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Determinants of Crop Diversification in Southeast Asian Countries

동남아시아 국가들의 농작물 다각화 결정요인 분석

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Graduate School of Agricultural Economics
and Rural Development
Seoul National University
Agricultural and Resource Economics Major

Clara Joan Joachim

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Professor Donghwan An

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Clara Joan Joachim

Confirming the master's thesis written by
Clara Joan Joachim
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Chair ______________(Seal)
Vice Chair ______________(Seal)
Examiner ______________(Seal)

Abstract[1]

The agricultural sector in Southeast Asia has gone through significant structural changes in the past few decades, although these changes vary across the region. Concerns such as large-scale cultivation of specific crops, climate change and food insecurity, have led to the need for crop diversification as a viable solution to these issues. This study aims to investigate the status of crop diversification and the factors that determine it in eight countries of Southeast Asia: Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Thailand, and Vietnam. Various factors were considered including technology (fertilizer consumption and irrigation), climatic conditions (temperature and rainfall), productivity of both food and non-food crops, gross national income (GNI), share of cropland area in agricultural land, arable land per rural capita and export activities. The study uses panel data from 1988 to 2020, and Simpson's Diversification Index to measure crop diversification. The determinants of crop diversification were evaluated using fixed effects model, with control for country dummy. To address issues of heteroskedasticity and cross-sectional correlation, the study uses Feasible Generalized Least Square (FGLS) estimation approach. The study found that crop diversification in Southeast Asian countries was

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significantly associated with factors such as fertilizer consumption, irrigation systems coverage, crop yield index, income levels, arable land per rural capita, and concentration of export. However, an increase in fertilizer consumption and arable land per rural capita, as well as reliance on a limited number of crops for exports, had a negative relation with crop diversification.

Keyword : Crop diversification, Sustainable Agriculture, Food Security, Panel Data, Southeast Asia
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List of Abbreviations

ASEAN	Association of Southeast Asian Nation
FAO	Food and Agriculture Organization
FGLS	Feasible Generalized Least Square
GDP	Gross Domestic Production
GNI	Gross National Income
HI	Herfindahl Index
IFA	International Fertilizer Association
LSDV1	Least Square Dummy Variable 1
OLS	Ordinary Least Square
SDI	Simpson's Diversification Index
UN	United Nations
VIF	Variance Inflation Factor

Chapter 1. Introduction and Background of the Study

1.0. Introduction

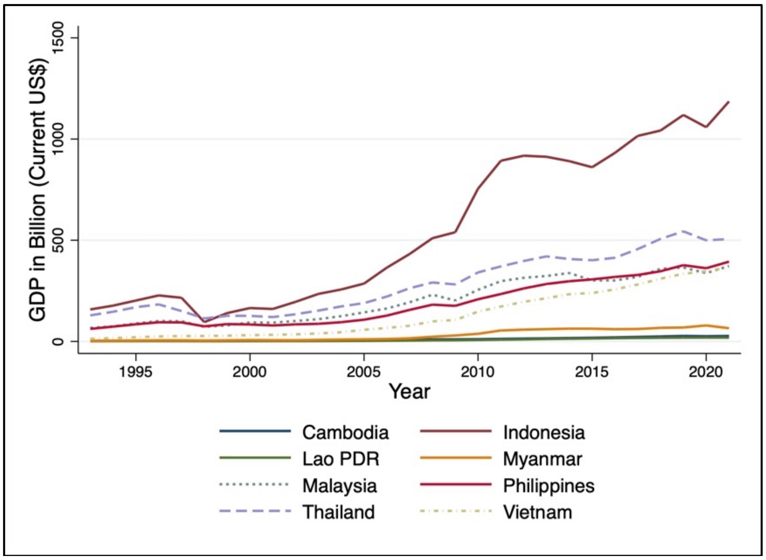
Crop diversification encompasses various strategies aimed at enhancing profitability, promoting market competitiveness, protecting the environment, and facilitating the integration of agriculture (Van Luat, 2001). It plays a crucial role in enhancing agricultural sustainability, improving food security, and promoting rural development.

In Southeast Asian countries, where agriculture has an important role in the economy, understanding the determinants of crop diversification is necessary. This research utilizes a panel data spanning 33 years (1988-2020) to investigate the factors that influence crop diversification in the region. Comprising of 11 countries, the region includes Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic (PDR), Malaysia, Myanmar, the Philippines, Singapore, Thailand, Timor-Leste, and Vietnam. However, countries like Singapore, Brunei Darussalam, and Timor-Leste were excluded from the analysis of this research. This is because agriculture is very much less significant in its contribution to domestic production in Singapore and Brunei, while there is limited data availability for Timor-Leste. By addressing this objective, the study aims to provide valuable insights to foster sustainable farming systems and potential strategies on enhancing food production and security.

Particularly, the first chapter of this thesis will present background about agricultural sector in Southeast Asian countries. The next section discusses on the problem statement and objective of the research. While the fourth section of this chapter argues on the relevance of the study and finally explains the organization of the remaining chapters in the thesis.

1.1. Agricultural Background and Issues in Southeast Asian Countries

Figure 1: Gross Domestic Production of Southeast Asian countries (1993-2021)



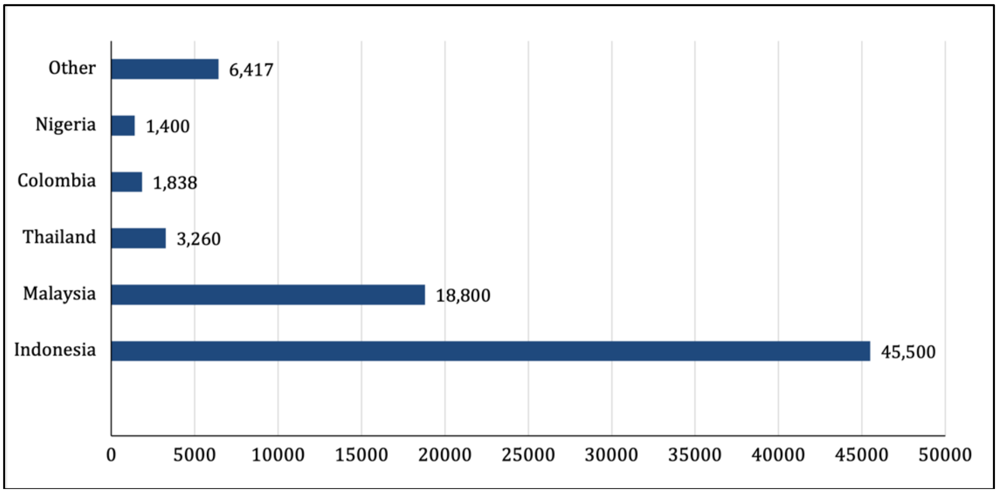
Source: World Bank

Between 2000 to 2016, Southeast Asia experienced a remarkable economic progress with its GDP expanding at an average growth close to 5% per year. The region's advantageous proximity to major markets has driven to be a key player in various manufacturing global value chains (OECD-FAO, 2017). Despite the growth of the manufacturing and service sectors in the region, the contribution of agriculture to the gross GDP has experienced a decline, decreasing from 15% to 11% during the same period (Birthal et al., 2022).

Southeast Asian region benefits from a rich diversity of crops owing to its favorable agro-ecological conditions. Agriculture sector plays significant roles in ensuring food security, rural livelihoods, and economics development in Southeast Asia. Since the 1960s, countries in Southeast Asia, such as Indonesia, the Philippines, and Malaysia have adopted green revolution policies, particularly in rice agriculture (De Koninck & Rousseau, 2013). Furthermore, starting from 1990s, there has been a significant emphasizes on designing irrigation and drainage systems to facilitate rice production (Taylor, 1994). The rate and scale of agricultural expansion have differed among countries, nevertheless all nations have adopted agricultural enhancement and experienced substantial increases in rice production, except for Malaysia as Malaysia's bulk of agricultural land is devoted to oil palm cultivation. Until today, rice plays a dominant role in the region's cropping system, especially in lower-income countries (Birthal et al., 2022) and there is a considerable cultivation of other crops such as maize, sugarcane, cassava, rubber, tea, spices, fruits, and vegetables (Sichoongwe, 2014).

Since 1990s, the Southeast Asia region has emerged as a key player in the global production and supply of commodities like palm oil and rubber (Figure 2 and Figure 3). This has led to a significant expansion of mono-cropping practices, particularly in countries such as Indonesia, Malaysia, Thailand, and Vietnam. Mono-cropping, characterized by the cultivation of a single crop over a large area, has enabled high yields and streamlined production processes, contributing to the region's dominance in these commodities. However, the expansion of a single crop has raised concerns about its sustainability and environmental impacts.

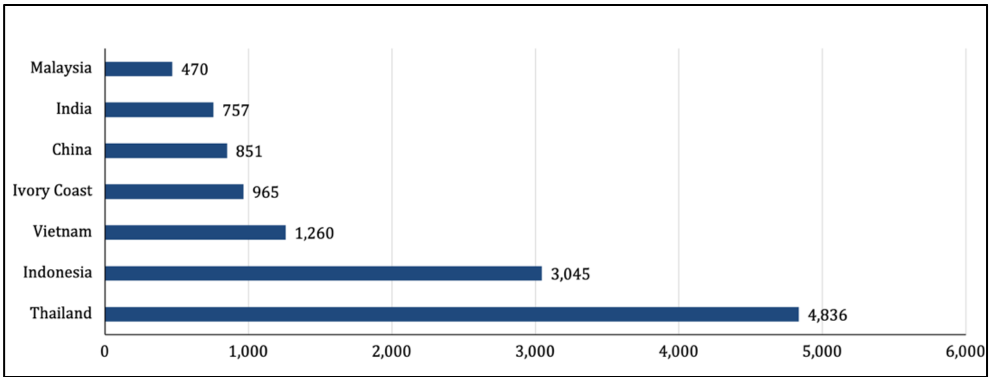
Figure 2: Leading producers of palm oil worldwide from 2022/2023 (in 1,000 metric tons)



Source: US Department of Agriculture (2023)

The conversion of non-agricultural land into vast mono-cropped plantations has resulted in habitat loss, deforestation, and the depletion of natural resources (Russell, 2020). Moreover, the intensified use of inputs such as fertilizers and chemicals for pest and disease control has had implications on the health of the ecosystem (ADB, 2009). Therefore, it is crucial for the region to address these challenges and seek sustainable approaches to agricultural production that balances the economic interest with environmental resilience.

Figure 3: Leading producers of natural rubber worldwide in 2021 (in 1,000 metric tons)



Source: Rubber Board (2022)

Moreover, this region is facing challenges in its food security. Many countries in the Association of Southeast Asian Nation (ASEAN) faced limited access to healthy foods in their food supply. Based on ASEAN Food and Nutrition Security Report, in 2021, fruits and vegetables only made up of a small portion, ranging from 1 to 13% of the energy people obtained from their diets. Similarly, meat, seafood, eggs, milk, and offal accounted for just 6 to 19% of dietary energy. This lopsided distribution of food resulted in a heavy reliance on carbohydrates, with not enough nutrient-rich foods available for the population. Starchy foods like rice were the main source of calories, making up significant 43 to 70% of the diet in ASEAN countries (ASEAN, 2022). Hence, the high dependence on rice as a primary staple in the country's food supply raises significant concerns on population's access to sufficient and more varied diet intakes.

Moreover, food security in the region was also challenged by extreme weather events due to global warming. A recent survey conducted by ISEAS (2022) found that 31.2% of Southeast Asians agreed that food supply was mostly threatened by extreme weather events, followed by disruption of global supply chain (25.3%) and the reduced export from producing countries (19.1%).

To summarize, agricultural activity in Southeast Asian countries is facing challenges in terms environmental resilience due to dependence on large expansion and less diverse crops. Besides, food security was also threatened as heavy reliance on starchy foods in food supplies as well as due to the extreme climate changes. These compelling issues provides evidence that there is a need for the region to come up with a strategy in solving the issues. One approach that has gained significant attention is by diversifying crops, though the concept of diversification has emerged as a prominent theme within ASEAN member states since early 1990s (Taylor, 1994). In response to the challenges, Southeast Asian countries have realized the need to work together and take decisive action (Papademetriou, 2001). Crop diversification was highlighted in ASEAN Framework and Action Plan spanning from 2018 to 2030; whereby, the focus of the strategy is to develop a policy guide for crop diversification that considers national food-based dietary guidelines, regional-level food consumption patterns, and overall nutrition objectives.

1.2. Problem Statement

The promotion of crop diversification in Southeast Asian countries is crucial for enhancing agricultural sustainability, improving food security, and mitigating environmental risks. However, there is a significant knowledge gap regarding the determinants of crop diversification in this region. Understanding the factors that influence farmers' decisions to diversify their crops is essential for developing effective policies and interventions that encourage diversified agricultural systems. Without this understanding, efforts to promote crop diversification may be limited in their impact and effectiveness. Therefore, it is imperative to thoroughly investigate and identify the determinants of crop diversification in Southeast Asian countries to formulate compelling strategies for sustainable agricultural development in the region.

1.3. Research Objective

The main objective of this study is to examine the determinants of crop diversification in Southeast Asian countries from 1988-2020. Specifically, this study seeks understanding of different factors that may determine crop diversification such as:

a) Fertilizer consumption

b) Cropland area equipped for irrigation

c) Climate factors (temperature and rainfall)

d) Food crop yield

e) Non-food crop yield

f) Gross National Income

g) Share of cropland area from total agriculture area

h) Arable land size per rural capita

i) Crop export

Understanding these factors is important in identifying the main physical and socio-economic influences on agricultural practices in this region. Simply, this study intended to provide new evidence by answering the question on:

What are factors that determine crop diversification in Southeast Asian countries?

While countries are a suitable administrative unit for studying regional level studies, the level of crop diversification varies significantly across different countries due to variations in regional characteristics such as resources, infrastructure, and climate. This thesis is fundamentally different from any other studies on investigating the determinants of crop diversification, for two reasons:

1) In this research, crop diversification is perceived from a macro-level perspective rather than being seen as a farm-level decision. The analysis of the study was done at national level based on data from several Southeast Asian countries.

2) The study employed a long-term analysis using extensive long-panel data. The estimation considered important factors like weather changes, crops yield productivity, economic growth, and crop export activity.

1.4. Relevance of the Study

There are several reasons to study on the determinants of crop diversification in this region. This includes the following:

1) The discussion on crop diversification has attracted considerable attention in this region, particularly due to the prevailing practice of less diverse intensive cropping. Therefore, gaining a comprehensive understanding of the determinants of crop diversification at the national level is essential for shedding light on the factors that drive the adoption of diversified cropping systems. This knowledge will provide valuable insights and inform decision-making processes aimed at promoting sustainable and diversified agricultural practices in the region.
2) Considering on the issue of food security due to population growth and changing of dietary patterns face in this region, crop diversification could help to promote cultivation of a balanced and nutritious diet. Therefore, this study helps to identify strategies to supply enough food to meet the region's demand.

1.5. Organization of Remaining Study

The thesis follows a structured format comprising of the following chapters: Chapter 2 provides an overview of the existing literature on assessing the determinants of crop diversification with their relative contributions and discussions. While chapter 3 offers detailed information on methodology employed for the study. Chapter 4 presents the data and key measurements of the variables. The next chapter delves into the findings derived from the analysis conducted. Finally, Chapter 6 summarizes and highlights the key findings, suggests potential policy guidelines, as well as limitations of the study and avenues for future work.

Chapter 2. Literature Review

2.0. Introduction

This chapter offers an overview of literature regarding crop diversification. The chapter is structured into three main sections. The first section examines literature pertaining to the concept and definition of crop diversification. The second section delves into the key determinants that influenced crop diversification derived from previous research findings. Finally, this chapter presents a review of the benefits and challenges associated with crop diversification, followed by an identification of the research gap based on the literature.

2.1. Crop Diversification: Concept and Definition

Heady (1952) earlier proposed crop diversification as a mean of managing uncertainty in agriculture, and it has been pursued globally for over 70 years. Crop diversification is an approach aimed at optimizing the utilization of land, water, and other resources to foster agricultural development and improve income in less-developed countries (Barghouti et al., 2004; Papademetriou, 2001). It offers farmers the opportunity to cultivate a variety of crops on their land, providing them with viable alternatives for cultivation (Acharya et al., 2011).

Diversification holds great potential for enhancing nutrition security, poverty alleviation and ecological sustainability (Feliciano, 2019). Existing studies discussed upon the term of crop diversification in many approaches and different perspectives. Gunasena (2001) revealed crop diversification in two ways, horizontally and vertically. Horizontal diversification refers to the act of introducing additional crops into an existing cropping system. By incorporating extra crops and implementing techniques such as multiple cropping and effective management practices, this strategy enhances the diversity of crops within the system. The later, reflects on the level of industrialization of the crop. It involves downstream activities that transform raw agriculture products into processed goods with higher value. For instance, farmers engaged in vertical diversification may establish processing facilities to manufacture products like canned foods, juices, syrups, or value-added agricultural products from their crops.

Petit and Barghouti (1992) discussed that diversification can be approached with four dimensions; farm, regional, sectoral, and inter-sectoral. Farm level or "on-farm" crop diversification is more associated with small and subsistence farming, specifically in the rural sector. At farm level, farmers have demonstrated the ability to adapt their product mix in response to changing profitability and risk levels. A systematic review of studies from 42 countries done by Tacconi et al. (2022) summarized that diversification at this dimension is influenced by;

1) human capital (farmers' age, education level and skills, the number of household members)

2) physical capital (farm characteristics, access to extension services, irrigation facilities, fertilizers, seeds, and other endowments)
3) economics and financial capital (access to market and roads, household economics) and,
4) social capital (cultural values, farmers' gender, access to information and network).

Crop diversification at the regional level is influenced by the region's ability to focus on specific industries that they are best suited for and shaped by technical factors. At regional level, crop diversification is less flexible due to regional-based characteristics. For instance, regions that are accessible to irrigation systems are more flexible on choosing different crops based on season and year. Contrarily, in rainfed agriculture, where water availability is limited, farmers are restricted to growing only few crops regardless the market demand for other crops (Petit & Barghouti, 1992).

Regional specialization can be beneficial for the development of a complete commodity system. When farmers in a region grow many different crops, both individual and regional crop diversification indicators will show high diversification. On the other hand, when farmers only grow a few crops while others in the region grow many different crops, the individual diversification will be low, but the regional diversification will be high (Kankwamba et al., 2018). When there is an increase in per capita income of consumers or the adoption of new production technologies, there is a tendency for regional specialization. Consequently, national-level diversification can occur as a result of regional specialization, without necessitating diversification at the individual farm level (Schuh & Barghouti, 1988).

There is significant conceptualization on crop diversification as the allocation of land to different crops or variation in acreage among crops in a region (Birthal et al., 2022; De, 2005; Singh et al., 2022). The concept of allocation of land resources among different crops is also influenced by several factors, including crop prices and yields, irrigation levels, availability and variability of agricultural inputs, and geographical characteristics of the region (De, 2005).

2.2. Key Factors of Crop Diversification

Agricultural technology plays a significant role in the development of farming community. According to Sonawane, More and Perke (2022), technological factors encompassed the following: the area under a high-yielding variety of food grains, the irrigated area, and the extent of mechanization. Seng (2014) found that access to irrigation has a significant positive impact on both the decision to diversify crops as well as to the intensity of diversification in the provinces of Cambodia. A study conducted in India (Acharya et al., 2011) reached a similar conclusion, demonstrating that the proportion of the gross irrigated area to the gross cropped area has a notable and positive influence on diversifying the variety of fruits and nuts. Contrarily, study on land allocation and crop varieties in Ethiopia, Benin et al. (2004) found evidence that a higher proportion of irrigated land on a farm significantly contributed to the specialization of maize crop, however diversifying on other cereal crops.

Moreover, existing literature consistently emphasize the significance of fertilizer inputs towards determining crop diversification. Acharya et al. (2011) discovered a significant contribution of fertilizer consumption towards the diversification of fruits and nuts. However, a study done by Di Falco and Zoupanidou (2017) in Italy revealed that soil fertility and crop diversification act as substitutes to each other towards agricultural productivity. The interaction was negative which means that, diversification helps to maintain productivity in agro-ecosystem when soil fertility levels are low.

The climate variables that often used in the literature include rainfall and temperature. According to study by Joshi et al. (2004) in South Asia countries, higher rainfall areas exhibited a significant negative correlation with crop diversification, indicating limited diversification in those regions. The study revealed that areas with high rainfall tended to specialize in rice cultivation, whereas farmers in medium and low rainfall areas pursued diversification to increase income and mitigate risks. The same finding was concluded by Mithiya et al. (2018). While a study in Sub-Saharan Africa (Asfaw et al., 2019) showed that all countries examined indicate a positive correlation between exposure to extreme rainfall events and both crop and livelihood diversification. Hence, suggesting that climate-related shocks play a crucial role as driving factors for diversification. Besides, Ochieng et al. (2020) reported that crop diversity exhibits a noteworthy correlation with long-term rainfall but a positive correlation with temperature in Kenya. The finding further supports the idea that in various parts of Africa, in warmer climate scenarios, farmers opt for crop diversification over specialization. Additionally, Tesfaye (2020) stated that at the household's level, crop choice or decision to diversify is determined by their willingness to bear risk. The degree of risk aversion was captured within wide range of variables. Factors include agro-climatic environment (soil, weather, and water availability), which at the same time play a crucial role in determining the potential for expanding crop production or adopting specialized agricultural technologies.

According to Devi and Sharma (2022), as income level increases, consumers tend to shift their preferences from staple food items to high-value food items. This change in consumption, therefore, incentivizes farmers to diversify their crop portfolio and prioritize the cultivation of high-value crops. Meanwhile, a study in regional India (Singh et al., 2018) resulted that crop diversification increased with the growth of land size holdings and per capita income. The acceleration of crop diversification is due to small land holders not having the ability to cultivate crops other than their staple food. Therefore, crop diversification at the small land was driven by the needs to produce food for their own consumption. It was also observed that in Asia, farm diversification is driven by the decrease of price for a particular commodity. This leads to reallocation of resources from that commodity to another with higher income potential (Schuh & Barghouti, 1988).

Literature also mentioned that trade affected global changes in crop diversification. According to a study on 152 countries, in the early 90s, diversification of the crop exported was less than diversification of the crop imported. Apart from that, Fraser (2006) in his/her paper opposed a view on potential impacts of international trade towards agricultural specialization. International trade promotes specialization among farmers in crops where they possess comparative advantages, irrespective of the ecological vulnerability associated with monocultures. Rather, the government supports on insurance and subsidies influences farmers' decision. Removing such programs from government leads to increase in diversification. While, the earliest discussion by Delgado (1995) highlighting rural rice-based economies in Asia, the absence of diversification was attributed to policy interventions aimed at promoting rice production. However, implementing macroeconomics and trade regime reforms that reducing the incentive to focus solely on irrigated rice cultivation could encourage greater diversity in agricultural output. Additionally, cropping intensity was found to have a favorable effect on crop diversification (Kumar & Gupta, 2015). Crop intensity can be defined as the proportion of the gross cropped area to the net sown area. It is because farmers tend to rotate crops to enhance the sustainability of their farms.

2.3. Benefits and Challenges of Crop Diversification

The importance of diversifying agriculture is well-documented in various sources. Studies have consistently found that crop diversification impacted to factor such as economic benefits to the farming community, especially in stabilizing and improving household income in less-developed countries (Pellegrini & Tasciotti, 2014). Crop diversification is often suggested as a microeconomic policy to lessen poverty and food insecurity (Khandoker et al., 2022; Mango et al., 2018; Tesfaye, 2020), which involves growing of several crops to counter self-insufficiency (Sonawane, More, & Perke, 2022) as well as to increase employment opportunity (Devi & Sharma, 2022).

Food security is an important issue that is not new everywhere around the globe and very much often highlighted at national, and moreover at the household's level. The objective of increasing food production faces challenges due to population growth, increasing incomes, and the degradation of natural resources. Besides, the shift in agriculture from food crops to non-food crops in the portfolio potentially leads to food insecurity. Therefore, diversification by an expansion of cropping intensity was found contributing to the overall agriculture landscape (Joshi et al., 2004; Kaur & Malhi).

Justified by the benefits of improving soil health, crop diversification is also a strategy in protecting the environment, reducing pests and diseases. Studies have shown that crop diversification practices help to buffer microclimatic fluctuations (Feliciano, 2019). The statement is validated by the case of deforestation in Malaysia (Dayang Norwana et al., 2011) due to the large-scale oil palm plantation which had brought to risks such as the degenerating animal's habitat, disruption of water river quality, and erosion of river banks. Large scale deforestation towards intensification of a specific type of crops not only harmed the ecosystem, but further affected the livelihood of the nearby community.

Despite the benefits of crop diversification on the society, there are discussions of challenges upon the practice. Crop diversification is mostly constrained by political and institutional barriers. The intensification of diversification strategies should be taken cautiously, as ignoring the constraints faced by farmers, such as transaction costs, preferences, and unique farming characteristics, may impact negatively on both production and welfare. Besides, the insufficiency of well-developed market infrastructure for sale of diverse crops will hinder effective diversification strategy (Isaacs et al., 2016; Kankwamba et al., 2018).

Constraint to diversifying crop includes the system of land tenure. The land tenure system limits the freedom of farmers to explore in diversifying their crops. In Central Eurasia, agricultural land is managed and controlled by state and collective farms, with small household gardens being the exception. As a result, rural residents have no capacity to be independent producers and decision-makers towards crop selection (Bobojonov et al., 2013; Spoor, 2007).

2.4. Research gap

Although numerous studies have explored the determinants of crop diversification, most of the research were implemented at household, provinces, or states level. While crop diversification is commonly viewed as a strategy to enhance food access and support rural communities, it is crucial to examine the factors influencing crop diversification within a broader framework. This analysis should encompass consideration on factors such as technologies, socioeconomics, climatic conditions, and export activities.

Existing literatures consisted of cross-sectional time analysis and very less research done by exercising on a huge panel data. Moreover, research and evidence on determinants of crop diversification in Southeast Asian demographic are still very limited. Therefore, there is a need for studies that examine crop diversification from a larger perspective, encompassing such important factors. To address these gaps, this study investigates the determinants of crop diversification at national level in selected Southeast Asian countries.

Chapter 3. Methodology

3.0. Introduction

In this chapter, an outline of the methodology utilized in the study is presented. The chapter is divided into few sections, each addressing specific aspects of the research methodology. The first section explains on the concept of panel data, followed by multicollinearity test on the second section. Next, modeling and estimation process will be discussed. Specifically, the third section encompasses aspects such as estimation tested and model test using Hausman. In section 4, it covers on diagnostic tests employed such as the cross-sectional dependence test, heteroskedasticity test, and serial correlation test. Finally, the last section will discuss on estimation issues based on the result of diagnostic tests conducted.

3.1. Panel Data

In this study, the approach of panel data was used. Panel data encompasses a collection of observations on the same unit, such as individuals, firms, states, or countries, recorded over multiple time periods (Gujarati, 2022). Baltagi (2008) listed the advantages of panel data method as follows.

1) Due to the information collected over time from units, there is likely to be heterogeneity among these units. However, panel data estimation able to explicitly consider this heterogeneity by incorporating subject-specific variables. The subject in this

sense is termed for the micro-units of individuals, firms, states, or countries.

2) It involves combination time series of cross-sectional observations, therefore providing more informative data, greater variability, less collinearity among variables, more degrees of freedom, and greater efficiency.
3) The repetition cross section of observations makes panel data better suited for studying the dynamics of adjustment. When the relationships are dynamic in nature, large cross-sectional observation, N and large time series observation, T.
4) Panel data is more effective in identifying and quantifying effects that are not observed in either pure cross-sectional or pure time series data. Besides, it provides a means to analyze complex behavioral models that are difficult to study using purely cross-section or time-series data.
5) By making the data available as large as possible, panel data able to minimize or eliminate the bias resulted from the aggregated units into broad aggregates. Hence, panel data considered more accurate.

3.2. Multicollinearity Test

Multicollinearity is observed when two or more explanatory variables are closely related in a linear or nearly linear manner. The presence of perfect multicollinearity in a regression model can render the conventional least square analysis unreliable. When the effects of individual explanatory variables are not clearly distinguishable or their independent influences are not accurately assessed, it can be challenging to avoid paradoxical outcomes and misleading p-values for each variable (Ashenfelter et al., 2003).

The study assessed the presence of multicollinearity by analyzing the correlation matrix. The correlation matrix measures the association between variables on a scale from zero to one. Diagonal elements represent perfect correlation (a value of one) between a variable and itself, while off-diagonal elements indicate the degree of correlation between variables. If the absolute value of the correlation coefficient close to 0.8, it indicates a substantial multicollinearity issue (Shrestha, 2020). This can introduce bias in the results, leading to inflated standard errors and covariance and potentially causing the failing to reject the null hypothesis (type 1 error).

Furthermore, to avoid multicollinearity being used for the following model, Variance Inflation Factor (VIF) test was also implemented. A general guideline suggests that variable with VIF values exceeding 10 should be further examine for potential issues (Shrestha, 2020). The following is the general formula of VIF:

$$VIF_i = \frac{1}{1 - R_i^2}$$

where R_i^2 is the unadjusted coefficient of determination for regressing i-th independent variable on the remaining ones. When R_i^2 equals 0, the VIF will be 1, indicating i-th dependent variable is not correlated with the other variables. This suggests the absence of multicollinearity.

To evaluate the degree of collinearity, tolerance (1/VIF) is utilized. A tolerance value below 0.1 is regarded as equivalent to a VIF of 10.

3.3. Model Specification

To determine the factors of crop diversification, the study employed the following mathematical model derivation:

$$CDI_{it} = f(FER_{it}, IRRIG_{it}, TEMP_{it}, RAIN_{it}, GNI_{it}, FCY_{it}, NFCY_{it}, CL_{it}, ALRU_{it}, EXP_{it},) \quad (1)$$

where $i = 1,..,N$ countries and $t = 1, ..., T$. CDI_{it} represents crop diversification index for country i in year t ; FER_{it} is fertilizer consumption for country i in year t ; $IRRIG_{it}$ is the proportion of cropland area equipped for irrigation for country i in year t; $TEMP_{it}$ represents the average temperature of country i in year t; $RAIN_{it}$ is average rainfall for country i in year t; GNI_{it} is gross national income for country i in year t; FCY_{it} is food crop yield index for country i in year t; $NFCY_{it}$ is non-food crop yield index for country i in year t; CL_{it} is the proportion of cropland area from total agriculture area for country i in year t ; $ALRU_{it}$ is the arable land per rural capita for country i in year t; and EXP_{it} is crop export index for country i in year t.

With panel data, different tests and estimations were performed using statistical software STATA/SE 17.0. The empirical model takes the following form:

$$CDI_{it} = a_i + \beta_1 LNFER_{it} + \beta_2 IRRIG_{it} + \beta_3 TEMP_{it} + \beta_4 RAIN_{it} + \beta_5 LNGNI_{it} + \beta_6 FCY_{it} + \beta_7 NFCY_{it} + \beta_8 CL_{it} + \beta_9 ALRU_{it} + \beta_{10} LNEXP_{it} + \epsilon_{it} \quad (2)$$

To achieve a more normal distribution, the variables FER_{it}, GNI_{it} and EXP_{it} were transformed into their logarithm form. Respectively, these variables presented in equation 2 as $LNFER_{it}$, $LNGNI_{it}$ and $LNEXP_{it}$.

Fixed effects model is more suitable when dealing with observations that pertain to distinct characteristics of each country that can impact to the outcome or/and explanatory variables. In other words, there are unique attributes of entities[2] that are not the result of random variation but represents fixed, longstanding differences. For instance, these factors can come from cultural factors or political variables, that are often difficult to be measured or unavailable. Given that individual characteristics are non-random and have the potential to influence outcome variable, it is important to account for them, ensuring that effects of the regressors are not confounded by these fixed characteristics. Entity's fixed effects model can also be expressed as:

$$CDI_{it} = a_i + \beta_1 LNFER_{it} + \beta_2 IRRIG_{it} + \beta_3 TEMP_{it} + \beta_4 RAIN_{it} + \beta_5 LNGNI_{it} + \beta_6 FCY_{it} + \beta_7 NFCY_{it} + \beta_8 CL_{it} + \beta_9 ALRU_{it} + \beta_{10} LNEXP_{it} + \beta_{11} INDO_{it} + \beta_{12} LAO_{it} + \beta_{13} MAL_{it} + \beta_{14} MYAN_{it} + \beta_{15} PHIL_{it} + \beta_{16} THAI_{it} + \beta_{17} VIET_{it} + \epsilon_{it} \quad (3)$$

As seen on equation 3, the national dummy variables are $INDO_{it}$ for Indonesia, LAO_{it} for Lao PDR, MAL_{it} for Malaysia, $MYAN_{it}$ for Myanmar, $PHIL_{it}$ for the Philippines, $THAI_{it}$ as for Thailand and $VIET_{it}$ for Vietnam. In entity's fixed effects model, the assumption is made that there exists a correlation between the error term of an entity and

[2] "entities" refers the same as countries.

the regressors. However, it is crucial to acknowledge that the fixed effects of one entity cannot be correlated with the fixed effects of another entity. a_i and β_i represent constant parameters and ϵ_{it} is the error terms. Any changes in explanatory variables may have an equal effect on all countries and across time, but the average level of all countries may differ to each other. The error term, ϵ_{it} is assumed to be independent and identically distributed across both country and time, with a mean of zero and variance (σ^2). On the other hand, a_i represents the effects of i-th country and is constant across both country and time. As a result, a_i is considered as N fixed unknown parameters, making the equation a fixed effects model.

According to Greene (2008), the fundamental distinction between fixed effects and random effects lies between unobserved individual effects and the regressors, rather than whether these effects are deterministic or stochastic. If the variations across entities potentially influence the dependent variable, but are not correlated with the predictors, a random effects model is suitable. The random effects model has the advantage of estimating the coefficient of regressors that do not vary over time, which is not possible with the fixed effects estimator. When employing random effects model, it is necessary to identify characteristics that may impact the explanatory variables. However, this can pose challenges if certain variables are unavailable, leading to omitted variable bias in the model. The random effects model can also encounter issues with the over-identifying restriction, assuming that individual-specific effects are independently distributed. If this assumption is violated and cross-sectional characteristic are correlated with regressors, the estimated parameters can be inconsistent and biased. Therefore, it is important to test for the presence of the correlation between the specific error term and the regressors.

To choose the appropriate panel model, the distinction between fixed effects and random effects is essential. The Hausman test can be conducted to test the null hypothesis that individual-specific effects are random (Hausman, 1978). In essence, the Hausman test determines whether there are systematic differences between the coefficient estimates of the two models.

3.4. Diagnostic Tests

Until now, the assumptions of classical Ordinary Least Square (OLS) (Nicholson et al., 2021) regarding homoscedasticity and correlation were not yet discussed. If these assumptions are satisfied, the model will have:

a) $E(e_{i,t}) = 0$

b) $Var(e_{i,t}) = \sigma^2$

c) $Cov(e_{i,t} | e_{j,s}) = 0 \; if \; t \neq s \; or \; i \neq j$

This is equivalent to consider that the default variance-covariance matrix (VCE) of the disturbance can be written as in Stata Manual (xtgls):

$$E(ee') = \ \Omega_{default} = \begin{bmatrix} \sigma^2 I & 0 & 0 \\ 0 & \sigma^2 I & 0 \\ 0 & 0 & \sigma^2 I \end{bmatrix}$$

Nevertheless, panel data structures frequently deviate from these standard assumptions regarding the error process. As a result, it becomes necessary to examine and assess these assumptions with regards to cross-sectional dependence, heteroskedasticity and serial correlation within units (sometimes referred as autocorrelation). Therefore, the following tests were conducted to diagnose the residuals.

3.4.1. Cross-section Dependence Test

Deviation from independent and identically distributed (i.i.d) errors could result from the contemporaneous correlation of errors across units, particularly to long panels (Baltagi, 2008):

$$E(e_{it}e_{jt}) \neq 0 \ \ for\ i \neq j$$

The objective of the cross-sectional dependence test is to ascertain whether there is a correlation between the residuals of observations from different entities within the same period. To investigate the presence of cross-sectional dependence, the Breusch-Pagan LM test was employed. This test is particularly suitable for cases where the number of entities N is small as period T approaches infinity, $T \rightarrow \infty$ (Baum, 2001). The test aims to assess the null hypothesis that the correlation matrix of residuals, computed using observations common to all cross-sectional units, is an identity matrix of order N. This implies that the error terms are not correlated across entities.

3.4.2. Heteroskedasticity Test

Heteroskedasticity is the situation of having the variance in the error terms differ across observation (Ashenfelter et al., 2003). Particularly, for panel datasets, the variation among cross-sectional units of data can vary. One reason for this is the differences in the scale of the dependent variables across units. To address the problem, Modified Wald test was conducted to identify whether there is group-wise heteroskedasticity within the residuals of the fixed effects regression (Baum, 2001). Under null hypothesis, variance of the error is the same for all individuals: $\sigma_i^2 = \sigma^2$ where $\forall\ i = 1, \ldots, N$.

3.4.3. Serial Correlation Test

Serial correlation occurs when the errors in the regression model are correlated with each other (Ashenfelter et al., 2003). When there is existence of serial correlation, the standard errors tend to be overly optimistic. To examine the issue, Wooldridge test was conducted where the null hypothesis assumes no first-order autocorrelation (Wooldridge, 2010). If serial correlation is detected, the correlation can be accounted for by replacing individual identity matrices with more general structures in the diagonal elements of the Ω matrix.

Earlier research has shown that when heteroskedasticity and autocorrelation are present, assuming homoskedasticity disturbance and disregarding serial correlation will yield regression coefficient estimates that are consistent, however inefficient. Such diagnostic tests are important to avoid bias in the standard errors and ensure efficiency of the result. Therefore, by applying these tests, the study enables to ensure proper estimation and non-spurious regression when estimation is freed from heteroskedasticity and serial correlation.

3.5. Estimation Issues

This study deals with long panel where time periods (T =33) are more numerous than the cross-sectional unit (N =8). Therefore, the dataset is temporal dominant and characterized as N is fixed, $T \rightarrow \infty$. Since T is relatively larger than N, the asymptotic behind correct functioning of robust and cluster options are violated (Cameron & Trivedi, 2009). Hence, long panels will not be able to rely on the option methods and require putting some structure on any assumed error process. Besides, if there is evidence from diagnostic tests that the panel data is facing the problems of heteroscedasticity, autocorrelation and cross-sectional dependence, there is a need to consider on other estimation such as the Feasible Generalized Least Square (FGLS) (Beck & Katz, 1995; Greene, 2012). Disregarding the problems will cause disturbance and rules out the simple random effects and fixed effects estimators.

The FGLS estimator, which is a variation of GLS for panel data models can be employed to counter such problems. FGLS is a weighted least squares estimator, specifying a transformed model that satisfies all the assumptions of classical Ordinary Least Square. It utilizes an estimated variance-covariance matrix $\widehat{\Omega}$, replacing Ω in the text formula, to obtain unbiased estimates of β coefficient under general conditions (Greene, 2012). The FGLS results are given by:

$$\hat{\beta}_{FGLS} = (X'\widehat{\Omega}^{-1}X)^{-1}X'\widehat{\Omega}^{-1}Y$$

Where $\widehat{\Omega}$ is use as an estimated matrix, known as the feasible (or, estimable) generalized least square. $\widehat{\Omega} = \widehat{\Omega}(\theta)$ is a parametric estimation of the true unknown matrix Ω. While the variance-covariance matrix of estimates for the FGLS estimator can be interpreted as:

$$\widehat{Var}(\hat{\beta}_{FGLS}) = (X'\widehat{\Omega}^{-1}X)^{-1}$$

Chapter 4. Data

4.0. Introduction

This chapter will be structured into four sections. The first section will focus on the data utilized for the study, followed by the second section, which will present the measurement of key variables. The third section will discuss the results of the multicollinearity test. Lastly, the final section will provide an overview of the descriptive statistics.

4.1. Data

The study was conducted involving developing countries in Southeast Asia, such as Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Thailand, and Vietnam. To investigate the determinants of crop diversification in these countries over a period of 33 years, time series secondary data from 1988 to 2020 was being used. Table 1 provides a summary of the sources and data used in this study.

Student package (software) STATA/SE 17.0 was used to estimate the calculation. The specification of variables, units and description is tabulated in Table 2. Explanatory variables used in this study include technological input (fertilizer consumption and irrigated cropland area), climatic factors (temperature and rainfall), productivity of food and non-food crops, socioeconomics factors (income and cropland area, arable land per rural capita), and crop export activity.

After checking on the distribution of these variables, variables such as fertilizer consumption, Crop Export Index, and Gross National Income were transformed to their natural log to make them more normally distributed.

Table 1: Sources of Data

Data	Sources
Area of harvested crops	FAOSTAT
Yield of crops	FAOSTAT
Arable land	FAOSTAT
Cropland	FAOSTAT
Area equipped for irrigation	FAOSTAT
Rural population	FAOSTAT
Fertilizer consumption	International Fertilizer Association (IFA)
Export of crops commodities	UN Comtrade
Temperature	Climate Change Knowledge Portal
Rainfall	Climate Change Knowledge Portal
Gross National Income	World Bank

Table 2: Specification and Description of Variables

Variable	Identification	Unit	Description
Crop Diversification Index	CDI		Index of crop diversification, 0 to 1.
Fertilizer Consumption	LNFER	Kg/Hectare	Total N, P_2O_5, K_2O nutrients from inorganic fertilizers and N from organic fertilizers applied to cropland area.
Irrigation	IRRIG	Percentage (%)	Share of land area proportion of cropland area equipped for irrigation.
Temperature	TEMP	Degree Celsius (°C)	Average temperature.
Rainfall	RAIN	mm/year	Precipitation millimeter per year.
Food Crop Yield Index	FCY	Percentage (%)	Productivity of food crop yield.
Non-Food Crop Yield Index	NFCY	Percentage (%)	Productivity of non-food crop yield.
Gross National Income	LNGNI	US Dollar (US$)	Total income earned by country's residents, including both domestic and foreign income.
Cropland Area	CL	Percentage (%)	Share of cropland area from total agriculture land.
Arable Land	ALRU	Hectare/Person	Size of land area per capita of rural population.
Crop Export Index	LNEXP		Index of export concentration, 0 to 1.

4.2. Measurement of Key Variables

4.2.1. Crop diversification index

The magnitude of crop diversification is typically measured through different statistical methods. For instance, there are Entropy Index, Jasbir Singh's method, Herfindahl Index (HI), or Bhatia's Method (Singh et al., 2022; Sonawane, More, Perke, et al., 2022). Each of these methods have their own strengths and weaknesses in terms of data needed, complexity, an ease of use and interpretation. However, the results are more or less very similar to each other.

In this study, to understand the extent of diversification in country level, Simpson's Diversification Index (SDI) was adopted following Parré and Chagas (2022) and Azad (2021), also similarly known as Transformed Herfindahl Index (Seng, 2014). This method is simple and measures the concentration or diversity that can be easily calculated from data on crop areas.

$$\text{CDI} = 1 - \sum_{i=1}^{N} {P_i}^2 \ , \qquad (4)$$

where $\sum_{i=1}^{N} {P_i}^2$ shows similarity with Herfindahl Index (HI), that is commonly used in economic concentration. P_i here is the land share of the i-th crop in total cropped area and i goes from $1, 2, \ldots, N$ total number of crops cultivated.[3] The resulting values range from 0 to 1, with 0 indicating low diversification and 1 indicating high

[3] See appendix A and B for the list of crops.

diversification. This index allows for easy interpretation and comparison across countries.

4.2.2. Share of Land Area Equipped with Irrigation in Cropland Area

The share is in percentage of land area equipped with irrigation[4] in cropland area for country n and year T is based on the calculation of :

$$Share\ of\ land\ area\ equipped\ with\ irrigation\ in\ cropland\ area_{(n,T)} =$$

$$\frac{Land\ area\ equipped\ with\ irrigation_{(n,T)}}{Cropland\ area_{(n,T)}} \times 100 \qquad (5)$$

Higher percentage of access to irrigation encourages development of the cropland area and is expected to have a positive impact on crop diversification. Therefore, this variable could be an important factor that contributes to the diversification of crop.

4.2.3. Food and Non-Food Crop Yield Index

Index was created to investigate the impact of the food and non-food crop yield grown at country level. Equation 6 shows the ratio of actual yield per hectare over potential yield per hectare for each

[4] "Land area equipped with irrigation" per defined by FAOSTAT is area that equipped with irrigation infrastructure and equipment to provide water to crops, which are in working order. The equipment does not have to be used during reference year. The area equipped for irrigation covers areas equipped for fully controlled irrigation by any of the methods of surface, sprinkler or localized irrigation. It also includes areas under partially controlled irrigation methods of spate irrigation (controlling flood waters to water crops), equipped wetlands and inland valley bottoms and equipped flood recession. It excludes manual watering of plants using buckets, watering cans or other devices.

crop in that locality. The index, which is measured in percentages, was computed, and discussed as follows:

$$\text{Production efficiency } (\text{P.F.}_{\cdot i}) = \frac{Y_i}{\text{P.Y.}_{\cdot i}} \times 100, \quad (6)$$

$$\text{Crop Yield Index} = \frac{\sum_{i=0}^{n}(\text{P.F.}_{\cdot i} \times A_i)}{\sum_{i=0}^{n} A_i}, \quad (7)$$

where $\text{P.F.}_{\cdot i}$ denotes production efficiency of the i−th crop, while Y_i denotes the actual yield per hectare of the i−th crop in the country. $\text{P.Y.}_{\cdot i}$ indicates the potential yield per hectare of the i−th crop in the country. The maximum amount of yield across 33 years was used as the crops potential yield. A_i in the index represents the area of land used to cultivate the i−th crop. Improving yields for both categories of crops have a bigger influence on the crop diversity index than increasing yields in monoculture systems.

4.2.4. Crop Export Index

Crop export index was generated from composite index. This index measures the concentration or dispersion of crop export, by combining multiple crop groups into a single value. Higher value indicates a more concentrated or unequal distribution of crop export group, while lower value suggests a more balanced and equally distributed among crop export groups. Crop export index defined as:

$$\text{Crop Export Index} = \frac{\sum_{i=1}^{n} {E_i}^2}{{E_t}^2} \quad (8)$$

where E_i is the export value of crop groups i−th and E_t is total export value for all crop groups exported.[5]

[5] See appendix C for the list of commodity crops.

4.3. Multicollinearity Test

In regression analysis, multicollinearity refers to a situation where two or more explanatory variables exhibit strong correlation, leading to a lack of uniqueness and independent information in the regression model. When variables are highly correlated, it can create challenges in accurately fitting and interpreting the regression model. The following table shows on result of correlation tests between all independent variables.

Table 3: Variance Inflation Factor for Inquiring Multicollinearity

Variable	VIF	1/VIF
LNFER	8.20	0.122
LNGNI	4.76	0.210
ALRU	4.57	0.219
RAIN	3.89	0.257
IRRIG	3.87	0.259
TEMP	2.62	0.382
NFCY	2.34	0.426
FCY	2.29	0.436
LNEXP	1.61	0.622
CL	1.57	0.635
Mean VIF		3.570

Source: Author's own calculation using STATA

Table 4: Multicollinearity Test

	LNFER	IRRIG	TEMP	RAIN	FCY	NFCY	LNGNI	CL	ALRU	LNEXP
LNFER	1.000									
IRRIG	0.357	1.000								
TEMP	0.091	−0.377	1.000							
RAIN	0.355	−0.519	0.116	1.000						
FCY	0.355	0.152	0.056	0.093	1.000					
NFCY	0.375	0.010	0.404	0.109	0.612	1.000				
LNGNI	0.588	−0.112	0.532	0.359	0.570	0.664	1.000			
CL	0.443	0.162	0.115	0.063	0.208	0.109	0.268	1.000		
ALRU	−0.654	−0.084	0.215	−0.593	−0.036	−0.009	−0.139	−0.055	1.000	
LNEXP	−0.378	−0.414	0.353	0.079	−0.308	−0.104	−0.104	−0.162	0.189	1.000

Source: Author's own calculation using STATA.

The result on Table 3 shows that mean VIF of 3.570, which was less than 10. Besides, Table 4 also shows that all the absolute values of the correlation coefficient did not exceed 0.80. Hence, the variables do not move in a systematic way enabling the study to separate the effect of one variable from another. Therefore, it confirmed the lack of multicollinearity between independent variables supporting that all variables are safe to be used in this study.

4.4. Descriptive Statistics

In Table 5, a summary of the descriptive statistics is presented. This panel data consists of observations for eight Southeast Asian countries over the period of 1988-2020. The study used 264 observations. Within standard deviation refers to a variable that varies over time on a specific individual, while the Between standard deviation is variation across individuals. It is important to distinguish between Within and Between standard deviation as they are two distinct concepts used as estimators in different contexts.

Firstly, the overall mean for crop diversification index (CDI) was 0.64 with overall minimum country index of 0.26 and overall maximum of 0.85. The standard deviation shows that the CDI variation Between countries was 0.15 which was larger than Within countries variation across time, 0.06.

Next, the overall mean of fertilizer consumption (FER) was 107.05 kg/ha. The overall standard deviation was 82.97, and it shows that Between country variation was much larger than Within country variation, which were 81.72 and 31.90 respectively. Overall maximum and overall minimum were 307.00 kg/ha and 11.64 kg/ha. The Within country minimum was 22.43 kg/ha with a negative sign which indicates the existence of individual observations Within each country that were below the overall minimum value. While the overall mean for cropland area covered with irrigation (IRRIG) was 19.34%. The overall standard deviation, overall minimum and overall maximum were 12.32, 5.28% and 48.67% accordingly. The Between country variation, 12.80, was much larger than Within country variation, 2.81.

The overall mean for average temperature (TEMP) and average rainfall (RAIN) were 25.67°C and 2183.20 mm/year respectively. Particularly for TEMP, the overall standard deviation was 1.25 while, the Between country variance was larger than the Within country variance for about 1.0. The standard deviation for RAIN in Between countries, 526.47 was larger than Within countries, 233.35. The overall minimums for TEMP and RAIN were 23.25°C and 1299.84 mm/year, respectively. While their overall maximums were 28.04°C and 3580.21 mm/year.

The overall mean for both food (FCY) and non-food crops (NFCY) yield index were 76.33% and 74.47%, with overall standard deviations of 13.69 and 16.69 respectively. Besides, the Within country variances for FCY and NFCY were 13.12 and 14.74 respectively. The range of productivity for both crops had slight differences, where the overall of FCY fell in the range of 41.87% to 98.64% compared to NFCY, which was 32.32% to 98.89%.

The overall mean, minimum and maximum of Gross National Income (GNI) were $2066.89, $40.00, and $10960.00, respectively. The Between country of GNI fell in the range of $473.93 to $6129.39. While the minimum GNI for Within country was $1852.20 with negative sign, indicating on existence of observation Within each country that was below the overall minimum value. Besides, the maximum of Within country was $6897.50. The results for share of cropland area from total agriculture land (CL) shows overall mean of 85.85%. While the overall standard deviation, overall minimum and overall maximum of cropland were 12.62, 51.51% and 97.63% respectively. The CL variation for Within country was 3.61, smaller than Between country, 12.91. The difference between maximum for both Between and Within country were almost the same. While the minimum share of CL of Between country was 61%, lower than Within country, which was 76.36%. Moreover, the overall mean for arable land per rural capita (ALRU) was 0.23 ha/person. The standard deviation for Between country was 0.12 which was larger than Within country, 0.03. The overall ALRU fell into the range of 0.09 to 0.50 ha/person.

Meanwhile the overall mean for the crop export index (EXP) was 0.43. The standard deviation, minimum and maximum for overall were 0.13, 0.21 and 0.95 accordingly. Variance of EXP for Within country, 0.11, was larger than the Between country, 0.08. Besides, the maximum for Within country, 0.88 was larger than Between country, 0.61.

The FER, GNI, and EXP in Table 5 were also described with log transformation as LNFER, LNGNI and LNEXP. Therefore, the interpretation of mean, for instance, indicates the average growth rate multiplicative factor rather than simple average. Likewise, their standard deviation values were therefore interpreted as coefficient of variation. A higher standard deviation indicates greater relative variability.

Table 5: Descriptive Statistics

Variable		Mean	Std. dev.	Min	Max
CDI	overall	0.64	0.15	0.26	0.85
	between		0.15	0.36	0.83
	within		0.06	0.49	0.79
FER	overall	107.05	82.97	11.64	307.00
	between		81.72	27.33	240.11
	within		31.90	-22.42	188.82
LNFER	overall	4.35	0.83	2.45	5.72
	between		0.82	3.19	5.43
	within		0.29	3.61	5.38
IRRIG	overall	19.34	12.32	5.28	48.67
	between		12.80	5.46	45.07
	within		2.81	11.22	29.21
TEMP	overall	25.67	1.25	23.25	28.04
	between		1.30	23.78	27.41
	within		0.28	24.94	26.42
RAIN	overall	2183.20	545.80	1299.84	3580.21
	between		526.47	1590.31	2983.87
	within		233.35	1503.66	3311.34
FCY	overall	76.33	13.69	41.87	98.64
	between		4.16	68.67	82.13
	within		13.12	47.24	104.18
NFCY	overall	74.47	16.69	32.32	98.89
	between		8.35	60.21	82.98
	within		14.74	41.80	107.06

Variable		Mean	Std. dev.	Min	Max
GNI	overall	2066.89	2305.64	40.00	10960.00
	between		1903.85	473.93	6129.39
	within		1460.27	-1852.50	6897.50
LNGNI	overall	7.01	1.22	3.68	9.30
	between		1.00	5.49	8.59
	within		0.79	5.17	8.74
CL	overall	85.85	12.62	51.51	97.63
	between		12.91	61.00	96.97
	within		3.61	76.36	95.91
ALRU	overall	0.23	0.12	0.09	0.50
	between		0.12	0.10	0.41
	within		0.03	0.16	0.36
EXP	overall	0.43	0.13	0.21	0.95
	between		0.08	0.32	0.61
	within		0.11	0.19	0.88
LNEXP	overall	0.35	0.09	0.19	0.67
	between		0.05	0.27	0.47
	within		0.07	0.20	0.64

Observations= 264, N = 8 and T =33.

Chapter 5. Findings and Discussion

5.0. Introduction

This chapter will be divided into four sections. Firstly, a discussion will be conducted on the key variables used in this study. In the second section, the results of fitting and evaluating the appropriate model will be presented. The tested models were the pooled OLS model and the random effects model. Moving on to the third section, the discussion will focus on the results of diagnostic tests conducted to control for the fixed effects model. These tests examined cross-sectional dependence, heteroskedasticity, and serial correlation (autocorrelation). Lastly, the fourth section will address the results pertaining to the determinants of crop diversification in Southeast Asia.

5.1. Key Variables

5.1.1. Trends of Crop Diversification in Southeast Asian Countries

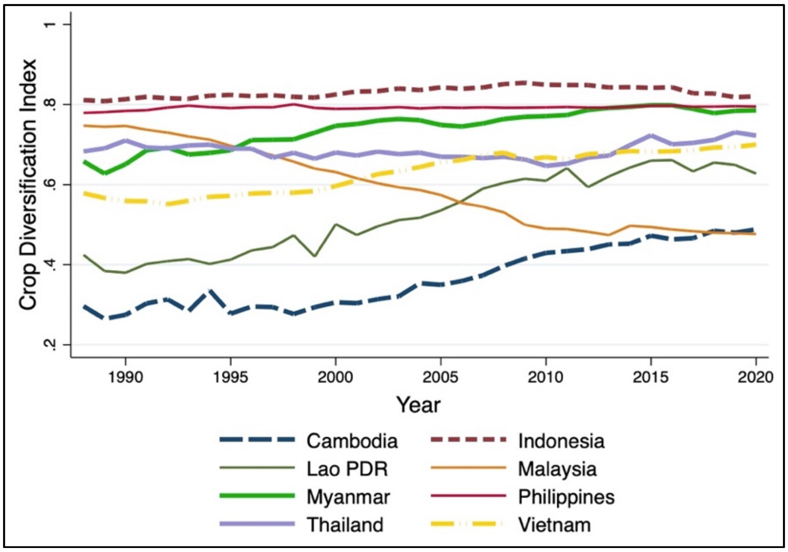
In this section, the trend in area of various crop sub-sectors using equation 4 was measured at the national level. Figure 4 presents on the country-wise crop diversification index under different crops[6] from year 1988 to 2020.

In this indexing, all crops (sub-groups) available from FAOSTAT were included as the weightage of diversification. CDI, or

[6] See appendix D for details.

crop diversification index, ranges from 0 to 1. Diversification on country level, in this sense, defined by the allocation of hectarage areas among crops. In other words, a CDI of which closer to 1 means that, one country is closer to a complete equal acreage allocation of all crops in the country. Therefore, CDI of 1 is a state of complete crop diversification. When one country shows transition from CDI of 1 to 0, it explains that there existed some shifting from diversifying system to specifying monocropping. Contrarily, when the CDI goes from 0 to 1, one country has undergone agricultural transformation towards diversifying.

Figure 4: Crop Diversification Index in Southeast Asia (1988-2020)



Source: Author's own calculation with data from FAOSTAT

It reveals that crop diversification in Southeast Asian countries have different trends; increasing, decreasing and constant. CDI of countries like Cambodia and Laos had gradually increased from early

1990s. Meanwhile, Myanmar and Vietnam, had an increasing trend but at a slower rate and with more diversification compared to Cambodia and Laos. Both Philippines and Indonesia show almost constant trend during the period of 33 years. However, at the same period, Malaysia had a drastic shifting from diversification to specializing on only certain crops. During the whole period, Indonesia was the most crop diversified country in Southeast Asia, followed by the Philippines.

5.1.2. Technological factors (Fertilizer consumption and Irrigated Cropland Area)[7]

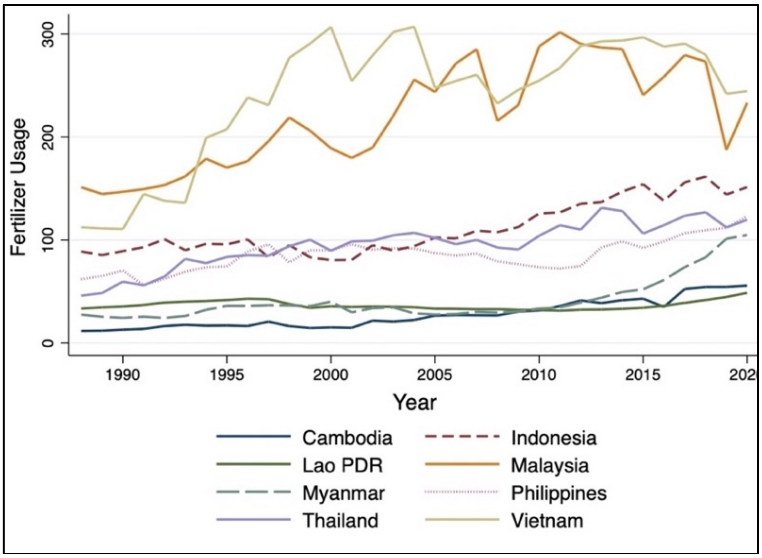
Figure 5 shows that Vietnam and Malaysia had the highest consumption of fertilizer (inorganic N, P_2O_5, and K_2O and organic N) per hectare of cropland area from 1988 to 2020. Both countries show high variance of fertilizer consumption across period. Contrarily, Cambodia was the lowest fertilizer consumer among all countries since early 1990 and surpassed Lao PDR in year 2010. On the same year, Myanmar showed an increasing fertilizer consumption until 2020. Lao PDR almost had constant trend of fertilizer consumption during the whole period. Moreover, fertilizer consumption in Indonesia, Thailand and the Philippines fell into ranges of 46.00 to 162.00 kg/ha over the period.

Next on Figure 6, it shows that cropland area in Vietnam had

[7] See appendix E and F for details.

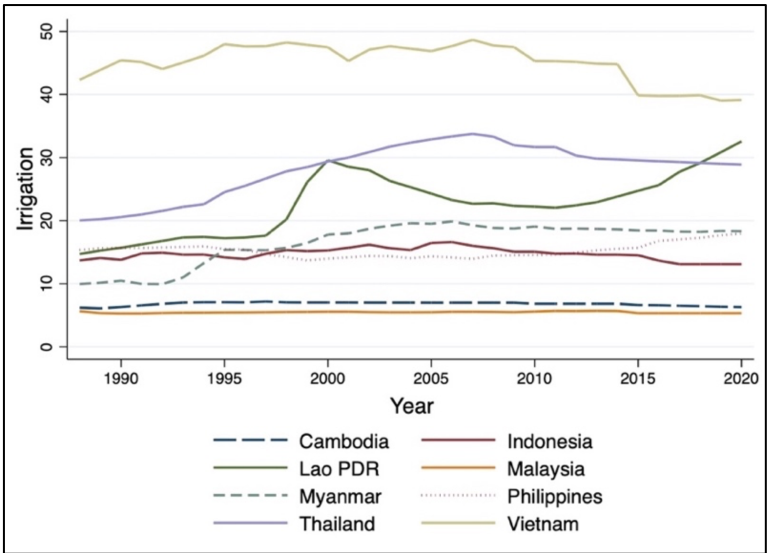
the highest proportion of irrigated cropland area compared to other countries, ranging from 39% to 48% during the period. Followed by Thailand that showed an increasing trend from 1988 reaching a maximum of 33.76% of irrigated cropland in 2007 and gradually decreasing towards 2020. Besides, Lao PDR at the third place, interestingly had a drastic increasing trend during period of year 1997 to 2000 and sudden drop until year 2013. Overall, majority of cropland areas in Southeast Asian countries are still lacking with technological input for irrigation. As shown, cropland area in Myanmar, Indonesia, the Philippines, Cambodia, and Malaysia in average were still less than 20% occupied with irrigation throughout 33 years.

Figure 5: Fertilizers applied to cropland area (Kg/Hectare)



Source: FAOSTAT

Figure 6: Share of land area proportion of cropland area equipped for irrigation (%)



Source: FAOSTAT

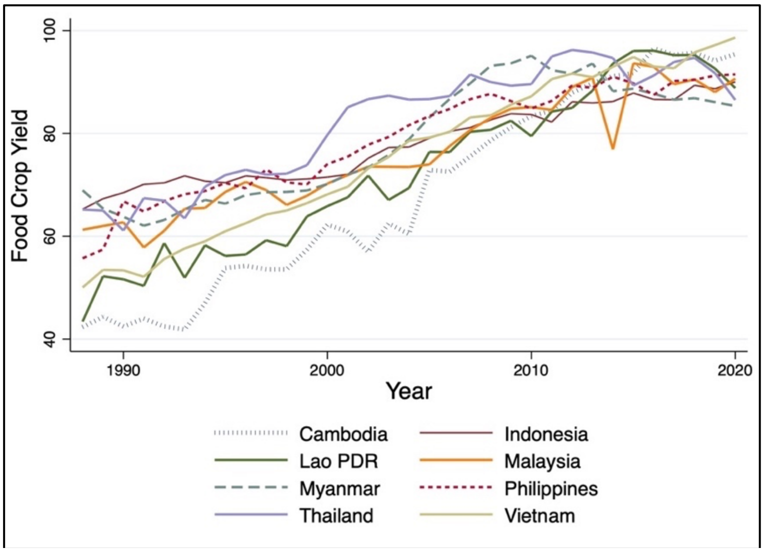
5.1.3. Climatic Factors (Average temperature and average rainfall)

Countries like Myanmar, Lao PDR, and Vietnam in general have lower average temperature compared to the other countries, which was below 25 °C. Meanwhile, for countries like Cambodia, Indonesia, Malaysia, the Philippines, and Thailand in average were in the ranges of 2.5°C to 28°C of temperatures. Across 33 years, there had been fluctuations and increasing trend of average temperature in all countries. Besides that, average rainfall for countries like Indonesia, Malaysia and the Philippines received more rainfall than the rest of the countries in the observed period of the study. The detailed data on average temperature and average rainfall in Southeast Asian countries can be found at the appendix.

5.1.4. Food Crop and Non-Food Crop Yield Index

Based on the indexing calculated using equation 6 and 7, Figure 7 shows the overview of productivity in food crop yield in Southeast Asian countries. As portrayed, all countries had an increasing trend of producing food crop yield. While Cambodia had the lowest productivity since early 1990s, for about 40%. However, the country managed to increase its food yield surpassing other countries reaching to end of 2020.

Figure 7: Food Crop Yield Index (%)



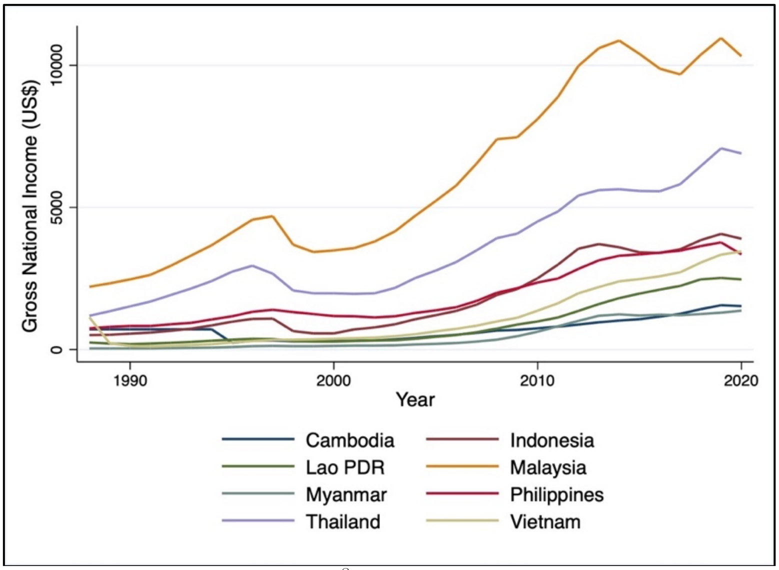
Source: Author's own calculation with data from FAOSTAT

The production of non-food crop yield of all countries showed inconsistent fluctuations in 33 years. Despite that, across time, all countries increased on their non-food crop yield except for the Philippines. The non-food crop yield index of the Philippines has tremendously declined, about 30% from year 2004 to 2020. While, Myanmar had the lowest productivity on yield of non-food crops compared to other countries since earlier 1990s. Nevertheless, the country increased its non-food crop yield almost 50% beginning from year 2000 towards 2015.

5.1.5. Gross National Income

As pictured in Figure 8, Malaysia has the highest GNI throughout the period, followed by Thailand. From late 1990s to 2016, third place alternately fell between Indonesia and the Philippines. Although, Malaysia and Thailand made a significant improvement in GNI throughout 33 years, countries like Myanmar, Cambodia, Lao PDR, and Vietnam had lower GNI in early 1990s and slowly progressing beginning from 2010.

Figure 8: Gross National Income (US$)



Source: WorldBank (2023)[8]

[8] Due to the limitation of data available, some missing data points were replaced by data measured using mean imputation.

5.1.6. Share of cropland area from total agriculture land

In general, the share of cropland area over agricultural area in all countries did not change much across the periods. Countries like Myanmar, Vietnam, Malaysia, and Thailand utilized above 90% of their agriculture land for cropland production. While since the 1990s, Lao PDR only used half of its agriculture land for area to farm crops. However, beginning from late 1990s, Lao PDR had expanded its crop land area until 2013 and later cropland area was slowly converted to other sector utilization. Contrarily, in Cambodia, the share of cropland area among agricultural land was declining slowly throughout 33 years and a drastic decline of almost 10% cropland share occurred around year 1999 to 2004.

5.1.7. Arable Land per Rural Capita

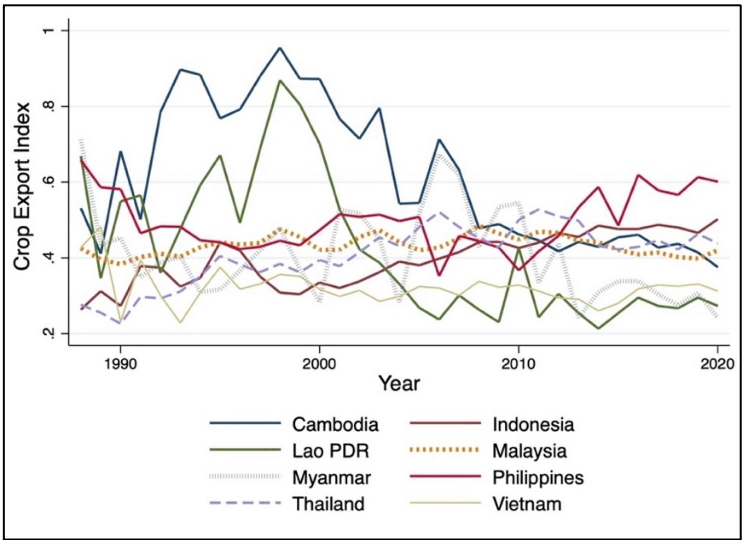
The size of arable land per rural capita in Cambodia has been decreasing throughout the period. While in Thailand, it decreased from 1988 to the early 2000s and increased towards 2020. Both Cambodia and Thailand had arable land size per rural capita ranges from 0.3 to 0.5 hectare, which were higher among other countries. While Myanmar had constant trend almost about 0.3 hectare of arable land size per rural capita across 33 years. The same constant trend with Malaysia and Vietnam, however smaller size of arable land per rural capita of about 0.1 hectare. Lao PDR had about 0.2 hectare per rural capita and had increasing trend to almost 0.35 hectare until year 2015, and consequently shows a decreasing trend. Across 33 years, the

Philippines' arable land size per rural capita ranges from 0.16 to 0.09 hectare and it had a decreasing trend.

5.1.8. Crop Export Index

As shown, crop export index was widely varied across countries. Higher index means higher concentration of crop exported on specific crops. Country such as Cambodia had an obvious concentration of export towards some crops only especially on commodities such as rubbers and oil seeds.[9] The huge concentration lasted for almost 2 decades and Cambodia slowly diversified its crops towards 2010. Same case with Lao PDR, around mid-1990s to mid-2000s, the country was focusing on exporting only crops like coffee, tea, mate, and spices. While Vietnam showed that there was diversification of crop products exported throughout the period.

Figure 9: Crop Export Index



Source: Author's calculation with data from FAOSTAT

[9] See appendix C: Commodities HS12 and HS40.

5.2. Model Fitting and Checking

5.2.1. Pooled Regression Model

The first step before applying panel data regression is to eliminate the effects of entity and time and conduct a pooled regression instead. An OLS regression is used to examine how the independent variables affect the dependent variable, without considering the cross-sectional and time series nature of the data. To ensure that the results of the pooled regression are suitable for the panel dataset, it is important to verify that the countries' dummies do not have joint effects on the results. If there are any joint effects, it means that the estimates from the pooled regressions are not reliable.

Table 6: Wald Test for Joint Significance

H_0: Entity dummies are jointly equal to 0	
F (7,246)	165.45
Prob > F	<0.0001

Source: Author's own calculation using STATA

Under this test, null hypothesis suggested that the joint effects of all dummies are zero, portraying that, any variations in data caused by the differences of each country do not influence this model. In fact, null hypothesis was rejected as the result shows that P-value was highly significant, confirming that pooled regression is not free from joint effects of the entity dummies.

From the result in Table 6, pooled regression technique is not considered suitable estimator for this dataset, leading to a preference for either fixed or random effects panel data regression. In the estimation result of Table 12, Least Square Dummy Variable (LSDV1) controlled for entity dummies was included. Next, diagnostic tools were applied to both random effect and fixed effect as to determine the appropriate model for this study using the panel data approach.

5.2.2. Random Effects Model

In random effects model, which is also known as the Error component model, the mean values of cross-sectional intercepts are represented by the intercepts in the regression equation. Conversely, the error terms represent random deviations of individual intercepts from the mean value. Consequently, the effects of the eight countries are internalized as random effects in the regression equation. The presence of unequal error variances and potential heteroskedasticity is addressed using the Breusch and Pagan Lagrange Multiplier test.

Table 7: Test for Random Effects

Breusch and Pagan Lagrangian multiplier test for random effects		
cdi[id,t] = Xb + u[id] + e[id,t]		
Estimated results:		
	Var	SD = sqrt (Var)
cdi	0.024	0.155
e	0.002	0.048
u	0	0
Test: Var(u) = 0		
chibar2(01) = 0.00		
Prob > chibar2 = 1.000		

Source: Author's own calculation using STATA

The test is implemented by using command xttest0 in STATA serving to identify the presence of heteroskedasticity. In Table 7, the finding indicates that the null hypothesis could not be rejected, suggesting the absence of random effects in the data. Hence, the random effects model does not significantly address heterogeneity better than the pooled OLS. Consequently, random effects model cannot be applied in the study.

Moreover, Hausman test was also conducted to check on the reliability between random and fixed effects and the result shows that P-value is less than 0.05, manifests that the two models are different enough to reject the null hypothesis.

Table 8: Hausman Specification Test

H_0: Difference in coefficient not systematic	
	Coef.
Chi-square test value	208.68
P-value	<0.0001

Source: Author's own calculation using STATA

Due to the presence of joint effects of dummies in the pooled regression and the random effects model's inability to significantly handle heterogeneity, along with significant increase in the goodness of fit observed in the fixed effects model compared to the other, the fixed effects model is superior to both the pooled OLS and the random effects model. Hence the effects are fixed, and the regression model should be entity fixed effects model.

5.3. Diagnostic Tests for Fixed Effects Model

The fixed effects regression model is employed when there is a need to control for omitted variables that differ between cases but remain constant over time. In fixed effects model, each of eight countries is allowed to have its own intercept value, reflecting heterogeneity or individuality, while ensuring that the intercepts remain unchanged over time. After verifying that the fixed effects model is suitable for further analysis, the presence of cross-sectional dependence, heteroskedasticity, and serial correlation was examined.

5.3.1. Cross-sectional Dependence Test

As discussed at Section 3.4., to ensure a consistent and efficient estimator, this thesis controlled for diagnostic tests such as cross-sectional dependence, heteroskedasticity, and serial correlation. These tests are advised as to avoid bias in the standard errors and less efficiency in the results.

Table 9: Cross-Sectional Dependence Test

Cross-sectional Dependence Breusch-Pagan (P-value)	
H_0 : No cross-sectional dependence	
chi2(28)	130.76
Prob	<0.0001

Source: Author's own calculation using STATA

The study applied Breusch-Pagan's cross-sectional dependence test, the results of which are presented in Table 9. The test rejected the null hypothesis of no cross-sectional dependence with P-value significant at 1% confidence level, therefore indicating the existence of cross-sectional dependence.

5.3.2. Heteroskedasticity Test

Table 10: Heteroskedasticity Test

Modified Wald test for groupwise heteroskedasticity in fixed effect regression model	
H_0 : sigma(i)^2 = sigma^2 for all i	
chi2 (8)	2073.60
Prob>chi2	<0.0001

Source: Author's own calculation using STATA

Moreover, Table 10 provides on the result for heteroskedasticity tested using Modified Wald Test. The test shows a rejection of null hypothesis with P-value is highly significant at 1% confidence level. Hence, there exists a problem of heteroskedasticity.

5.3.3. Autocorrelation Test

Table 11: Autocorrelation Test

Wooldridge test for autocorrelation in panel data	
H_0 : No first order autocorrelation	
F (1,7)	4.08
Prob > F	0.0829

Source: Author's own calculation using STATA

For autocorrelation test, the study employed Wooldridge serial correlation test. The result shows a P-value of larger than 0.05, indicating that null hypothesis was failed to be rejected. This validated the absence of first order autocorrelation in the panel data.

To conclude on the diagnostic tests, it was observed that there existed problems of both heteroskedasticity and cross-sectional dependence in the panel results, however there was no autocorrelation problem. As mentioned on previous section, the presence of such problems will rule out fixed effects estimator alone. Hence, a remedial measure using FGLS estimation with entities fixed effects was used to analyze the result again. FGLS allows for estimation in the presence of cross-sectional correlation and heteroskedasticity across panels.

5.4. Determinants of Crop Diversification

As previously mentioned, the FGLS estimator on fixed entities was applied, considering the problem of heteroskedasticity and cross-sectional dependence across panels. Hence, the result of FGLS estimation will be discussed in this section. Table 12 presents the result of FGLS estimator on fixed entities, together with LSDV1 and fixed effects regression.

The findings from this estimation revealed notable differences compared to the other estimations in their standard errors and level of significancy. FGLS estimation considers the problems in the error terms by estimating a more appropriate variance-covariance matrix. This allows entities' fixed effect FGLS to provide more efficient and consistent estimate compared to LSDV1 and Fixed Effects models.

The table shows that each country has its own coefficient, which represents the average difference in the CDI between that country and the reference country (in this case, Cambodia). The coefficient provides an estimate of the effect of that specific country on the dependent variable, while holding other independent variables constant. FGLS estimation shows that all countries' coefficients are statistically significant, suggesting that country-specific effect is unlikely to have occurred by chance and provides evidence of a meaningful relation between the country and dependent variable.

Table 12: Estimation Results

Variables	LSDV1	Fixed Effects	FGLS with Fixed Effects
LNFER	-0.0315 (0.017)	-0.0314 (0.017)	**-0.0235***** **(0.005)**
IRRIG	0.0021 (0.001)	0.0021 (0.001)	**0.0011**** **(0.000)**
TEMP	0.0032 (0.012)	0.0031 (0.012)	0.0027 (0.004)
RAIN	-0.00002 (0.000)	-0.00002 (0.000)	-6.16E-06 (0.000)
FCY	0.0007 (0.000)	0.0007 (0.000)	**0.0008***** **(0.000)**
NFCY	**0.0008***** **(0.000)**	**0.0008***** **(0.000)**	**0.0004***** **(0.000)**
LNGNI	0.0110 (0.008)	0.0109 (0.008)	**0.0121***** **(0.002)**
CL	0.0021 (0.001)	0.0021 (0.001)	0.0011 (0.000)
ALRU	-0.2177 (0.159)	-0.2176 (0.154)	**-0.1312**** **(0.055)**
LNEXP	**-0.3029***** **(0.043)**	**-0.3029***** **(0.043)**	**-0.1906***** **(0.019)**
Countries (Reference: Cambodia)			
Indonesia	**0.4248***** **(0.042)**	-	**0.4321***** **(0.016)**
Lao PDR	**0.1340**** **(0.051)**	-	**0.1466***** **(0.019)**
Malaysia	**0.1690**** **(0.081)**	-	**0.1782***** **(0.038)**
Myanmar	**0.3077***** **(0.062)**	-	**0.3404***** **(0.025)**
Philippines	**0.3667***** **(0.058)**	-	**0.3816***** **(0.021)**
Thailand	**0.2149***** **(0.042)**	-	**0.2558***** **(0.015)**
Vietnam	0.1050 (0.085)	-	**0.1844***** **(0.031)**
Constant	0.2814 (0.349)	0.4967 (0.337)	**0.2460**** **(0.124)**
Observation	264	264	264
R-Squared	R^2 = 0.9102 Adjusted R^2 = 0.9040	Within R^2 = 0.4294 Between R^2 = 0.1186 Overall R^2 = 0.1674	Not Applicable
Model Significance	F(17, 246) = 146.68 Prob > F = 0.0000	F(10, 246) = 18.52 Prob > F = 0.0000	Waldχ^2(17) = 22086.65 Prob > χ^2 = 0.0000

Note: *** and ** indicates significant at 0.01 and 0.05 level.

From Table 12, the result shows that fertilizer consumption (LNFER) exhibits a negative relation with crop diversification, which is highly statistically significant at 1% confidence level. Specifically, a 1% increase in fertilizer consumption corresponds with a decrease in the crop diversification index by 0.0002. Hence, this indicates that less fertilizer being consumed is associated with more diversified crops. Moreover, the share of land area proportion of cropland area equipped for irrigation (IRRIG) shows a positive relation towards CDI, and it is statistically significant at the 5% confidence level. One unit of increase in cropland equipped with irrigation increases the crop diversification index by 0.0011. This finding highlights the importance of irrigation in crop diversification. Irrigation provides a reliable water supply to crops, allowing farmers to cultivate a wider range of crops and potentially increase their yields. With irrigation, farmers have more flexibility in choosing crops that are suited to different water requirements, growing seasons, and market demands. Thus, this can lead to increased crop diversification as farmers are able to grow a variety of crops throughout the year.

For the climatic variables, average temperature (TEMP) is positively related towards CDI. However, it is important to note that this relationship is not statistically significant. One unit increase in average temperature decreases crop diversification index by 0.0027. Despite the lack of statistical significance, the positive relationship between average temperature and crop diversification is consistent with prior research (Huang et al., 2014; Ochieng et al., 2020) as a mean for climate risk adaptation, highlighting the potential challenges that global warming may pose to not only agricultural productivity but also diversity. Moreover, average rainfall (RAIN) has a negative relation towards crop diversification, although this result is not statistically significant. The result indicates that an increase of one unit in average rainfall is associated with a 0.000006 decrease in crop diversification index.

Besides, it is worth noting that FGLS estimation shows that food crop yield index (FCY) has a positive linkage with crop diversification index. The relation is statistically significant at 1% confidence level, whereby one unit increase in FCY increases crop diversification index by 0.0008. This finding is consistent with a study conducted by Singh et al. (2022), which supported the same positive relation. At the same time, non-food crop yield index (NFCY) also has a positive relation towards crop diversification and highly statistically significant at 1% confidence level. The result shows that when one unit of NCFY increases, it will increase CDI about 0.0004. From these results, it could be interpreted that higher yields in both food crops and non-food crops are associated to the increases of agricultural productivity and provides a foundation for diversifying crops.

Additionally, it is important to highlight that a variable of income (LNGNI) shows a positive relationship with CDI, indicating that a 1% increase in Gross National Income (GNI) is associated with 0.0001 increase in crop diversification index. This relation is highly statistically significant at 1% confidence level. The result indicates that when the per capita income increase, it enables consumer to afford a wider variety of crops and agricultural products. Income increase stimulates food demand, hence encouraging farmers to diversify their crops. Besides, with changes of increasing income, consumers seek for greater diversity in their diets prioritizing the nutrition and health benefits (French et al., 2019; Mottaleb et al., 2021).

Next, share of cropland area from total agricultural land (CL) exhibits positive relation with crop diversification index. The analysis reveals that a one unit increase in the cropland area over agriculture area is associated with a 0.0011 increase in crop diversification index. However, this relation is not statistically significant. Besides, the result shows that an increase in one unit of arable land per capita of rural population (ALRU) is associated with the decrease of about 0.1312 in crop diversification index. This is highly statistically significant at 1% confidence level. When one individual has a larger arable land, specialization will be more efficient in managing the farm. Besides, small arable land is more significant for those who cultivate crops and diversify, to meet their necessary food needs.

The result of the estimation also indicate that agriculture export (LNEXP) has a statistically significant negative relation with crop diversification index at the 1% confidence level. Specifically, the coefficient estimate suggests that a 1% increase in the concentration of exporting a specific type of crop only is associated with a decrease in crop diversification index by 0.0019. When a country focuses on exporting a single crop, there may be less incentive for farmers to grow different type of crops. The allocation of resources and efforts towards maximizing the production and quality of the specific crop for export restrict farmers from diversifying on agricultural activities (Delgado, 1995).

Chapter 6. Conclusion

6.1. Summary of the findings

The purpose of this study was to examine the factors related to crop diversification in eight Southeast Asian countries. Based on the estimation of a Fixed Effects FGLS model with country dummies, the findings indicate that an increase in fertilizer consumption is associated with less crop diversification. Conversely, larger cropland area equipped with irrigation systems positively related to the diversification of agricultural crops. Additionally, a higher average temperature has a positive relation with crop diversification, while average rainfall has a negative relation with crop diversification. However, neither average temperature nor average rainfall are statistically significant. Moreover, the productivity of both food and non-food crops is statistically significant and associated with more diversification of crops. Furthermore, an increase in income per capita and a larger proportion of crop land area over total agriculture area are associated with positive outcomes of crop diversification. However, a larger arable land per rural capita and specialization in a limited number of export-oriented crops were found to be relatively related to a low level of crop diversification.

In a nutshell, the findings of the FGLS model estimation, considering factors such as technological inputs like fertilizer consumption and irrigation, climate factors (temperature and rainfall), food and non-food crops yield productivity, socioeconomic factors (income, percentage of available cropland, arable land per rural capita) and exports activities are particularly relevant to the agricultural landscape and challenges faced in Southeast Asia. They provide insights into this region and can inform policy decisions aimed at promoting sustainable and diversified agricultural practices.

6.2. Policy Implications and Recommendations

Based on the findings, policymakers involved in Southeast Asian region can take several steps to promote crop diversification and address challenges. Firstly, the findings suggested that there is a need to look further on the consumption of fertilizer in the agricultural system. Policy aimed at promoting diversification can be employed, such as providing incentives and support to farmers who adopt crop diversification practices. For instances, offering incentives like fertilizer subsidies, along with expert guidance, could encourage farmers to cultivate on wider range of crops.

Moreover, the study highlights the importance of irrigation system in promoting crop diversification. Access to reliable water supply is crucial to grow a wider range of crops. This can be done by promoting efficient water use, investment in water infrastructure especially in regions with low water availability and prone to natural disaster such as floods. There is also a need to develop strategies on helping farmers in adapting to impact of climate change on water resources such as implementing water management strategies for changing rainfall patterns and risk management mechanism to protect farmers against climate-related risk.

Furthermore, the study recommends that the region should enhance both food and non-food crops yield to promote crop diversification. This can be done by improving agricultural practice such as the consumption of high-quality seeds, appropriate fertilization techniques, and integrated pest management. Moreover, to enhance the production, extension services should be strengthened. Farmers, especially those who live in very rural area should be reached out for knowledge dissemination and best practices related to improving crop yield. Enhancing food crops yields to promote crop diversification can contribute to improving food and nutrition security. This can be achieved by producing nutrient-rich crops to reduce the overreliance on staple crops that may not provide adequate nutrition. Besides enhancing on the yield, the adoption of sustainable farming practices should be highlighted as to minimize environmental impacts.

Other than that, given the constraint of limited available arable land per rural capita, a policy that can be considered based on the study includes focusing on maximizing crop diversification on the existing arable land in each country. Farmers at rural area should be trained and educated to focus on maximizing crop diversification. Measure such as diversifying by targeting on the nutritional needs of the people should be highlighted. Thereby, the increasing of land percentage dedicated to diverse crops will be able to reduce on dependency to only few staple crops for consumption.

Finally, given the negative relation of export concentration with crop diversification, it is recommended to implement policies that promote crop diversification in export-oriented agriculture. Policy measures on export diversification can be implemented. Export diversification can be encouraged by promoting the production and export of a wider range of agricultural products. For instance, farmers can be incentivized to grow diverse crops for export as well as developing value chains for diverse agricultural products to create market opportunity. Besides, farmers should be provided with market information, facilitating the market linkages and support value addition activities such as processing and packaging.

To conclude, the study suggests that applying and strengthening policies in agriculture focusing on fertilizer, water, crop productivity and crop export are important in Southeast Asian countries. With that, the region will be able to diversify more crops to cater on the needs of food security, by promoting more balance and nutritious diets.

6.3. Limitations and Future Research

Firstly, this study is limited by data availability. The diversification index could only be measured using the yield and cultivated crop data that are accessible from FAOSTAT. For instance, in the case of Indonesia, only the 60 available data points on crops over a span of 33 years were used to calculate the diversification index.

There may be crops that were not formally recorded and thus went unnoticed or unmeasured. Furthermore, there was a lack of export data in UN Comtrade for certain export data points. To address this issue, the missing export data were substituted with mirrored data from import records. This substitution allowed the utilization of world import data as a proxy. Additionally, the study encountered a few missing data points, which was addressed through data imputation. For instance, mean imputation was used to fill in the missing values GNI per capita data for Cambodia and Vietnam in the late 1980s. Mean imputation assumes that the missing values are random and not related to their true values. It is important to note that mean imputation helps to preserve the sample size, however this approach reduces data variability and underestimate the standard error.

The study faced challenges in classifying crops as either food or non-food group. These arose because certain crops, like coconut, have multiple uses in both food and non-food industries. Coconut, for instance, are utilized for producing cooking oil and milk, but they are also used in various non-food products. Determining the primary consumption of each crop in each country proved to be a complex task. However, to address this issue, the study relied on the general guideline provided by FAO.

Other than that, the estimation of potential crop yield in each country relied on the highest recorded yield observed during the 33-years period. However, it is crucial to acknowledge that this measurement does not encompass potential future yield. While methods exist for forecasting future yield, our study does not delve into such predictions. Consequently, the estimation of potential yield is confined to the available historical data, which limits its scope to observable patterns from the past.

Finally, the research was exercised in only static panel data analysis due to data availability challenges. Therefore, future study can be explored by using other advanced research methods and techniques such as the dynamic panel data analysis.

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Appendix

Appendix A: List of Food Crops

Groups	Sub-groups
Fruits and Nuts	Areca nuts
	Avocados
	Bananas
	Mangoes, guavas and mangosteens
	Other fruits, n.e.c.
	Watermelons
	Other tropical fruits, n.e.c.
	Papayas
	Pineapples
	Cashew nuts, in shell
	Other nuts (excluding wild edible nuts and groundnuts), in shell, n.e.c.
Pulses	Beans, dry
	Other pulses n.e.c.
Vegetables	Cabbages
	Cantaloupes and other melons
	Carrots and turnips
	Cauliflowers and broccoli
	Chillies and peppers, green (Capsicum spp. And Pimenta spp.)
	Cucumbers and gherkins
	Eggplants (aubergines)
	Green garlic
	Leeks and other alliaceous vegetables
	Onions and shallots, dry (excluding dehydrated)
	Other beans, green
	Tomatoes
	Spinach
	Other vegetables, fresh n.e.c.
	Pumpkins, squash and gourds

Appendix A. List of Food Crops (Cont.)

Groups	Sub-groups
Roots/Tubers	Cassava, fresh Edible roots and tubers with high starch or inulin content, n.e.c., fresh Sweet potatoes Potatoes
Stimulant, spices, and aromatic crops	Cinnamon and cinnamon-tree flowers, raw Cloves (whole stems), raw Ginger, raw Nutmeg, mace, cardamoms, raw Vanilla, raw Other stimulant, spice and aromatic crops, n.e.c. Pepper (Piper spp.), raw Cocoa beans Coffee, green Tea leaves
Cereals	Green corn (maize) Maize (corn) Rice
Sugar crops	Sugar cane Other sugar crops n.e.c.
Citrus	Oranges Grapefruits Tangerine

Appendix B: List of Non-food Crops

Group	Sub-groups
Industry crops	Natural rubber in primary forms
	Unmanufactured tobacco
Fibers	Abaca, manila hemp, raw
	Kapok fruit
	Kenaf, and other textile bast fibres, raw or retted
	Seed cotton, unginned
	Sisal, raw
Oil crops	Castor oil seeds
	Oil palm fruit
	Soya beans
	Coconuts, in shell
	Groundnuts, excluding shelled

Appendix C: List of Commodity Crop in Measuring Crop Export Index

UN Comtrade Code (HS)	Descriptions
07	Vegetables and certain roots and tubers; edible
08	Fruit and nuts, edible; peel of citrus fruits or melons
09	Coffee, tea, mate, and spices
10	Cereals
12	Oil seeds and oleaginous fruits; miscellaneous grains, seeds, and fruits, industrial or medicinal plants; straw and fodder
1507	Soya-bean oil and its fractions, whether or not refined, but not chemically modified
1508	Ground nut oil and its fractions; whether or not refined, but not chemically modified
1511	Palm oil and its fractions; whether or not refined, but not chemically modified
18	Cocoa and cocoa preparations
2401	Tobacco, unmanufactured; tobacco refuse
40	Rubber and articles thereof
53	Vegetable textiles fibres; paper yarn and woven fabrics of paper yarn

Appendix D: Crop Diversification Index

YEAR	CAMBODIA	INDONESIA	LAO PDR	MALAYSIA	MYANMAR	PHILIPPINES	THAILAND	VIETNAM
1988	0.29	0.81	0.42	0.75	0.66	0.78	0.68	0.58
1989	0.26	0.80	0.38	0.74	0.63	0.78	0.69	0.57
1990	0.27	0.81	0.38	0.75	0.65	0.78	0.71	0.56
1991	0.30	0.81	0.40	0.74	0.69	0.79	0.69	0.56
1992	0.31	0.81	0.41	0.73	0.69	0.79	0.69	0.55
1993	0.28	0.81	0.41	0.72	0.68	0.80	0.70	0.56
1994	0.33	0.82	0.40	0.71	0.68	0.79	0.70	0.57
1995	0.27	0.82	0.41	0.70	0.69	0.79	0.69	0.57
1996	0.29	0.82	0.44	0.69	0.71	0.79	0.69	0.58
1997	0.29	0.82	0.44	0.67	0.71	0.79	0.67	0.58
1998	0.27	0.82	0.47	0.66	0.71	0.80	0.68	0.58
1999	0.29	0.82	0.42	0.64	0.73	0.79	0.66	0.58
2000	0.30	0.83	0.50	0.63	0.75	0.79	0.68	0.60
2001	0.30	0.83	0.47	0.62	0.75	0.79	0.67	0.61
2002	0.31	0.83	0.50	0.60	0.76	0.79	0.68	0.63
2003	0.32	0.84	0.51	0.59	0.76	0.79	0.68	0.63
2004	0.35	0.84	0.52	0.59	0.76	0.79	0.68	0.64
2005	0.34	0.84	0.54	0.57	0.75	0.79	0.67	0.66
2006	0.35	0.84	0.56	0.55	0.75	0.79	0.67	0.66
2007	0.37	0.84	0.59	0.54	0.75	0.79	0.67	0.67
2008	0.39	0.85	0.60	0.53	0.76	0.79	0.67	0.68
2009	0.29	0.81	0.42	0.75	0.66	0.78	0.68	0.58
2010	0.26	0.80	0.38	0.74	0.63	0.78	0.69	0.57
2011	0.27	0.81	0.38	0.75	0.65	0.78	0.71	0.56
2012	0.30	0.81	0.40	0.74	0.69	0.79	0.69	0.56
2013	0.31	0.81	0.41	0.73	0.69	0.79	0.69	0.55
2014	0.28	0.81	0.41	0.72	0.68	0.80	0.70	0.56
2015	0.33	0.82	0.40	0.71	0.68	0.79	0.70	0.57
2016	0.27	0.82	0.41	0.70	0.69	0.79	0.69	0.57
2017	0.29	0.82	0.44	0.69	0.71	0.79	0.69	0.58
2018	0.29	0.82	0.44	0.67	0.71	0.79	0.67	0.58
2019	0.27	0.82	0.47	0.66	0.71	0.80	0.68	0.58
2020	0.29	0.82	0.42	0.64	0.73	0.79	0.66	0.58

Appendix E: Fertilizer Consumption (Kg/Hectare)

YEAR	CAMBODIA	INDONESIA	LAO PDR	MALAYSIA	MYANMAR	PHILIPPINES	THAILAND	VIETNAM
1988	11.64	88.79	33.49	151.22	27.54	61.90	46.00	112.29
1989	11.91	85.29	34.59	144.63	25.38	65.12	48.45	111.18
1990	12.91	89.06	35.36	146.72	24.38	70.38	59.55	110.64
1991	13.69	92.98	36.91	149.35	25.45	56.18	55.97	144.57
1992	16.39	100.81	39.18	153.29	24.25	62.43	64.43	138.00
1993	17.71	90.02	40.07	161.69	26.17	69.23	81.62	136.14
1994	16.83	96.32	40.61	178.82	32.20	73.49	77.55	199.13
1995	17.00	95.75	41.68	170.16	36.06	74.25	83.58	207.50
1996	16.48	100.54	42.90	176.54	35.96	88.82	85.29	238.39
1997	20.73	82.99	42.52	195.88	36.69	95.77	84.80	230.91
1998	16.33	94.93	37.73	218.86	36.52	78.33	93.93	276.94
1999	14.57	83.14	34.10	206.07	35.78	90.07	100.27	290.71
2000	15.14	80.47	35.54	189.01	40.09	89.90	89.56	306.78
2001	14.76	80.70	34.95	179.67	29.75	95.88	98.60	254.26
2002	21.66	94.90	35.34	189.64	33.86	90.50	99.31	279.16
2003	20.79	89.72	35.13	220.67	34.56	92.15	104.56	301.90
2004	22.32	94.02	34.71	255.66	28.72	91.67	106.87	307.00
2005	26.57	102.30	33.34	243.72	27.66	87.23	102.00	247.71
2006	27.10	101.56	33.20	271.35	28.09	84.90	95.90	254.30
2007	26.92	108.97	32.78	285.14	30.16	86.72	100.09	260.49
2008	26.76	107.57	32.83	215.63	29.64	79.26	92.61	232.49
2009	11.64	88.79	33.49	151.22	27.54	61.90	46.00	112.29
2010	11.91	85.29	34.59	144.63	25.38	65.12	48.45	111.18
2011	12.91	89.06	35.36	146.72	24.38	70.38	59.55	110.64
2012	13.69	92.98	36.91	149.35	25.45	56.18	55.97	144.57
2013	16.39	100.81	39.18	153.29	24.25	62.43	64.43	138.00
2014	17.71	90.02	40.07	161.69	26.17	69.23	81.62	136.14
2015	16.83	96.32	40.61	178.82	32.20	73.49	77.55	199.13
2016	17.00	95.75	41.68	170.16	36.06	74.25	83.58	207.50
2017	16.48	100.54	42.90	176.54	35.96	88.82	85.29	238.39
2018	20.73	82.99	42.52	195.88	36.69	95.77	84.80	230.91
2019	16.33	94.93	37.73	218.86	36.52	78.33	93.93	276.94
2020	14.57	83.14	34.10	206.07	35.78	90.07	100.27	290.71

Appendix F: Share of Land Area Proportion of Cropland Area Equipped for Irrigation (%)

YEAR	CAMBODIA	INDONESIA	LAO PDR	MALAYSIA	MYANMAR	PHILIPPINES	THAILAND	VIETNAM
1988	6.20	13.69	14.71	5.63	9.96	15.35	20.04	42.32
1989	6.08	14.09	15.26	5.34	10.15	15.62	20.22	43.89
1990	6.31	13.79	15.70	5.28	10.49	15.69	20.57	45.43
1991	6.56	14.80	16.24	5.28	9.97	15.68	20.98	45.14
1992	6.82	14.92	16.78	5.36	9.94	15.76	21.55	44.05
1993	7.02	14.61	17.34	5.40	11.00	15.84	22.19	45.07
1994	7.07	14.63	17.42	5.41	13.26	15.92	22.59	46.14
1995	7.07	14.18	17.22	5.43	15.38	15.49	24.52	47.98
1996	7.05	13.93	17.33	5.44	15.36	15.41	25.52	47.62
1997	7.18	14.75	17.63	5.47	15.32	14.67	26.68	47.65
1998	7.05	15.34	20.21	5.50	15.68	14.23	27.83	48.24
1999	7.03	15.16	26.10	5.52	16.45	13.68	28.49	47.87
2000	7.03	15.28	29.57	5.55	17.79	13.99	29.37	47.48
2001	7.03	15.70	28.54	5.55	17.98	14.19	30.01	45.33
2002	7.01	16.18	28.01	5.49	18.71	14.40	30.86	47.11
2003	7.01	15.62	26.29	5.46	19.21	14.36	31.73	47.65
2004	7.01	15.34	25.30	5.46	19.59	14.06	32.36	47.25
2005	7.00	16.46	24.29	5.47	19.50	14.34	32.89	46.87
2006	7.00	16.60	23.26	5.54	19.88	14.17	33.36	47.67
2007	7.00	16.00	22.67	5.54	19.27	13.95	33.76	48.67
2008	7.00	15.63	22.75	5.52	18.84	14.46	33.32	47.77
2009	7.00	15.07	22.34	5.48	18.75	14.53	31.95	47.51
2010	6.83	15.07	22.22	5.57	19.06	14.56	31.66	45.31
2011	6.83	14.77	22.05	5.69	18.71	14.60	31.66	45.28
2012	6.83	14.77	22.42	5.67	18.75	14.89	30.32	45.17
2013	6.83	14.61	22.92	5.71	18.69	15.31	29.82	44.90
2014	6.83	14.61	23.82	5.68	18.62	15.53	29.69	44.81
2015	6.61	14.52	24.73	5.33	18.44	15.70	29.55	39.85
2016	6.58	13.66	25.63	5.33	18.42	16.79	29.41	39.77
2017	6.50	13.10	27.75	5.33	18.26	17.03	29.28	39.78
2018	6.44	13.10	29.15	5.33	18.23	17.28	29.15	39.87
2019	6.36	13.10	30.84	5.33	18.36	17.70	29.01	39.03
2020	6.30	13.10	32.57	5.33	18.32	17.95	28.88	39.13

Appendix G: Average Temperature (Degree Celsius)

YEAR	CAMBODIA	INDONESIA	LAO PDR	MALAYSIA	MYANMAR	PHILIPPINES	THAILAND	VIETNAM
1988	27.23	25.77	23.94	26.08	23.85	26.27	26.74	24.54
1989	27.29	25.62	23.93	25.86	23.50	25.82	26.74	24.57
1990	27.64	25.85	24.18	26.24	23.72	26.08	27.05	24.86
1991	27.61	25.79	24.37	26.23	23.66	26.07	27.12	24.89
1992	27.35	25.79	23.83	26.13	23.25	25.91	26.73	24.5
1993	27.30	25.75	23.95	26.05	23.43	26.02	26.75	24.57
1994	27.42	25.78	24.11	26.13	23.70	26.14	26.82	24.77
1995	27.28	25.82	23.92	26.17	23.76	26.01	26.71	24.55
1996	26.89	25.82	23.57	26.08	23.54	25.88	26.32	24.33
1997	27.42	25.93	24.07	26.40	23.44	25.97	26.87	24.74
1998	28.04	26.18	24.84	26.78	24.17	26.65	27.51	25.42
1999	26.85	25.77	23.75	26.15	23.81	26.00	26.31	24.55
2000	27.10	25.85	23.80	26.28	23.43	26.13	26.54	24.49
2001	27.29	25.91	24.04	26.38	23.84	26.19	26.71	24.70
2002	27.39	26.04	24.09	26.56	23.76	26.07	26.81	24.82
2003	27.30	25.90	24.09	26.36	23.71	25.95	26.72	24.88
2004	27.29	25.92	23.85	26.32	23.55	26.04	26.65	24.59
2005	27.44	25.93	24.22	26.35	23.99	26.14	26.86	24.79
2006	27.42	25.82	24.18	26.26	23.92	26.20	26.75	24.91
2007	27.26	25.84	23.89	26.19	23.69	26.19	26.65	24.59
2008	26.86	25.71	23.51	26.00	23.59	25.87	26.30	24.16
2009	27.25	25.98	24.13	26.30	24.12	25.90	26.69	24.79
2010	27.80	26.08	24.65	26.42	24.41	26.17	27.33	25.04
2011	26.82	25.88	23.40	26.21	23.65	25.93	26.27	24.13
2012	27.70	25.99	24.49	26.40	23.90	26.27	27.17	24.90
2013	27.29	26.05	24.09	26.50	23.69	26.28	26.81	24.67
2014	27.42	26.04	24.26	26.40	23.94	26.15	26.91	24.90
2015	27.81	26.12	24.67	26.64	23.89	26.36	27.31	25.27
2016	27.98	26.23	24.63	26.92	24.11	26.70	27.43	25.20
2017	27.45	26.03	24.15	26.48	23.90	26.26	26.94	24.82
2018	27.48	26.04	24.15	26.52	23.67	26.45	26.92	24.80
2019	27.99	26.20	24.88	26.79	24.21	26.52	27.52	25.40
2020	27.90	26.18	24.71	26.67	24.05	26.64	27.43	25.22

Appendix H: Average Rainfall (mm/year)

YEAR	CAMBODIA	INDONESIA	LAO PDR	MALAYSIA	MYANMAR	PHILIPPINES	THAILAND	VIETNAM
1988	2023.04	2077.59	2999.83	3284.54	2180.00	2619.91	1737.01	1651.49
1989	1704.35	2951.05	1705.02	2708.12	1895.57	2662.15	1415.11	1632.68
1990	1889.76	2877.74	1666.06	2415.85	1938.51	2486.00	1525.66	1859.13
1991	1707.44	2610.07	2043.70	2656.63	2011.36	2061.11	1419.74	1691.19
1992	1599.92	2471.10	1682.63	2448.28	2003.13	1968.9	1365.60	1648.95
1993	1473.67	2679.12	1703.20	2807.68	1806.02	2344.51	1322.40	1622.83
1994	1993.98	2583.31	1401.57	2966.26	2077.89	2257.55	1647.50	1923.12
1995	1870.98	2545.18	1956.38	3199.47	2039.30	2697.94	1663.12	1743.70
1996	1864.59	2936.84	1805.00	3179.93	2152.29	2569.08	1748.56	1854.81
1997	1623.68	2836.27	1989.81	2506.13	1999.35	2103.31	1384.94	1794.92
1998	1837.25	2274.98	1759.17	2647.41	1949.94	2198.98	1513.01	1713.36
1999	1939.08	2877.67	1654.71	3415.41	2148.52	3364.06	1764.49	1902.35
2000	2016.44	2916.10	2032.31	3270.83	2064.57	3122.39	1753.95	1709.14
2001	1904.00	2935.10	1853.64	2973.96	2064.53	2861.34	1587.29	1923.82
2002	1814.22	2877.01	2090.84	2625.94	2195.98	2426.02	1641.72	1891.34
2003	1773.88	2596.60	2144.88	3111.67	1903.46	2760.83	1532.93	1632.19
2004	1684.60	2890.05	1628.16	2785.82	2039.34	2445.22	1434.43	1626.34
2005	1719.74	2638.79	1762.92	2789.03	1922.76	2559.62	1575.65	1801.41
2006	2027.30	2743.29	1911.18	3116.61	2232.00	2531.17	1708.40	1744.61
2007	2213.00	2651.61	1914.22	3248.58	2214.63	2771.97	1655.69	1760.02
2008	1769.55	2869.10	1856.30	3580.21	2048.18	3170.11	1707.16	1946.59
2009	1857.25	3012.77	2130.34	3404.89	1918.52	2836.31	1632.47	1623.26
2010	1740.16	2775.49	1667.37	3104.02	2105.11	2619.48	1630.99	1648.05
2011	2093.57	3289.37	1776.94	3444.4	2331.40	3375.24	1984.69	1813.42
2012	1814.14	2908.97	2191.26	3222.63	1823.11	2966.87	1530.78	1875.61
2013	2093.66	2866.86	1866.91	3095.04	2112.87	2737.32	1753.06	1895.79
2014	1845.58	2908.12	2064.22	2808.68	1626.87	2522.72	1465.95	1684.78
2015	1655.83	2601.32	1555.52	2661.86	1945.67	2381.57	1412.83	1762.60
2016	1734.76	2482.19	1568.48	2829.83	2222.67	2506.76	1593.23	1790.49
2017	2028.18	2947.50	1904.04	3262.68	2276.91	3181.31	1976.01	1888.86
2018	1762.19	3017.20	2069.18	3242.88	2024.74	2770.69	1561.74	1787.84
2019	1708.65	2823.96	1863.98	2598.71	1848.58	2424.06	1299.84	1630.94
2020	1808.94	2512.99	1545.95	3053.99	1966.00	2529.66	1534.40	1672.84

Appendix I: Food Crop Yield Index (%)

YEAR	CAMBODIA	INDONESIA	LAO PDR	MALAYSIA	MYANMAR	PHILIPPINES	THAILAND	VIETNAM
1988	42.35	65.26	43.42	61.27	68.95	55.72	65.20	50.04
1989	44.34	67.30	52.23	62.00	65.40	57.43	65.00	53.47
1990	42.45	68.48	51.64	62.71	63.79	66.80	61.12	53.38
1991	43.99	70.10	50.35	57.83	62.05	64.82	67.41	52.13
1992	42.45	70.39	58.68	61.08	63.18	66.85	66.93	55.58
1993	41.87	71.75	51.93	65.35	65.21	68.17	63.50	57.63
1994	46.97	70.71	58.25	65.51	67.07	68.80	69.63	59.03
1995	53.82	70.42	56.18	68.64	66.35	70.37	71.91	61.00
1996	54.24	71.74	56.47	70.56	68.02	69.33	72.92	62.54
1997	53.58	71.39	59.23	68.99	68.57	73.01	72.01	64.25
1998	53.56	70.96	58.08	66.12	68.63	70.47	72.18	65.01
1999	57.37	71.15	63.87	67.88	68.91	70.08	73.83	66.45
2000	62.25	71.51	65.86	70.25	70.14	74.05	79.71	68.16
2001	60.92	72.03	67.58	71.90	72.02	75.48	85.09	69.63
2002	56.97	75.17	71.80	73.54	73.36	77.80	86.67	73.20
2003	62.50	77.26	67.06	73.51	75.81	79.31	87.35	75.42
2004	60.43	77.36	69.39	73.47	78.87	81.61	86.58	78.59
2005	72.90	79.09	76.42	73.97	83.11	83.37	86.67	79.21
2006	72.57	80.41	76.38	77.54	86.72	84.77	87.27	80.30
2007	75.53	81.13	80.32	80.64	89.73	86.66	91.46	83.11
2008	78.63	82.64	80.70	82.99	93.13	87.70	90.00	83.51
2009	81.19	83.85	82.48	84.79	93.63	86.30	89.27	85.60
2010	83.37	83.68	79.46	85.11	95.10	84.85	89.59	87.21
2011	84.40	82.22	84.26	84.58	92.31	86.32	94.96	90.57
2012	87.91	86.16	84.97	89.00	91.62	89.32	96.24	91.64
2013	89.76	85.92	88.32	90.84	93.59	88.87	95.75	90.92
2014	91.13	86.20	93.59	76.91	88.22	91.03	94.66	92.96
2015	91.74	87.85	96.04	93.64	88.71	89.76	89.32	94.86
2016	96.53	86.62	96.09	92.95	87.73	87.49	91.26	92.99
2017	95.28	86.56	95.21	89.56	86.56	90.19	93.91	92.69
2018	95.70	89.36	95.24	90.53	86.86	90.43	94.70	95.77
2019	94.15	88.68	92.62	88.04	86.09	91.25	91.75	97.16
2020	95.41	90.03	88.82	90.66	85.32	91.50	86.51	98.65

Appendix J: Non-food Crop Yield Index (%)

YEAR	CAMBODIA	INDONESIA	LAO PDR	MALAYSIA	MYANMAR	PHILIPPINES	THAILAND	VIETNAM
1988	59.24	70.41	39.01	90.18	33.77	61.22	49.12	43.86
1989	62.28	67.23	37.28	87.40	32.33	58.73	54.35	44.97
1990	59.28	69.40	40.03	83.21	33.37	57.53	57.17	43.62
1991	67.08	70.33	38.04	71.16	43.10	68.77	59.34	44.82
1992	68.14	70.72	40.76	69.91	42.11	66.50	64.44	48.15
1993	64.84	75.98	56.91	73.87	43.81	64.99	68.41	46.27
1994	68.21	77.22	57.67	72.04	46.98	70.08	71.06	53.95
1995	68.38	74.90	58.85	74.45	37.41	69.07	72.49	53.56
1996	71.43	74.63	50.60	74.46	40.84	69.53	75.19	51.86
1997	68.40	73.09	58.63	73.08	43.86	72.13	75.94	61.77
1998	76.71	74.15	63.75	65.35	36.92	76.27	74.17	58.90
1999	85.74	77.38	67.05	72.30	37.57	73.84	77.53	67.01
2000	89.35	76.35	67.20	76.77	39.72	81.87	83.00	70.97
2001	83.89	75.66	66.65	76.95	43.55	86.80	89.67	74.65
2002	80.77	72.88	58.53	75.77	44.06	76.63	89.64	71.42
2003	87.10	76.88	59.43	82.94	44.43	81.63	94.82	78.78
2004	90.41	83.89	61.61	88.99	47.44	86.48	96.09	79.03
2005	83.86	84.48	59.35	89.93	48.08	82.51	92.48	82.95
2006	87.13	95.78	54.49	95.16	51.70	79.28	93.98	88.46
2007	87.74	89.16	56.12	91.21	56.66	77.46	88.81	90.53
2008	83.27	82.19	60.68	93.61	70.81	76.31	95.26	94.71
2009	87.22	77.77	87.62	88.34	81.95	73.06	88.08	97.22
2010	86.72	82.84	87.31	85.27	84.88	71.49	83.77	97.27
2011	90.33	86.28	91.85	92.04	88.44	68.34	90.03	97.68
2012	92.69	85.63	97.03	91.11	90.35	66.41	90.67	98.38
2013	88.02	85.59	78.64	87.16	90.41	63.67	91.75	98.89
2014	87.25	85.30	91.16	92.91	91.31	61.14	87.71	97.90
2015	91.59	84.66	90.19	93.46	91.80	56.25	81.97	96.89
2016	91.79	86.37	90.30	80.71	92.82	53.90	82.80	96.26
2017	91.27	88.67	81.65	92.52	90.49	55.74	82.52	97.00
2018	88.08	88.01	89.06	86.62	91.42	56.64	83.86	95.66
2019	94.26	86.79	68.39	86.89	87.80	57.16	82.83	96.70
2020	97.06	84.28	71.32	82.78	87.08	56.24	79.17	97.33

Appendix K: Gross National Income (US$)

YEAR	CAMBODIA	INDONESIA	LAO PDR	MALAYSIA	MYANMAR	PHILIPPINES	THAILAND	VIETNAM
1988	712.31	510.00	250.00	2210.00	40.00	750.00	1190.00	1133.75
1989	712.31	520.00	210.00	2330.00	40.00	800.00	1350.00	220.00
1990	712.31	560.00	190.00	2470.00	40.00	830.00	1520.00	130.00
1991	712.31	600.00	210.00	2630.00	40.00	830.00	1690.00	110.00
1992	712.31	660.00	240.00	2950.00	50.00	890.00	1920.00	130.00
1993	712.31	740.00	270.00	3310.00	60.00	940.00	2150.00	160.00
1994	712.31	850.00	310.00	3670.00	70.00	1060.00	2410.00	190.00
1995	240.00	980.00	350.00	4120.00	90.00	1170.00	2740.00	250.00
1996	310.00	1080.00	380.00	4570.00	120.00	1330.00	2950.00	300.00
1997	320.00	1090.00	370.00	4690.00	130.00	1400.00	2670.00	340.00
1998	290.00	650.00	300.00	3690.00	120.00	1320.00	2080.00	350.00
1999	300.00	570.00	280.00	3430.00	120.00	1250.00	1980.00	360.00
2000	300.00	570.00	280.00	3490.00	130.00	1180.00	1980.00	380.00
2001	310.00	710.00	300.00	3570.00	140.00	1170.00	1960.00	400.00
2002	320.00	780.00	320.00	3800.00	140.00	1130.00	1980.00	420.00
2003	360.00	890.00	330.00	4160.00	150.00	1170.00	2170.00	470.00
2004	410.00	1070.00	380.00	4710.00	180.00	1290.00	2520.00	540.00
2005	470.00	1210.00	450.00	5230.00	200.00	1380.00	2780.00	640.00
2006	520.00	1360.00	510.00	5770.00	230.00	1490.00	3080.00	730.00
2007	590.00	1580.00	610.00	6540.00	280.00	1710.00	3490.00	840.00
2008	670.00	1920.00	740.00	7400.00	350.00	2000.00	3920.00	990.00
2009	690.00	2130.00	880.00	7470.00	470.00	2160.00	4080.00	1120.00
2010	750.00	2510.00	990.00	8110.00	630.00	2360.00	4510.00	1370.00
2011	810.00	2990.00	1130.00	8890.00	820.00	2500.00	4860.00	1630.00
2012	880.00	3550.00	1360.00	9980.00	1010.00	2840.00	5420.00	1980.00
2013	960.00	3710.00	1600.00	10600.00	1190.00	3140.00	5610.00	2200.00
2014	1020.00	3600.00	1810.00	10870.00	1240.00	3300.00	5640.00	2400.00
2015	1070.00	3420.00	1970.00	10400.00	1200.00	3350.00	5580.00	2480.00
2016	1160.00	3400.00	2110.00	9880.00	1230.00	3410.00	5570.00	2580.00
2017	1260.00	3530.00	2240.00	9680.00	1210.00	3480.00	5820.00	2720.00
2018	1420.00	3850.00	2470.00	10370.00	1250.00	3640.00	6450.00	3060.00
2019	1560.00	4070.00	2520.00	10960.00	1300.00	3770.00	7080.00	3340.00
2020	1530.00	3900.00	2470.00	10320.00	1370.00	3350.00	6900.00	3450.00

Appendix L: Share of Cropland Area from total Agriculture Land (%)

YEAR	CAMBODIA	INDONESIA	LAO PDR	MALAYSIA	MYANMAR	PHILIPPINES	THAILAND	VIETNAM
1988	85.54	71.18	51.52	95.74	96.51	88.97	96.43	95.08
1989	85.34	70.08	51.57	95.92	96.53	88.83	96.39	95.01
1990	85.41	70.92	51.81	95.92	96.56	88.69	96.35	94.92
1991	84.48	71.76	51.87	95.91	96.55	88.62	96.33	95.17
1992	84.50	71.46	51.92	95.89	96.55	88.48	96.26	95.33
1993	84.55	71.92	51.95	95.92	96.56	88.43	96.23	95.37
1994	83.59	71.89	52.66	95.98	96.69	88.38	96.21	95.41
1995	83.59	72.54	52.94	95.97	96.75	87.93	96.23	95.37
1996	83.62	73.99	52.94	95.91	96.52	87.66	96.17	91.17
1997	83.62	74.32	52.96	95.90	96.53	87.21	96.09	91.82
1998	82.72	74.53	53.26	95.90	96.56	87.15	96.01	92.03
1999	82.76	75.64	54.03	95.90	96.95	87.09	96.00	92.37
2000	80.50	76.31	55.43	95.89	97.10	86.65	95.97	92.69
2001	78.53	76.73	57.09	95.90	97.13	86.59	95.97	93.23
2002	77.00	76.96	58.42	95.95	97.13	86.53	95.94	93.21
2003	75.49	78.43	59.71	96.00	97.16	86.65	95.91	93.27
2004	73.61	79.39	60.95	96.00	97.19	86.92	95.91	93.45
2005	71.99	78.78	62.22	96.01	97.27	86.79	95.92	93.61
2006	71.99	78.64	63.70	95.97	97.35	87.05	95.94	93.63
2007	71.99	79.25	64.86	95.99	97.45	87.28	95.96	93.62
2008	71.99	79.63	66.02	96.01	97.52	87.51	96.01	93.73
2009	71.99	80.22	67.71	96.05	97.54	87.60	96.17	93.76
2010	72.50	80.22	68.92	96.14	97.53	87.60	96.20	94.03
2011	72.50	80.53	70.13	96.22	97.55	87.77	96.20	94.04
2012	72.50	80.53	70.53	96.36	97.55	87.93	96.36	94.05
2013	72.50	80.70	71.01	96.46	97.57	87.97	96.41	94.08
2014	72.50	80.70	71.07	96.48	97.58	88.00	96.43	94.10
2015	73.13	80.80	71.07	96.67	97.60	88.03	96.45	94.72
2016	73.23	81.73	71.07	96.67	97.63	88.05	96.46	94.73
2017	73.46	82.34	70.09	96.67	96.31	88.08	96.48	94.72
2018	73.64	82.34	69.05	96.67	96.32	88.11	96.49	94.71
2019	73.90	82.34	67.93	96.67	96.31	88.14	96.51	94.82
2020	74.09	82.34	66.73	96.67	96.31	88.17	96.52	94.81

Appendix M: Arable Land per Rural Capita (Hectare/Person)

YEAR	CAMBODIA	INDONESIA	LAO PDR	MALAYSIA	MYANMAR	PHILIPPINES	THAILAND	VIETNAM
1988	0.48	0.17	0.23	0.10	0.32	0.17	0.45	0.10
1989	0.50	0.17	0.23	0.10	0.32	0.17	0.45	0.10
1990	0.49	0.16	0.22	0.10	0.32	0.17	0.44	0.10
1991	0.47	0.14	0.22	0.10	0.31	0.16	0.43	0.10
1992	0.46	0.14	0.21	0.10	0.31	0.16	0.42	0.10
1993	0.45	0.14	0.21	0.10	0.31	0.15	0.42	0.10
1994	0.43	0.14	0.21	0.10	0.30	0.15	0.41	0.09
1995	0.42	0.14	0.21	0.10	0.30	0.14	0.41	0.09
1996	0.41	0.14	0.20	0.10	0.30	0.14	0.40	0.09
1997	0.40	0.15	0.21	0.10	0.29	0.13	0.39	0.10
1998	0.39	0.15	0.21	0.10	0.29	0.13	0.37	0.10
1999	0.38	0.16	0.21	0.10	0.29	0.12	0.37	0.10
2000	0.37	0.17	0.22	0.10	0.30	0.12	0.36	0.10
2001	0.37	0.17	0.23	0.10	0.29	0.12	0.36	0.11
2002	0.36	0.16	0.24	0.11	0.29	0.11	0.36	0.11
2003	0.36	0.18	0.25	0.11	0.29	0.11	0.36	0.11
2004	0.35	0.20	0.26	0.11	0.29	0.11	0.37	0.11
2005	0.35	0.19	0.27	0.11	0.29	0.11	0.37	0.10
2006	0.34	0.18	0.28	0.11	0.29	0.11	0.38	0.10
2007	0.34	0.18	0.29	0.10	0.30	0.11	0.38	0.10
2008	0.33	0.19	0.30	0.10	0.30	0.11	0.39	0.10
2009	0.33	0.19	0.31	0.10	0.30	0.11	0.41	0.10
2010	0.33	0.19	0.32	0.10	0.30	0.10	0.42	0.11
2011	0.33	0.19	0.33	0.11	0.30	0.11	0.42	0.10
2012	0.32	0.19	0.33	0.11	0.30	0.11	0.45	0.10
2013	0.32	0.19	0.34	0.10	0.30	0.11	0.46	0.10
2014	0.32	0.19	0.34	0.10	0.30	0.10	0.46	0.10
2015	0.32	0.20	0.34	0.10	0.30	0.10	0.47	0.11
2016	0.32	0.21	0.34	0.11	0.30	0.10	0.47	0.11
2017	0.31	0.22	0.32	0.11	0.30	0.10	0.48	0.11
2018	0.31	0.22	0.30	0.11	0.30	0.10	0.49	0.11
2019	0.31	0.22	0.29	0.11	0.29	0.10	0.49	0.11
2020	0.31	0.22	0.27	0.11	0.29	0.10	0.50	0.11

Appendix N: Crop Export Index

YEAR	CAMBODIA	INDONESIA	LAO PDR	MALAYSIA	MYANMAR	PHILIPPINES	THAILAND	VIETNAM
1988	0.53	0.26	0.67	0.43	0.71	0.66	0.28	0.43
1989	0.41	0.31	0.35	0.40	0.43	0.59	0.26	0.48
1990	0.68	0.27	0.55	0.38	0.45	0.58	0.23	0.23
1991	0.50	0.38	0.57	0.40	0.35	0.47	0.30	0.39
1992	0.78	0.37	0.36	0.41	0.39	0.48	0.29	0.30
1993	0.90	0.32	0.48	0.40	0.40	0.48	0.31	0.23
1994	0.88	0.35	0.59	0.43	0.31	0.45	0.35	0.31
1995	0.77	0.44	0.67	0.44	0.32	0.44	0.41	0.38
1996	0.79	0.42	0.49	0.44	0.37	0.42	0.38	0.32
1997	0.88	0.35	0.69	0.44	0.42	0.43	0.36	0.33
1998	0.96	0.31	0.87	0.48	0.48	0.45	0.38	0.36
1999	0.87	0.30	0.81	0.46	0.37	0.43	0.36	0.35
2000	0.87	0.34	0.70	0.42	0.28	0.47	0.39	0.32
2001	0.77	0.32	0.53	0.42	0.53	0.52	0.38	0.30
2002	0.71	0.34	0.42	0.46	0.52	0.51	0.42	0.31
2003	0.80	0.36	0.39	0.47	0.45	0.51	0.45	0.29
2004	0.54	0.39	0.33	0.44	0.28	0.50	0.43	0.30
2005	0.55	0.38	0.27	0.42	0.52	0.51	0.48	0.32
2006	0.71	0.40	0.24	0.43	0.67	0.35	0.52	0.32
2007	0.63	0.42	0.30	0.45	0.62	0.46	0.48	0.30
2008	0.48	0.44	0.26	0.49	0.43	0.44	0.45	0.34
2009	0.49	0.44	0.23	0.46	0.53	0.43	0.43	0.32
2010	0.46	0.43	0.43	0.45	0.55	0.37	0.50	0.33
2011	0.45	0.44	0.24	0.47	0.34	0.42	0.53	0.31
2012	0.42	0.47	0.31	0.47	0.44	0.46	0.51	0.29
2013	0.44	0.46	0.25	0.45	0.24	0.53	0.50	0.29
2014	0.43	0.49	0.21	0.44	0.31	0.59	0.43	0.26
2015	0.45	0.48	0.25	0.42	0.34	0.49	0.42	0.28
2016	0.46	0.48	0.30	0.41	0.34	0.62	0.43	0.32
2017	0.43	0.49	0.27	0.41	0.30	0.58	0.45	0.33
2018	0.44	0.48	0.27	0.40	0.28	0.57	0.42	0.33
2019	0.41	0.47	0.30	0.40	0.31	0.61	0.46	0.33
2020	0.38	0.50	0.27	0.42	0.24	0.60	0.44	0.31

국문 초록

동남아시아 국가들의 농작물 다각화 결정요인 분석

Clara Joan Joachim[10]

농경제사회학부

농업.자원경제학전공

서울대학교 대학원

동남아시아의 농업 부문은 지난 수십 년간 상당한 구조적 변화를 겪었지만, 이러한 변화는 지역에 따라 다르다. 특정 작물의 대규모 경작, 기후 변화 및 식량 불안과 같은 우려로 인해 이러한 문제에 대한 실행 가능한 해결책으로 농작물 다각화가 필요 해졌다. 본 연구에서는 동남아시아 8개국 (캄보디아, 인도네시아, 라오스, 말레이시아, 미얀마, 필리핀, 태국, 베트남)의 작물 다각화 현황과 그것을 결정하는 요인을 조사하였다. 기술 (비료 사용량 및 관개), 기후 조건 (온도 및 강우량), 식량 및 비 식량 작물의 생산성, 국민총소득(GNI), 농경지의 경작지 점유율, 농촌 인구 1인당 경작지 및 수출 활동을 포함한 다양한 요인을 고려하였다. 본 분석에서는 1988년 ~ 2020년의 패널 데이터와 Simpson의 다양성 지수를 사용하여 작물 다양성을 측정했다. 농작물 다각화의 결정 요인은 Fixed Effect Model을 사용하여 국가 Dummy에 대한 제어를 통해 평가되었다. 이분산성(heteroskedasticity)과 단면적

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상관관계의 문제로 인해 Feasible Generalized Least Square (FGLS) 방법을 사용하였다. 그 결과 동남아시아 국가들의 농작물 다각화는 비료사용량, 관개, 농작물 수확량 지수, 국민총소득, 농촌 인구 1인당 경작지, 그리고 연구기간 동안 수출지수의 집중 등의 영향을 크게 받은 것으로 나타났다. 그러나 비료 사용량과 농촌 인구 1인당 경작지의 증가, 수출을 위한 제한된 수의 작물에 대한 의존도는 작물 다각화에 부정적인 영향을 미쳤다.

주요어 : 농작물 다각화, 지속가능농업, 식량 안보, 패널 데이터, 동남아시아
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