weak purchasing power of importers in the world (Purnamasari et al., 2002), but Venkatachalam et al. (2013) predicted the global natural rubber consumption was steadily increasing and the production would also increase to meet the demand.

**Table 3.2: Global natural and synthetic rubber consumption, 2000–2012**

| **Year** | **Natural rubber** (.000 tonnes) | **Synthetic rubber** (.000 tonnes) | **Total rubber consumption** (.000 tonnes) | **Share of natural rubber** (%) |
|---|---|---|---|---|
| 2000 | 7340 | 10 830 | 18 170 | 40.40% |
| 2001 | 7333 | 10 253 | 17 586 | 41.70% |
| 2002 | 7556 | 10 874 | 18 430 | 41.00% |
| 2003 | 7937 | 11 350 | 19 287 | 41.15% |
| 2004 | 8716 | 11 877 | 20 593 | 42.33% |
| 2005 | 9205 | 11 889 | 21 094 | 43.64% |
| 2006 | 9690 | 12 675 | 22 365 | 43.33% |
| 2007 | 10 178 | 13 296 | 23 474 | 43.36% |
| 2008 | 10 175 | 12 748 | 22 923 | 44.39% |
| 2009 | 9330 | 12 248 | 21 578 | 43.24% |
| 2010 | 10 778 | 14 086 | 24 864 | 43.35% |
| 2011 | 10 924 | 14 926 | 25 850 | 42.26% |
| 2012 | 10 950 | 15 650 | 26 600 | 41.17% |

*Source: The AGROINFO (2013)*

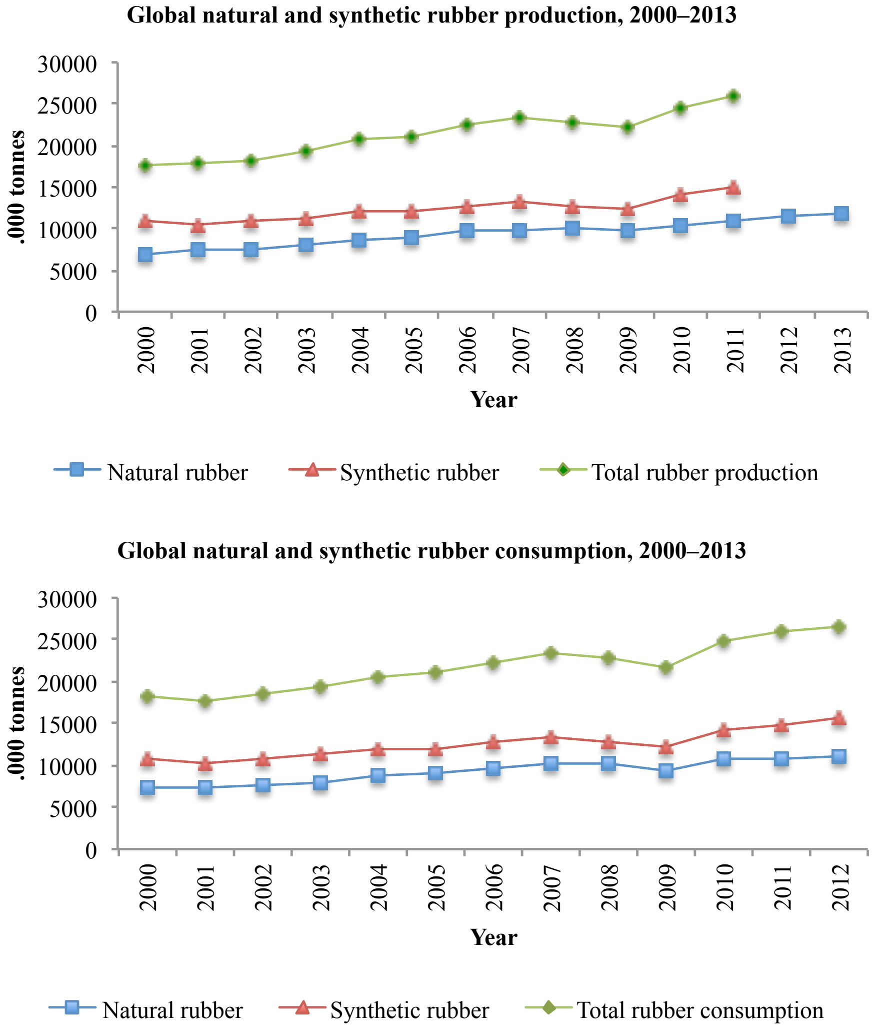


**Figure 3.1: Global natural and synthetic rubber production and consumption, 2000–2013**

*Source: Estimated using data sourced from the AGROINFO (2013)*

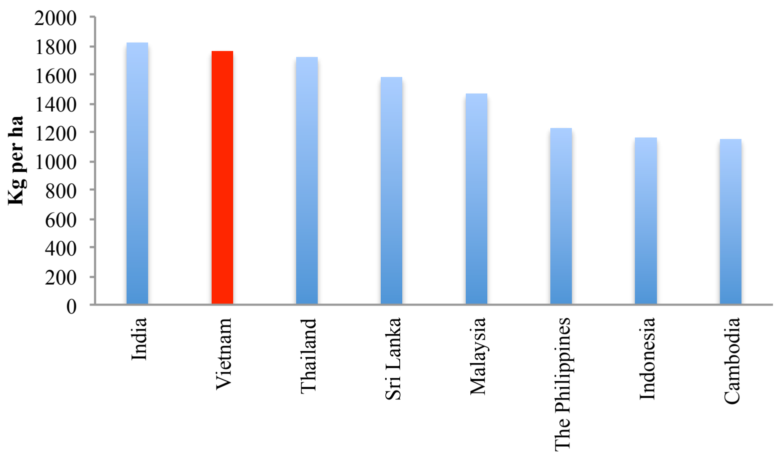


**Figure 3.2: Average latex yield by country, 2012**

*Source: Estimated using data sourced from the AGROINFO (2013)*

Thailand is the largest producer of natural rubber. The production of natural rubber in Thailand was about 3.55 million tonnes in 2012, accounting for 31 per cent of global natural rubber production, while Indonesia, Malaysia, Vietnam and India produced about 3.00, 0.95, 0.86 and 0.69 million tonnes, accounting for 26 per cent, 8 per cent, 8 per cent and 6 per cent respectively (Table 3.3). Although the largest area under cultivation was in Indonesia (AGROINFO, 2013), this nation had lower latex yield compared to India and Vietnam where latex yield was the highest (Figure 3.2).

**Table 3.3: Natural rubber production and export by country, 2012**

Unit: Million tonnes

| Country | Thailand | Indonesia | Malaysia | Vietnam | India |
|---|---|---|---|---|---|
| Natural rubber production | 3.55 | 3.00 | 0.95 | **0.86** [*] | 0.69 |
| Natural rubber export | 3.40 | 2.80 | - | **1.02** | - |

"-": unavailable data

*Source: The AGROINFO (2013)*

China is the largest importer of natural rubber, with a share of about 25 per cent in 2012; the USA and Japan follow in the second and third positions, with shares of about 13 per cent and 9 per cent respectively. European Union countries are also important import markets of natural rubber (AGROINFO, 2013). Since China is a key destination for global natural rubber consumption, Asia has become the largest natural rubber consumer in the world with about 60 per cent of the total. Thailand, Indonesia, Malaysia and Vietnam made up about 82 per cent of the global natural rubber export value into China in 2012, equivalent to about 85 per cent in volume (Table 3.4). Asia is also the largest natural rubber exporter (AGROINFO, 2013).

**Table 3.4: Export structure of natural rubber into China by country, 2012**

| Country | Thailand | Indonesia | Malaysia | Vietnam | Others |
|---|---|---|---|---|---|
| Export value | 54.0% | 19.9% | 14.5% | **8.2%** | 3.4% |
| Export volume | 55.5% | 18.6% | 13.7% | **8.6%** | 3.6% |

*Source: Estimated using data sourced from the AGROINFO (2013)*

[*] The production volume is less than the export volume in this case because of rubber latex imported into Vietnam.

## 3.3 Overview of the Vietnam Rubber Industry

### 3.3.1 The Role of Agricultural Production and Rural Area Development in Vietnam

Agricultural development is identified by the Party and Government of Vietnam as a strategy to reduce poverty, improve rural living standards, protect the environment and implement the MDG successfully (GSO, 2012). Efforts are being made to implement sustainable agricultural development accompanied with ecological and environmental protection, to bring about improvements in rural economies and social life. According to the GSO (2012), Vietnam focused its national socio-economic development strategy during the period 2001 to 2010 on agricultural production and rural development. The socio-economic development plan during the period 2006 to 2010 focused on some of the goals of the Party and Government of Vietnam: the improvement of the agricultural, forest and fishery sectors[22] (accounting for 15–16 per cent of GDP in 2010) and a decrease in levels of poverty (by 10–11 per cent). To implement such a range of goals, the Vietnamese Government has committed to comprehensive reform; active and effective integration into the world economy; social and political stabilisation with the overall aim of taking Vietnam out of the underdeveloped group of countries.

These strategies and goals have been regulated by documents such as the Resolution of the 5th Conference of the Party Central Committee (Session IX) in February 2002; the Resolution of Congress X of the Party in April 2006; the Resolution of the 7th Conference of the Party Central Committee (Session X); and Resolution No. 26-NQ/TW in August 2008. These have confirmed the pathway of industrialisation of agriculture and rural areas, which would be one of the most significant tasks needed to accelerate industrialisation and modernisation of the country. The industrialisation of agriculture and rural areas has aimed at (i) building large-scale commodity agriculture with high competitiveness, and (ii) diversifying agricultural products with high quality and yields, on the basis of rapid and sustainable agricultural development.

The Vietnamese Government has implemented five basic steps to enhance these strategies and goals (GSO, 2012):

**(1) Rural infrastructure**

Rural infrastructure has been constructed and upgraded throughout the country to support production activities. Four main aspects of rural infrastructure (electricity, roads, schools and health care units) have been improved in both quality and availability.

[22] Agriculture in a broad sense consists of forestry and fishery (GSO, 2012).

(i) Electrification is a priority for the industrialisation and modernisation of agriculture and rural areas. Development of a rural electricity network has created good conditions for rural and agricultural electrification and for narrowing the development gap between rural and urban areas. Electrification has supported agricultural production, processing industries, services and social life. Most households in Southeast Vietnam can now access electricity, with about 98.65 per cent coverage in 2011.

(ii) Rural traffic has been significantly changed to create favourable conditions to attract investment in local socio-economic development. This effort has been made possible through cooperation between the government and the people. Almost all the communes' committee offices in Southeast Vietnam (99.79 per cent) were easily accessed by roads, of which 97.70 per cent were mostly covered by asphalt and concrete.

(iii) The government's policies on educational socialisation have resulted in the development of the school system, particularly in rural areas. This provides a solid background for development of a qualified workforce. The educational system has been improved in terms of school quantity, school quality, teaching and learning quality. Most communes in Southeast Vietnam have primary and lower secondary schools; in particular the average number of communes with upper secondary schools is higher than that of the whole country. In 2011, the percentage of the communes with upper secondary schools was 20.88 per cent, compared with 12.84 per cent for the country.

(iv) The rural health care system has been enhanced in both quantity of health care units and quality of health service providers. These results have been obtained by the principle of "encouraging doctors to work at communes" and the development of a private health care system to expand the grassroot health care system. Although in 2011 all communes had medical stations, the number of doctors per 10 000 inhabitants (0.7) was lower than that of the whole country (1.1).

Other important aspects of rural infrastructure have also been improved.

(v) Irrigation systems for agricultural activities have been improved, which contributes to an increase in crop yield and production. However, it remains the case that the average number of pumping stations per commune in Southeast Vietnam is lower than in other regions of the country.

(vi) Clean water and sanitation in rural areas have been improved, which ensures quality of life and health protection of rural people. All indicators such as the number of communes with a centralised water supply, sewage drainage system and garbage collection in 2011 were higher than those of the whole country. The majority of the rural households (59.73 per cent) buried or burned garbage. About 36.7 per cent of them had garbage collected. Two thirds of them had sewage drainage systems with gutters. These show the improvement in rural infrastructure and sanitary conditions in Southeast Vietnam. However, the performance varies considerably among the provinces.

(vii) Rural communication systems help enhance agricultural production and the spiritual life of farm households via their access to information and cultural facilities. Southeast Vietnam reached the highest density of private Internet service suppliers (90.2 per cent of the communes in 2011) in comparison with other regions of the country. The number of households with telephone increased quickly from 456 672 (representing 40.42 per cent) in 2006 to 1 321 386 (representing 92.99 per cent) in 2011. About half of the communes had post offices and community houses; and about a fourth of the communes had free libraries. Most communes supplied loudspeaker systems to villages.

(viii) Development of agricultural-product processing units is encouraged at the local level in order to link agricultural production, processing and consumption of agricultural products.

(ix) Rural market places have been upgraded to meet the demands resulting from the development of rural markets.

(x) Rural credit systems have covered almost all business activities. Southeast Vietnam had the highest proportion, with 18.4 per cent (in 2011), of communes with bank branches. This creates favourable conditions for farmers in accessing credit. Other indicators such as the number of communes with market places and credit funds in 2011 were also higher than those of the whole country.

**(2) Rural occupation and labour structures**

Rural occupation and labour structures have transitioned from labour-intensive agricultural activities to other activities that require more skill and capital. The development of industrial parks, industrial clusters and handicraft villages has improved rural economics, occupation and labour structures. There was a decrease in the proportion of labour in agriculture, and an increase in the proportion of labour in industry, construction and services.

Southeast Vietnam made positive progress in restructuring the number of rural households and reducing household size. Agricultural households in Southeast Vietnam made up just under 40 per cent of rural households, while the percentages of industrial, construction households and service households were equal at 30 per cent (in 2011). The income structure of rural households likely shifted with the change in occupation structure in all regions. Households with their main income from agriculture, forestry and fishery sectors were 57.1 per cent in 2011, a decrease of 10.7 per cent compared with 2006. By contrast, the proportion with income from industrial and construction sectors was 17.6 per cent in 2011, an increase of 6.0 per cent compared with 2006. Similarly, the service sector is shared 19.4 per cent in 2011, an increase of 4.2 per cent compared with 2006.

The transition of occupation structure of rural households means there are more jobs other than agricultural activities for rural labour. However, there still existed a problem. Industrial parks and clusters often lacked workers, but they could not employ a large proportion of unskilled workers from rural areas. Accordingly, only about 0.3 per cent of the rural households had jobs regularly in handicraft villages.

**(3) Rural economic growth**

Rural economic growth is shown via the income and savings of rural households. Southeast Vietnam had the highest national average accumulated capital, reaching nearly 23.6 million VND per household in 2011. This number was higher than that in 2006. However, this accumulated capital of agricultural households was only higher than forest and salt production households. Average accumulated capital of service households was the highest (34.9 million VND in 2011). Standardised farms[23] in Southeast Vietnam obtained an average income of 2398 million VND for the year 2011, while the average of all six regions was 1952 million VND.

**(4) Social welfare**

Social welfare for poor households has been also targeted by government; for example, support for house building and house repairs, as well as preferential loans now exist. Accommodation types in Southeast Vietnam under the Vietnam Living Standard in 2011 include permanent houses (accounting for 50.5 per cent), semi-permanent houses (32.9 per cent) and less-permanent houses and simple dwellings (7.2 per cent).

**(5) Administration**

Local governments at grassroot levels, such as communes and districts have a very important role in implementing state policies and guidelines at local levels. Government staffing has been enhanced in terms of their knowledge and professional qualifications. Southeast Vietnam had the highest percentage (54.5 per cent in 2011) of commune leaders with bachelor degrees. This helps strengthen administrative reform, state leadership and management in rural areas.

Although the process of industrialisation and modernisation has taken place throughout the country, there are some considerable challenges to agricultural production. Rapid urbanisation, with a range of new urban areas, industrial parks and clusters has led to decline of agricultural land area, redundancy of agricultural labour and unemployment of rural labour. The rural economy and social

[23] By regulation, a standardised farm in Southeast Vietnam must have a cultivation area of over 3.1 ha and the value of output goods must be at least 700 million VND/year. Southeast Vietnam had the largest average farm size of 11.2 ha (GSO, 2012).

life have suffered from the process of integration of the country into the world economy and the process of successfully entering into WTO in 2007. Competition in markets of agricultural outputs and inputs has become more intense. The rural economy and agricultural sector have become more vulnerable to external shocks, such as the 1997–2001 Asian financial crisis, the global economic downturn of 2009–2011 and climate-caused negative effects.

### 3.3.2 Policy Reforms for Agricultural Development and Rural Markets in Vietnam

#### *3.3.2.1 Agricultural, Economic and Land Policy Reforms*

This section presents an overview of market-oriented reforms from 1976, one year after the reunification, when Vietnam was in transition from a centrally planned economy to a market oriented economy. Most of the information in this section is based on the review of Dung (2007) and Kirk and Tuan (2009) who present a detailed historical account of Vietnamese agricultural policy.

The Vietnamese Government launched agricultural, economic and land policy reforms as part of the transition after the Sixth Plenum of the Communist Party Central Committee in September 1979. The reforms known as "renovation" or "đổi mới" in Vietnamese started in 1981 and have been strongly accelerated since 1986. The reforms impacted directly on the expansion of agricultural production in general (Dung, 2007; Kirk & Tuan, 2009).

Agricultural policy reform started well the decentralisation of agricultural input supply as well as the introduction of an agricultural output contract system. The first and most important reform introduced was the agricultural output contract system during the period 1981–1985 (Directive No. 100CT of the Party in January 1981). Farm households were allowed to sign contracts of agricultural output supply for cooperatives, up to a certain level of output. This level was based on the given allocation of land and agricultural inputs. Farm households themselves managed farming activities, and had to sell the contracted output level at a given price; however, the remaining output belonged to them to use freely. The Government recognised the objective existence of a multi-sectorial economy and lessened state control that featured high centralisation and direct planning. State enterprises ran a large segment of the domestic market compared with private enterprises, and played an important role in wholesale trade throughout the country (Dung, 2007; Kirk & Tuan, 2009).

Agricultural outputs were strictly purchased only within the region where they were produced. Resolution No. 10 on 5 April 1988 aimed at decentralising the responsibility for agricultural management from collectives to farm households and towards identifying private property rights. Collectivised land was allocated to farm households with long-term profitable rights from 10 to 20 years, and such allocations could be renewed. The Resolution recognised the economic autonomy of farm households regarding allocation and use of family resources, production and consumption of their agricultural products. Eventually, private enterprises were allowed to buy agricultural outputs from farmers freely, thereby ending the government's monopoly in purchasing agricultural outputs (Dung, 2007; Kirk & Tuan, 2009). This period of economic policy reform was associated with market liberalisation, privatisation and new pricing mechanisms. The process of market liberalisation affected agriculture.

Land policy reform, especially for agricultural land, modified and changed during the de-collectivisation process in Vietnam in the 1980s and 1990s. The reforms greatly influenced farmer behaviour in making farming decisions, and created incentives for farmers in agricultural production. Farmers were able to make most of their decisions about farm management and agricultural product marketing, because the collective or cooperative regimes lost their influence over agricultural input supply after 1988 (Dung, 2007; Kirk & Tuan, 2009). In developing countries, regulations on land-use and agricultural production could hinder farmers' willingness and ability to adapt to climate change. There is evidence that strengthening property rights enhances farmers' access to credit to undertake adaptive measures that improve the value of the land (Kirk & Tuan, 2009; Kurukulasuriya & Rosenthal, 2003).

There were important differences in terms of tenure regimes between the north and the south of Vietnam before and after 1975. In the north, before 1956, agricultural production was run mainly by cooperatives through a central mechanism. Agricultural land and other means of production were owned by the state, and collectively managed by agricultural cooperatives under the collective regime. Farmers were cooperative members, and were allocated agricultural land and means of production. During the period 1956–1972, agricultural land alone was privately managed, but the state ownership of land and collective allocation of agricultural land and other means of production continued (Dung, 2007; Kirk & Tuan, 2009).

Collectivisation in the south was different from that in the north, because the south had been a market economy with privately managed land up until 1975. Most small-scale farmers had been assigned agricultural land by the former Saigon regime. After 1975, efforts were made to organise farmers into agricultural cooperatives, which were based on the northern model. Farmers were reorganised into farmer groups, and agricultural land was further redistributed to other farm households under the collective regime. Agricultural land allocation per capita was based on differences in soil quality and irrigation water access. However, the government paid insufficient attention to specific conditions there. There was no long-term security of land-use rights for farm households. Hence, farm households lacked incentives to stabilise their production on their assigned land, and as a result, agricultural production stagnated and collectivisation in the south suffered from resistance (Dung, 2007; Kirk & Tuan, 2009).

The land law of July 1993 (and modifications through to 2014) has created stability of tenure, made land-use rights marketable, and limited state control over land usage. This law sets out principles for long-term land-use rights, including rights to use, transfer, lease, inherit and mortgage. It also defines several categories of land for the purpose of regulation, taxation and reference for rent. Land-use rights of 15 years are granted for urban land and up to 50 years for agricultural land, but the state has retained ownership of the land. Security of land-use rights brought positive effects in agricultural production, especially in terms of gender balance since the law stipulated that land-use right certificates included the names of both husband and wife (Dung, 2007; Kirk & Tuan, 2009). Good security of tenure would encourage rubber farmers to choose adaptive measures, because it helps guarantee long-term investments.

#### *3.3.2.2 Rural Market Development*

There were positive changes in the markets of key agricultural inputs such as fertilisers and pesticides. The supply system for pesticides was the same as for fertilisers. Until 1988 the state sector had had a monopoly over fertiliser and pesticide supply. The Government entrusted state enterprises with importing given quantities and types of fertilisers. State enterprises were responsible for receiving and distributing around 90 per cent of imported fertilisers (Dung, 2007).

State enterprises distributed fertilisers within the agricultural system, from the provincial to district level, prior to coming to the cooperative level. Fertilisers were distributed according to schemes, which were verified by local committees. Then, based on available fertiliser quantity, cooperatives decided the fertiliser quantity to apply to plantations and to redistribute to farm households. Farm households received a certain amount of fertiliser according to their contract with cooperatives. Quantity of fertiliser supply was thus variable, but the State Pricing Committee determined the fertiliser price in advance. The supply of fertilisers, pesticides and other agricultural inputs was insufficient for domestic demand, while the purchasing power of farm households was limited. This was an administratively run system as opposed to a market mechanism, where market forces determine the supply and demand of goods. Market prices and production costs were not an issue for farmers, only for the government and cooperatives (Dung, 2007).

Until 1991, 60–70 per cent of fertilisers were imported from Russia and partly from Eastern European countries under the CMEA trade agreements; the rest was imported from non-socialist countries. The composition of fertilisers and their import timing at domestic ports depended on suppliers. Dissolution of the CMEA disrupted the supply chain, creating an imbalance amongst domestic demand, fertiliser types and import timing. Domestic production of chemical fertiliser[24] was insufficient to meet domestic demand, about 90 per cent of domestic demand in 2000 still depended on imports (Dung, 2007).

From 1996, the Government adjusted the import policy on fertilisers. The MARD and VCCI were entrusted with the responsibility for estimating domestic demand and controlling import quotas for fertilisers. Some trade management agencies were nominated to grant the quotas. The quotas were adjusted according to the domestic balance of supply and demand every mid-year. More restrictions on import timing and quota transferring were imposed. Although fertiliser-import quantity was controlled through quotas, domestic fertiliser prices varied seasonally and geographically throughout the country. Some private enterprises were also allowed to import fertilisers, but the government maintained its important role in coordinating the fertiliser market. However, the fertiliser market depended on the performance of such enterprises. Even though policies were usually modified, the imbalance in the fertiliser market was not markedly improved. After 10 years of restrictions, the fertiliser market has been fully free since 2001, following Decree No. 46/2001/QD-TTg on Vietnam's export-import management mechanism during the period 2001–2005 (Dung, 2007).

The reforms have been gradual but persistent in markets for agricultural outputs and inputs. There has also been a change in the pricing system in order to end the dual price system where the state sector paid much less for outputs than buyers in the non-state sector. Both state and private sectors now have equal rights to engage in the market. Fertilisers were mostly imported by state enterprises who then distributed fertiliser. In the south, most of imported fertiliser was sold to private enterprises who then transported it to provinces and sold it to retailers at district and village levels. Obviously, the state monopoly added to fertiliser costs at the beginning of the market chain. Therefore, the fertiliser market was distorted by state intervention through allocation of import quotas (Dung, 2007).

### 3.3.3 Rubber Trees in Vietnam

After independence in 1975, rubber tree development was a crucial source of foreign exchange earnings for the Vietnamese Government. Nowadays, in the Vietnam economy the rubber tree is one

[24] In general, fertilisers are substances, either natural or manufactured, containing at least five per cent of one or more essential nutrients for normal growth and development of plants. Fertilisers manufactured industrially are called chemical fertilisers or mineral, artificial and synthetic fertilisers. Hereafter, called chemical fertilisers or fertilisers in short, in order to differentiate from natural nutrient substances (such as manure) (Dung, 2007).

of the three most important agricultural products that contribute to moving rural households and communities out of poverty (AGROINFO, 2013).

Rubber cultivation in Vietnam stretches from the south to the north. The most extensive cultivation occurs in Southeast Vietnam. Nine primary technical standards were issued by the MARD for determining proper rubber growing regions including (i) climatic conditions (average temperature of 25–30$^0$C, no frost in wet seasons, annual average precipitation of over 1500 mm, and few storms of force eight and above); (ii) elevation above sea level (below 700 m); (iii) slope (below 30$^0$); (iv) soil depth (at least 0.7 m); (v) groundwater level (higher than 1.2 m) and adequate drained soil in wet seasons; (vi) soil texture (good drainage); (vii) soil components (mixed rocks lower than 50 per cent); (viii) humus content in mulch (higher than one per cent and $pH_{kcl}$ of 4–6); and (ix) other techniques for site preparation. There is an estimated total annual precipitation of 2260 mm and an estimated annual average temperature of 26$^0$C in the study area; these figures are estimated using data from the VNCHMF (2013). These are the necessary conditions for successful rubber tree development in Vietnam.

### 3.3.4 The Vietnam Rubber Industry

Vietnam has considerable potential in natural rubber production compared to other nations. Vietnam is also the fifth largest producer of natural rubber and is the fourth largest exporter. The 0.76 million-ton production of natural rubber in Vietnam in 2012 brought an export value[25] of 2.37 billion USD (equivalent to three per cent of the total national exports, third highest product in terms of export value after rice and coffee) (AGROINFO, 2013).

Vietnam had planted 910 500 ha of rubber trees up to 2012, with an increase of about 13.6 per cent compared with 2011 (Table 3.5). The planted rubber area in Vietnam has exceeded the national target, which was set to reach 800 000 ha in 2015. The harvested rubber area reached about 505 800 ha in 2012, with an increase of about 7.2 per cent compared with 2011. In line with extending rubber cultivation areas (Figure 3.3), natural rubber production in Vietnam has increased sharply. Total latex production increased from 57 900 tonnes in 1990 to 863 600 tonnes in 2012 (Figure 3.4). The rapid growth of total latex production is achieved through the expansion of the area of rubber cultivation and also by productivity improvements in both the small-scale and estate rubber sectors (AGROINFO, 2013).

[25] Value of export is total value of goods, leaving Vietnamese economic territory over certain period of time. The value of exports is calculated on a FOB basis. FOB values include the transaction value of goods and the value of services used to deliver goods to the border of the exporting country (DS, 2012).

**Table 3.5: Planted rubber area and other perennial crop area in Vietnam, 2011–2012**

| Perennial crop | Area in 2011 (ha) | Area in 2012 (ha) | Change 2012/2011 (%) |
|---|---|---|---|
| **Rubber** | **801 600** | **910 500** | **113.59%** |
| Coffee | 586 200 | 622 100 | 106.12% |
| Cashew | 363 700 | 325 900 | 89.61% |
| Coconut | 144 800 | 149 300 | 103.11% |
| Tea | 127 800 | 129 100 | 101.02% |
| Pepper | 55 500 | 58 900 | 106.13% |

*Source: Estimated using data sourced from the AGROINFO (2013)*

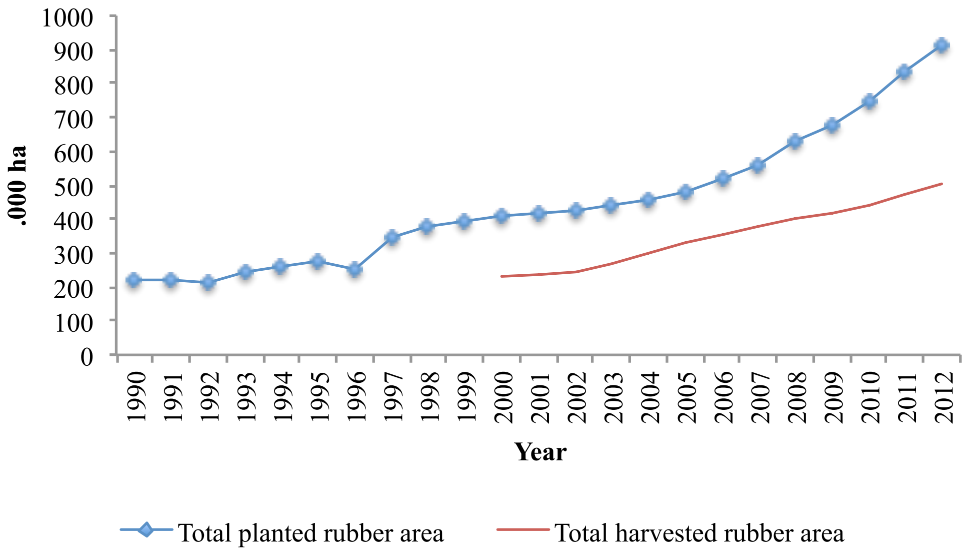


**Figure 3.3: Planted and harvested rubber area in Vietnam, 1990–2012**

*Source: Estimated using data sourced from the AGROINFO (2013)*

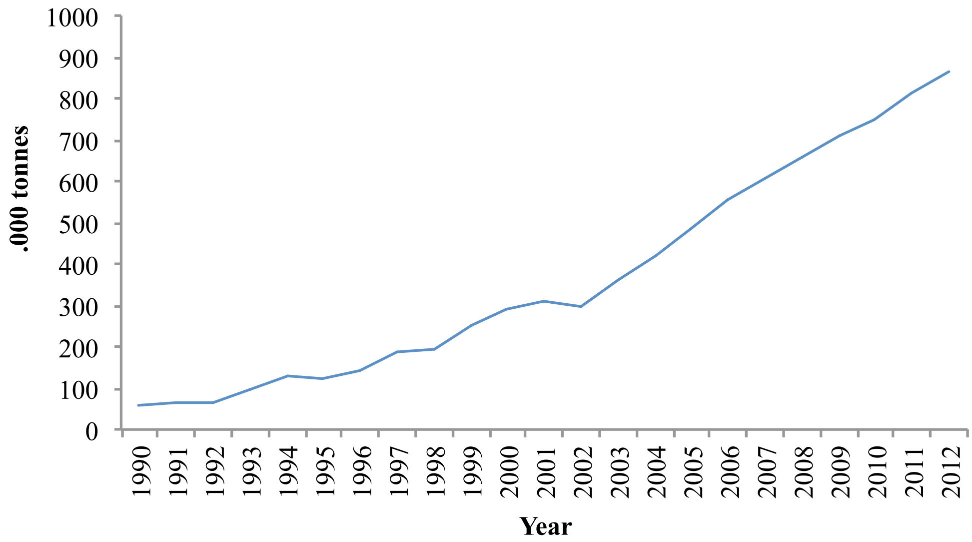


**Figure 3.4: Latex production in Vietnam, 1990–2012**

*Source: Estimated using data sourced from the AGROINFO (2013)*

Most latex production in Vietnam is exported. Vietnam's three most important destinations for natural rubber export are China, Malaysia and India, which accounted for 72 per cent of the natural rubber exports of Vietnam in 2012 (Figure 3.5). Vietnam exported 1.02 million tonnes of natural rubber in 2012, which was equivalent to 2.85 billion USD. There was an increase of about 25 per cent in volume, but a decrease of about 12 per cent in value, due to fluctuations in latex prices. The volatility in natural rubber prices for exports also depends on harvest seasons. During the harvest latex prices reduce due to the abundant supply. At the end of the harvest the latex price increases due to the short supply. During periods of shortage of latex supply, latex prices at rubber plantations are usually higher.

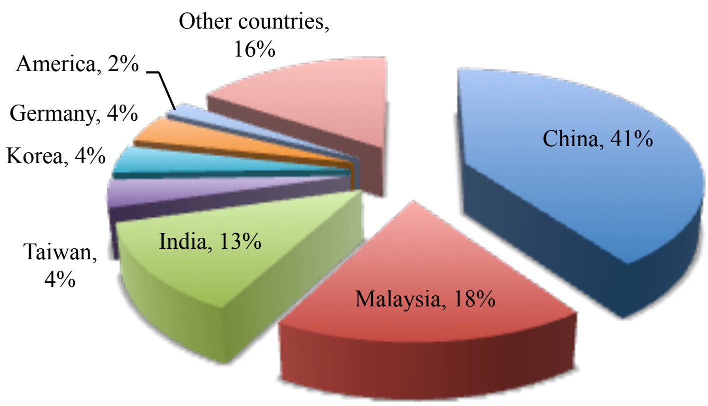


**Figure 3.5: Main destinations for natural rubber export from Vietnam by volume, 2012**

*Source: Estimated using data sourced from the AGROINFO (2013)*

Natural rubber exports from Vietnam consist of three key groups (AGROINFO, 2013):

(1) HS code 40012 (rubber latex in forms including RSS, TSNR and some others, making up about 94.4 per cent in volume and 96.1 per cent in value).
(2) HS code 40011 (natural rubber latex, whether or not pre-vulcanised, making up about 5.5 per cent in volume and 3.9 per cent in value).
(3) HS code 400130 (with only 1.4 per cent in volume and 0.9 per cent in value).

In addition to natural rubber exports in 2012, Vietnam imported about 302 000 tonnes from about 40 natural rubber export countries, in particular Cambodia (with 59 per cent in volume and 60 per cent in value), Thailand (with 17 per cent in volume and 18 per cent in value), Laos PDR (with four per cent in volume and four per cent in value) and Korea (with three per cent in volume and three per cent in value). Total import value[26] was about 802 million USD. Imported natural rubber in the forms of HS code 40012 accounted for about 67 per cent in volume and 96 per cent in value in 2012 (AGROINFO, 2013).

Compared with the other main perennial crops (coffee, cashew, coconut, tea and pepper trees) rubber trees occupied the greatest planted area (Table 3.5). In recent years, the VRG and other companies have been establishing strong international cooperation in planting, nursing rubber trees and processing rubber latex in Laos PDR and Cambodia. It was forecast that in 2013 Vietnamese natural rubber production would remain at about 1 million tonnes, with an export value of about 2.57 billion USD (AGROINFO, 2013).

## 3.4 Brief Profile of the Small-Scale Rubber Sector in Southeast Vietnam

### 3.4.1 Geographic Position and Socio-Economic Conditions of Southeast Vietnam

For the purpose of agricultural production, Vietnam is divided into nine agro-ecological zones: Northwest, Northern, Northeast, Red River Delta, Northern Central Coast, Southern Central Coast, Central Highlands, Northeast Mekong Delta (Southeast) and Mekong River Delta (NISF, undated).

[26] Value of import is total value of all goods, entering Vietnamese economic territory over certain period of time. The value of imports is calculated on a CIF basis. CIF values include the transaction value of goods, the value of services used to deliver goods to the border of the exporting country and the value of the services used to deliver goods from the border of the exporting country to the border of the importing country (DS, 2012).

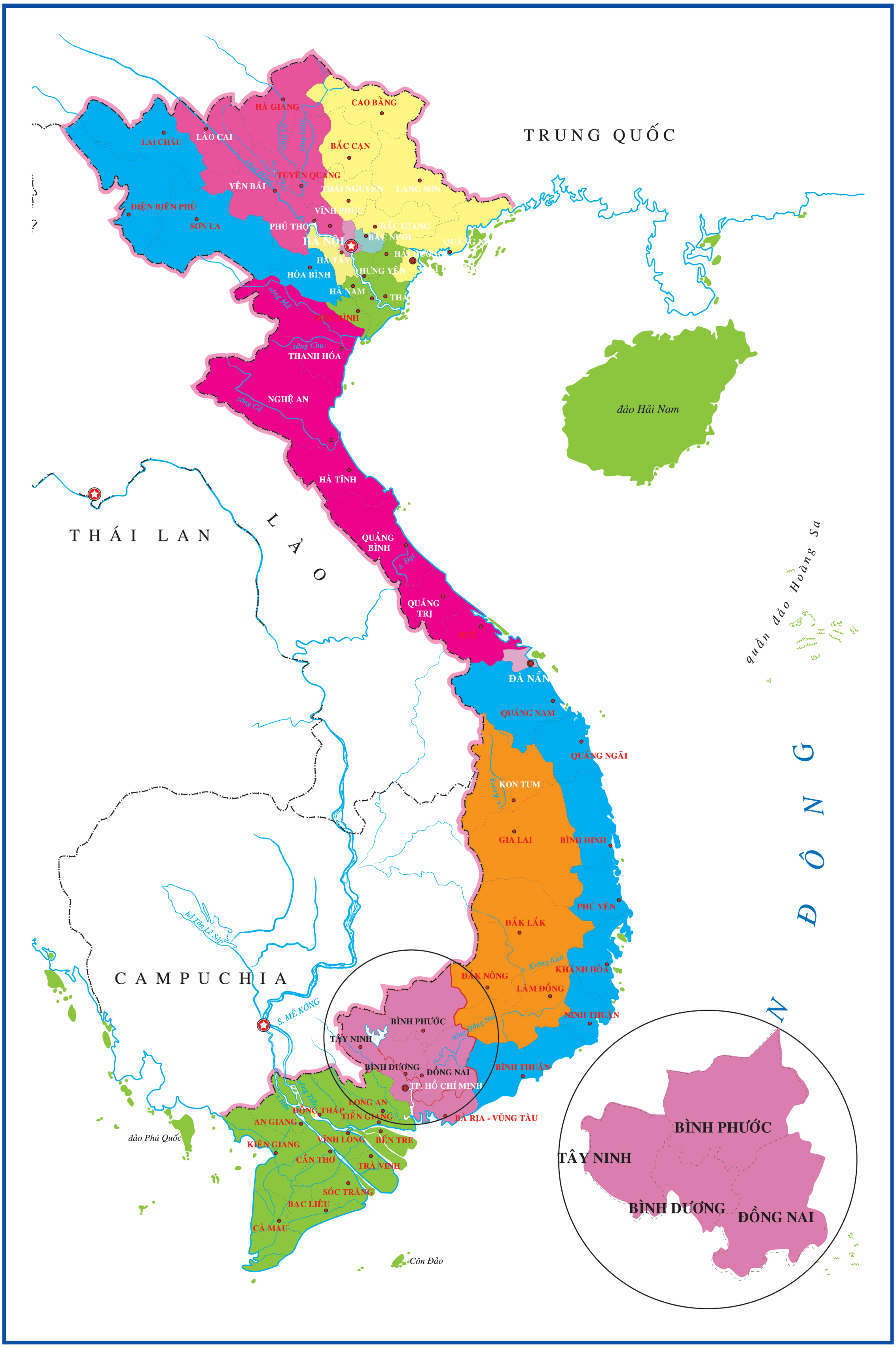


**Figure 3.6: Map of Vietnam's provinces**

*Source: Modified using the map sourced from Chuong (2015)*

“Vietnam is entirely within the tropical monsoon climate zone. While the warmth and humidity allow the cultivation and good growth of tropical crops in Vietnam” (Dung, 2007, p. 55). Southeast Vietnam consists of five provinces (Binh Phuoc, Tay Ninh, Dong Nai, Binh Duong and Ba Ria - Vung Tau) and one city (Ho Chi Minh City) (Figure 3.6). The region has a tropical monsoon and equatorial climate (Lal et al., 2001).

Southeast Vietnam is considered an arid region of the country because of extreme dry weather events and low precipitation. Almost 47 per cent of the region is classified as highland, 41 per cent as medium altitude and the rest is lowland. Agriculture is undertaken on almost 80 per cent of its hill slopes (GSO, 2012). Rainwater is the sole source of groundwater recharge in the area. These provinces are bounded by Ho Chi Minh City in the south, Cambodia in the west and Highland provinces in the east.

The cluster of Binh Phuoc, Dong Nai, Tay Ninh and Binh Duong is categorised into the same climate zone, comprising a total area of about six per cent of the country (DS, 2012). Binh Duong is in the centre of the region and is bounded by Binh Phuoc, Dong Nai and Tay Ninh (Figure 3.6). The total average population[27] of the four provinces represents 7.2 per cent of Vietnam’s total (Table 3.6). The population density of Binh Duong was highest with 628 people per $km^2$, while the population density of Binh Phuoc was only 132 people per $km^2$. In 2011 the four provinces contributed about 13.9 per cent of the GDP of the country (Table 3.7). The average GDP per capita of the four provinces was 12.8 million VND in 2011 (at constant 1994 prices), which was just under twice the national average and far higher than other regions (Table 3.8).

**Table 3.6: Average population in the study area, 2008–2011**

Unit: .000 people

| | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|
| Binh Phuoc | 858 | 875 | 888 | 905 |
| Dong Nai | 2433 | 2500 | 2575 | 2665 |
| Tay Ninh | 1061 | 1067 | 1073 | 1081 |
| Binh Duong | 1403 | 1513 | 1620 | 1691 |
| **Vietnam** | **85 122** | **86 025** | **86 933** | **87 840** |

*Source: The DS (2012)*

[27] Average population is the average number of population of a certain area in a certain period of time, a year (DS, 2012).

**Table 3.7: GDP in the study area at constant 1994 prices, 2008–2011**

Unit: Billion VND

| | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|
| Binh Phuoc | 4890 | 5387 | 6083 | 6874 |
| Dong Nai | 29 172 | 31 903 | 36 206 | 41 029 |
| Tay Ninh | 10 491 | 11 654 | 12 982 | 14 791 |
| Binh Duong | 12 896 | 14 292 | 16 370 | 18 661 |
| **Vietnam** | **489 833** | **516 566** | **551 609** | **584 073** |

*Source: The DS (2012)*

**Table 3.8: GDP per capita in the study area at constant 1994 prices, 2008–2011**

Unit: Million VND

| | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|
| Four provinces[28] | 9.98 | 10.62 | 11.64 | 12.83 |
| **Vietnam** | **5.75** | **6.00** | **6.35** | **6.65** |

*Source: Estimated using data sourced from the DS (2012)*

Most important crops in the study area are rubber and cashew trees (Dung, 2007). Although all four provinces have certain strengths in rubber cultivation development, the three provinces Binh Phuoc, Dong Nai and Tay Ninh were chosen as the study area. Binh Duong differs from these provinces because of the relatively small contribution that the agriculture, forestry and fishery sectors make to the total GDP of the province (Table 3.9 and Figure 3.7). In addition, this study does not choose Binh Duong so that the site dispersal of the sample is satisfied.

[28] Binh Phuoc, Dong Nai, Tay Ninh and Binh Duong

**Table 3.9: Annual GDP structure of the study area at current prices, 2008–2011**

Unit: %

| Provinces | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|
| **Binh Phuoc** | **100.00** | **100.00** | **100.00** | **100.00** |
| *Agriculture, forestry and fishery* | *56.32* | *51.38* | *50.44* | *49.45* |
| *Industry and construction* | *18.20* | *20.54* | *22.44* | *24.35* |
| *Services* | *25.48* | *28.08* | *27.12* | *26.20* |
| **Dong Nai** | **100.00** | **100.00** | **100.00** | **100.00** |
| *Agriculture, forestry and fishery* | *10.60* | *9.90* | *8.60* | *7.50* |
| *Industry and construction* | *57.90* | *57.29* | *57.20* | *57.30* |
| *Services* | *31.50* | *32.81* | *34.20* | *35.20* |
| **Tay Ninh** | **100.00** | **100.00** | **100.00** | **100.00** |
| *Agriculture, forestry and fishery* | *40.47* | *36.39* | *38.07* | *43.07* |
| *Industry and construction* | *25.23* | *27.71* | *29.86* | *30.01* |
| *Services* | *34.30* | *35.90* | *32.07* | *26.92* |
| **Binh Duong** | **100.00** | **100.00** | **100.00** | **100.00** |
| *Agriculture, forestry and fishery* | *5.70* | *5.26* | *4.44* | *4.14* |
| *Industry and construction* | *64.80* | *62.32* | *63.00* | *62.17* |
| *Services* | *29.50* | *32.42* | *32.56* | *33.69* |

*Source: Estimated using data sourced from the DS (2012)*

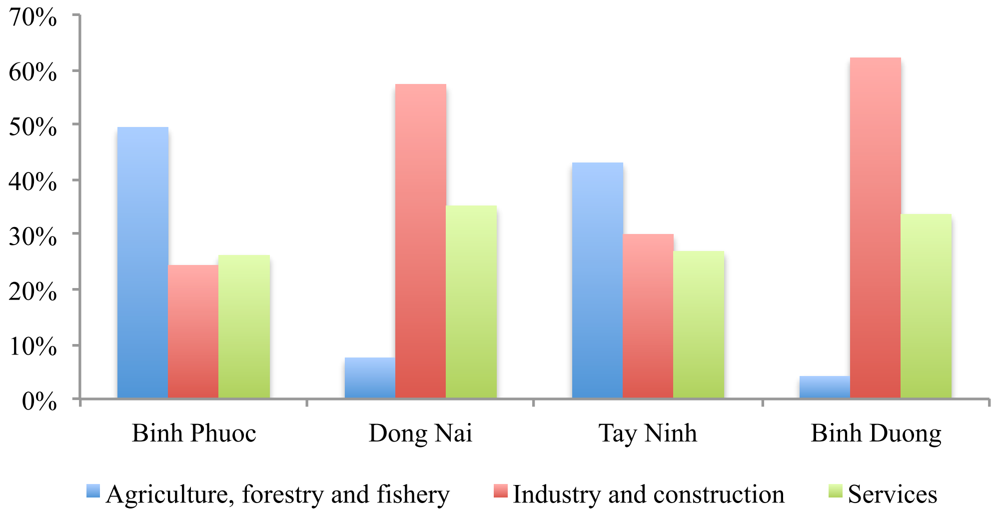


**Figure 3.7: GDP structure of the study area at current prices, 2011**

*Source: Estimated using data sourced from the DS (2012)*

The Decision of the Prime Minister No. 44/1998 on 23 February 1998 made most of the provinces of Southeast Vietnam – Ho Chi Minh City, Dong Nai, Binh Duong and Ba Ria - Vung Tau – belong to the main economic region in the south. In June 2003 Tay Ninh, Binh Phuoc and Long An provinces were added to the list. Southeast Vietnam, which is also the most active economic region in the country, is rapidly being urbanised and developed.

### 3.4.2 Trends in Agricultural Land[29] Use in Southeast Vietnam

In 2011, Vietnam had nearly 3.7 million ha of land under perennial crops, of which Southeast Vietnam had the high proportion of 28.1 per cent. All six regions had an increased trend of land being used for perennial crops because of changes in land-use. Forestland[30] in Southeast Vietnam decreased by 157 000 ha, mostly transitioning into agricultural production land for perennial crops such as rubber, coffee and fruit trees. Land for aquaculture had a slight increase of about 1.2 per cent. The speed of urbanisation and industrialisation also impacted on land-use purposes. There is a positive trend of accumulating land to meet scale economies, especially rubber and coffee cultivation (GSO, 2012).

In Southeast Vietnam, perennial cropland occupied about 54.58 per cent of total agricultural land in 2011, while this number was only 43.10 per cent in 2006. Perennial cropland had an increase in scale of about 23 per cent, from 844 040 ha in 2006 to 1 038 200 ha in 2011. The majority of the agricultural households used under five ha, in particular about 17.58 per cent of the agricultural households were landless[31]. About 20.8 per cent of the households in Southeast Vietnam used arable land of over two ha; this number was the highest compared to the country's other regions. Cropland was concentrated mainly in four provinces: Binh Phuoc, Dong Nai, Tay Ninh and Binh Duong. About 30 per cent of rubber farm households in Southeast Vietnam used from 1–2 ha for growing rubber trees. The percentage of the households using 2–3 ha and more than 3 ha were about 13 per cent and 14 per cent, respectively (Figure 3.8) (GSO, 2012).

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[29] Agricultural land consists of agricultural production land, forestland, aquaculture land and other agricultural land. Agricultural production land consists of annual cropland and perennial cropland. Perennial cropland consists of perennial industrial crop land and land for perennial fruit trees. Perennial industrial crop land consists of rubber growing land and land for other industrial perennial crops (GSO, 2012).

[30] Forestland refers to land used in forestry production or experiment, including: productive forest, protective forest and specially used forest (GSO, 2012).

[31] Landless refers to a household that has no land other than that which it is renting or borrowing (Kirk & Tuan, 2009).

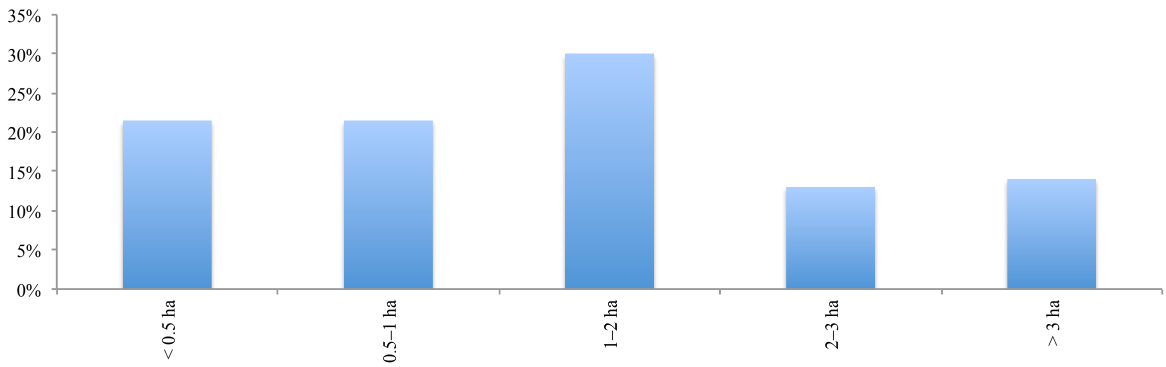


**Figure 3.8: Rubber land size of farm households in Southeast Vietnam, 2012**

*Source: Estimated using data sourced from the GSO (2012)*

In 2011, Vietnam had over 258 000 households planting rubber trees, an increase of 43 per cent compared to 2006. Southeast Vietnam accounted for the majority (56 per cent) of households planting rubber trees in the country, an increase of 118 per cent compared to 2006. The Central Highlands made up 22 per cent and the North Central and Central Coast Areas made up nearly 20 per cent. Rubber production is a relatively new development in the Northern Midland and Mountainous Areas with only about 5200 households (Figure 3.9).

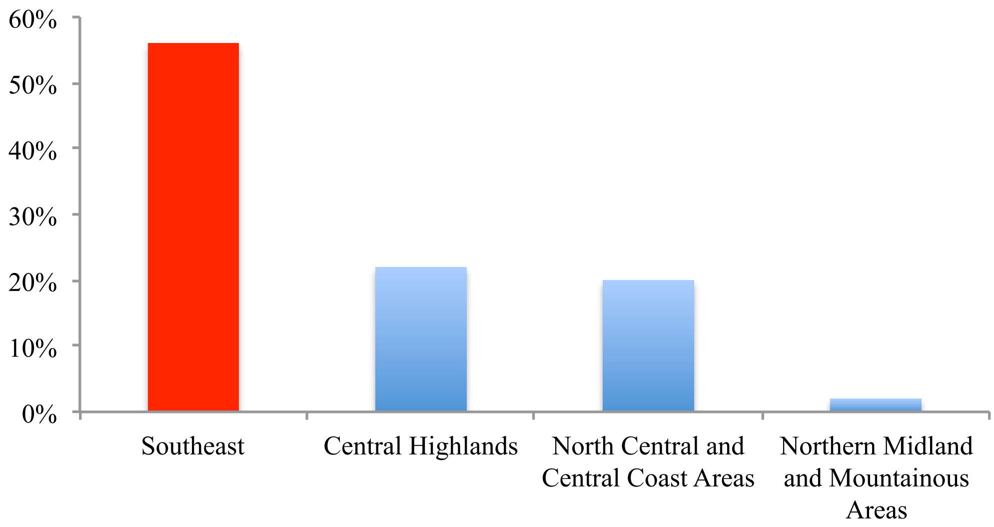


**Figure 3.9: Proportion of households planting rubber trees by region of Vietnam, 2011**

*Source: Estimated using data sourced from the GSO (2012)*

### 3.4.3 Demographic Status of Farm Households in Southeast Vietnam

According to the GSO (2012), in 2011 the number of rural households in Southeast Vietnam was 1 429 582, an increase of 26.55 per cent compared to 2006. The number of agricultural households was about 48.78 per cent in 2006, but only 37.54 per cent in 2011. Although the number of rural households has increased, the proportion of agricultural households has decreased. Non-agricultural households do in other domains for income, including industry, construction and services.

People of labouring[32] age in agriculture in 2011 represented about 34.82 per cent of the total in rural areas of Southeast Vietnam. However, this number decreased slightly in both absolute and relative terms in comparison to 2006. Most of agricultural households employed from one to three family members for farming activities (representing about 84.4 per cent), with the remaining 15.6 per cent employing four to nine family members.

### 3.4.4 Natural Rubber Production in Southeast Vietnam

Binh Phuoc, Binh Duong, Tay Ninh and Dong Nai are key rubber growing provinces in Southeast Vietnam (Figure 3.10). Gia Lai and Dak Lak have also large planted area, but they belong to the Central Highlands. Their strengths are shown in planted rubber area, latex production and yield (Figure 3.11 and Figure 5.8). Planted rubber area in Southeast Vietnam in 2012 made up about 56 per cent of the planted rubber area of the whole country. Binh Phuoc in particular, occupied over 36 per cent of the planted rubber area in Southeast Vietnam, and about 22 per cent compared with the whole country. Natural rubber production in Binh Phuoc made up about 30 per cent and 20 per cent of the total natural rubber production of Southeast Vietnam and the country respectively. Average latex yield in Binh Phuoc in 2012 (1980 kg/ha) was higher than that of the whole country (1760 kg/ha) (AGROINFO, 2013).

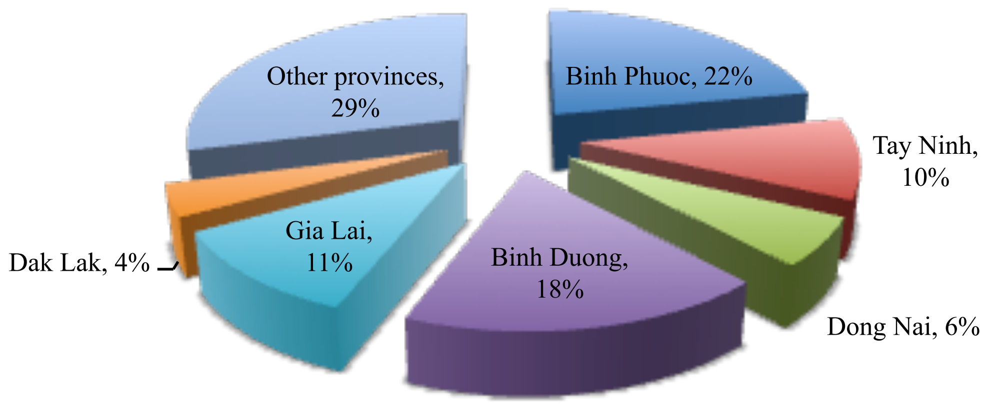


**Figure 3.10: Share of planted rubber area in Vietnam, 2012**

*Source: Estimated using data sourced from the AGROINFO (2013)*

[32] The working age in Vietnam for male workers is from 15 to 60 years old, and for female workers from 15 to 55 years old (GSO, 2012).

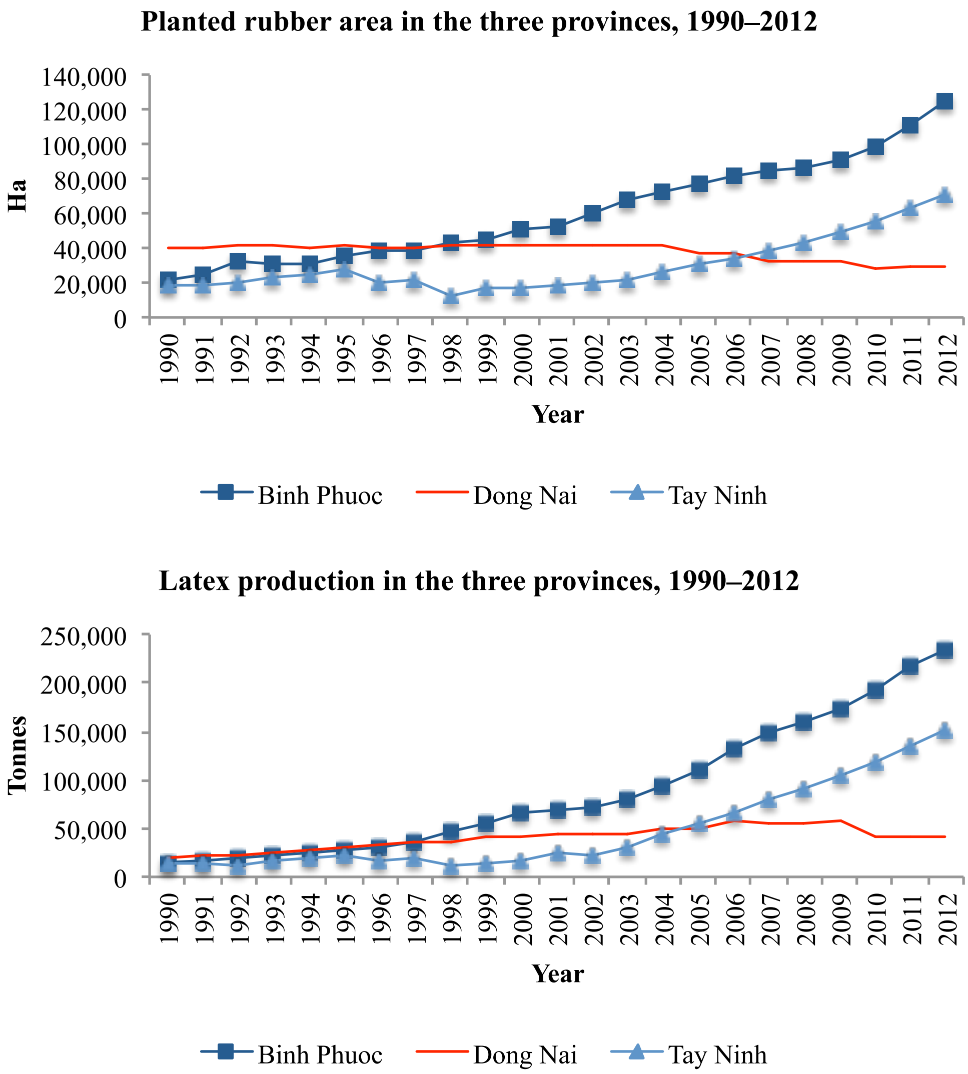


**Figure 3.11: Planted rubber area and latex production in the study area, 1990–2012**

*Source: Estimated using data sourced from the DS (2012)*

## 3.5 Conclusion

This chapter presented several similar features among rubber cultivating nations in Southeast Asia, role of the Vietnam rubber industry in the region, its contributions to the country, and its challenges caused by climate change and market uncertainties. This chapter also described the context of the rubber industry and natural rubber development in Southeast Vietnam. It emphasised the advantages and potential of Binh Phuoc, Dong Nai and Tay Ninh that were chosen as the study area. Their natural, institutional and socio-economic conditions are conducive to natural rubber development, compared with other regions of the country. The overview of the local rubber industry and the basic information of the small-scale rubber sector in Southeast Vietnam underpins findings presented later in chapters 5–7.

# Chapter 4 Method of Analysis and Data

## 4.1 Introduction

This chapter presents the methods of analysis and the empirical models developed to answer each of the nine remaining research questions. It presents the data types and the data requirements pertaining to the empirical models. Hence, it identifies the sources of data and the methods to obtain the necessary data.

Chapter 2 provided the basis for measuring climate change and climate variability as well as the nature of the relationship between them. Climate-related hazards can affect all aspects of social life and agricultural production. Evidence shows that climate impacts on plant performance are occurring, and that they are mostly negative and sometimes severe. There are methods, relevant for the present study, to evaluate climate change, climate variability and their impacts on crop production. The focus of this research is on climate change adaptation with emphasis on the relationships between perception, vulnerability and adaptive capacity. There is a range of methods to evaluate perception, vulnerability, adaptive capacity and adaptation of farmers in the agricultural context.

When studying adaptation at the farm level, farmer preference heterogeneity among adaptive measures must be accounted for in models of behaviour. The approach applied in the present study is to analyse farmers' adaptive responses according to attributes of adaptive measures, and then analyse the determinants of farmers' adaptive responses. The ultimate purpose of the research is to understand the relationships required to align policy responses to farmer segments. The present study applies a comprehensive approach to estimate these functional relationships, following the analytical framework explained below.

Central to the methods of analysis are the following objectives, to: (i) examine the occurrence of change and variability in the local climate; (ii) examine the occurrence of change and variability in latex yield at both the provincial and farm level; (iii) evaluate climate effects on latex yield; (iv) evaluate vulnerability, perception and adaptation of rubber farm households to changing climatic conditions; and (v) understand the determinants of farmers' adaptive responses and the probability that a given farmer belongs to a targeted segment. This refers to segments of the farmer population that are vulnerable to climate change.

This chapter is organised as follows. A brief discussion of the analytical framework is presented in Section 4.2. An outline of the methods of analysis and the empirical models is presented in Section

4.3. A discussion of the data requirements, data sources, data preparation and data calibration is presented in Section 4.4. The secondary data collection is presented in Section 4.5. The design of the field survey and the data collection is presented in Section 4.6 followed by brief summary and concluding comments in Section 4.7.

## 4.2 Analytical Framework

The general framework of analysis is presented in Figure 4.1. The empirical strategy of this study is constructed based on an analytical framework (Figure 4.1) that maps out the determinants of farmers' adaptation strategies and thus identifies the type of information required and the methods to obtain it. The arrows indicate relationship directions either cause/effect or mutuality. The plus and minus signs are relationship types, either positive/improved or negative/limited. The description of this framework is governed by the existing literature review in Chapter 2. The first objective of this study is to examine the potential and actual impacts of climate change and variability on natural rubber cultivation and production in Southeast Vietnam. Their impacts are revealed in variables such as plant growth, latex yield and quality. Before examining their impacts, it is important to establish if there is sufficient evidence of climate change and variability in the study area. If climate change and variability can be established, their impacts on these key outcome variables are worth studying.

Farmers sometimes act on farming practices as if they acted on livelihood strategies or adaptation strategies. Both livelihood and adaptation strategies can improve plant performance in terms of growth, latex yield and quality. Mutual relationships between plant performance and livelihood strategies or adaptation strategies indicate that these improve plant performance. Meanwhile, knowledge of plant performance through these efforts enhances the strategies themselves. This study assumes that farmers are able to distinguish between livelihood and adaptation strategies so that the source of adaptation can be evaluated.

Adaptation is enhanced by strong perceptions of community and farm households of the nature and dynamic relationships among the variables listed below, reducing vulnerability of farm households and improving their adaptive capacity. The potential adaptation is demonstrated through adaptive types which are influenced by the different adaptive attributes of the adaptive measures. The initial collection of adaptive measures and attributes is based on the existing literature and local empirical context. This study also assumes that farmer-segment preferences for adaptive methods are heterogeneous so that the sources of heterogeneity are evaluated.

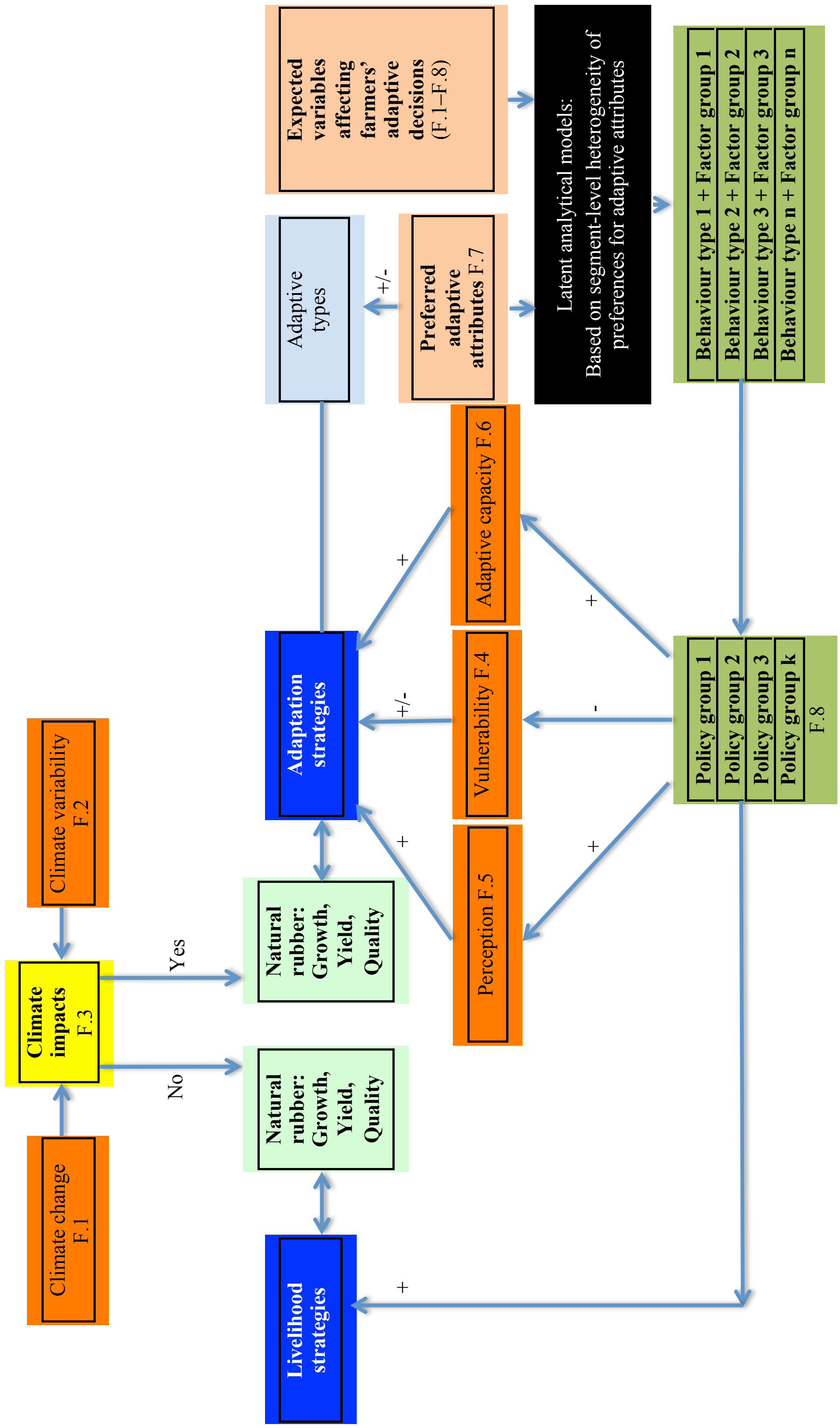


**Figure 4.1: Diagram of the analytical framework**

+ (-): positive (negative) contributions

*Source: Author*

The variables included in the analyses represent climate variables, institutional factors, socio-economic conditions, agro-environments, demographic characteristics, farm characteristics and farmers' stated preferences for adaptive attributes. In Figure 4.1, these variables are scattered through factors F.1 to F.8 and are sources of heterogeneity. These variables, based on the survey data, are inputs to the latent analytical models. These models consider the segment-level heterogeneity of preferences for adaptive attributes. Their main outputs are segment-adaptive behaviour types, calculated based on stated attribute preferences (utility model), and determinants affecting the probability of a given farmer belonging to a particular segment (segment membership model).

These outputs provide evidence for improving perception of climate change and variability, reducing vulnerability and enhancing adaptive capacity. This approach provides practical findings for local particular situations. This will help rubber farm households address challenges of climate change and variability in their natural rubber cultivation and production.

## 4.3 Outline of Method of Analysis

This section discusses the choice of methodology, presents the technical details regarding the choice of the appropriate methods of analysis and justifies the empirical models.

This study employs quantitative research methods to allow us to better understand the relationships among climate variables, institutional factors, socio-economic conditions, agro-environments, demographic characteristics, farm characteristics and rubber farming practices that affect latex yield. According to Dung (2007), qualitative research methods could be used to improve over understanding of the relationships among such variables. However, a quantitative analysis is required if quantitative measures of the interactions between them is sought. Testing various hypotheses allows us to examine the significance of each of the variables.

Table 4.1 provides an overview of the methods to obtain the determinants of farmers' adaptation strategies. The methods start out with descriptive statistics; include testing of means, medians and proportions using both parametric and non-parametric tests, correlation analysis and econometric models. Among the latter the latent class model is the most advanced method used in this study. These draw on secondary data and survey data which include categorical, continuous and time series data. This table shows how to perform a number of related statistical tests. The StataSE version 12.0 software package and the IBM SPSS Statistics version 20 software package are used to perform all of the analyses cited in this study. Each section gives a brief description of the aim of each econometric model, statistical test and requirements of the type of variables and the nature of their distributional normality.

**Table 4.1: Summary of empirical models and compatible tests**

| No. | Type of models and tests | Requirement of data |
|---|---|---|
| **I** | **Descriptive statistics** | |
| 1 | Mean, standard deviation, min and max, median and frequency | |
| 2 | Severe outliers | |
| **II** | **Test for stationarity of time series data** | |
| 1 | Fisher-type unit-root test for unit root | |
| **III** | **Tests for normality of a continuous variable** | |
| 1 | Skewness and Kurtosis test | |
| 2 | Shapiro-Wilk W test | |
| **IV** | **Statistical comparison among sample means** | ***var*. is assumed to be normally distributed** |
| 1 | One-sample *t*-test | Test whether a sample is dawn from a population with a given mean value (hypothesised value) |
| 2 | Two independent samples *t*-test with equal variances/unequal variances | Differences in the mean of *var.* broken into two categories |
| 3 | One-way analysis of variance (ANOVA) | Differences in the mean of *var.* broken into three categories |
| **V** | **Statistical comparison among sample medians** | ***var*. has no assumption of normality but is a continuous variable** |
| 1 | Wilcoxon signed-rank test | Test whether a sample is dawn from a population with a given median value (hypothesised value) |
| 2 | Two-sample Wilcoxon rank-sum (Mann-Whitney) test | Differences in the median of *var.* broken into two categories |
| 3 | Kruskal Wallis test | Differences in the median of *var.* broken into three categories |
| **VI** | **Statistical comparison among percentages** | **Both of *var*.(s) are categorical variables with 2 or more categories** |
| 1 | Chi-squared test | Chi-squared test assumes the expected value (frequency) of each cell is five or higher |

*Source: Author's classification*

**Table 4.1: Continued.**

| No. | Type of tests | Requirement of variable(s) |
|---|---|---|
| 2 | Fisher's exact test | Fisher's exact test has no assumptions of the expected value (frequency) of each cell |
| **VII** | **Correlation** | |
| 1 | *Pearson* correlation | Two variables are assumed to be normally distributed |
| 2 | *Spearman* correlation | One or both of variables has no assumption of normality |
| **VIII** | **Econometric models** | |
| 1 | Simple linear regression using OLS | Dependent variable is assumed to be normally distributed |
| 2 | Multiple linear regression using OLS<br>*Test for statistical significance of the overall model*<br>*Test for normality of residuals*<br>*Test for independence of residuals*<br>*Test for heteroscedasticity of residuals*<br>*Test for multicollinearity*<br>*Test the collective effect of dummy variables* | Dependent variable is assumed to be normally distributed |
| 3 | Simple linear regression using QR | Dependent variable has no assumption of normality |
| 4 | Multiple linear regression using QR | Dependent variable has no assumption of normality |
| 5 | Reliability analysis | *Details in Section 4.3.4* |
| 6 | Factor analysis | *Details in Section 4.3.4* |
| 7 | Latent class model | *Details in Section 4.3.4* |

*Source: Author's classification*

### 4.3.1 Method to Examine Climate Change and Climate Variability

Simple linear regression using OLS allows us to look at the linear relationship between a normally distributed predictor and a normally distributed outcome variable; in other words, predicting a normally distributed outcome variable from a normally distributed predictor variable. The relationship between them is positive (or negative) and the associated importance is based on related *t*-value(s) and *p*-value(s). These allow us to conclude whether there is a statistically significant positive (or negative) linear relationship between them.

Multiple linear regression using OLS is very similar to simple linear regression, except multiple linear regression has more than one predictor variable in its equation. Dependent variable is assumed to be normally distributed. We can predict a normally distributed outcome variable from a range of predictor variables. Predictor variables are expected that they have linear relationships with the outcome variable. Based on $F$-test and $p$-value we can conclude whether the overall model is statistically significant. Furthermore, based on associated $t$-value(s) and $p$-value(s) we can conclude whether predictor variable(s) are statistically significant.

When there is heterogeneity of variance in an OLS regression model, we estimate the OLS regression model with robust standard errors (the *robust* option). This option is very useful and does not affect the estimates of the regression coefficients. However, after running an OLS regression model with the *robust* option we do not need the test for heterogeneity of variance. The reason is that the *robust* option is used to optimise this problem in the model. OLS regression with the *xi* option is to create dummy variables from a categorical variable in the model. Predictor variables in OLS regression can be either dichotomous or continuous, but cannot be categorical. Therefore, a predictor variable has three categories will require two dummy-coded variables. When using dummies in OLS regressions, the *test* command is used to test the collective effect of such dummies.

This study used both types of regression: the ordinary least square regression (OLS) and the quantile regression (QR). OLS regression aims at estimates which approximate the conditional mean of the dependent variable given certain values of the independent variables, while QR regression results in estimating either the conditional median or other quantiles of the dependent variable. The normality of a dependent variable helps determine appropriate application of OLS regression (normally distributed dependent variable) or QR regression (not depending on distributional normality). Major advantages of the QR method over the OLS method are that:

(1) The QR method is more flexible in modeling data with heterogeneous conditional distributions.
(2) The OLS method can be applied only when a dependent variable is distributed normally, while the QR method can be applied independently of the distribution.
(3) The QR method is more robust to outliers than the OLS method.
(4) The QR method allows a better understanding of the changes in climate variables and latex yield over time or effects of each explanatory variable at quantiles.
(5) The QR method is suitable for heteroscedastic data.

The QR method is a more comprehensive method to analyse the time series data of yield against each climate variable, which will reveal the extent of changes and extreme values along with the whole range of conditional quantile values at different points of time[33] (Sarker, 2012). The objective is to estimate median values of a dependent variable. The QR method expands the estimation technique used for the linear trend model to any part or selected quantile of a dependent variable. This can provide a comprehensive analysis of the pattern of climate change and variability (Timofeev & Sterin, 2010) as well as latex yield. However, the QR method is not suitable for differenced data after their stationarity propensity is corrected.

The first part of the study assesses past change and variability of climate variables as well as latex yields at the provincial level. Time series data are required to study the effects of climate variables and latex yields in a particular location. Cross-sectional time series data of climate variables and latex yields are also considered, as we study the change and variability of climate variables and latex yields among the three provinces. To explore both climate change and climate variability at the provincial level, data were aggregated at monthly, annual and five-year moving average. The sub-questions are addressed by analysing the changes (annual and five-year moving average) and variations (monthly) in four key variables: monthly average maximum temperature, monthly average temperature, monthly average minimum temperature and total monthly precipitation. The monthly variables are converted into annual variables and their 5-year moving averages as needed. The datasets of climate variables and yields are organised into cross-sectional time-series data to analyse change and variability in climate variables and yields in each province.

Multiple linear regressions are used to point out individual impacts of each climate variable on latex yield by province. Linear trend models are also employed to detect changes in climate variables and latex yield over time. A linear trend model is a particular type of simple linear regressions, which considers a time trend ***t*** as an explanatory variable over the whole period. It provides only a temporal aspect of climate variables or yield (Sarker, 2012). The time trend, in the model that estimates latex yield against ***t***, is a proxy for technological advances, improved cultivation practices, market and policies over time (hereafter technology).

The *F*-value is used to assess overall significance of OLS, which shows whether there is a linear relationship between latex yields against ***t*** or each climate variable, and each climate variable against ***t***. The *Adjusted R-squared* value indicates what percentage of the variation in latex yield or each climate variable is explained by variation in explanatory variables. The *t*-value with relevant *p*-value is to assess individual significance of each slope coefficient.

[33] from 0 to 1 (i.e. quantiles at $0.01^{th}$, $0.05^{th}$, $0.10^{th}$,… $0.95^{th}$, $0.99^{th}$ correspond to 1%, 5%, 10%, 95% and 99% of the observations respectively) of the conditional distribution of climate variables

Graphical analysis, descriptive statistics, correlational analysis, statistical comparisons, linear trend models, simple linear regressions and multiple linear regressions provide the background to analyse change and variability of climate variables and yield as well as their individual impacts on latex yield in each province in particular. This section thus addresses the second research question whether there is evidence of climate change and variability in the three provinces.

### 4.3.2 Method to Examine Climate Impacts on Latex Yield

The individual impacts of climate variables on latex yield in each province provide background to analyse their simultaneous effects on latex yield across the three provinces in general. In principle, we can estimate 3 regressions for time series data (a regression for each of the three provinces) or 22 regressions for cross-sectional data (a regression for each year from 1991 to 2012). However, there are limitations of the number of observations and degrees of freedom. A multiple linear regression provides the background to analyse the simultaneous impacts of climate change and variability on latex yield among the three provinces using dummies. This section presents methods to answer the third research question on whether there are simultaneous relationships between climate change, climate variability and latex yields in the study area. This section also helps answer which climate variables most affect latex yield in the study area.

Efforts to improve latex yield and respond to the challenges of climate change are two sustainable goals that need to be achieved together. These efforts should rely on a solid quantitative evidence base, while accounting for spatial heterogeneity. Econometric analysis of the datasets provides useful insights into policy responses to enhance natural rubber development and encourage adoption of desirable practices. To ensure validity of results in time series analysis, the yield and climate variables must be stationary. This study uses the Fisher-type unit-root test for stationarity. If variables in the same regression models are differentiated with different orders, regression results are inconsistent. It was decided to differentiate the same order any of latter regression models to avoid confusion.

From the findings in Chapter 2, consultation with local professional experts and empirical evidence, the hypotheses tested in Chapter 5 are that an increase in the temperature variables impacts negatively on latex yield, but an increase in the precipitation variables impacts positively on latex yield. However, high latex yield requires differential temperature to create imbalance between the outside and inside pressures on cut bark of rubber trees. That is the reason latex is harvested in the early morning when the difference in temperature is obvious. Temperature and precipitation have mutual influence. Temperature is lower when it rains, and higher during the dry season when there is no rain. Precipitation also affects latex yield indirectly during the period of rubber tree growth and latex harvest via plant biological mechanisms that are directly affected by temperature.

### 4.3.3 Method to Evaluate Vulnerability, Perception and Adaptation to Climate Change

This section presents methods of analysis to address four research questions: (i) How vulnerable are rubber farmer households to climate change and variability? (ii) How do rubber farmers perceive climate change and variability and their adverse effects? (iii) Is there any adaptive deficit to climate change? If not so (iv) what attributes underlie adaptive measures and their likelihood of adoption?

#### *4.3.3.1 Evaluate Farmer Vulnerability to Climate Change and Variability*

Yusuf and Francisco (2009) classify vulnerability caused by climate variables into three types: income, poverty and inequality. Income vulnerability represents farmers' losses of on-farm income caused by climate variables through decreasing crop yields or other causes such as decreasing output prices and increasing production costs. The scope of this study excludes poverty and inequality vulnerability, which would make data collection both expensive and time-consuming. Fluctuations in output prices and production costs are sometimes caused by climate change and variability. For example, extreme weather events can cause a partial scarcity of agricultural inputs thereby increasing production costs. These can cause a decrease in crop quality and thereby a decrease in output prices. In this study (Chapter 6), on-farm income is positively correlated with crop yields, which means market uncertainties caused by output prices and production costs can be ignored for the purposes of this study.

Income vulnerability of farmers can be estimated from their statements of lost on-farm income or lost crop yields. Farmers commonly remember these events. Farmers are assumed to be able to distinguish whether total latex yield is lost due to climate variables or from other causes. Asking farmers for their perception of any change in climatic conditions at their locality and any impacts on latex yield they have noticed can test this assumption. To evaluate farmer vulnerability, they are asked about the portion of total latex yield that was lost in a previous year due to climate variables. We can estimate lost on-farm income through lost portions of total latex yield by relevant output prices at that time. Such questionnaire responses should be presented as descriptive statistics of percentage, min and max. Portions of lost total latex yield are compared among farmer segments or other categories as needed. Hence, to what extent farmer vulnerability of income to climate change is estimated quantitatively.

If income vulnerability of farmers is present, it will contribute to an understanding of adaptation at the farm level and provide information on policy suggestions. Policy suggestions aim to reduce income vulnerability of farmer households, which helps enhance their adaptation at the farm level (Figure 4.1, page 62). A decrease in income vulnerability enhances resilience, thereby enhancing the adaptive capacity of farmers. Based on the common definition of vulnerability to climate change, previous studies that measure community vulnerability identify it as a function of three indicators: exposure, sensitivity and adaptive capacity (Pandey & Jha, 2012; Yusuf & Francisco, 2009). Some others use a utilitarian approach to determine community vulnerability (Ligon & Schechter, 2003). These factors are complex to measure and commonly are applied to community vulnerability, while vulnerability of farmer households is usually measured qualitatively. As discussed above, the present study uses data of lost total latex yield in a previous year by climate variables to determine income vulnerability of farmer households.

#### *4.3.3.2 Evaluate Farmer Perception of Climate Change and Variability*

Farmers are assumed to be able to perceive climate change and variability when asked about any change in climatic conditions at their locality over the past 20 years. They can point out the climate variables they think have changed and describe how they have changed. Based on the local climate regime, variables like *temperature*, *precipitation*, *drought*, *heavy wind*, *hours of sunshine*, *soil moisture*, *groundwater* and *surface water* are paired with their features of being *increased*, *decreased* and *unchanged*. Asking these questions reveals farmers' perceptions. We can also ask them whether latex yield is affected negatively by such climate variables and if so to describe their severity of impacts. Such questionnaire responses should be reported as descriptive statistics. The portion of farmers who stated increasing trends in each variable and the portions of farmers who stated decreasing trends were compared among the three provinces. These findings can then be used to confirm the results of analysing the secondary data of historical records.

An understanding of farmer perception in this study contributes to an understanding of adaptation at the farm level and provides information on policy suggestions. Policy suggestions aim to improve farmer perception which helps enhance farmer adaptation at the farm level (Figure 4.1, page 62). These methods have been used in previous studies; for example, Van et al. (2015) in the study of rice farmers in the Northern Central Coast of Vietnam or McElwee (2010) in the study of farmers in Ben Tre and Can Tho provinces (Vietnam). Descriptive statistics and statistical comparisons are used for measuring perception of climate change by farm households (Charles & Rashid, 2007).

#### *4.3.3.3 Evaluate Adaptive Capacity of Farmers to Climate Change and Variability*

Adaptive capacity of farmer households is affected by national adaptive capacity and individual adaptive capacity. The scope of this study builds up a profile of the small-scale rubber sector that reflects most factors affecting adaptive capacity of farmer households. This profile includes the institutional contexts, socio-economic conditions, and agro-environments in the study area; as well as demographic and farm characteristics of rubber farm households. Farmers can reveal such conventional information through questionnaire responses.

The present study examines adaptive capacity of the small-scale rubber sector through farmer households' profiles, where determinants of farmers' adaptive responses also determine directly their adaptive capacity. A profile using the farm-level data is presented by descriptive statistics and statistical comparisons. Asking whether there are constraints affecting farmer households' choice of adoption also complements information on adaptive capacity of farmer households.

#### *4.3.3.4 Evaluate Farmer Adaptation to Climate Change and Variability*

Following Lal et al. (2001), measuring adaptation consists of evaluating availability, economic feasibility and applicability of adaptive measures. Lasco et al. (2011) assessed the adaptive deficit of farmers through key steps as follows: (i) assess the climate-related hazards that farmers face, (ii) analyse farmers' vulnerability due to climate impacts, (iii) assess the strengths and weaknesses of local adaptive actions, (iv) assess the effectiveness of each adaptive option with respect to its cost-benefit ratios or cost efficiency, and (v) determine if an adaptive deficit exists. The present study uses the approach of Lasco et al. (2011) to analysis adaptation at the farm level. However, assessing the effectiveness of each adaptive option with respect to its cost-benefit ratios or cost efficiency is not explored, being beyond the scope of this study.

Farmers are assumed to be able to distinguish between actions to cope with climate change and variability, and actions to adapt to them. To what extent we can distinguish their response types through attributes of actions that they chose or they have a propensity to choose. Asking their adaptive deficit commonly helps identify farmer adaptation to climate change, if not so to describe methods of adoption and the most preferred adaptive measure. We can test their incentives for adaptation by asking about their prediction of how much their yield will increase if particular adaptive measures are conducted, or their prediction of increased latex quality. The portions of farmers who prefer each adaptive measure and the most preferred adaptive measure are compared among farmers, and portions of farmers who prefer each adaptive attribute are also compared among farmers.

The analytical results in chapters 6 and 7 are based on the survey data, which include different types of continuous, categorical and dichotomous variables in the form of static data. Before these data were used for empirical analyses, data cleaning and calibrations had been conducted. A range of requirements such as treating outliers, inspecting descriptive statistics, testing for normality of continuous variables, statistical comparisons and tests for correlation are reported in those two chapters.

### 4.3.4 Method to Assess Determinants of Farmers' Adaptive Responses

This section considers three issues in the study area: preferred adaptive methods to changing climatic conditions, underlying attributes of adaptive measures being practised, and adaptive behaviour of rubber farmers. Econometric models of reliability analysis, factor analysis and the LCM are used to assess possible strong correlations among these three issues from statements of rubber farmers employ adaptive measures. Using reliability analysis and factor analysis allows preferred adaptive attributes and different adaptive behaviour groups to be identified.

A reliability analysis provides information on statistically significant variables that need to be further estimated in a factor analysis. It analyses the reliability of measuring discrete attributes across the respondents. Underlying attributes that have the strongest correlations of agreement scores to every adaptive measure are differentiated from others with weaker correlations across the respondents but also across the attributes, thereby underlying attributes are grouped together. The method of reliability analysis is also applied to assess opinions of farmers in the survey about the local supply of agricultural inputs. A reliability analysis model identifies reduced underlying attributes among a full adaptive attribute set which can explain best the choice behaviour of farmers among these attributes. The choice behaviour can be more easily understood when a factor analysis model is used to classify attributes, which underlies the reliability analysis model, into finite groups. The number of finite groups is usually fewer than the number of included attributes. Each group contains one or some of underlying attributes, and is representative of a behaviour type of farmers.

A factor analysis helps identify underlying attributes that can differentiate adaptive preferences across the respondents best. Some underlying attributes that have weak explanatory power in differentiating adaptive preferences across the respondents are dropped from factor analysis. Each final factor after a rotated procedure is estimated to consist of the only underlying attribute(s) on it. Different final factors consist of different underlying attribute(s). The goal of this procedure is to facilitate interpretation of factors, because rotated factors receive either very high or very low loadings on each factor. Factor analysis is also used to either reduce the number of variables in analyses or detect relationships among variables, but in this study a reliability analysis helps filter important attributes from a pool of attributes.

Final factors are drawn from the factor analysis and are standardised in the form of a new dataset. This new dataset is further analysed in latent class econometric analysis, using the LCM. The LCM estimates utility of final factors among farmer segments, and estimates determinants of segment-adaptive responses among segments. The LCM analyses the probability of a given farmer belonging to a segment that has particular preferences regarding adaptive behaviour. Based on these probabilities, the LCM helps group rubber farmers with similarity of household-specific and site-specific characteristics into a segment. The LCM is based on first estimating rubber farmers' evaluation of various attributes of adaptive measures, and then identifying segments of rubber farm households whose preferences for adaptive attributes are similar.

#### *4.3.4.1 Reliability Analysis*

The 5-point Likert scale was used to measure a rubber farmer's preferences for 14 attributes of adaptive measures. According to Hoang and Chu (2005), there are no absolute advantages or disadvantages in using the 5-point scale. Each of the 14 attributes is considered a vector within the preference for adaptive measures.

Data for measurement of attributes in this study were collected through stated preference questions during the field survey. The data collected needed to be tested for reliability before using them for further analyses. Reliability analysis helps identify a reduced set of attributes. In other words, it helps optimise the attribute set.

The Cronbach alpha test is used to test the strength of correlations among attributes. It is defined as:

$$\alpha = \frac{N*\rho}{1+\rho*(N-1)} \qquad (4.1)$$

where $\rho$ is the average correlation coefficient among attributes, and $N$ is the number of attributes. A good value of $\alpha$ is expected to be > 0.8, but a range of 0.7 to 0.8 is acceptable in terms of statistical significance of the model (Hoang & Chu, 2005). In this study the model is accepted if its $\alpha$ value is > 0.7. Each attribute is considered statistically significant if its individual $\alpha$ value, when the attribute is deleted, is < the *Cronbach's alpha* of the full model. Attributes with $\alpha$ values > the *Cronbach's alpha* need to be removed, because such attributes have less explanatory power in the model. Removing those attributes increases the explanatory power among the remaining attributes. Comparing $\alpha$ values of the remaining attributes after removing provides evidence to produce a reduced set of attributes. All remaining attributes are used in further factor analyses to identify farmers' behaviour groups among adaptive attributes.

#### *4.3.4.2 Factor Analysis*

Unlike individual attributes in the reliability analysis, factors containing attributes which have a strong correlation with each other provide more information. Such factors provide a basis for formalising preferences for adaptive measures. A factor analysis model helps identify basic attributes through grouping them into main factors (Hoang & Chu, 2005). Attributes that have a strong correlation are grouped together and thus are differentiated from others with a weaker correlation. Factor analysis does not distinguish between dependent variables and explanatory variables. It uses an interdependence technique that considers correlations of all attributes.

In factor analysis each attribute is expressed as a linear association of the main factors. If attributes are standardised, the model is defined as:

$$X_i = A_{i1}F_1 + A_{i2}F_2 + A_{i3}F_3 + \cdots + A_{im}F_m + V_iU_i \quad (4.2)$$

where:

$X_i$: $i^{th}$ standardised attribute[34] ($i = 1, 2... n$),

$A_{ij}$: standardised multiple regression coefficient of $j^{th}$ common factor against $i^{th}$ standardised attribute ($j = 1, 2... m$),

$F_m$: $m^{th}$ common factor,

$V_i$: standardised regression coefficient of $i^{th}$ unique factor against $i^{th}$ standardised attribute,

$U_i$: unique factor of $i^{th}$ standardised attribute, and

$m$: number of common factors.

Unique factors are correlated to each other and correlated with common factors. Common factors are also defined as linear associations of standardised attributes as:

$$F_i = W_{i1}X_1 + W_{i2}X_2 + W_{i3}X_3 + \cdots + W_{ik}X_k \quad (4.3)$$

where:

$F_i$: $i^{th}$ common factor,

$W_{ig}$: weight or factor score coefficient in a component score coefficient matrix ($g = 1, 2... k$),

$k$: number of attributes.

Various key tests exist to analyse the results of a factor analysis model including:

(i) The KMO test that measures the goodness of fit of the factor analysis. KMO value varies between 0.5 and 1 is compatible, otherwise a factor analysis is not compatible with variables given. The KMO test checks a correlation matrix of attributes before analysing factors as needed. Correlation coefficients greater than 0.3 are sometimes considered significant.

(ii) The Bartlett test is used to test the null hypothesis that there is no correlation of attribute variables in the population. If this test is rejected ($p < 0.05$), the model is compatible to the attribute variables included. The Bartlett test is based on a *Chi-squared* mathematical transformation. The larger the approximated *Chi-squared* value of the Bartlett test is, the higher the probability of rejecting the null hypothesis is.

(iii) Cumulative percentage indicates total percentage of the variation of data explained by included factors. The percentage of variance indicates the percentage of each factor that can explain variation in the data.

[34] After being standardised, original variables will have variances of one.

To find a balance of sample size, costs and the need to collect necessary information, the questionnaire was designed to satisfy the research objectives and answer the research questions. The sample size is large enough to ensure statistically significant results. The sample size in factor analysis must cover at least four or five times the number of original attributes (Hoang & Chu, 2005). In this study there are 430 observations and 10 original attributes so this requirement is satisfied. There are five methods to identify the number of common factors: a priori determination, determination based on eigenvalues, scree plot, percentage of variance, splitting the sample into two sub-samples, and significance level test. This study uses eigenvalues to identify the optimal number of common factors; only factors with eigenvalues > 1 are selected. Other factors are not able to summarise information better than the original attribute variables. Eigenvalue is representative of the variation portion which is explained by each factor. Each final factor is considered as a reason why an adaptive method is preferred.

A rotated component matrix helps enhance interpretation of the results. The rotated component matrix contains factor loadings. Factor loadings are individual correlation coefficients of all attribute variables against extracted factors. Higher factor loadings show stronger correlations. The correlation matrix indicates correlation coefficients between any pair of attribute variables. Each factor loading in a component matrix explains a relationship between an attribute and a main factor. However, there may be many relationships between several attributes and main factors and so the analysis can become complex, which requires a decrease in mutual relationships of factors and attributes. This study uses the extraction method with the Principal Component Analysis (PCA) and the rotation method of Varimax with Kaiser normalisation. These methods are popularly applied in studies using factor analysis. Different rotation methods identify different factors and factor loadings. However, communalities and cumulative percentage are unchanged. Communality measures the variation of each attribute, which is explained by other attributes in the model and common factors. Common factors are estimated for each attribute variable against extracted factors. The Varimax procedure rotates factors in order to minimise the number of attributes with high factor loadings (usually greater than 0.7) within a main factor. Final factors are normally given names to make them more descriptive of their underlying attributes.

The statistical software packages help calculate common factors ($F_i$) for every observation. Likert-scaled values in an original attribute set are replaced by common factors standardised as deviation units. A dataset of these factors, which are created from the factor model, is used for other analyses later. This common factor set is ready to use for further analyses in latent class economic analyses.

#### *4.3.4.3 Latent Class Econometric Analysis (the LCM)*

According to Sagebiel (2011), the application of the LCM depends on the purpose of research and behavioural assumptions. If the purpose of research is to inform policy-makers as well as related stakeholders, the structure of the LCM satisfies the purpose; because choice experiments are often conducted to inform these stakeholders. If a researcher assumes antipodal preferences of different segments that show within-segment homogeneity but significant variance between segments, the structure of the LCM satisfies the context. In case each individual has different preferences, the LCM is not the compatible model. The ultimate purpose of the study is focus on providing related stakeholders knowledge of climate change adaptation, so the study considers antipodal preferences of different farmer segments. These domains require the application of the LCM.

Using latent class econometric analysis allows determinants affecting farmers' decisions when choosing adaptive measures to be identified. Such determinants can be directly observable or unobservable, and can be directly measureable or immeasurable. These determinants include farm-level factors and farmers' stated preferences for adaptive measures. Therefore, sources of heterogeneity in farmer preferences at each segment level are potentially demonstrated. Estimating the heterogeneity of their preferences can ensure unbiased results, which enhances the accuracy and reliability of findings (Birol et al., 2007; Falck-Zepeda et al., 2011). The LCM allows us to identify different segments of rubber farm households whose preferences are relatively homogenous within each segment, but their preferences vary between segments. Hence, the LCM helps in differentiating possible kinds of farmers' decisions on choosing adaptive measures and in differentiating characteristics of sample segments (Birol et al., 2007). According to Charles and Rashid (2007), it is particularly useful in evaluating the determinants that impact on such decisions.

According to Magidson and Jeroen (undated), the LCM has some key features:

(i) The LCM classifies a population into a finite and identifiable number of segments (groups of individuals), based on their choices, their characteristics and stated preferences. In other words, it shows who has a propensity to belong to one segment of interest and what would be their preferences. Preferences are often linked to attributes of any hypothesised products or goods. This method determines the number of segments endogenously.

(ii) Suitable variables in the model may be continuous, categorical (dichotomous, nominal or ordinal) or any combination of these. LCM does not rely on traditional modeling assumptions (e.g. distribution), which are often violated in practice. According to Sagebiel (2011), for example, the LCM derives heterogeneity from different segments and each has its own parameters. However, it does not require any assumption on the distribution of the parameters. Meanwhile, the RPL assumes a continuous distribution of the parameters to introduce heterogeneity. Nonetheless, it has potential drawbacks not to guarantee the maximum likelihood solution.

(iii) Description of segments can contain the surveyed information on respondents. The LCM derives the most affected segments and the least affected segments from the attributes given. Policies, thus, can be designed to impact on different segments.

According to Birol et al. (2007) and Falck-Zepeda et al. (2011), the LCM can be written as follows:

$$U_{ij/s} = \beta_s X_{ij} + \varepsilon_{ij/s} \tag{4.4}$$

where:

$U_{ij/s}$: utility of a farmer *i* belonging to a production segment *s*, choosing an adaptive measure *j* (j ∈ C),

$X_{ij}$: vector representing attributes of an adaptive measure *j* that is adopted by a farmer *i*,

$\beta_s$: vector of estimated coefficients that is segment-specific, and

$\varepsilon_{ij/s}$: error term.

Differences in $\beta_s$ vectors allow the researcher to measure heterogeneity in attribute preferences of adaptive measures among segments.

The probability of adoption of a measure *j* by a farmer *i* in a segment *s* is as follows (*h = 1, 2... j*):

$$P_{ij/s} = \frac{exp(\beta_s X_{ij})}{\sum_{h=1}^{C} exp(\beta_s X_{ih})} \tag{4.5}$$

The membership likelihood function of a farmer *i* in a segment *s* is:

$$M_{is}^{*} = \lambda_s Z_i + \xi_{is} \tag{4.6}$$

where:

$M^*$: the function that classifies farmers into a segment *s* with the probability $P_{is}$,

$Z_i$: characteristics of farmer *i*,

$\lambda_s$: vector of estimated parameters that is segment-specific, and

$\xi_{is}$: error term.

Suppose that error terms in the function are independent and identically distributed random (*i.i.d*) among farmers and segments. The choice probability of a rubber farmer *i* belonging to a segment *s* is as follows (*k = 1, 2... s*):

$$P_{is} = \frac{exp(\lambda_s Z_i)}{\sum_{k=1}^{S} exp(\lambda_k Z_i)} \tag{4.7}$$

Equation 4.7 indicates that the probability of a farmer becoming a member of a segment is a function of the farmer's characteristics. The sign of $\lambda$ depends on these characteristics ($Z_i$) and affects the probability that a farmer *i* belongs to a segment $s$ ($P_{is}$).

Bringing Equations 4.5 and 4.7 together we can build a finite mixture model (Boxall & Adamowicz, 2002) that takes simultaneously into account decisions of a rubber farmer *i* in a segment $s$ choosing an adaptive measure $j$, the probability can be written as follows:

$$P_{ijs} = (P_{ij/s}) \times (P_{is}) = \left[\frac{exp(\beta_s X_{ij})}{\sum_{h=1}^{C} exp(\beta_s X_{ih})}\right] \times \left[\frac{exp(\lambda_s Z_i)}{\sum_{k=1}^{S} exp(\lambda_k Z_i)}\right] \quad (4.8)$$

This model incorporates three domains of respondents' choices, their stated preferences for attributes and characteristics to simultaneously explain choice behaviour; it estimates the joint distribution of choice probability and segment membership probability (Boxall & Adamowicz, 2002).

A range of requirements of descriptive statistics, statistical comparisons, reliability analysis, factor analysis and latent class econometric analysis are examined in Chapter 8, using the survey data. Policy implications in Chapter 9 focus on these segments of rubber farmers, segment-specific adaptive preferences and segment-specific determinants to obtain the efficacy of policies in practice.

## 4.4 Data and Data Sources

Using primary and secondary data, the empirical analyses are conducted in two stages: (i) a provincial-level analysis in Chapter 5 involving the cross-sectional time series data of climate and latex yield in the three provinces of Southeast Vietnam and (ii) a farm-level analysis in chapters 6, 7 and 8 involving the field survey data in these provinces.

### 4.4.1 Data Requirements

The potential relationship between latex yield and climate status across the three provinces is estimated using cross-sectional time series data. The climate status in this study is limited to three temperature variables (annual maximum average ***Tmax***, annual average ***Tmean*** and annual minimum average temperature ***Tmin***), total annual precipitation ***Pmean*** and their five-year moving averages (***Tmax5***, ***Tmean5***, ***Tmin5*** and ***Pmean5***). Climate variables in this study (***Tmax***, ***Tmean***, ***Tmin***, ***Pmean*** and their 5-year moving averages) may influence the change and variability of latex yield (***Yield***) at the provincial level. Other factors, i.e. technological advances, improved cultivation practices, market and policies over time, may also influence the change of ***Yield***.

This study analyses farmers' behaviour in adaptation to climate change and variability. Therefore, it needs to employ the farm level data. A farmer survey was conducted in the three provinces in

Southeast Vietnam. The survey was designed to address the research questions. The types of data collected and the information that can be obtained from the primary data are presented in Chapter 6. Rubber farmers were interviewed in person. The survey was administered over a period of three months between January and April 2014. The research questions 3–9 introduced in Chapter 1 are answered based on the field survey data.

### 4.4.2 Data Preparation and Calibration

The data employed for the analysis are in the forms of cross-sectional time series data and survey data. Before these data were used for empirical analyses, data cleaning and calibrations had been conducted.

#### *4.4.2.1 Test for Outliers of Data*

Following Hamilton (1992), means, medians, standard deviations and Pseudo standard deviations are used to detect outliers in the data series. Severe outliers[35] in datasets may have unusual effects on OLS regression estimates, because it inflates the usual Skewness and Kurtosis statistics of normality. This is implemented using the interquartile range test, whereby an interquartile range (75th percentile - 25th percentile) and Pseudo standard deviations are calculated. The *iqr var.* command tests if a value < (25th percentile - 3×Pseudo standard deviation) or > (75th percentile + 3×Pseudo standard deviation) shows the presence of severe outliers of each variable in dataset. After removing the outliers and possible irregularities in the dataset, various descriptive statistics are then considered.

Following Sarker (2012), the standard deviation is used as an indicator of absolute variability of climate and yield datasets. It is a useful measure for determining variability of yield. This study requires indicators of mean, median, standard deviation, min, max and frequency. The *summarize var.* command estimates mean, standard deviation, min and max. The *tabstat var., statistics*(median) command estimates median, and the *table var.*, *contents*(freq) command estimates frequency.

Graphical analysis helps understand variable trends (using scatter plot diagrams) and high-low features of climate and latex yield datasets. This method supports latter relevant regression estimations visually.

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35 Severe outliers: < (25th percentile - 3×Pseudo standard deviation) or > (75th percentile + 3×Pseudo standard deviation)

### *4.4.2.2 Test for Normality of Data*

The normality of continuous data helps determine the appropriate types of parametric or non-parametric tests. The normality of a continuous dependent variable helps determine the appropriate types of ordinary least squares (normally distributed dependent variable) or quantile (non-normally distributed dependent variable) regression estimations (Hoang & Chu, 2005). Following D'Agostino et al. (1990), the Skewness and Kurtosis test for normality are powerful and informative. The third sample moment ($b_1^{-1/2}$) and fourth sample moment ($b_2$) are used to detect deviations from normality due to either Skewness or Kurtosis. Equations of $b_1^{-1/2}$ and $b_2$ are presented in D'Agostino et al. (1990). The expected values of $b_1^{-1/2}$ and $b_2$ are 0 and 3(n - 1)/(n + 1) under normality, respectively. Values differ from these considered to be under non-normality. This study employs both the Shapiro–Wilk test and the Skewness and Kurtosis test for normality, where the null hypothesis assumes that the dataset is distributed normally. The reason is that, in case, the value of *Adjusted Chi-squared* of the Skewness and Kurtosis test is infinite this study uses the Shapiro-Wilk test to judge normality. However, if any dataset has tied data (some the same values), the Shapiro–Wilk test should not be used (Royston, 1992). Following Royston (1992), the median value of *V* in the Shapiro–Wilk test is 1 for a sample from normal populations. The 95% critical points of *V* are between 1.2 and 2.4. Median values of *V* out of this range indicate non-normality, but its significance also depends on the sample size.

The *sktest var.* command tests an overall test statistic (*Adjusted Chi-squared* statistic) for the null hypothesis based on the Skewness and Kurtosis test. The *swilk var.* command tests the *z*-statistic for the null hypothesis based on the Shapiro-Wilk test. After identifying the normality in the data set, selection of OLS and QR regression estimations and selection of parametric or non-parametric tests regarding correlation and comparison tests are then considered.

### *4.4.2.3 Test for Correlation of Datasets*

In order to examine the correlation of each pair of data, a pairwise correlation analysis is conducted. The *Pearson* correlation test is useful when we wish to test for a linear relationship between two normally distributed variables. If one or two continuous variables has no assumption of normality, the *Spearman* correlation test converts the values of the variables in ranks for the test. This study uses the *corr var.1 var.2* command to test *Pearson* correlation or the *spearman var.1 var.2* command to test *Spearman* correlation ($\rho$-statistic). The null hypothesis is that the pair of variables is not correlated, and the alternative hypothesis is that they are correlated. Pairwise correlation coefficients are also useful for exploratory analysis of individual climate impacts on latex yield as well as for identifying multicollinearity among explanatory variables in regression estimations.

#### *4.4.2.4 Test for Statistical Differences among Datasets*

**(1) Parametric tests**

The one-way analysis of variance (ANOVA) is used when we have a categorical independent variable (2–3 provinces, 2–3 categories or with four or more categories) and a normally distributed dependent variable. This parametric test tests for differences in the mean of the dependent variable broken into three categories of the independent variable. In other words, we wish to test whether the means of the dependent variable differ between categories of the independent variable. The *anova var.* 3 category-*var.* command tests differences in the mean of *var.*, broken into three categories. The null hypothesis is that the means of three samples are equal, and the alternative hypothesis is that the means of the three samples are unequal. The mean of the dependent variable may differ significantly among three categories of the independent variable, but we do not know if the difference is between only two of the three categories or all three of them. Based on the *F*-test and *p*-value of the full model we can conclude whether this difference is statistically significant. The *F*-test of the full model is the same as *F*-test of an independent variable if there is the only independent variable entered into the model. The *F*-test of the full model differs from the *F*-test(s) of independent variables if other independent variables are included in the model. We can use the *tabulate* 3 category-*var.*, *summarize*(*var.*) command with the *summarize* option to see the mean of a normally distributed dependent variable for each category to be the highest or the lowest.

In cases where there are two provinces or two categories, this study uses the two independent samples *t*-test with equal variances or unequal variances. The two independent samples t-test is used when we wish to compare the mean of a normally distributed dependent variable broken into two categories of a categorical independent variable; in other words, we wish to test whether the means of the dependent variable are the same for two categories of the independent variable. The null hypothesis is that the means of the two samples are equal, and the alternative hypothesis is that the means of two samples are unequal. The *ttest var.*, by(2 category-*var.*) command or the *ttest var.*, by(2 category-*var.*) *unequal* command tests differences in the mean of *var.* broken into two categories (*t*-statistic). We can use the *unequal* option to obtain results for unequal variances. The *ttest var.*, by(2 category-*var.*) command default assumes equal variances. Based on the associated *t*-value and *p*-value, we can conclude whether there is a statistically significant difference between them. Also, one category has a statistically significantly higher mean than the remaining category.

In cases where this study tests whether a sample is dawn from a population with a given mean value (hypothesised value - *constant*), the one-sample *t*-test is used with the *ttest var.* = *constant* command.

**(2) Non-parametric tests**

The Kruskal Wallis test is used when we have a categorical independent variable (2–3 provinces, 2–

3 categories or with four or more categories) but do not assume normality of a continuous dependent variable. This non-parametric test tests for differences in the median of the dependent variable broken into three categories of the independent variable. In other words, we wish to test whether the medians of the dependent variable differ between categories of the independent variable. The *kwallis var.*, by(3 category-*var.*) command tests differences in the median of *var.* broken into three categories. We can use this command to see if the median of the dependent variable for each category is the highest or the lowest.

In cases where there are two provinces or two categories, this study uses the two-sample Wilcoxon rank-sum (Mann-Whitney) test for differences in the median of *var.* broken into two categories. The null hypothesis is that the medians of samples are equal, and the alternative hypothesis is that the medians of samples are unequal. The two-sample Wilcoxon rank-sum (Mann-Whitney) test is also the non-parametric Wilcoxon-Mann-Whitney test that applies to the two independent samples t-test. Based on the associated *z*-value and *p*-value, we can conclude whether there is a statistically significant difference between the underlying distributions of the medians of two categories. We can determine which category has the higher rank by looking at the how the actual rank sums compare to the expected rank sums; in other words, is the sum of the one category ranks higher than the sum of the remaining ranks. The *ranksum var.*, by(2 category-*var.*) command tests differences in the median of *var.* broken into two categories. We can use this command to see if the median of the dependent variable for each category is higher or lower.

In cases where this study tests whether a sample is dawn from a population with a given median value (hypothesised value - *constant*), the Wilcoxon signed-rank test (*z*-statistic) is used with the *signtest var.* = *constant* command or the *signrank var.* = *constant* command.

The Chi-squared test is used when we wish to see if there is a statistically significant relationship between two categorical variables, based on the associated *Chi-squared*-value and *p*-value. Each categorical variable may have more than two categories, but the number of categories in each variable may be different. The *tabulate* category-*var.1* category-*var.2*, *chi2* command with the *chi2* option is used to obtain the *Chi-squared* statistic and its associated *p*-value, but the Chi-squared test assumes the expected frequency of each cell is five or higher. If one or more of cells has an expected frequency of less than five, the *tabulate* category-*var.1* category-*var.2*, *exact* command with the *exact* option of the Fisher's exact test will fit. The Fisher's exact test has no such assumption and can be used regardless of how small an expected frequency is. The Fisher's exact test does not have a test statistic, but it calculates the *p*-value directly. The Fisher's exact test sometimes does work for two variables having many categories because of the memory limited, in this case the Chi-squared test is used.

According to Hoang and Chu (2005), non-parametric tests are used to test both normally distributed and non-normally distributed datasets, while parametric tests are best suited for normally distributed datasets. Thus, non-parametric tests are sometimes also used to test whether there are mean and median differences of samples.

#### *4.4.2.5 Test for Stationarity Propensity of Data*

For time series data, a test and, if necessary, correction for stationarity is performed before using a variable in model estimation. The application of any regression models with time series data requires related variables to be stationary, as direct use of non-stationary data in regression estimations can produce spurious results (Chen et al., 2004; McCarl et al., 2008). A time series variable is non-stationary if it has non-constant mean, non-constant variance and auto-covariance (at various lags) over time, which means that their means and variances do vary systematically over time (Sarker, 2012). Stationarity and unit roots of the dataset need to be corrected.

In this study, we have two sets of time series data: (i) climate data for 35 years covering the period 1978 to 2012, (ii) latex yield for 23 years covering the period 1990 to 2012. The Fisher-type unit-root test based on the ADF test in Dickey and Fuller (1979) was employed to examine the presence of unit roots. Maddala and Wu (1999) observe that the Fisher-type unit-root test combines the *p*-value(s) from individual unit root tests. An advantage of this test is that it can be employed for different lag lengths in individual ADF regressions and for any unit root test. This study employs the Fisher-type unit-root test for time series data, because of its superiority over other tests (Baltagi, 2005).

A non-stationary time series dataset has to be differenced *d* times to become stationary. This differenced version of the dataset is said to be integrated of order *d*, written as I(*d*). The *dfuller var.*, *lags*(0) command is used to perform the ADF test (*z*-statistic) for the presence of unit roots for each variable, with critical values of 1%, 5% and 10%. The null hypothesis that the variable contains a unit root, and the alternative hypothesis that the variable is generated by a stationary process.

#### *4.4.2.6 Hypothesis Tests in Multiple Linear Regression Models*

Econometric analysis with cross-sectional time series data can face problems of multicollinearity and heteroscedasticity (Sarker, 2012). According to Marill (2004), Chen et al. (2004) and McCarl et al. (2008), there are five assumptions that need to be considered to ensure that results of multiple linear regression models are valid:

(i) The overall goodness of fit of the model is statistically significant,

(ii) Error values (random error term or residual) are statistically independent,

(iii) Error values are normally distributed for any given set of values of independent variables (the mean of errors is close to zero and their standard deviation is close to one),

(iv) The probability distribution of errors has a constant variance, and

(v) Multicollinearity is corrected.

**(1) Checking for the overall goodness of fit of the model**

The *F*-test for the full model shows the overall goodness of fit of the model; in other words, the model is statistically significant. The null hypothesis is that all coefficients as a group ($\beta$) are equal to zero, and the null hypothesis is that all coefficients as a group ($\beta$) are statistically different from zero. The model is applicable if the null hypothesis is rejected. A coefficient in the model is statistically different from zero, this means that a change in its predictor has a statistically significant relationship with a change in an outcome variable. Adjusted R-squared shows how well this model explains variation in the dataset.

**(2) Checking for independence of residuals**

The hypothesis of the standard model is that the residuals associated with one observation are not serially correlated with the residuals of other observations. All observations must be independent. According to Lobell et al. (2007), auto-correlation or serial correlation in crop yields, when analysing sources of yield variation, should be removed. The Durbin-Watson statistic identifies whether residuals of the model are serially correlated, its *d*-statistic is in the range of dL to (4 - dU) at the 5% significance points of dL and dU. The Durbin-Watson value ranges from 0 to 4. Residuals are not serially correlated if a Durbin-Watson value is approximately 2 (from dL bound to (4 - dU) bound). A positive correlation is strong if a Durbin-Watson value is close to 0, while a negative correlation is strong if a Durbin-Watson value is close to 4. Available values of dL and dU are taken from the Durbin-Watson Significance Tables. The *dwstat* command is used to perform the Durbin-Watson test for the presence of serial correlation among residuals.

**(3) Checking for normality of residuals**

Normality of residuals of the model is assumed for valid hypotheses of *p*-value(s) for *t*-test(s) and *F*-test(s) in regression models. The *p*-value is based on an assumption that the individual distribution is normal, which is an essential feature of OLS regression (Sarker, 2012). After running an OLS regression model we test whether the residuals from the regression are normally distributed. The *predict* command with the *resid* option calculates the residuals. The Skewness and Kurtosis test or the Shapiro–Wilk test tests the normality of the residuals.

**(4) Checking for homoscedasticity of residuals**

Homoscedasticity of variance of residuals is one of the main assumptions of OLS. If the variance of residuals is non-constant, it is said to be heteroscedastic. The *estat hettest* command tests for heteroscedasticity using the Breusch-Pagan test. The outcome of the Breusch-Pagan test indicates whether the regression does need to be corrected for heteroscedasticity. The null hypothesis is that the variance of residuals is homogeneous and its rejection indicates that the variance of residuals is not homogeneous. These tests are very sensitive to the assumption of normality (Sarker, 2012).

**(5) Checking for multicollinearity**

Multicollinearity can lead to inaccurate coefficient estimation. Multicollinearity implies that there are strong linear relationships between two or more explanatory variables. These variables contribute redundant information and result in inconsistent regression results (Marill, 2004). The estimates of coefficients become unstable and the estimated standard errors of coefficients can be inflated. VIF tests for the presence of multicollinearity under OLS regressions. VIF values reveal whether there is the problem of multicollinearity amongst explanatory variables (Sarker, 2012). The *vif* command is compatible with OLS regression models. The *vif* command, after running an OLS regression with all variables included in the model, calculates *vif* values for each explanatory variable. A *vif* value > 10 indicates instability. Variables with very high *vif* values are possibly redundant, because if one variable is known in advance, another variable can be predicted well (Sarker, 2012). Variables with very high *vif* values identify evidence of multicollinearity. The tolerance indicator, calculated as 1/*vif*, is used to test for instability of regression coefficients. A tolerance value < 0.1 is comparable to a *vif* value of 10 or more.

## 4.5 The Secondary Data Collection of Climate and Yield

The purpose of the secondary data used in the study is to highlight change and variability in climate variables and latex yield as well as testing for impacts of climate on latex yield in the study area. Climate data were sourced from the hydro-meteorological stations (Table 4.2).

**Table 4.2: The hydro-meteorological stations in the study area**

| Province | Name of station | Location | Period of time for data analysis |
|---|---|---|---|
| Binh Phuoc | Phuoc Long | Latitude: $11^0$50'<br>Longitude: $106^0$59' | 1978–2012 |
| Dong Nai | Xuan Loc | Latitude: $10^0$56'<br>Longitude: $107^0$14' | 1978–2012 |
| Tay Ninh | Tay Ninh | Latitude: $11^0$20'<br>Longitude: $106^0$07' | 1979–2012 |

*Source: The VNCHMF (2013)*

There is at least one hydro-meteorological station in each province in the study area. Secondary climate data were collected from the VNCHMF. Analysing climate impacts on latex yield requires yield data for each period and location for which climate variables exist. Therefore, yield data were sourced from the relevant provinces. These data are normally available in annual statistics yearbooks published in each province. Climate variables are usually collected daily and compiled in electronic data files, so they are easy to extract and use in analyses. Yield data are formatted as monthly and annual figures by province and district, but climate data are formatted as monthly and annual figures by stations. For the sake of simplicity, annual data are used throughout analyses of climate impacts on latex yield. However, analyses of climate change and variability also require monthly and five-year moving average patterns to be studied.

The climate dataset covers 35 years for the period 1978–2012 in the three provinces. The original dataset consists of:

(1) Monthly average maximum air temperature[36]. These data were converted to annual average maximum temperature (***Tmax***) by averaging over the 12 calendar months[37],

(2) Monthly average air temperature. These data were converted to annual average temperature (***Tmean***) by averaging over the 12 calendar months,

(3) Monthly average minimum air temperature. These data were converted to annual average minimum temperature (***Tmin***) by averaging over the 12 calendar months, and

(4) Total monthly precipitation. These data were converted to total annual precipitation (***Pmean***) by summing over the 12 calendar months.

(5) ***Tmax5***, ***Tmean5***, ***Tmin5*** and ***Pmean5*** were calculated by averaging over the 5 closest consecutive years of ***Tmax***, ***Tmean***, ***Tmin*** and ***Pmean***.

The secondary climate data for the three provinces provide a good opportunity to detect temporal and spatial climate changes if they are present. Cross-sectional information on latex yield and climate variables can enable spatial comparisons among the three provinces. It is noteworthy that provincial level data are able to depict regional variations of climate variables and their impacts on crop yield (Chen et al., 2004; Lobell et al., 2007).

[36] Average air temperature each month is the average of average air temperature of days in the month. Daily average air temperature is the average of the results of 4 main observations in a day at 1 am, 7 am, 13 am, 19 am or from the results of 24 observations at from 1 am, 2 am, 3 am… to 24 pm of the thermometer (DS, 2012).

[37] From January to December

The secondary data on latex yields (***Yield***) in the three provinces were collected from the DS (2012). The yield data at the national and provincial levels were compiled from the annual statistics yearbooks of the Vietnam General Office of Statistics; Departments of Statistics of Binh Phuoc, Dong Nai and Tay Ninh; and rubber industry reports. Latex yield is usually reported for production years that coincide with the calendar year. The yield dataset covers 23 years during the period 1990–2012. There are no latex-yield data available in the local annual statistics yearbooks before this period. Latex yield in the three provinces for the period 1990–2012 are available without distinguishing the portion of rubber clones through time.

Evidence indicates that when levels of precipitation and temperature increase, latex yield may increase, following Lobell et al. (2007). However, the frequency and the duration of rainy events are important compared with total precipitation received (Purnamasari et al., 2002). This is not considered in the present study due to unavailability of data on the frequency and the duration of rain events in the study area.

This study also considered seasonal properties of the climate variables. All *Spearman* correlations of each annual variable (the 12-month average) and its seasonal equivalent (the 9-month average during the harvest period) are higher than 0.86 ($p < 0.01$) (Table 4.3). In Vietnam, rubber latex is usually harvested within nine months from April to December. In the remaining three months, which coincide with the dry seasons, rubber trees need to have a rest for recovery. This means that the annual variables can be used consistently in all analyses instead of seasonal variables. Rao et al. (1998) found that prevailing climatic conditions prior to tapping contribute to yield variability on tapping days. Rubber trees have different features compared with other perennial crops such as coffee or cashew trees. After nine consecutive months of latex harvest, rubber trees need a period of rest to resynthesise latex[38]. Therefore, it is recommended to tap every other day to avoid lowering DRC, as well as the cessation of latex production or dryness of tapping panels (Nugawela, 2008a). In comparison, coffee or cashew trees are harvested over a short period of time. Daily weather affects directly rubber trees and their latex yield over the nine consecutive months of the harvest. For this reason, the climate data and yield data were analysed for the whole year and not seasonally.

[38] Yearly, latex yield increases after foliation, and decreases during periods of defoliation, flowering and setting fruits.

**Table 4.3: Correlations of annual climate variables and their seasonal propensity, 1990–2012**

| Variables | Binh Phuoc | Dong Nai | Tay Ninh |
|---|---|---|---|
| **Tmax** | 0.93** | 0.95** | 0.92** |
| **Tmean** | 0.97** | 0.93** | 0.89** |
| **Tmin** | 0.89** | 0.91** | 0.86** |
| **Pmean** | 0.99** | 0.99** | 0.98** |

*: $p < 0.05$ and **: $p < 0.01$

*Source: Estimates using data sourced from the VNCHMF (2013)*

The second and third research questions address evidence of climate change and variability in Southeast Vietnam and their effects on latex yields. They address evidence of the most important climate variables affecting yield. These information as well as details and summary statistics of the secondary data are presented in Chapter 5.

## 4.6 The Survey Data Collection of the Small-Scale Rubber Sector's Profile

The field survey of this study was aimed at collecting primary data to analyse rubber farmer vulnerability to, perception of and adaptation to climate change in the three provinces, as well as factors affecting rubber farmer groups' decisions concerning adaptive measures. The survey followed standards such as ensuring quality of the questionnaire, using experienced interviewers, and obtaining reasonable time for field surveys. Evidence of quality of the questionnaire is presented below in terms of reliability and validity. The Human Research Ethics Committee in the University of New England approved[39] the interview plans and the questionnaire for the survey. The assistant interviewers understand the study area, speak the language and have contacts with farmers and local agencies. These assistants were sourced from local agencies that have experience in agricultural activities dealing with farmers. Such experience gives the assistant interviewers a unique skill set to undertake the survey. Field surveys took place from January to April 2014, during the three months of the dry season when rubber farmers are not tapping. This rest period is necessary for the growth and development of rubber trees. Rubber farmers were relatively free of agricultural activities during this period, so they were expected to have time to participate in the survey.

### 4.6.1 Study Population and Sampling Strategy

The population of this study is all rubber farm households residing in all six provinces in Southeast Vietnam. The standard statistical formula for selecting a sample size results in a large number, which

[39] The Committee issued the approval number of HE13-192 on 16 August 2013, and the ethics approval was valid until 16 August 2014.

is not practical for a sole researcher due to cost and time constraints to conduct a comprehensive survey over the six provinces as a whole. Rubber farm households were sampled according to the following criteria:

(1) They are in provinces, districts and villages where rubber cultivation dominated as a major livelihood activity.
(2) They have been being involved directly in rubber cultivation.
(3) Only respondents[40] (interviewed rubber farmers) over 18 years of age are included in the sample.
(4) There is a relatively wide geographical distribution of study sites.
(5) The sampled sites are close to the hydro-meteorological stations to ensure the dataset reflects the climate features at each study site.
(6) Study sites are away from cities and urban areas. Agricultural land in such areas may be reallocated to other purposes of land-use in coming years. Therefore, this may not be representative of sustainable agricultural development in Southeast Vietnam (Dung, 2007).

The three provinces Binh Phuoc, Dong Nai and Tay Ninh satisfy these criteria.

Rubber farm households were selected using a combination of stratified purposive sampling and stratified random sampling (Denscombe, 2010) by subdividing the research population into different subgroups (districts and villages) and then choosing the required number of rubber farmer households from within each subgroup using stratified random sampling. This ensures smaller groups of rubber farmers match the sampling criteria. This technique is appropriate for sampling from a geographically scattered population (Burton, 2000). Although stratified random sampling offers a high probability of accuracy and reduced sampling error (Babbie, 2001; Burns, 2000), it was not feasible within cost and time constraints. Besides, complete lists of the population were unavailable for stratified random sampling (Dung, 2007). This study employed both the stratified purposive sampling and stratified random sampling methods in the three provinces where a list of districts and villages was available.

Rubber farmers in the same village face similar institutional, socio-economic, agro-environmental and climatic conditions in their farming activities. They belong to a mostly homogeneous group. Although the study area is considered to be homogeneous in terms of physical, environmental and socioeconomic conditions, each village has its specific resource endowment, history of agricultural development and traditional farming practices (Dung (2007, p. 118)). Therefore, a small sample size can be representative of the whole population. The sample size is determined based on criteria other

[40] A respondent is a family member, either the household head or another member, who is considered to be a key decision maker of the household in farming activities.

than a standard statistical formula (Perry, 1998). Burns (2000) argues that the distribution of sample means tends to be normal, as long as the sample size is greater than 30. A sample size of 350 observations is considered as an optimal size for a structured interview in quantitative research (Perry, 1998). Additionally, about five per cent of the population is considered as a large enough size for quantitative research (Barlett et al., 2001). The interval random method was used to select the rubber farm households.

Complete lists of rubber farm households were not available in the three provinces, so the author used a complete list of villages in districts of the three provinces. The database used to select rubber farmer households is public information. Samples were based on the statistics yearbooks of Departments of Statistics of Binh Phuoc, Dong Nai and Tay Ninh in 2012 and consultations with extension officials at the district and provincial levels. Thirty per cent of villages in each province were randomly picked from the list. Then about 5 rubber farm households from each village in Binh Phuoc, about 13 rubber farm households from each village in Dong Nai and 9 rubber farm households from each village in Tay Ninh were chosen after consultation[41] with local authorities at the village level. About 170 rubber farm households in Binh Phuoc, 165 in Dong Nai and 165 in Tay Ninh were the initial selection for the survey. Besides these respondents, there was a 10-per cent complementary list of farmer households for each province to replace respondents who might be absent or refuse to be interviewed.

Seventy villages in 14 districts of the three provinces were selected for the field survey. Based on a complete and numbered lists of villages in the three provinces, a random sample was selected using the Microsoft Excel software to obtain 42 villages in Binh Phuoc, 17 villages in Dong Nai and 11 villages in Tay Ninh (Table 4.4). In this way the randomness in the sampling procedure was ensured.

**Table 4.4: The population of rubber farm households and sample size for the survey**

| Province | Number of districts sampled | Number of villages sampled | Sample size |
|---|---|---|---|
| Binh Phuoc | 7 | 42 | 150 |
| Dong Nai | 4 | 11 | 140 |
| Tay Ninh | 3 | 17 | 140 |
| **Sample size** | **14** | **70** | **430** |

*Source: Estimates using data sourced from the DS (2012)*

[41] The rubber farmer households to be interviewed were sourced from the three provinces in Southeast Vietnam with the help of the following agencies: (i) Sub-department of Agriculture, the Department of Agriculture and Rural Development, Binh Phuoc Province, (ii) The Women Association, Dong Nai Province and (iii) The Department of Statistics, Tay Ninh Province.

The author engaged three assistant interviewers for the fieldwork to help interview rubber farmer households in the three provinces. Local agencies and three assistant interviewers helped the author to contact rubber farmers before the field trip planned for January to April 2014. Although the sample size of 430 rubber farm households in this study is not large, it covers 30 per cent of the villages in the districts of each province where rubber cultivation dominates, and rubber trees are planted in different conditions. Hence, results from this study are expected to be representative of rubber farming features in Southeast Vietnam.

### 4.6.2 Survey Design

#### *4.6.2.1 Design of the Questionnaire*

The main objectives of the questionnaire are to determine rubber farmer households' vulnerability, their perception of climate impacts on latex yield and to evaluate how rubber farmer households are responding to climate change and variability.

The questions are directly related to the research questions and objectives of this study. The questionnaire consists of five sections, except a general information section (Appendix 2). Some questions are designed as a complement or substitute to each other, in order to track whether a respondent is answering randomly or purposively. The details of these sections are presented below:

(1) General information section identifies locality of the farm households by villages, districts and provinces.

(2) The first section of the questionnaire (rubber farm households' demographic information) gathers data on:

- Age, gender, ethnic group, marital status, occupation, education of the respondents as well as their role in the households,
- The total land area, household size, income sources of households,

(3) The second section (socio-economic information) obtains information on:

- Status of rubber plantation, characteristics and tenure status of rubber-growing land,
- Access to processing units, market of rubber products, market of agricultural inputs as well as social and professional activities,

(4) The third section (rubber farmer perception of climate change) focuses on:

- Changes in key climate variables and their levels,
- Changes in latex yield due to changes in key climate variables, the severity of the climate impacts on latex yield,

(5) The fourth section (rubber farmer households' adaptation to climate change) contains:

- Adaptive types to climate change,

- The application status of eight adaptive measures given,
- Relevant attributes of each adaptive measure as well as constraints to adoption,

(6) The final section (rubber farmer households' overall assessment of rubber cultivation prospects) is designed to elicit:

- The adoption propensity of adaptive measures in terms of improving latex yield and quality,
- Prediction of prospects for future the local rubber industry as well as rubber farm household's responses to this prediction.

#### *4.6.2.2 Validity and Reliability of the Questionnaire*

Validity and reliability of the questionnaire are two significant tests for the survey. They are influenced by the psychological characteristics of measurement and respondents' subjective evaluations. Such measurements and evaluations may be hard to measure accurately in questionnaire responses (Sarker, 2012; Williams, 2003).

The test for validity is to evaluate whether an estimate of a concept actually measures that concept within the precision that is required. The questions of adaptation at the farm level in the questionnaire are reviewed to ensure that the questions are content valid.

Reliability implies consistency of measures, which refers to the capability of a statistical instrument to estimate the same things in different circumstances (Sarker, 2012). The reliability of the questionnaire can be assured if internal consistency is satisfied (Williams, 2003). The internal consistency is tested by asking respondents questions in several different ways and testing for the consistency among responses (Sarker, 2012).

Local authorities familiar with rubber farmer households in the area were consulted during the design of the questionnaire to ensure its suitability. When designing the questionnaire, related information such as rubber farm households' characteristics was put on a table or a cause and effect diagram[42], so that no piece of information was omitted in the questionnaire.

#### *4.6.2.3 Pre-Piloting and Piloting the Questionnaire*

It is important to reject any ambiguity in the questions and to identify a range of possible responses for each question (Williams, 2003). The questionnaire was pretested with academics and discipline experts in the Vietnam rubber industry. The questionnaire was also pretested with extension officials and rubber farmers in the study area to check how respondents responded to the questions. Based on

[42] A cause and effect diagram, for instance, depicts the multi-direction relationship of factors affecting on latex yield (Wijesuriya & Dissanayake, 2009).

the pre-piloting test and informal interviews with professional individuals about the topic, the questionnaire was modified to add new questions and to remove ambiguous ones after each session. The questionnaire was not too long, to obtain accurate information from the respondents, but not too simple either, to avoid important variables being omitted.

The amended questionnaire underwent a formal pilot stage with six individual rubber farmers, two farmers from each province. The above procedures were repeated to ensure the questionnaire was ready for the survey.

#### *4.6.2.4 Conducting the Survey*

A face-to-face personal interview is the most pertinent method for this study to generate the most reliable information. The survey took place from January to April 2014. Three assistants were invited to assist the author. The three fieldwork assistants were trained briefly in both theoretical and practical issues to be able to conduct the survey with the support of the author. The author monitored the survey and participated in the fieldwork. The final questionnaires were completed either in the houses or on the farms of the rubber farmer households during the interview. The English version of the questionnaire was translated into Vietnamese and 430 rubber farmer households in Binh Phuoc, Dong Nai and Tay Ninh were given the Vietnamese version of the questionnaire. The interview enables the author to explain the questions in detail and in different ways to the respondents as required. An interview usually took approximately one hour.

#### *4.6.2.5 Data Coding, Compiling and Cleaning*

After collecting the completed questionnaires, the author encoded data for entry. The dataset then was compiled into the StataSE version 12.0 software package. Once the data entry was completed, the dataset was checked by producing frequency figures for each question or analysing severe outliers. This procedure helped to avoid inconsistencies. At this stage, the dataset was ready for initial analysis.

## 4.7 Summary and Concluding Comments

This study tests a number of hypotheses that, for a particular crop within a study area of interest, if there is presence of climate change and climate variability as well as presence of adverse impacts on crop production and cultivation. Farmers are assumed to have strong perception of prevailing climate and weather changes and their adverse impacts on crops. They are assumed to have preference heterogeneity among adaptive measures, while they can distinguish between actions to adapt and actions to cope with prevailing adverse impacts of climate and weather patterns. Understanding the determinants of different farmer types' adaptive responses brings insights into aligning policy responses for successful adaptation at the farm level.

This chapter justifies the choice of methodology, the technical details regarding the choice of appropriate method of analysis and the empirical models used to solve the research questions introduced above. This study uses a case study application to demonstrate a particular situation of interest but with broader application. The range of methods of data preparation and calibration and the tests compatible with specific research findings are systematically presented to ensure that the findings have a strong quantitative basis. Finally, the methods of data collection were presented in detail.

# Chapter 5 Climate Change, Climate Variability and Climate Effects on Latex Yield: Evidence Using Cross-Sectional Time Series Data

## 5.1 Introduction

This chapter assesses climate change, climate variability, latex yield growth and relationships between trends of climate variables and change of yield in the three provinces selected. The analysis draws on secondary data. The variability of latex yield and change of latex yield through time are both assessed. Such assessments require regional level data, because impacts of climate variables on crop yield are usually specified regionally. There is evidence that provincial level data are able to depict regional trends of climate variables and their impacts on crop yield (Chen et al., 2004; Lobell et al., 2007). Provincial level data of climate variables and yields –using cross-sectional time series data– allowed assessments of climate change, climate variability and latex yield growth to be conducted. Time series data allowed assessments of relationships between trends of climate variables and change of yield to be conducted. Effects of provincial unique features[43] and events[44] that also might impact on natural rubber production were highlighted. According to Lobell et al. (2007), it is important to take events into account when estimating climate–yield relationships.

Previous studies have attempted to address patterns of climatic variables (Le et al., 2014b; Sarker, 2012; Van et al., 2015) and their relationships to selected outcome variables (Almaraz et al., 2008; Lobell et al., 2007; Raj et al., 2005; Rao et al., 1998; Sarker, 2012). Lobell et al. (2007) and Almaraz et al. (2008) used time series data of climate variables in California (the USA) and Monterregie (Canada), respectively; they estimated climate–crop yield relationships, using multiple linear regression models (simultaneous models). There were several farm-level estimates of the relationship of dry rubber latex yield (DRC) with climate variables such as maximum, average and minimum temperatures, hours of sunlight[45], total precipitation and humidity[46] (Raj et al., 2005; Rao et al., 1998). Although those studies employed simultaneous models to estimate such relationships,

[43] e.g. agro-ecological settings, socio-economic conditions

[44] e.g. advanced management practices, new technologies, increases in market demand and latex prices

[45] Number of sunshine hours in months is the sum of sunshine hours of days in the month (DS, 2012).

[46] Average humidity in months is the average of relative humidity of days in the month. Relative humidity is the ratio of the vapor in the air and saturate vapor (maximum) at the same temperature. It is indicated in per-cent form (%). Daily average relative humidity is the average results of 4 main observations at different time in a day (DS, 2012).

they observed only several particular clones at small experiment scales. They also did not take violations of some relevant OLS assumptions into account (e.g. the problem of severe outliers, stationarity of time series data, normality of variables, normality of residuals, independence of residuals, heteroscedasticity and multicollinearity); thus the estimated parameter values may be inconclusive (Sarker, 2012). This study applies various data cleaning, data calibration and appropriate tests before the proper estimation of empirical econometric models.

There are several reasons to conduct these assessments in the context of rubber-farming systems. The climate in Southeast Vietnam can be characterised in terms of temperature, precipitation, wind speed and solar radiation (VNCHMF, 2013). Available data of temperature, precipitation and latex yield were obtained. Most documents of local governments in the study area cite climate change as a challenge to perennial crops such as rubber, cashew and coffee trees. They usually recognise severe impacts of climate change on agricultural production, but no quantitative evidence is available at the local level. Local farmers are usually concerned about consequences of climate and weather changes (such as spreading plant diseases, plant deaths, and reductions in latex yield and quality) and influences of market uncertainties (e.g. low latex prices, high production costs). Studies on climate variables and their effects on latex yields in rubber-farming systems based on clones are rare (Raj et al., 2005; Rao et al., 1998), particularly research on the simultaneous effects of climate variables on latex yields in current systems which are largely based on clones. There is a need for empirical studies to assess relationships between climate variables and latex yields using quantitative models (RRII, 2010).

This chapter addresses two research questions:

(1) Is there evidence of climate change and climate variability in the study area?
(2) Are there negative or positive relationships between climate variables and latex yields? If so, which climate variables affect latex yield most severely in the study area?

These questions are addressed based on provincial-level analyses involving cross-sectional time series data of climate variables and latex yields in Binh Phuoc, Dong Nai and Tay Ninh.

## 5.2 Analysis of Climate Data

Rubber farmers usually assess the information on the local climate status before deciding on annual planting periods to ensure technical efficiency. They also observe the daily weather status before deciding on planting seedlings and latex harvest. Latex harvest occurs during a nine-month period coinciding with the wet season, while harvest of other perennial crops (e.g. coffee, cashew, pepper) only occurs in a short period of time. The timing of harvest is of concern to rubber farmers and it is affected by rain; “precipitation is of great concern to the rubber growers as it affects the tree at all stages of growth from planting through felling" (Samarappuli & Wijesuriya, 2009, p. 105). Besides lost latex production by run-out rainwater, increased precipitation could lead to other problems such as soil erosion and agrochemical leaching (Ben et al., 2002). Decreased precipitation could affect supplement of soil moisture and length of immature plant periods (Adesina & Chianu, 2002; Baethgen et al., 2003; Kurukulasuriya & Mendelsohn, 2007a), thereby affecting agricultural productivity.

The analysis of climate change and variability in Binh Phuoc, Dong Nai and Tay Ninh was based on ***Tmax***, ***Tmean***, ***Tmin*** and ***Pmean*** (Section 4.5). Monthly patterns, yearly patterns, their five-year moving averages and standard deviations were also used in the analysis. Five years is the minimum age of a young rubber tree before tapping starts. Therefore, at this early stage young rubber trees are assumed be most influenced by prevailing climatic conditions. It is supposed that average temperature in previous years affects the growth and development of rubber trees, which in turn impact on latex yield (Purnamasari et al., 2002; Venkatachalam et al., 2013), because crop yield is sensitive to stages of agricultural production (Kurukulasuriya & Rosenthal, 2003).

Monthly climate patterns in the three provinces during the period 1978–2012 were used to describe variations of climate variables around their mean values across months in each province. Yearly climate patterns and five-year moving averages in the three provinces over the same period were used to describe changes in mean values of climate variables over time in each province. Standard deviations of climate variables across the three provinces measure variations of climate variables around their mean values across the three provinces. Section 5.2 helps answer the second research question.

### 5.2.1 Monthly Patterns of Climate Variables

Figure 5.1 presents general monthly climate patterns of average temperature and total precipitation in the three provinces during the period 1978–2012. There are two distinct seasons in Southeast Vietnam, the dry season from November to March and the wet season from April to October (VNCHMF, 2013). Latex harvest lasting nine months overlaps this wet period. Average temperature decreases considerably in the first month of the wet season until the second month of the dry season (April to December). During the wet season, the variability of monthly average temperature is small, but this variability is higher in the dry season (particular in January and February in Tay Ninh) when average temperature increased considerably.

Total monthly precipitation increases significantly in the wet season, but decreases markedly in the dry season. Total monthly precipitation is very low in the dry season and its variability is also low compared with the wet season. The variability is high in the wet season, particularly in Binh Phuoc

(April to October) and in Dong Nai (October). A further increase in average precipitation may lead to an increase in precipitation variability (Giorgi et al., 2001).

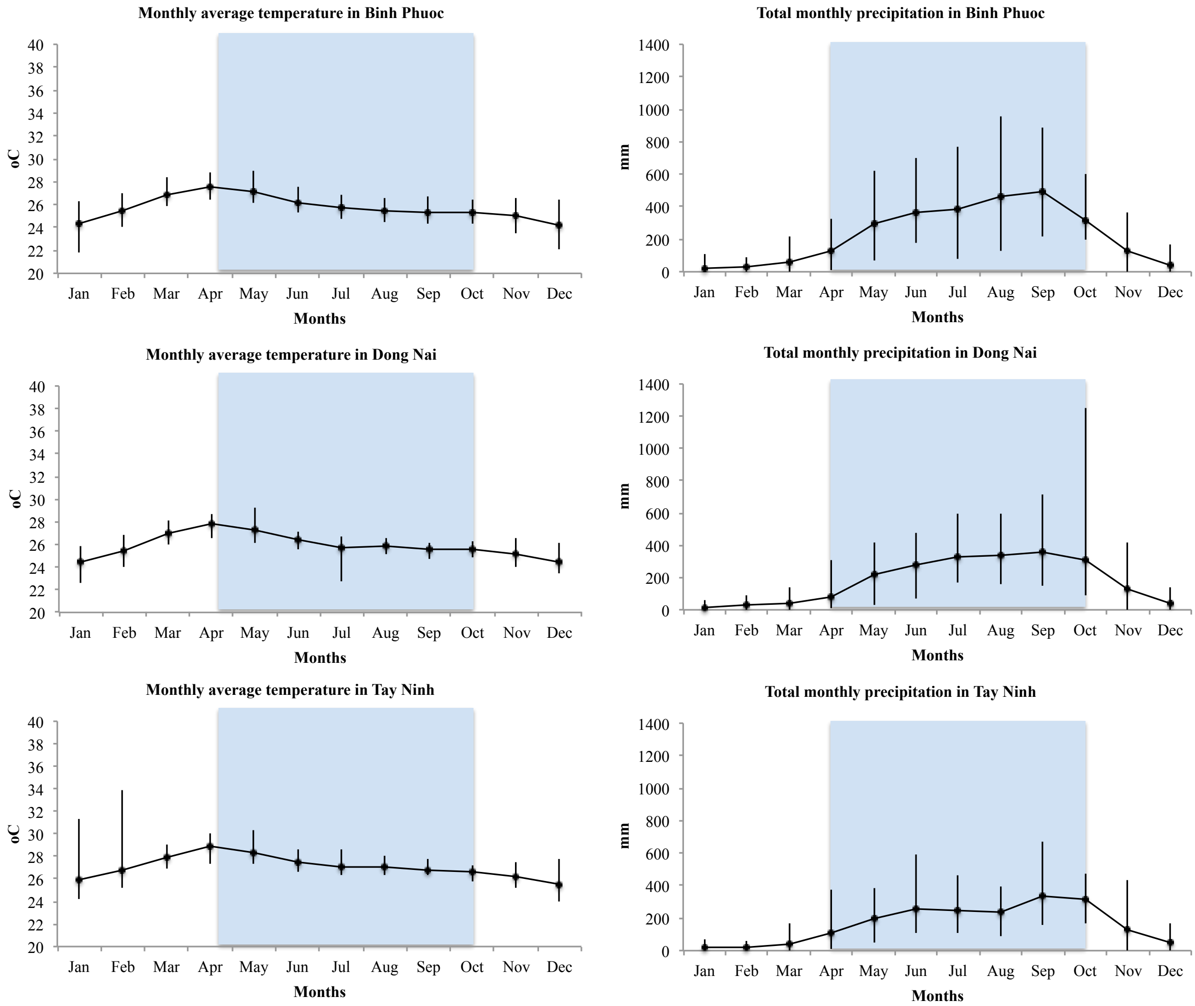


**Figure 5.1: Monthly patterns of average temperature and total precipitation, 1978–2012**

Shaded area shows months during the wet season. The vertical lines represent the range of observations (minimum-maximum).

*Source: Estimates using data sourced from the VNCHMF (2013)*

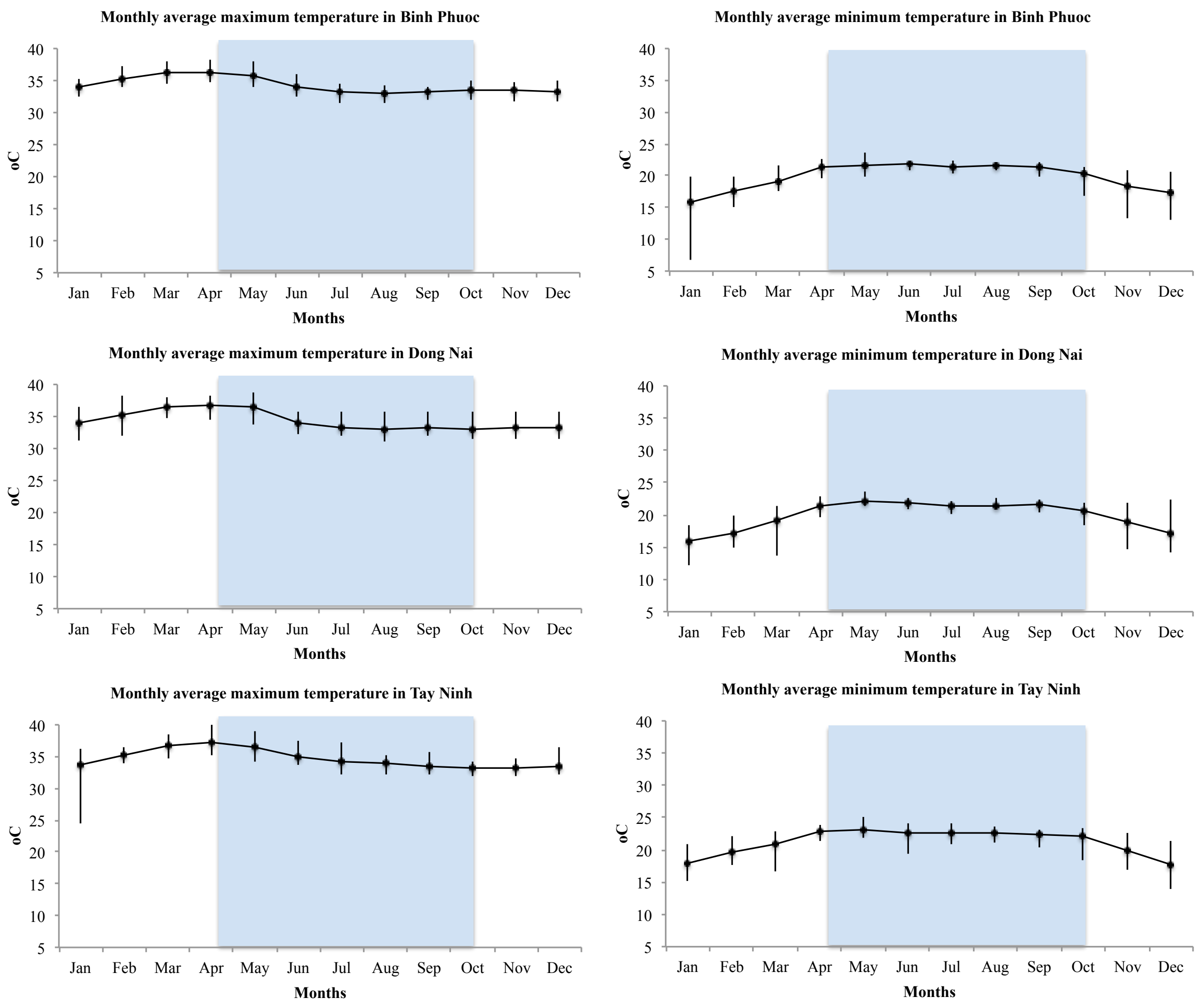


**Figure 5.2: Monthly patterns of average maximum and minimum temperature, 1978–2012**

Shaded area shows months during the wet season.

The vertical lines represent the range of observations (minimum-maximum).

*Source: Estimates using data sourced from the VNCHMF (2013)*

In Figure 5.2, monthly average maximum temperature seems to have similar trends to average temperature in the three provinces. Monthly average minimum temperature is higher and more stable in the wet season, but its variability is lower compared with the dry season. Monthly average minimum temperature decreases at the start of the dry season and increases until the end of the dry season. Graphical analyses above help detect variations of these variables around their mean values across months by province.

## 5.2.2 Yearly Patterns of Climate Variables and Their Five-Year Moving Averages

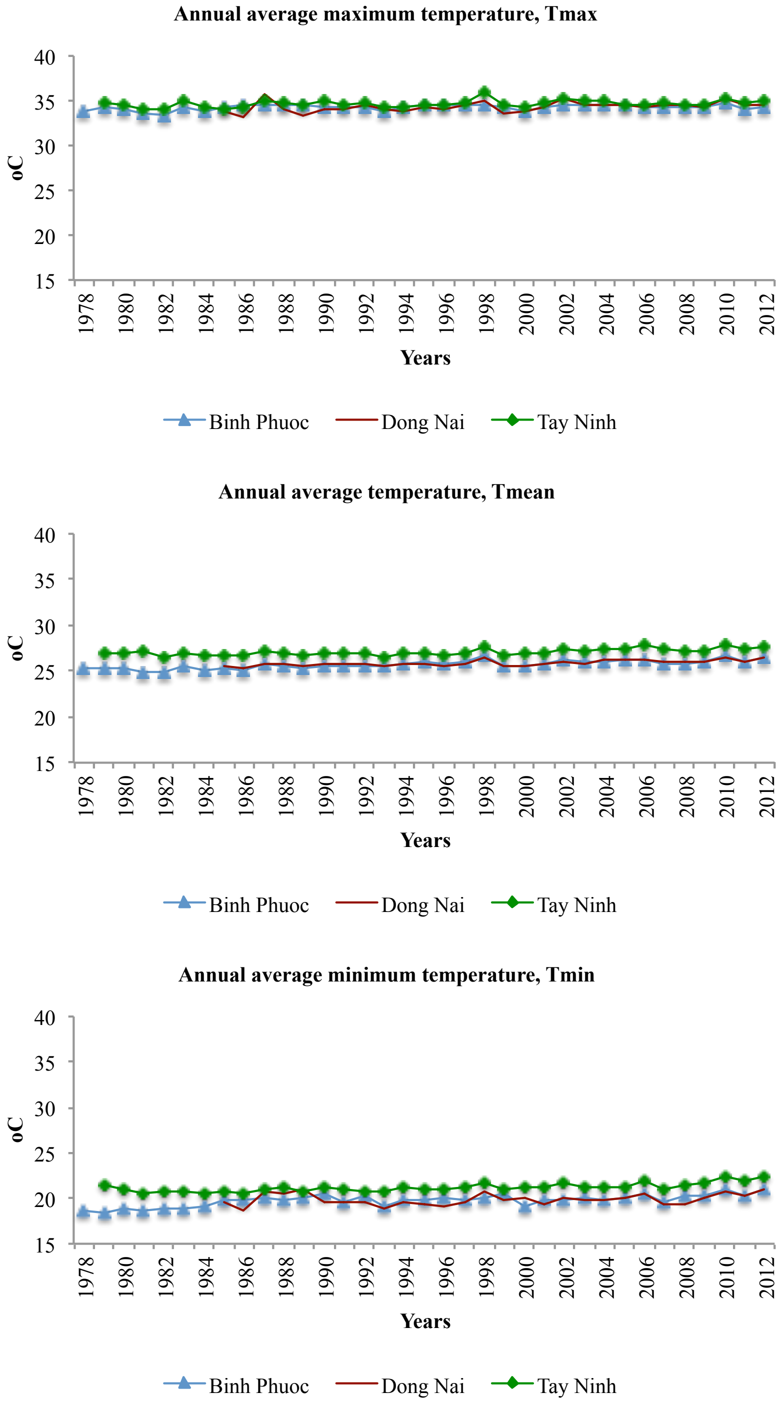


**Figure 5.3: Trends in annual temperature variables, 1978–2012**

*Source: Estimates using data sourced from the VNCHMF (2013)*

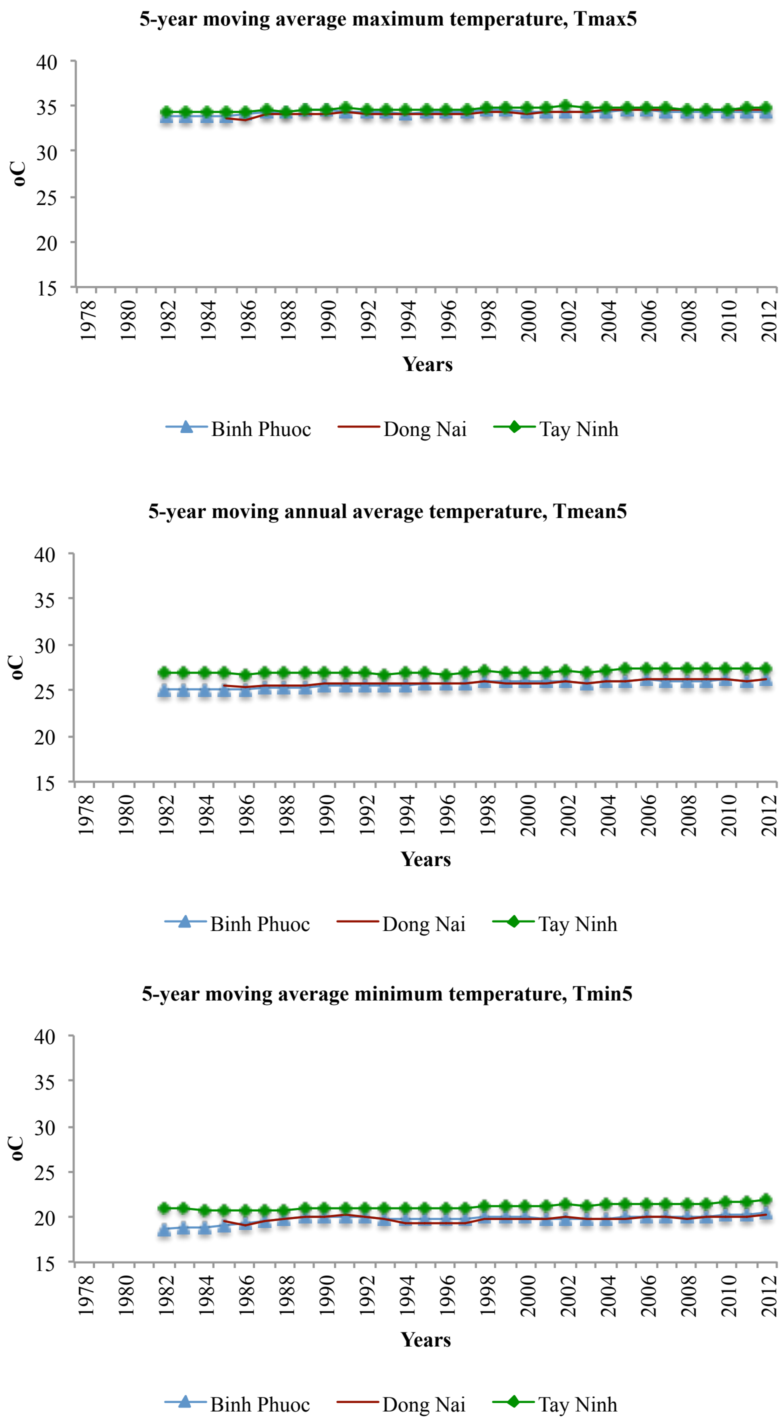


**Figure 5.4: Trends in 5-year moving average temperature variables, 1978–2012**

*Source: Estimates using data sourced from the VNCHMF (2013)*

In Figures 5.3–5.4, trends of the annual and 5-year moving climate variables are quite stable and similar across the three provinces, but ***Tmax***, ***Tmean*** and ***Tmin*** are the highest in Tay Ninh. Increasing trends in ***Tmean*** and ***Tmean5*** are clear in all the three provinces (see tests in Table 5.3)..***Tmax*** and ***Tmax5*** have an unclear trend over time. Figure 5.6 shows heterogeneity of the annual climate variables around mean values over time across the three provinces.

**Table 5.1: Summary statistics for yield and climate variables by province, 1978–2012**

| Variable (N = 35) | Mean ± SD | | |
|---|---|---|---|
| | **Binh Phuoc** | **Dong Nai** | **Tay Ninh** |
| **Yield** | **1.25** ± 0.47 | **1.08** ± 0.39 | **1.35** ± 0.58 |
| *Min* | *0.57* | *0.48* | *0.59* |
| *Max* | *1.97* | *1.72* | *2.15* |
| *Median* | *1.21* | *1.05* | *1.16* |
| | | | |
| **Tmax** | **36.79** ± 0.77 | **37.25** ± 0.84 | **37.34** ± 0.86 |
| **Tmean** | **25.71** ± 0.47 | **25.89** ± 0.32 | **27.07** ± 0.38 |
| **Tmin** | **15.34** ± 3.03 | **15.48** ± 1.32 | **16.95** ± 1.32 |
| **Pmean** | **2699.41** ± 446.94 | **2144.37** ± 433.55 | **1918.87** ± 270.30 |
| | | | |
| **Tmax5** | **36.77** ± 0.29 | **37.23** ± 0.35 | **37.30** ± 0.31 |
| **Tmean5** | **25.71** ± 0.37 | **25.90** ± 0.18 | **27.04** ± 0.27 |
| **Tmin5** | **15.23** ± 1.46 | **15.41** ± 0.55 | **16.77** ± 0.65 |
| **Pmean5** | **2707.32** ± 163.5 | **2903.08** ± 161.65 | **1929.45** ± 117.13 |

*Source: Estimates using data sourced from the DS (2012) and the VNCHMF (2013)*

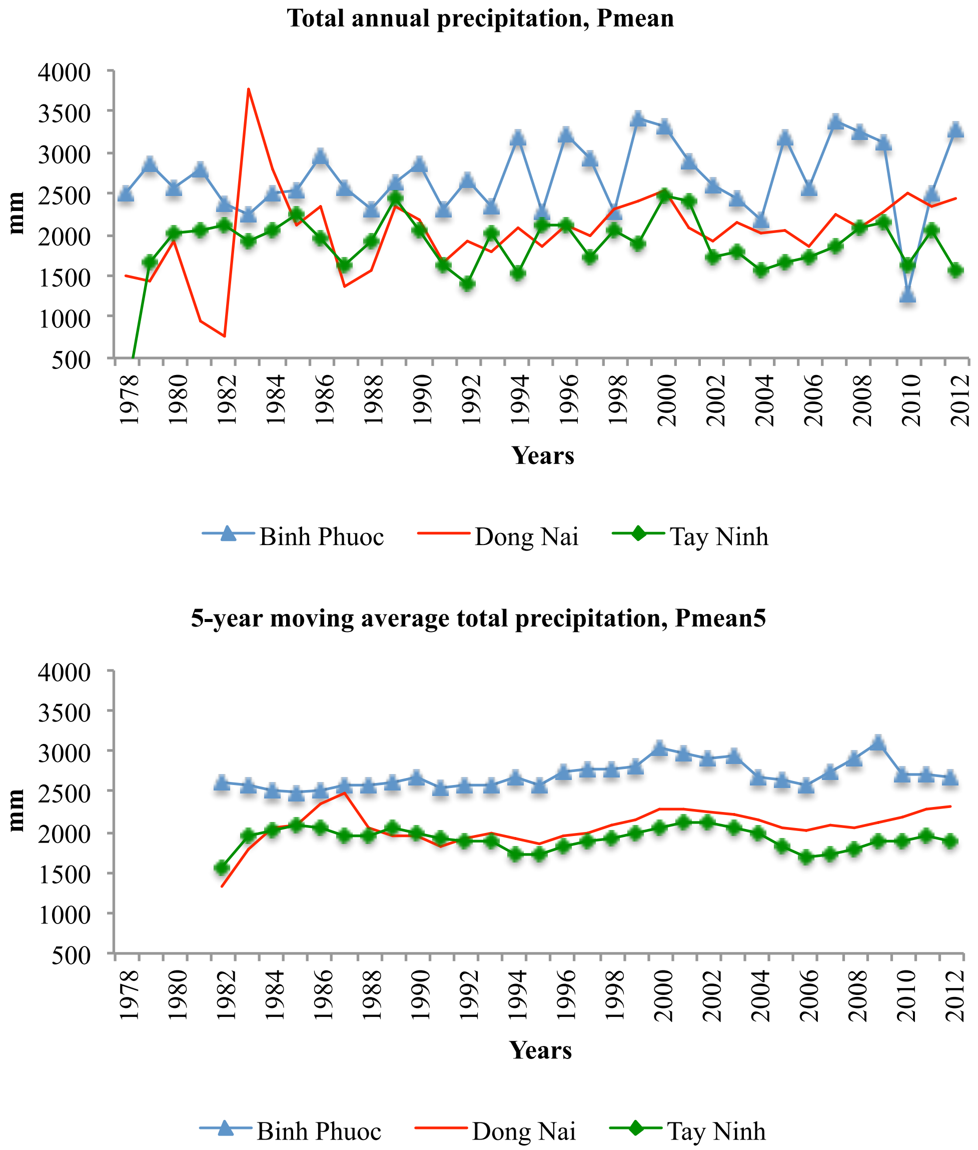


**Figure 5.5: Trends in total annual precipitation and its 5-year moving average, 1978–2012**

*Source: Estimates using data sourced from the VNCHMF (2013)*

The 5-year moving averages are smoother than the annual data, and their trends are more consistent than the annual data. However, trends of ***Pmean*** and ***Pmean5*** are inconsistent over time (Figure 5.5).

All the climate variables exhibit considerable differences in mean values among the three provinces, based on descriptive statistics (Table 5.1). Annual temperature is the highest in Tay Ninh in all indicators of ***Tmax*** (37.3$^0$C), ***Tmean*** (27.1$^0$C) and ***Tmin*** (17.0$^0$C). In contrast, annual temperature is the lowest in Binh Phuoc in all indicators of ***Tmax*** (36.8$^0$C), ***Tmean*** (25.7$^0$C) and ***Tmin*** (15.3$^0$C). ***Pmean*** is the highest in Binh Phuoc (2699.4 mm) and the lowest in Tay Ninh (1918.9 mm) (Table 5.1 and Figure 5.6). These rankings are similar to those of the 5-year moving averages. Therefore, they seem to show that climatic conditions in Tay Ninh are drier than in Binh Phuoc and Dong Nai.

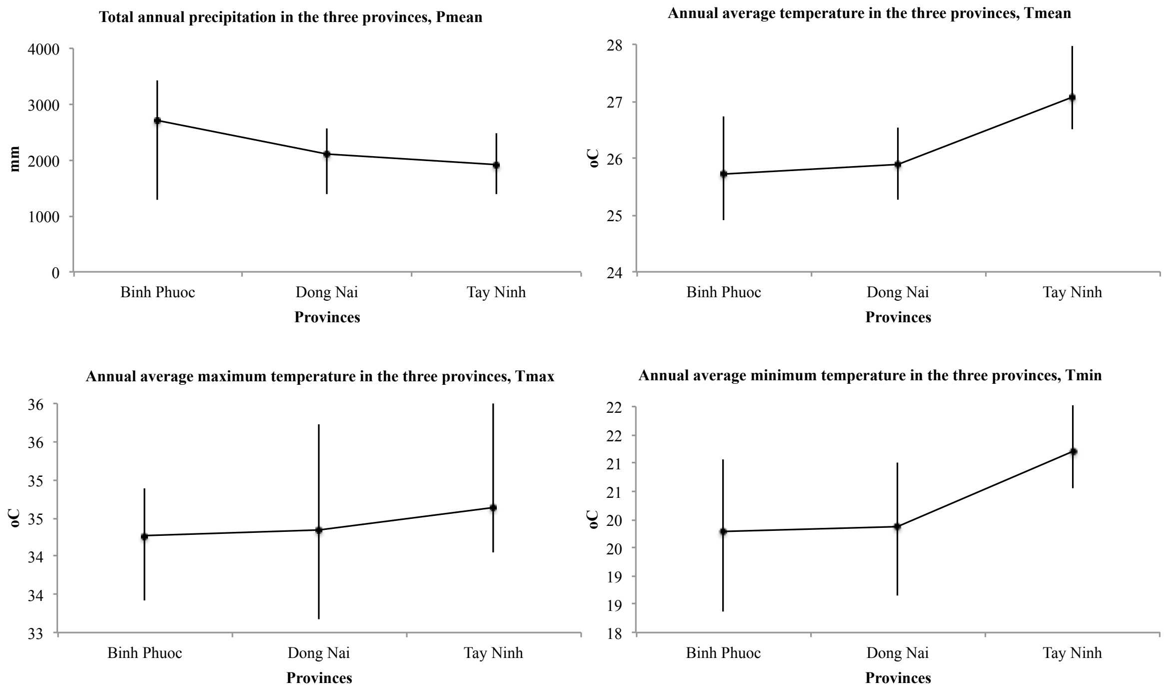


**Figure 5.6: Heterogeneity of climate variables over time across the three provinces, 1978–2012**

The vertical lines represent the range of observations (minimum-maximum).

*Source: Estimates using data sourced from the VNCHMF (2013)*

Graphical analyses above help detect variations of these variables around their mean values across years by province.

The Skewness and Kurtosis test was employed to test for the normality of the climate variables before choosing appropriate regression and test methods. Most climate variables and their five-year moving averages are normally distributed (Table 5.2) with the exception of ***Yield*** ($p < 0.01$), ***Tmin*** ($p < 0.01$), ***Pmean*** ($p < 0.05$), ***Tmean5*** ($p < 0.01$), ***Tmin5*** ($p < 0.05$) and ***Pmean5*** ($p < 0.01$). We cannot reject that the rest of all the climate variables in the three provinces are normally distributed at the 5% level of significance.

**Table 5.2: Statistical differences of yield and climate variables across the three provinces**

| Variable | Test for statistical differences | | Skewness and Kurtosis test | | |
|---|---|---|---|---|---|
| | **One-way ANOVA** ($F$-test) | **Kruskal-Wallis test** (*Chi-squared*) | N | *Adjusted Chi-squared* | $p$-value |
| **Yield**** | | 2.49 | 69 | 10.48 | 0.0053 |
| *Binh Phuoc* | | *1.21* | | | |
| *Dong Nai* | | *1.05* | | | |
| *Tay Ninh* | | *1.16* | | | |
| | | | | | |
| **Tmax** | 4.44* | | 97 | 3.22 | 0.1997 |
| *Binh Phuoc* | *36.79* | | | | |
| *Dong Nai* | *37.25* | | | | |
| *Tay Ninh* | *37.34* | | | | |
| **Tmean** | 113.07** | | 97 | 5.44 | 0.0657 |
| *Binh Phuoc* | *25.72* | | | | |
| *Dong Nai* | *25.89* | | | | |
| *Tay Ninh* | *27.07* | | | | |
| **Tmin**** | | 15.67** | 97 | 44.89 | 0.0000 |
| *Binh Phuoc* | | *16.4* | | | |
| *Dong Nai* | | *15.4* | | | |
| *Tay Ninh* | | *16.5* | | | |
| **Pmean*** | | 49.23** | 101 | 6.13 | 0.0467 |
| *Binh Phuoc* | | *2614.1* | | | |
| *Dong Nai* | | *2110.4* | | | |
| *Tay Ninh* | | *1946.0* | | | |
| | | | | | |
| **Tmax5** | 29.04** | | 85 | 0.48 | 0.7862 |
| *Binh Phuoc* | *36.77* | | | | |
| *Dong Nai* | *37.23* | | | | |
| *Tay Ninh* | *37.36* | | | | |
| **Tmean5**** | | 58.69** | 85 | 9.46 | 0.0088 |
| *Binh Phuoc* | | *25.8* | | | |
| *Dong Nai* | | *25.9* | | | |
| *Tay Ninh* | | *27.0* | | | |

*: $p < 0.05$ and **: $p < 0.01$

*Source: Estimates using data sourced from the DS (2012) and the VNCHMF (2013)*

**Table 5.2: Continued.**

| Variable | Test for statistical differences | | Skewness and Kurtosis test | | |
|---|---|---|---|---|---|
| | **One-way ANOVA** (*F*-test) | **Kruskal-Wallis test** (*Chi-squared*) | N | *Adjusted Chi-squared* | *p*-value |
| **Tmin5*** | | 31.32** | 85 | 6.41 | 0.0406 |
| *Binh Phuoc* | | *14.7* | | | |
| *Dong Nai* | | *15.5* | | | |
| *Tay Ninh* | | *16.7* | | | |
| **Pmean5**** | | 64.58** | 87 | 13.90 | 0.0010 |
| *Binh Phuoc* | | *2682.9* | | | |
| *Dong Nai* | | *2066.8* | | | |
| *Tay Ninh* | | *1941.6* | | | |

*: $p < 0.05$ and **: $p < 0.01$

*Source: Estimates using data sourced from the DS (2012) and the VNCHMF (2013)*

The parametric and non-parametric tests indicate spatial differences of all the variables (Table 5.2) with the exception of ***Yield***. These tests were based on the distributional normality of variables to accept the validity of the statistical results. Test results for the equality of 3-sample means show that the mean differences of ***Tmax***, ***Tmean*** and ***Tmax5*** among the three provinces are statistically significant ($p < 0.05$, Table 5.2).

Test results for the equality of 3-sample medians show that the median differences of ***Tmin***, ***Pmean***, ***Tmean5***, ***Tmin5*** and ***Pmean5*** among the three provinces are statistically significant ($p < 0.01$, Table 5.2). From the output in Table 5.2, we cannot reject the hypotheses that the mean and median differences of these climate variables and their five-year moving averages are statistically significant ($p < 0.05$), but no literature is found that explains the reason for those differences in the study area. These results consolidate evidence that climatic conditions in Tay Ninh are drier than in Binh Phuoc and Dong Nai. Similarly, climatic conditions in Dong Nai are drier than in Binh Phuoc.

The climate variables that are non-normally distributed (Table 5.2) can be best fit under QR regressions to test for climate change. All other variables that are normally distributed can be best fit under OLS regressions to test for climate change. Climate change was analysed in detail for each province as follows.

### 5.2.3 Climate Change in the Study Area

The output in Table 5.3 shows clear evidence of change through time in some climate variables based on OLS and QR regressions. There is an increasing trend in variables ***Tmean***, ***Tmin***, ***Tmean5*** and ***Tmin5*** during the period 1978–2012 across the three provinces ($p < 0.01$). ***Pmean*** and ***Pmean5*** have negligible increasing trends over time which are no statistically significant. There is a decreasing trend in ***Tmax*** and ***Tmax5*** during the period 1978–2012 based on OLS regressions, but no statistical significances are found.

**Table 5.3: Linear estimates of yield and climate variables against time by province, 1978–2012**

| **Model** | **Multiple linear regression using OLS or QR** | | | | | | **Effect of** |
|---|---|---|---|---|---|---|---|
| ***var.* vs. *t* by province** | N | *F*-test | *cons_* | Trend variable-*t* | Dummy -*Dong Nai* | Dummy -*Tay Ninh* | **province-specific features** (*F*-test) |
| **Yield** | 69 | | -0.40** | 0.07** | -2.55** | -4.78** | 128.84** |
| **Tmax** | 97 | 3.61* | 37.02** | -0.01 | 0.95* | 1.45* | 2.78 |
| **Tmean** | 97 | 186.10** | 25.17** | 0.03** | -0.99** | -0.79** | 55.57** |
| **Tmin** | 97 | | 14.72** | 0.07** | -3.73** | -4.52** | 10.38** |
| **Pmean** | 101 | | 2541.28** | 5.04 | -692.68** | -999.27** | 5.48** |
| **Tmax5** | 85 | 26.70** | 36.92** | -0.007 | 0.74** | 1.10** | 9.22** |
| **Tmean5** | 85 | | 25.08** | 0.03** | -1.02** | -0.89** | 52.95** |
| **Tmin5** | 85 | | 13.70** | 0.06** | -1.90** | -2.42* | 5.92** |
| **Pmean5** | 87 | | 2547.18** | 5.13 | -781.04** | -1086.61** | 21.85** |

*: $p < 0.05$ and **: $p < 0.01$

The *F*-test is not applicable to QR regressions.

*Source: Estimates using data sourced from the DS (2012) and the VNCHMF (2013)*

There are main effects of province-specific features ($p < 0.01$) when the variable *province* was coded as two dummy variables in the models (Table 5.3), with the exception of ***Tmax***. Although Tay Ninh is considered drier than Binh Phuoc and Dong Nai, the decreasing trend of ***Tmax*** and ***Tmax5*** is expected as a positive signal to reduce its drier status.

In Table 5.4, there is no evidence of any severe outliers in the dataset, except for a small proportion (3 per cent) of ***Tmin***, according to the interquartile range test. Therefore, there is no effect of severe outliers on means, standard deviations and other OLS estimates presented in Table 5.3.

**Table 5.4: The interquartile range test for severe outliers**

| Variable | N | Severe outliers (%) | |
|---|---|---|---|
| | | Low | High |
| **Yield** | 69 | 0.00 | 0.00 |
| | | | |
| **Tmax** | 97 | 0.00 | 0.00 |
| **Tmean** | 97 | 0.00 | 0.00 |
| **Tmin** | 97 | 3.09 | 0.00 |
| **Pmean** | 101 | 0.00 | 0.00 |
| | | | |
| **Tmax5** | 85 | 0.00 | 0.00 |
| **Tmean5** | 85 | 0.00 | 0.00 |
| **Tmin5** | 85 | 0.00 | 0.00 |
| **Pmean5** | 87 | 0.00 | 0.00 |

*Source: Estimates using data sourced from the DS (2012) and the VNCHMF (2013)*

Although there are not consistent trends of temperature or precipitation variables in the three provinces, there is an increasing trend in ***Tmean*** and ***Tmean5*** as well as ***Tmin*** and ***Tmin5*** over the period 1978–2012. According to the MONRE (2008), there was an annual average temperature increase of about $0.7^0$C between 1951 and 2000 in Vietnam. A temperature increase of about 0.1–$0.3^0$C per decade occurred throughout Southeast Asia during the period 1951–2000 (Lal et al., 2001). According to Carew-Reid (2007), the average temperature may increase by $2.5^0$C by the end of the $21^{st}$ century.

Giorgi et al. (2001) predict that daily high temperature extremes are likely to increase, but daily low temperature extremes are likely to decrease. These predictions differ from this study's findings (decreasing trend in ***Tmax*** and ***Tmax5***, but increasing trend in ***Tmin*** and ***Tmin5***) found in Table 5.3. However, the trends of ***Tmax*** and ***Tmax5*** in Table 5.3 are not statistically significant.

### 5.2.4 Climate Variability in the Study Area

OLS and QR regressions were used to detect trends of the climate variables over time. Graphical analyses below help detect variations of these variables around their mean values across the three provinces over time.

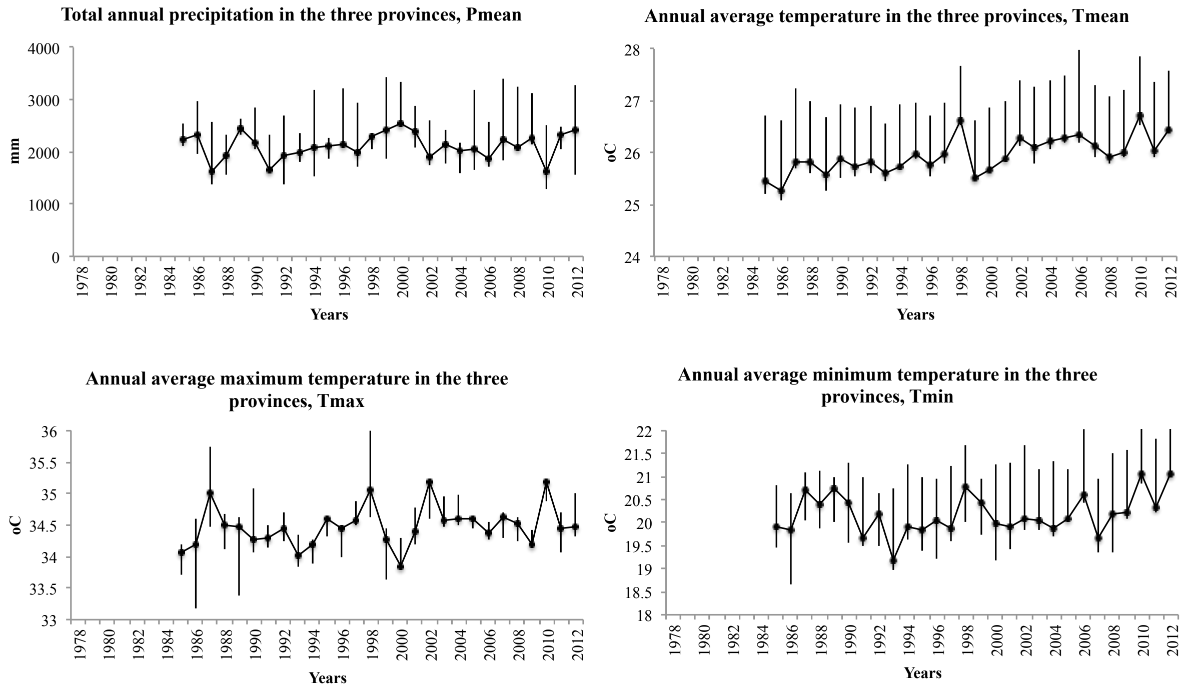


**Figure 5.7: Heterogeneity of climate variables across the three provinces over time, 1978–2012**

The vertical lines represent the range of observations (minimum-maximum).

*Source: Estimates using data sourced from the VNCHMF (2013)*

**Table 5.5: SD of yield and climate variables across the three provinces, 1979–2012**

| **Trend model *var.* vs. *t*** | **N** | **Skewness and Kurtosis test** (*Adjusted Chi-squared*) | **Simple linear regression using OLS or QR** | | | | |
|---|---|---|---|---|---|---|---|
| | | | **OLS** | | | **QR** | |
| | | | *F*-test | *cons_* | Trend variable-*t* | *cons_* | Trend variable-*t* |
| **YieldSD** | 23 | 2.07 | 27.12** | -26.63** | 0.01** | | |
| **TmaxSD** | 34 | 7.08* | | | | 1.25 | -0.0003 |
| **TmeanSD** | 34 | 16.97** | | | | 8.83 | -0.0040 |
| **TminSD** | 34 | 23.47** | | | | 33.47 | -0.0162 |
| **PmeanSD** | 34 | 2.59 | 0.62 | -6200.35 | 3.36 | | |

*: $p < 0.05$ and **: $p < 0.01$

*Source: Estimates using data sourced from the DS (2012) and the VNCHMF (2013)*

Figure 5.7 shows heterogeneity of the annual climate variables around mean values across the three provinces over time. Climate variability in the study area is shown clearly across the three provinces. Mean values of ***Tmax***, ***Tmean***, ***Tmin*** and ***Pmean*** across the three provinces scatter widely around average lines. In Table 5.5, there are no clear trends in standard deviations of ***Tmax***, ***Tmean***, ***Tmin*** and ***Pmean*** over time. However, climate variability to some extent existed across the three provinces.

According to Giorgi et al. (2001), there is an increasing trend in daily temperature variability in Southeast Asia, but only a mild change in precipitation. These do not consolidate findings (decreasing trend in ***TmaxSD***, ***TmeanSD*** and ***TminSD***, but increasing trend in ***PmeanSD***) found in Table 5.5. However, the trends of ***TmaxSD***, ***TmeanSD***, ***TminSD*** and ***PmeanSD*** in Table 5.5 are not statistically significant.

The evidence of the geographically inconsistent variable trends that is found in the three provinces of Southeast Vietnam is significant in practice. The observations of Kurukulasuriya and Rosenthal (2003) also show differences in precipitation geographically. Sarker (2012) also found inconsistent variable trends of some climate variables at the provincial level in Bangladesh. These show partly the complexity in prediction of future climate change and variability.

Even though the climate impacts often go beyond changes in precipitation and temperature patterns (Breisinger et al., 2011; Thurlow et al., 2009; Yu et al., 2013), the evidence above suggests that climate change and climate variability have occurred to some extent in the three provinces Binh Phuoc, Dong Nai and Tay Ninh. Latex yield growth in the three provinces is addressed in the next section. Section 5.4 analyses the magnitude of individual impacts and simultaneous impacts of these climate variables on latex yields.

## 5.3 Analysis of Latex Yield Data

A 23-year dataset of latex yields in the three provinces was used to analyse their trend properties against time. Scatter plot diagrams show that latex yields increased over time (Figure 5.8). In Table 5.4, latex yield data in the three provinces have no severe outliners. In Table 5.2, latex yield data are not normally distributed, so QR regression is used to estimate change of ***Yield*** over time. There is a distinct increase in ***Yield*** in all the three provinces during the period 1990–2012 ($p < 0.01$, Table 5.3). There is a main effect of province-specific features ($p < 0.01$) when the variable *province* is coded as two dummy variables in the model (Table 5.3).

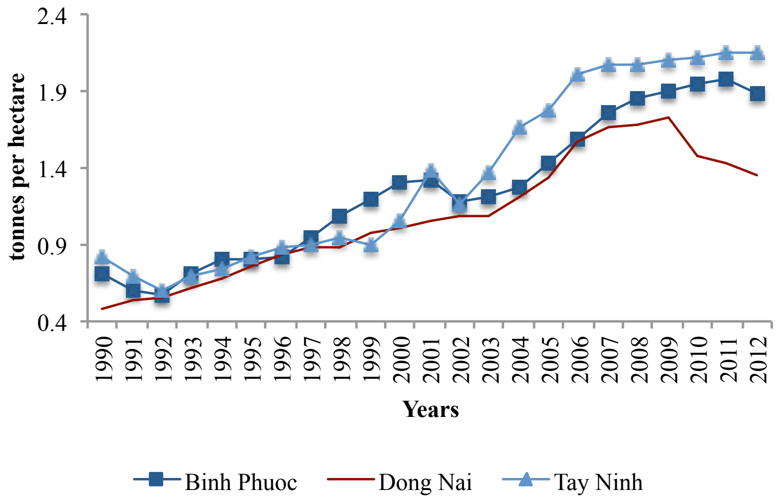


**Figure 5.8: Trends of latex yield in the three provinces, 1990–2012**

*Source: Estimates using data sourced from the DS (2012)*

In Table 5.1, mean latex yield is highest in Tay Ninh (1.35 tonnes/ha) followed by Binh Phuoc (1.25 tonnes/ha), and is lowest in Dong Nai (1.08 tonnes/ha). In contrast, median latex yield is highest in Binh Phuoc (1.21 tonnes/ha) and is lowest in Dong Nai (1.05 tonnes/ha). However, there is no statistically significant difference in median latex yield across the three provinces according to the Kruskal-Wallis test in Table 5.2. In other words, based on the normality of latex yield data the non-parametric test indicates no spatial differences of latex yield across the three provinces.

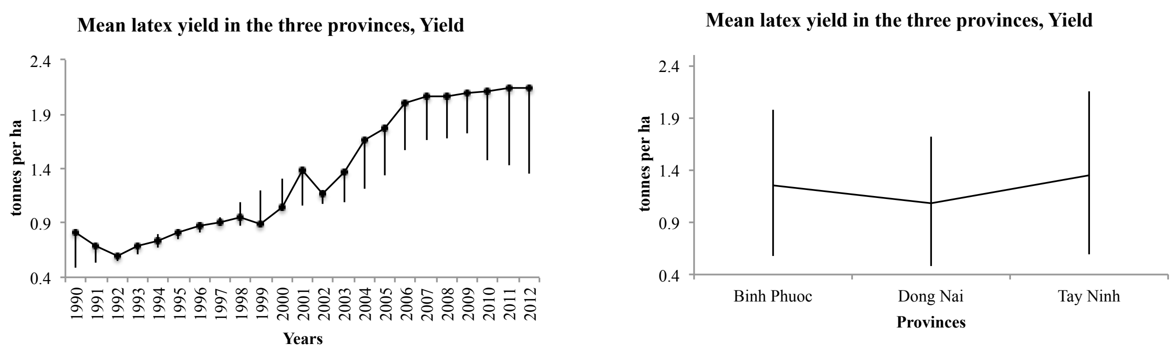


**Figure 5.9: Heterogeneity of latex yield across provinces and years, 1990–2012**

The vertical lines represent the range of observations (minimum-maximum).

*Source: Estimates using data sourced from the DS (2012)*

Figure 5.9 shows heterogeneity of ***Yield*** around mean values across the three provinces over time (left-hand side) and heterogeneity of ***Yield*** around mean values over time across the three provinces (right-hand side). High mean latex yields in Binh Phuoc and Tay Ninh are accompanied by high deviations, whereas the lowest mean latex yield in Dong Nai is accompanied by a smaller deviation. Particularly, yield variability is the highest in Tay Ninh where climatic conditions are considered drier than Binh Phuoc and Dong Nai (Section 5.2). In Table 5.5, yield variability has an increased trend over time, using OLS regression ($p < 0.01$). The standard deviation of latex yield is a useful measure for determining its variability. Variability in latex yield is of great concern to rubber farmers and the local rubber industry, since yield together with rubber market price determines the profit from rubber cultivation. High latex yield, accompanied by high variability, implies higher crop risks for rubber farmers (Senevirathna et al., 2010).

## 5.4 Relationship between Climate Variables and Latex Yields

### 5.4.1 Individual Effects of each Climate Variable on Yield

This section focuses on the third question, whether there are negative or positive relationships of climate variables with ***Yield***. Latex yield data are non-normally distributed (Table 5.2), so QR regressions of ***Yield*** against each climate variable by province are estimated.

The results presented in Table 5.6 provide quantitative evidence of individual impacts of each climate variable on ***Yield*** in the study area. Only ***Tmean***, ***Tmin***, ***Tmean5***, ***Tmin5*** and ***Pmean5*** have strong positive and consistent correlations with ***Yield*** in all the three provinces ($p < 0.05$). There are main effects of province-specific features of ***Tmean*** and ***Tmean5*** ($p < 0.01$) when the variable *province* is coded as two dummy variables in the models (Table 5.6).

**Table 5.6: Individual impacts of climate variables on yield by province, 1990–2012**

| Model ***Yield*** vs. ***var.*** by province | Multiple linear regression using QR: N | *cons_* | Climate variable | Dummy -*Dong Nai* | Dummy -*Tay Ninh* | Effect of province-specific features (*F*-test) |
|---|---|---|---|---|---|---|
| **Tmax** | 69 | 3.81 | -0.07 | -0.13 | -0.06 | 0.10 |
| **Tmean** | 69 | -25.16** | 1.01** | -0.18 | -1.03** | 12.36** |
| **Tmin** | 69 | -0.78 | 0.13* | -0.09 | -0.07 | 0.07 |
| **Pmean** | 69 | 0.69 | 0.0002 | -0.03 | 0.15 | 0.15 |
| | | | | | | |
| **Tmax5** | 69 | 1.60 | -0.01 | -0.15 | -0.04 | 0.13 |
| **Tmean5** | 69 | -49.96** | 1.98** | -0.22* | -2.32** | 63.80** |
| **Tmin5** | 69 | -4.57* | 0.37** | -0.07 | -0.39 | 1.02 |
| **Pmean5** | 69 | -2.47 | 0.0013* | 0.81* | 1.08* | 2.78 |

*: $p < 0.05$ and **: $p < 0.01$

*Source: Estimates using data sourced from the DS (2012) and the VNCHMF (2013)*

***Tmax*** and ***Tmax5*** have a positive correlation with ***Yield***, but their correlations are not statistically significant. ***Pmean*** has a positive correlation with ***Yield***, but its correlation is also not statistically significant. The results showed that higher temperature and higher rainfall were associated with higher variances. A decrease in rainfall and higher variances of temperature and rainfall all might cause variability in latex yield, thereby increasing on-farm income risks.

### 5.4.2 Simultaneous Effects of Climate Variables on Yield

The evidence in Section 5.2 provides the status of climate change and variability in the study area. The drier status in the study area is represented by high annual average temperature, high variability of precipitation in the wet season and low precipitation in the dry season. Although mean latex yield is higher in drier regions, variation of latex yield is also higher. The evidence in Section 5.3 shows an increasing trend in ***Yield*** and also a higher variability of ***Yield*** across the three provinces. The evidence in Section 5.4.1 shows individual impacts of ***Tmean***, ***Tmean5***, ***Tmin5*** and ***Pmean5*** on ***Yield*** in the three provinces.

**Table 5.7: Tests for stationarity and unit roots in cross-sectional time series data, 1991–2012**

| **Variable** | **Dickey-Fuller test for unit root** | | |
|---|---|---|---|
| | Ho: variable contains a unit root - Ha: variable is generated by a stationary process | | |
| | N | **I**(*0*) | **I**(*1*) |
| **Yield** | 65 | -1.62 | -6.72** |
| | | | |
| **Tmax** | 65 | -7.77** | |
| **Tmean** | 65 | -2.47 | -12.07** |
| **Tmin** | 65 | -7.21** | |
| **Pmean** | 65 | -4.76** | |
| | | | |
| **Tmax5** | 65 | -2.50 | -8.31** |
| **Tmean5** | 65 | -0.46 | -8.48** |
| **Tmin5** | 65 | -1.97 | -8.41** |
| **Pmean5** | 65 | -1.55 | -8.01** |

*: $p < 0.05$ and **: $p < 0.01$

*Source: Estimates using data sourced from the DS (2012) and the VNCHMF (2013)*

There is a need to identify whether such climate variables influence ***Yield*** simultaneously over time using cross-sectional time series data. Stationary data on yield and climate in the three provinces (1991–2012) are presented in Table 5.7. Data for the year 1990 was excluded in OLS regressions, because a full dataset of the period 1990 to 2012 did not reveal any statistically significant findings from empirical models. Meanwhile, a reduced dataset of the period 1991 to 2012 gave several important findings. Iterative regressions were conducted to compare OLS regression models when periods of time were added or removed. This method allows us to choose a best-fit model[47].

In Table 5.7, some variables in time series analysis are stationary as indicated by stars. The dependent variable ***Yield*** and some climate variables (***Tmean***, ***Tmax5***, ***Tmean5***, ***Tmin5*** and ***Pmean5***) are non-stationary according to the Fisher-type unit-root test, but they are stationary when differenced *1* time. This differenced version is written as **I**(*1*), and variables differenced are written as **d**.***var***. For this version, **d**.**Yield** and variables **d**.**Tmean**, **d**.**Tmax5**, **d**.**Tmean5**, **d**.**Tmin5** and **d**.**Pmean5** are stationary with the same order, so it was decided to simultaneously use for OLS regression models to avoid confusion of interpreting the regression coefficients.

OLS (pooled) regressions of **d**.**Yield** against **d**.**Tmean**, **d**.**Tmax5**, **d**.**Tmean5**, **d**.**Tmin5** and **d**.**Pmean5** were undertaken to choose a best-fit model. A time variable ***t*** was included in regressions to examine effects of events if present. Variables ***Tmax***, ***Tmin*** and ***Pmean*** are excluded in regressions, because these variables have a different order from **d**.**Yield**.

The $F$-test for the full model in Table 5.8 with the 5% level of significance shows the goodness of fit of the model; in other words, the model is statistically significant ($p < 0.01$). Coefficient of **d**.**Pmean5** in the model is statistically different from zero ($p < 0.01$). This means that a change in **Pmean5** has a statistically significant positive linear relationship with a change in **Yield**. According to the outcome in Table 5.8, the average change of ***Yield*** increases 0.0008 units for each a unit increase in change of ***Pmean5***, holding all other variables constant. Adjusted R-squared shows this model explains about 40 per cent of variation in the dataset. Variables ***t***, ***Tmean***, ***Tmax5***, ***Tmean5*** and ***Tmin5*** found are not statistically significant in the simultaneous model, even though ***t***, ***Tmean***, ***Tmean5*** and ***Tmin5*** have a strong correlation with ***Yield*** in Table 5.6. According to Lobell et al. (2007), auto-correlation or serial correlation in crop yields when analysing sources of yield variation should be removed. Residuals of the model are serially uncorrelated according to the Durbin-Watson statistic results, because its $d$-statistic is in the range of 1.404 (dL) to 2.195 (4 - dU) at the 5% significance points of dL and dU. All VIF values in this regression are ≤ 2; therefore, there is no evidence of multicollinearity. However, we cannot reject that the residuals of the model are non-

[47] Iterative regressions with fixed effect model, random effect model, generalised method of moments estimation and pooled panel data are inconclusive. These models are not applied, because some assumptions of panel data for these iterative regressions are violated.

normally distributed at the 5% level of significance. The outcome of the Breusch-Pagan test indicates that the regression does need to be corrected for heteroscedasticity ($p < 0.01$).

**Table 5.8: Results of climate-yield relationship regression model**

| **Multiple linear regression using OLS** (N = 65) | **Coef.** | **Std. Err.** | ***t*-value** | ***p*-value** | **VIF** |
|---|---|---|---|---|---|
| Dependent variable (**d**.**Yield**) | | | | | |
| Predictor variables | | | | | |
| *cons_* | *0.0194* | *0.0438* | *0.44* | *0.659* | |
| ***T*** | 0.0002 | 0.0011 | 0.14 | 0.892 | 1.03 |
| **d**.**Tmean** | 0.0132 | 0.0622 | 0.21 | 0.832 | 1.52 |
| **d**.**Tmax5** | -0.0919 | 0.1140 | -0.81 | 0.423 | 1.88 |
| **d**.**Tmean5** | 0.2121 | 0.2113 | 1.00 | 0.320 | 2.00 |
| **d**.**Tmin5** | 0.0270 | 0.0394 | 0.68 | 0.496 | 1.46 |
| **d**.**Pmean5**** | 0.0008 | 0.0002 | 4.91 | 0.000 | 1.60 |
| | | | | | |
| ***F***(6, 58) | 8.21** | | | | |
| **R-squared** | 0.46 | | | | |
| **Adjusted R-squared** | 0.40 | | | | |
| **Normality of residuals** *(Skewness and Kurtosis test with Adjusted Chi-squared)* | 60.91** | | | | |
| **Independence of residuals** *(Durbin-Watson d-statistic with $dL_{1.404} < d < 4\text{-}dU_{1.805}$)* | 1.42* | | | | |
| **Heteroscedasticity** *(Breusch-Pagan test with Chi-squared)* | 34.87** | | | | |
| **Multicollinearity** (VIFs) | ≤ 2 | | | | |

*: $p < 0.05$ and **: $p < 0.01$

*Source: Estimates using data sourced from the DS (2012) and the VNCHMF (2013)*

This study expects to see that increased precipitation has a positive correlation with latex yield, but increased temperature has a negative correlation. The finding of **d**.**Pmean5** in the model is consistent with this expectation. More importantly, increasing precipitation benefits rubber tree growth, while current growth influences future growth and thus influences latex yield over the rotation cycle. High temperature seems to constrain rubber plant growth and development, but the finding of temperature variables in the model is not statistically significant.

According to the results in Table 5.8, the finding of significance regarding **d**.***Yield*** and **d**.***Pmean5*** implies that rubber growers should consider trend effects of precipitation to adjust crop management practices at their rubber plantations. The results in Table 5.8 are consistent with the evidence of Lobell et al. (2007) that shows when levels of precipitation increase latex yield increases.

The effects of temperature and total precipitation on latex yields were assessed at the provincial level in Southeast Vietnam. Latex yields have a clearly increasing time trend but are associated with increasing variation. Increasing latex yields are negatively correlated with a decreasing time trend and high variability of 5-year moving average precipitation. This evidence is important, because it shows the challenge of prevailing climatic condition as follows. Temperature variables have an increasing trend when the dry season starts and a decreasing trend when the wet season starts. The variability of temperature variables is not as clear as the variability of total precipitation. Total precipitation is high when the wet season starts, but its variability is also high. Total precipitation is low when the dry season starts, but its variability is also low. Therefore, the dry season is becoming drier, which is considered a challenge to natural rubber cultivation in some areas. Most farmers in the survey concurred they had experienced severe latex yield and quality losses caused by changing climatic conditions.

## 5.5 Discussion and Conclusion

The purpose of this chapter is to test hypotheses about climate change, climate variability, latex yield growth and yield variability as well as the climate effects on yield growth in the study area. There is strong evidence that annual average temperature, annual average minimum temperature and their 5-year moving average have an increasing trend across the three provinces, but total annual precipitation and its 5-year moving average have unclear trends. ***Yield*** has increased over time, but the variation of ***Yield*** has also increased. Conclusive evidence is found in the three provinces that the positive correlation of 5-year moving average precipitation with ***Yield*** is statistically significant. This indicates that aggregate secondary data do provide enough information on the effects of climate variables on latex yield. However, there are two limitations. The goodness of fit of the model is acceptable for the period 1991–2012, but the goodness of fit of the model disappears when using the original data (1990–2012). Some assumptions of normality of residuals as well as heteroscedasticity in the final estimate are not addressed. Additionally, panel data allow us to account for heterogeneous effects across the three provinces simultaneously when estimating impacts of climate variables on ***Yield***. Panel data also allow us to account for heterogeneous effects of other factors (e.g.

technological advances, improved cultivation practices, market and policies) across years. However, goodness of fit is not present when attempting to estimate the models using panel data.

Southeast Vietnam is considered an arid region because of extreme dry weather events and low precipitation in the dry season, while rainwater is the sole source of groundwater recharge in the area. According to indigenous knowledge, high levels of latex yield require moderate temperature but with low variability in the morning, which ensures flow of latex due to a pressure imbalance between the inside and outside of the cut bark. Precipitation is low in the dry season and its variability is high in the wet season. Total annual precipitation and its 5-year moving average have unclear trends. Therefore, an increase in this variable could bring a positive effect on ***Yield*** in this region. Increased water conservation, soil moisture conservation, high temperature resistance of rubber trees, and irrigation facilities would appear to be useful adaptations. Irrigation technologies, especially those that save water, should be emphasised in this region to address the challenges of climate change. However, expanded irrigation using groundwater extraction should not be considered a sustainable solution in the long term.

The magnitude of the climate impacts on latex yield is further studied with the farm-level data in the next chapter, and the findings in this chapter and other chapters help suggest solutions in Chapter 9 (policy implications).