



TITLE:

# Assessing the impact of climate change on the agricultural economy in Thailand: an empirical study using panel data analysis

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1 **Assessing the impact of climate change on the agricultural economy in Thailand: An**  
2 **empirical study using panel data analysis**

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15

16 **Abstract**

17 This study estimates the impact of climate change on the economic growth of the agricultural sector and its  
18 variability using a panel dataset from 1995 to 2019 for 76 provinces in Thailand. The panel data analysis consists  
19 of unit root tests for identifying stationary characteristics, autoregressive distributed lag (ARDL) bounds for  
20 analyzing cointegration, and pool mean group (PMG) estimation for detecting long-run and short-run effects. The  
21 cointegration results indicate the existence of long-run equilibrium in the agricultural economy and its variability  
22 to climatic and non-climatic variables. Results from the PMG estimation suggest that extreme weather events have  
23 a negative impact on the agricultural economy, but increased total rainfall has a positive association with the  
24 agricultural economy. The increases in mean average and mean minimum temperatures will reduce the variability  
25 of agricultural growth. The obtained results suggest that the productivity of agricultural households and water  
26 resources increases the agricultural revenue and reduces its variability for long-term development in the  
27 agricultural sector of Thailand.

28 **Keywords** Cointegration; ARDL; PMG; Climatic Change; Agriculture; Global Warming

## 29 Introduction

30 Climate change is a concern for many countries around the world and generally has a negative impact on the  
 31 economy, society, and environment. Climate variability is becoming more serious with heavy rains, flooding,  
 32 droughts, rising sea levels, and El Niño-Southern Oscillation (ENSO). This may, therefore, result in the occurrence  
 33 of serious global epidemics. In addition, extreme climate and weather events have a profound impact on  
 34 ecosystems and biodiversity, including air pollution, and pose a threat to life in terms of affecting both health and  
 35 livelihoods, creating food and drinking water shortages, and so on. The causes of climate change can be attributed  
 36 to the fluctuation of the Earth's average temperature rise due to the greenhouse effect, which influences changes  
 37 with respect to other climatic factors, such as precipitation, sunlight, wind patterns, heatwaves, etc. Hence,  
 38 governments across the world have enacted proactive measures to adapt to climate change on various levels of  
 39 economic development in order to minimize the potential consequences that might occur. For all these reasons,  
 40 climate change is seen as a global issue that needs to be addressed seriously and rapidly, requiring cooperation  
 41 from all countries of the world.

42 Thailand is also facing challenges to its sustainable development due to the impact of climate change. The  
 43 country has been suffering from natural disasters more than before, with notable events being the 2004 tsunami,  
 44 the great flood in 2011, and the extreme droughts during the past couple of years. In particular, the great flood in  
 45 2011, caused by the La Niña phenomenon, was estimated to cause damage to the Thai economy of approximately  
 46 US\$ 6.23 billion. The impact dramatically affects the export sector because most of the flooded areas were in the  
 47 major industrial estates located in the central region of Thailand. It was found that the total value of exported  
 48 products, which can be grouped into four categories, including automobiles, electronics, electrical appliances, and  
 49 agricultural commodities, decreased by US\$ 2.5 billion. At that time, the country had shortages of consumer goods  
 50 and products of many different types, which resulted in headline inflation as high as 3.9 percent in 2011 (Fiscal  
 51 Policy Office 2011). As mentioned previously, it would therefore be concluded that climate change has a  
 52 tremendously negative effect on economic growth as a whole, including making more people's livelihoods more  
 53 difficult and destroying the environment as well.

54 Climate change is an important challenge for the agricultural development of Thailand because agricultural  
 55 outputs depend on climatic conditions such as rainfall, temperature, solar radiation, and humidity. In recent years,  
 56 Thailand has constantly faced droughts. The factors that mainly cause droughts occur from natural conditions  
 57 such as faults in circulation forms within the monsoon trough as well as human actions, such as greenhouse gas  
 58 emissions, deforestation, encroachment on natural water resources, improper land use, and so on. In 2016,  
 59 Thailand faced a severe drought, partly from the accumulated drought since 2015, due to the El Niño phenomenon  
 60 that caused temperatures to rise above normal and delayed the monsoons, resulting in agricultural activities not  
 61 having enough water, especially to grow crops during the planting season. The impact of the drought crisis during  
 62 the period 2015-2016 affected 187,351 farmers, damaging 474,409 hectares of agricultural land, with total  
 63 estimated damage of US\$ 468.72 million (Department of Water Resources 2017). The Department of Disaster  
 64 Prevention and Mitigation reported that agricultural areas had been damaged by disasters caused by climate  
 65 change in the past 24 years (from 1989 to 2012), mainly from floods, droughts, and windstorms. It was found that  
 66 2.72 million hectares of agricultural land had been damaged in 1994 by droughts, 4.64 million hectares had been  
 67 damaged in 2001 by floods, 16,000 hectares had been damaged during the period 2009-2011 by windstorms, and  
 68 1.6 million hectares had been damaged during the period 2010-2011 by floods, respectively. In summary, the  
 69 damage to agriculture due to droughts, floods, and windstorms in the past 24 years (from 1989 to 2012) was  
 70 approximately US\$ 5.77 billion (Department of Disaster Prevention and Mitigation 2013; Ministry of Agriculture  
 71 and Cooperatives 2017). Hence, the effect of climate change has explicitly affected the efficiency of agricultural  
 72 production in Thailand.

73 Even though the impact of climate change on national income has been analyzed in the previous literature,  
 74 only a few studies have been conducted at the sub-sectoral level of the economy. This study differs from previous  
 75 studies, which have largely emphasized assessing the impact of climate change on productivity rather than value-  
 76 added in the agricultural sector. Therefore, this study examines the factors that determine the aggregate values of  
 77 the agricultural sector in Thailand, namely, non-climatic (i.e., agricultural land use and households) and climatic  
 78 (i.e., rainfall and temperature) variables. The study includes 76 provinces that cover the agricultural areas of the  
 79 country. The data collection is fully accessed from Thailand's Office of Agricultural Economics in the form of  
 80 time series data over the period of 1995 to 2019. The findings could provide useful information for policy planning  
 81 to determine measures in order to support and mitigate climate change impacts as well as adaptation and climate  
 82 resilience in the agricultural sector. Thus, the main purpose is to estimate the impact of climate and weather  
 83 variability on the economic growth of the agricultural sector in Thailand using panel data analysis. The remainder  
 84 of this study is structured as follows. The following literature review section provides previous studies related to  
 85 this issue. Then, the methodology section describes panel datasets and econometric techniques, such as testing

86 stationarity using common unit root and individual unit root tests, analyzing cointegration using general-to-  
 87 specific ARDL bounds tests, and estimating short-run and long-run coefficients using the PMG estimation. The  
 88 empirical results are presented in the empirical analysis and discussion section. Finally, the conclusion and policy  
 89 recommendations section presents concluding remarks and implications.

## 90 Literature review

91 From the literature review related to climate change and agriculture, most recent studies have analyzed the effect  
 92 of climate and weather variability on the efficiency of agricultural output in the form of yield and its variance  
 93 using Just and Pope's stochastic production function. Just and Pope (1978, 1979) introduced an analysis technique  
 94 of panel data using climatic and non-climatic factors that are associated with the yield and the variance of the  
 95 yield. The estimation utilized maximum likelihood (MLE) and feasible generalized least squares (FGLS), which  
 96 was more efficient and accurate than a classical panel data technique. However, Saha et al. (1997) suggested that  
 97 the MLE was more efficient and unbiased than the FGLS in cases of a small sample size. For an example of  
 98 previous studies that used the MLE, Chen et al. (2004) analyzed the impacts of precipitation and temperature on  
 99 crop yields such as corn, cotton, sorghum, soybean, and wheat in the U.S. The results revealed that the effect of  
 100 climate change influenced crop yields and their variance differently. Moreover, Kim and Pang (2009), Aye and  
 101 Ater (2012), and Poudel et al. (2014) confirmed that the variability of climate and weather factors affected crop  
 102 productivity, with these effects having different associations, both positively and negatively. Numerous studies  
 103 have employed a three-step FGLS method to estimate climatic factors affecting crop productivity; the study of  
 104 Sarker et al. (2019) evaluated the impact of climate change on the rainfed Aman rice yields in Bangladesh using  
 105 Just and Pope's procedure. The panel datasets over 48 years for the district levels were analyzed using the linear  
 106 and quadratic functions. The results indicated that changes in temperature and rainfall series would be a risk factor  
 107 for Aman rice productivity in Bangladesh. Guntukula and Goyari (2020) estimated the impacts of climatic  
 108 variables on major crop yields of rice, cotton, jowar, and groundnut in Telangana using a panel dataset from 1956  
 109 to 2015. The results of Guntukula and Goyari (2020) were consistent with the findings of Sarker et al. (2019),  
 110 indicating that changes in temperature and rainfall affected the efficiency of crop production. In addition,  
 111 Sinnarong et al. (2019) and Pipitpukdee et al. (2020) confirmed that climate and weather factors were negatively  
 112 associated with crop yields in Thailand in the projections of rice and cassava, respectively.

113 To assess the impact of climate change on crop production, Zaied and Zouabi (2016) and Attiaoui and Boufateh  
 114 (2019) applied a panel cointegration test to capture the short-run and long-run effects of climatic factors on  
 115 agricultural commodities such as cereal and olive oil in Tunisia. The results indicated that increases in climate  
 116 and weather variability would reduce Tunisian olive oil production. Attiaoui and Boufateh's (2019) findings also  
 117 confirmed that temperature and rainfall had a negative effect on cereal farming in Tunisia, and these factors were  
 118 likely to reduce crop productivity. However, Warsame et al. (2021) studied the impact of climate change on crop  
 119 production in Somalia using time series analysis. The results of the cointegration test suggest that rainfall increased  
 120 crop productivity in the long-term period but reduced crop productivity in the short-term period. At the same time,  
 121 the temperature harmed both long-term and short-term crop yields. Abbas (2020) argued that temperature changes  
 122 were not associated with the efficiency of cotton production in Pakistan using cointegration analysis.

123 While climate change has a direct impact on productivity in agriculture, it also indirectly impacts the economic  
 124 value of the agricultural sector. Following the Ricardian approach, Benhin (2008) estimated climatic and non-  
 125 climatic factors affecting the average farm revenue of farmers in South Africa. The results indicated that increases  
 126 in annual mean temperature and precipitation would increase net crop revenue. These findings were in line with  
 127 Hossain et al. (2019), which found that the increase in temperature and rainfall had a positive relationship with  
 128 net income from crop farming in Bangladesh. On the other hand, Huong et al. (2019) revealed that changes in  
 129 temperature and rainfall were negatively associated with net revenue by studying the impact of climate variability  
 130 on the economic value of household revenue in northwest Vietnam using the Ricardian concept. Furthermore,  
 131 Lanzafame (2014) investigated the effects of temperature and rainfall on economic growth in Africa using an  
 132 econometric procedure. An autoregressive distributed lag (ARDL) model was applied to estimate the annual panel  
 133 dataset from 1962 to 2000 for 36 African countries using the mean group (MG) estimator. The results revealed  
 134 that there were short-run and long-run relationships between temperature and economic growth, while rainfall  
 135 was less closely associated with economic growth. Alagidede et al. (2016) also examined the linkage of  
 136 temperature and rainfall to economic growth in sub-Saharan Africa by applying a panel cointegration test. The  
 137 pool mean group (PMG) estimator was considered to estimate the panel dataset based on the ARDL model with  
 138 the Cobb-Douglas production function. The results indicated that the economic growth was significantly affected  
 139 negatively in the short-run and long-run by temperature. Accordingly, this study has drawn upon the previous  
 140 literature by investigating the impact of climate change on the economic growth of the agricultural sector at the  
 141 provincial level in Thailand. The ARDL model based on the Cobb-Douglas concept has been considered to

142 estimate the linkage of climatic and non-climatic factors to the aggregate values of the agricultural economy in  
143 Thailand.

## 144 Methodology

145 Numerous studies on the issue of climate change have mainly focused on the impacts of temperature and rainfall  
146 variability on crop yields that were mentioned previously. However, the effect of climate variables not only affects  
147 crop outputs of a country but also influences economic value in different economic sectors (Lanzafame 2014;  
148 Alagidede et al. 2016; Dafermos et al. 2018; Rezai et al. 2018). For instance, Lanzafame (2014) and Alagidede et  
149 al. (2016) studied the effects of climatic variables on the national income of African countries. These studies  
150 employed the panel cointegration methodology to capture the long-run and short-run effects of climate change on  
151 economic growth. In this study, an augmented neoclassical Cobb-Douglas production function in equation (1) is  
152 considered to detect the impacts of climatic and non-climatic variables on the economic growth of the agricultural  
153 sector. The Cobb-Douglas structure using the aggregate values of the agricultural sector, which applies the natural  
154 logarithmic function, is modified from the studies of Lanzafame (2014) and Alagidede et al. (2016), as expressed  
155 in equation (2).

$$156 \quad Y_{it} = A_{it}^{\beta_1} \cdot L_{it}^{\beta_2} \cdot CF_{it}^{\beta_3} \quad (1)$$

$$157 \quad \ln Y_{it} = \alpha_0 + \beta_1 \ln A_{it} + \beta_2 \ln L_{it} + \beta_3 \ln CF_{it} + e_{it} \quad (2)$$

158 where Y is the agricultural economy represented by the gross provincial product (GPP) of the agricultural sector  
159 (million Thai baht),  $\alpha$  and  $\beta$  are the estimated parameters, e is the random error term with zero mean and constant  
160 variance, A is the agricultural land use (rai: 6.25 rai equals one hectare), L is the number of agricultural households,  
161 and CF represents the climatic factors, including Rf as the amount of total rainfall in a year (millimeters: mm),  
162 Rfd as the rainfall intensity (millimeters/day: mm/day), AverT as the mean average temperature (degrees  
163 Celsius: °C), MinT as the mean minimum temperature (degrees Celsius: °C), and MaxT as the mean maximum  
164 temperature (degrees Celsius: °C). The subscript (it) represents a panel dataset that consists of the province i at  
165 the time period of t over the period of 1995 to 2019. The descriptive statistics of the variables used are reported  
166 in Table 1.

167 <<< Insert Table 1 >>>

168 The panel variables of the agricultural economy (Y), agricultural land use (A), agricultural households (L),  
169 mean average temperature (AverT), mean minimum temperature (MinT), mean maximum temperature (MaxT),  
170 rainfall (Rf), and rainfall intensity (Rfd) display summary statistics, including mean (Mean), maximum (Max),  
171 minimum (Min), and standard deviation (S.D.). The study includes 76 provinces that cover the agricultural areas  
172 of the country. The panel dataset comprises 1,900 observations in total collected from the Office of Agricultural  
173 Economics, Thailand.

174 This study applies panel cointegration using an autoregressive distributed lag (ARDL) structure which is well-  
175 known as a bounds cointegration analysis, proposed initially by Pesaran et al. (1996, 2001). The main advantage  
176 of the panel bounds cointegration using the ARDL structure is to capture long-run and short-run dynamic effects,  
177 even though the relationship of the variables is questionable as it features a mixture of stationary and non-  
178 stationary datasets. In other words, the variables can be cointegrated without a purely I(1) process which is  
179 different from the traditional cointegration tests, such as the methods of Kao (1999) and Pedroni (2004).

180 Therefore, for the first step in estimating panel cointegration, it needs to be confirmed that the variables are  
181 not integrated more than order one, with the expectation of containing the stationary I(1) or I(0) process. A  
182 common unit root (e.g., LLC) and an individual unit root (e.g., IPS, ADF-Fisher, PP-Fisher) are used to analyze  
183 the characteristics of the panel dataset before performing the cointegration. The pooled mean group (PMG)  
184 estimation of Pesaran et al. (1999) is considered for the ARDL model regarding the homogeneity of the long-run  
185 coefficients to be identical for all provinces, and for heterogeneity of the short-run coefficients to be random. To  
186 estimate the long-run and short-run effects, there are two steps included (Attiaoui et al., 2017; Attiaoui and  
187 Boufateh 2019): (1) confirmation of the existence of cointegration using the ARDL bounds test, and then (2)  
188 detection of the short-run response using the error correction model (ECM).

189 To confirm the existence of cointegration, according to Pesaran et al. (1996, 2001), the bounds model,  
190 including previous lags of endogenous and exogenous variables, is structured as ARDL (p, q, ..., q) as expressed  
191 in equation (3).

$$192 \quad \Delta \ln Y_{it} = \alpha_0 + \beta_1 \ln Y_{it-1} + \beta_2 \ln A_{it-1} + \beta_3 \ln L_{it-1} + \beta_4 \ln CF_{it-1}$$

$$193 \quad + \sum_{j=1}^{p-1} \beta_5 \Delta \ln Y_{it-j} + \sum_{j=0}^{q-1} \beta_6 \Delta \ln A_{it-j} + \sum_{j=0}^{q-1} \beta_7 \Delta \ln L_{it-j} + \sum_{j=0}^{q-1} \beta_8 \Delta \ln CF_{it-j} + e_{it} \quad (3)$$

194 where  $p$  and  $q$  are the lag lengths of the time period for endogenous and exogenous variables selected from the  
195 Akaike information criterion (AIC) and the Schwarz information criterion (SIC).

196 The null hypothesis ( $H_0$ ) of the ARDL bounds tests is based on the F-statistics or the Wald coefficient test that  
197 provides the absence of a long-run relationship as  $H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$ , as well as the alternative hypothesis  
198 ( $H_A$ ) for indicating the presence of a long-run relationship as  $H_A: \beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq 0$ . The outputs of the bounds  
199 test can be derived from three conclusions. First, if the computed F-statistic value of the Wald coefficient is greater  
200 than the upper critical bounds value, then the null hypothesis of the absence of cointegration is rejected. It can be  
201 concluded that all of the variables included in the specification ARDL model contain the  $I(1)$  process. On the  
202 other hand, if the computed F-statistic value is less than the lower bounds, the null hypothesis of the absence of  
203 cointegration cannot be rejected. However, if the computed F-statistic value falls within the bounds, then this  
204 would indicate that any absence or presence of cointegration is inconclusive.

205 To detect the short-run dynamic effects, the ARDL based on the ECM structure is applied with the specified  
206 model, which can be expressed in equation (4).

$$207 \quad \Delta \ln Y_{it} = \alpha_0 + \sum_{j=1}^{p-1} \beta_1 \Delta \ln Y_{it-j} + \sum_{j=0}^{q-1} \beta_2 \Delta \ln A_{it-j} + \sum_{j=0}^{q-1} \beta_3 \Delta \ln L_{it-j} + \sum_{j=0}^{q-1} \beta_4 \Delta \ln CF_{it-j} + \gamma ECT_{it-1} + \omega_{it} \quad (4)$$

208 where ECT is the error correction term (ECT) or the part of disequilibrium that is derived from the long-run  
209 relationship,  $\gamma$  is the speed of adjustment of the model returning to the equilibrium state, and  $\omega$  is the white noise  
210  $\sim N(0, \sigma^2)$ . In addition, this study captures the expected variance ( $e_{it}^2$ ) of  $\ln Y$  from equation (2) to estimate the  
211 variability or risk of economic value in the agricultural sector, which is influenced by climatic and non-climatic  
212 factors, following the same process as the analysis of  $\ln Y$ .

## 213 Empirical analysis and discussion

214 First, to prevent a spurious relationship from occurring before performing panel data analysis, we need to verify  
215 the characteristics of the panel dataset because it might be influenced by the time effect (Granger and Newbold  
216 1974). Even though the ARDL bounds test does not require stationarity of all variables in the same order, it is  
217 necessary to confirm that the variables should not be integrated more than order one or  $I(1)$  level. To handle this  
218 issue, a common unit root of Levin, Lin, and Chu (LLC) and an individual unit root of Im, Pesaran, and Shin  
219 (IPS), ADF-Fisher, and PP-Fisher are employed to identify the order of integration in each panel dataset. The  
220 Schwarz information criterion (SIC) is considered to determine the optimal lag selection in testing. The panel  
221 dataset for all unit root tests using the model, including a constant and time trend, can be used to reject the null  
222 hypothesis of non-stationarity when the  $p$ -values from the analysis are below the 0.05 level. Suppose the  
223 hypothesis of non-stationarity cannot be rejected; in that case, it is necessary to include more than one order of  
224 integration to perform the unit root tests again until the results approach stationarity.

225 <<<Insert Table 2>>>

226 The results of the LLC, IPS, ADF-Fisher, and PP-Fisher unit root tests in Table 2 indicated that the variables  
227 have different test outputs. The unit root tests of  $\ln Y$ ,  $\ln A$ , and  $\ln L$  cannot be used to reject the hypothesis at the  
228  $I(0)$  level because the  $p$ -values in parenthesis are greater than the 0.05 level, except for  $\ln A$ , which can be used to  
229 reject the hypothesis at  $I(0)$  level only when testing under the LLC method. Then, the first order of integration or  
230 the  $I(1)$  level must be tested again, and it was found that the variables of  $\ln Y$ ,  $\ln A$ , and  $\ln L$  can be used to reject  
231 the hypothesis, which means that these three variables contain unit roots at the stationary  $I(1)$  level, except for  
232  $\ln A$  which contains  $I(0)$  for a common unit root test and  $I(1)$  for an individual unit root test. However, the variables  
233 of  $\ln \text{AverT}$ ,  $\ln \text{MinT}$ ,  $\ln \text{MaxT}$ ,  $\ln \text{Rf}$ ,  $\ln \text{Rfd}$ , and  $\ln e^2$  are found to reject the hypothesis at the  $I(0)$  level as there are  
234  $p$ -values in parenthesis below the 0.05 level. Hence, it can be concluded that the variables of  $\ln \text{AverT}$ ,  $\ln \text{MinT}$ ,  
235  $\ln \text{MaxT}$ ,  $\ln \text{Rf}$ ,  $\ln \text{Rfd}$ , and  $\ln e^2$  contain unit roots at the stationary  $I(0)$  level. The results in Table 2 confirm that  
236 the variables used in this study can be integrated with not more than order one, which is in compliance with the  
237 conditions of the ARDL bounds test.

238 <<<Insert Table 3>>>

239 According to the unit root results, this study can apply the ARDL bounds test for establishing cointegration  
240 based on  $\ln Y$  and the variance of  $\ln Y$  ( $\ln e^2$ ) equations, including the independent variables of  $\ln A$ ,  $\ln L$ ,  $\ln \text{AverT}$ ,

241 lnMinT, lnMaxT, lnRf, and lnRfd in analysis. The ARDL bounds structure estimates a general-to-specific  
 242 cointegration. The F-statistic value can be calculated using the Wald coefficient test. The results of general-to-  
 243 specific ARDL bounds tests shown in Table 3 indicate that the equations of lnY and  $\ln e^2$  have F-statistic values  
 244 of 8.624 and 10.961, respectively, with a statistical significance at the level of 0.01. The computed F-statistic  
 245 values of lnY and the variance of lnY ( $\ln e^2$ ) equations are greater than the upper critical bounds value or I(1) level  
 246 in all cases of Pesaran et al.'s (2001) statistical table. Thus, the null hypothesis of the absence of cointegration is  
 247 rejected. The results in Table 3 suggest that the lnY and  $\ln e^2$  equations included in the specification ARDL model  
 248 have cointegration with the variables of lnA, lnL, lnAverT, lnMinT, lnMaxT, lnRf, and lnRfd.

249 The results of the long-run and short-run effects of climatic and non-climatic variables on the economic growth  
 250 of the agricultural sector and their variability are presented in Table 4. The PMG estimation based on the ARDL  
 251 structure is performed using the Cobb-Douglas function. The assumptions from the PMG control are that the long-  
 252 run coefficients are to be homogeneous for all provinces, and the short-run coefficients are to be heterogeneous  
 253 for provincial-specific effects.

254 <<<Insert Table 4>>>

255 The long-run coefficients show that agricultural households and total rainfall have a significant positive effect  
 256 on the agricultural economy. A one percent increase in the number of agricultural households will increase the  
 257 agricultural economy by 0.335 percent, and a one percent increase in total rainfall will increase the agricultural  
 258 economy by 2.491 percent. However, mean minimum temperature, mean maximum temperature, and rainfall  
 259 intensity have a significant adverse effect on the agricultural economy. A one percent increase in the mean  
 260 minimum temperature, mean maximum temperature, and rainfall intensity will reduce the agricultural economy  
 261 by 6.223 percent, 6.238 percent, and 0.944 percent, respectively. There is no long-run association of agricultural  
 262 economy with agricultural land use and mean average temperature when considering the statistical significance  
 263 at the level of 0.05. The variability of the agricultural economy in Table 4 indicates that agricultural households  
 264 and mean average temperature have a significant negative effect on the variability of the agricultural economy. A  
 265 one percent increase in the number of agricultural households will decrease the variability of the agricultural  
 266 economy by 0.094 percent, and a one percent increase in mean average temperature will lead to a reduction in the  
 267 variability of the agricultural economy by 2.565 percent. However, agricultural land use has a significant positive  
 268 effect on the variability of the agricultural economy. A one percent increase in agricultural land use will lead to  
 269 increased variability of the agricultural economy by 0.128 percent. There is no long-run association of agricultural  
 270 economy variability with mean minimum temperature, mean maximum temperature, total rainfall, and rainfall  
 271 intensity when considering the statistical significance at the level of 0.05. The results of short-run coefficients in  
 272 Table 4 indicate that changes in mean average temperature and total rainfall are positively associated with the  
 273 agricultural economy, while changes in rainfall intensification are negatively associated with the agricultural  
 274 economy. In addition, variability of the agricultural economy is positively associated with the agricultural  
 275 households but negatively associated with the mean minimum temperature. Responding to sudden shocks, the  
 276 models of the agricultural economy and variability of the agricultural economy both have small convergence  
 277 coefficients ( $ECT_{it-1}$ ) of 0.063 and 0.248, respectively, with a negative sign as expected, and statistical significance  
 278 to indicate an adjustment to the equilibrium state that is not immediately returned to the steady-state.

279 From the results of the long-run coefficient analysis above, it is found that the climatic and non-climatic factors  
 280 that positively affect the agricultural economy, considering the magnitude of the impact, are the increases in total  
 281 rainfall and agricultural households, respectively. The findings point out that rainfall is a climatic factor that  
 282 positively influences the aggregate values of the agricultural sector, with most of Thailand's agricultural  
 283 production structure being crops such as rice, cassava, Para rubber, oil palm, sugarcane, etc. (Office of  
 284 Agricultural Economics 2021). There is a need to use a lot of water for growing these crops, especially in rainfed  
 285 agriculture, which accounts for approximately 78 percent of the country's total arable land. In addition, some  
 286 agricultural areas are found to be unsuitable for crop production, especially in the Northeast, which occupies  
 287 almost a third of the country. This is due to the fact that most of the aforementioned agricultural areas are outside  
 288 irrigated areas, have arid soil conditions, and have low productivity compared to other regions of the country. This  
 289 is consistent with the findings of Holst et al. (2013), which found that an increase in rainfall by 100 mm would  
 290 result in increased grain yields in cases of northern and southern China. Therefore, increased total rainfall will  
 291 result in an adequate water supply for cultivation and thus increase agricultural productivity (Holst et al. 2013;  
 292 Sinnarong et al. 2018), which will ultimately result in increased income for the agricultural sector. Meanwhile,  
 293 the climatic factors that negatively affect the agricultural economy, considering the magnitude of the impact, are  
 294 the increase in mean maximum temperature, mean minimum temperature, and rainfall intensity, respectively. The  
 295 findings can explain that mean maximum and mean minimum temperatures have a negative effect on the  
 296 productivity of agriculture because, during the period of maximum and minimum temperature increases, it will  
 297 affect plant growth, which will ultimately affect crop revenue. This finding is in line with the study of Alagidede

298 et al. (2016), which found that higher temperatures could affect economic performance in Sub-Saharan Africa.  
 299 Akram and Gulzar (2013) also confirmed that temperature harms economic growth and efficiency of agricultural  
 300 production, consistent with the studies by Cabas et al. (2010), Aye and Ater (2012), and Holst et al. (2013), which  
 301 found that temperature increased could reduce the productivity of agriculture. The distribution of rainfall is also  
 302 important for plant growth. Rainfall intensity has a detrimental effect on crops, causing crop damage and flooding  
 303 as well as causing the soil to lose its fertility and nutrients due to the leaching of the soil surface. The variability  
 304 in rainfall intensity has a direct negative effect on crop productivity (Nciizah and Wakindiki 2014). This finding  
 305 is in line with the study of Poudel and Kotani (2013), which found that variability of rainfall generally has adverse  
 306 impacts on crop productivity, consistent with the Weersink et al.'s (2010) results, which found that variation in  
 307 seasonal rainfall has a negative effect to the yields of corn, soybean, and winter wheat. Hence, the rainfall intensity  
 308 ultimately affects the income of the agricultural sector indirectly. The short-run coefficient analysis reveals that  
 309 climatic factors positively influencing the agricultural economy, considering the magnitude of the impact, are  
 310 mean average temperature, and the increase in total rainfall, while the intensity of total rainfall has a negative  
 311 influence on the agricultural economy. The findings show that changing climate factors such as decreases in mean  
 312 average temperature and total rainfall, as well as increases in rainfall intensification each year, will affect the  
 313 efficiency of agricultural production, which will reflect the agricultural value accordingly. For this reason,  
 314 governments and related stakeholders can use these findings, along with annual climate predictions, to effectively  
 315 plan to optimize seasonal cultivation patterns for producing crops, such as changing crop varieties to suit the  
 316 climatic conditions, for example, switching to crops that need less water, particularly during periods of drought  
 317 (i.e., cultivating maize instead of rice), changing techniques and cropping patterns to suit water sufficiency and  
 318 temperature conditions, and reserving water availability for cultivation during the dry season. Therefore, it is  
 319 concluded that optimizing cultivation patterns in each crop year will mitigate the effects of climate change on  
 320 agricultural productivity, thereby reducing the risk and income damage to the agricultural economy.

## 321 Conclusion and policy recommendations

322 The agricultural sector is essential to economic development in Thailand as it is responsible for the production of  
 323 food for humans and animals, as well as raw materials for other industrial sectors. Agriculture in the country is  
 324 particularly vulnerable due to its dependence on climatic factors such as rainfall, temperature, humidity, sunlight,  
 325 and so on, especially crop production, which represents most of the agricultural revenue from this sector, which  
 326 is directly and normally affected by weather and climate fluctuations. Climate change has a direct impact on  
 327 agricultural productivity, which also affects agricultural revenue. Thus, the main purpose of this study is to assess  
 328 the impact of climate change on the agricultural economy in Thailand. The panel datasets were obtained from  
 329 1995 to 2019 for 76 provincial levels. The ARDL-PMG estimation is employed using the Cobb-Douglas structure  
 330 to detect the impacts of non-climatic factors such as agricultural land use and agricultural households, as well as  
 331 climatic factors such as mean average temperature, mean minimum temperature, mean maximum temperature,  
 332 total rainfall, and rainfall intensification, on the agricultural economy and the variability of the agricultural  
 333 economy.

334 First, the results of general-to-specific ARDL bounds tests confirm the existence of long-run equilibrium in  
 335 the agricultural economy and its variability. This means that climatic and non-climatic factors have a long-term  
 336 association with the agricultural economy and variability of the agricultural economy in Thailand. Second, the  
 337 long-run estimation presents that the positive factors affecting the agricultural economy are the increase in total  
 338 rainfall and agricultural households. At the same time, the negative factors affecting the agricultural economy are  
 339 the increase in mean maximum temperature, mean minimum temperature, and rainfall intensity. The factor  
 340 contributing to the higher variability of the agricultural economy in the long-run association is the increase in  
 341 agricultural land use. The factors that reduce the variability of the agricultural economy are the increases in mean  
 342 average temperature and agricultural households. Third, the short-run estimation presents that the positive factors  
 343 affecting the agricultural economy are mean average temperature and total rainfall. The negative factor affecting  
 344 the agricultural economy is the increase in rainfall intensification. The factor contributing to the higher variability  
 345 of the agricultural economy in the short-run association is the increase in agricultural households, but the mean  
 346 minimum temperature is shown to reduce the variability of the agricultural economy.

347 The findings highlight the contributing factors to long-term increases in the agricultural economy and reducing  
 348 variability in the agricultural economy. This study confirms that extreme events, such as the increase in mean  
 349 maximum temperature, mean minimum temperature, and rainfall intensification, severely affect the agricultural  
 350 economy, but an increase in total rainfall will help mitigate that impact and will increase the growth of the  
 351 agricultural sector in the short-term and long-term period. Hence, from the findings of this study, it can be  
 352 concluded that agricultural households with better access to water resources can contribute to raising the  
 353 agricultural revenue of the country. Although extreme events such as increases in maximum and minimum  
 354 temperatures and rainfall intensification will affect agricultural productivity, having sufficient water resources



355 such as irrigation and rainfall for agriculture will mitigate the effects of such extreme events. In addition, the  
356 government and related stakeholders should raise awareness of climate change as it affects the economic growth  
357 of the country, which may have serious impacts on the economy, society, and environment in the near future. The  
358 growth of the agricultural sector must be calculated in terms of its effect on the environment, as agricultural  
359 production is one of the key factors for global warming. There should be appropriate agricultural production  
360 supervision and control measures to mitigate the negative impact on the environment to the greatest possible  
361 extent, such as using fertilizers properly to reduce carbon dioxide emissions or using suitable production  
362 techniques that help reduce environmental pollution as well as transferring responsibility for these impacts to the  
363 contributors such as farmers or producers, consumers, manufacturers, traders, and others throughout the  
364 agricultural supply chain. For the limitations, this empirical study provides an indirect analysis of the impact of  
365 climate and weather variability on the agricultural economy, so it would be worthwhile to focus directly on the  
366 efficiency of agricultural production, while other function forms, estimators, methods, and climatic factors might  
367 be considered in order to analyze the appropriate model to be most suitable for estimation.

368 **Table 1** Summary statistics of the variables

Variable	Mean	Max	Min	S.D.	Obs.
Y (million baht)	11,628	74,734	810	10,282	1,900
A (rai)	1,970,765	9,079,441	109,406	1,441,063	1,900
L (household)	76,944	344,880	1,930	58,317	1,900
AverT (°C)	27.415	29.773	22.342	1.003	1,900
MinT (°C)	22.798	31.950	15.858	1.535	1,900
MaxT (°C)	33.255	35.900	29.708	0.976	1,900
Rf (mm)	1,302.769	5,883.500	210.560	665.914	1,900
Rfd (mm/day)	8.489	30.886	2.570	3.475	1,900

369 Source: Office of Agricultural Economics, Thailand.

370 **Table 2** The results of panel unit root tests

Variable	LLC		IPS		ADF-Fisher		PP-Fisher	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
lnY	2.436 (0.992)	-28.481 ( $<0.001$ )	3.069 (0.998)	-26.332 ( $<0.001$ )	98.180 (0.999)	821.284 ( $<0.001$ )	93.371 (0.999)	1132.060 ( $<0.001$ )
lnA	-2.756 (0.002)		-1.204 (0.114)	-19.943 ( $<0.001$ )	177.920 (0.073)	636.959 ( $<0.001$ )	163.904 (0.240)	966.739 ( $<0.001$ )
lnL	13.170 (1.000)	-21.911 ( $<0.001$ )	6.946 (1.000)	-17.453 ( $<0.001$ )	125.453 (0.943)	582.076 ( $<0.001$ )	74.291 (1.000)	663.410 ( $<0.001$ )
lnAverT	-30.116 ( $<0.001$ )		-28.516 ( $<0.001$ )		893.831 ( $<0.001$ )		1567.120 ( $<0.001$ )	
lnMinT	-22.029 ( $<0.001$ )		-20.988 ( $<0.001$ )		667.874 ( $<0.001$ )		1456.920 ( $<0.001$ )	
lnMaxT	-26.908 ( $<0.001$ )		-23.882 ( $<0.001$ )		745.133 ( $<0.001$ )		1396.190 ( $<0.001$ )	
lnRf	-11.338 ( $<0.001$ )		-11.688 ( $<0.001$ )		404.166 ( $<0.001$ )		429.987 ( $<0.001$ )	
lnRfd	16.546 ( $<0.001$ )		-18.279 ( $<0.001$ )		593.208 ( $<0.001$ )		1173.100 ( $<0.001$ )	
ln $e^2$	-6.402 ( $<0.001$ )		-10.483 ( $<0.001$ )		382.741 ( $<0.001$ )		397.688 ( $<0.001$ )	

371 Note: The values in ( ) are the corresponding p-values.

372 **Table 3** The results of general-to-specific ARDL bounds tests

Variable	F-statistic		p-value		Conclusion	
lnY	8.624		<0.001		Cointegration	
ln $e^2$	10.961		<0.001		Cointegration	
Bounds test (F-statistic)	0.01 level		0.05 level		0.1 level	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
Case I	2.45	3.79	1.91	3.11	1.66	2.79
Case II	2.62	3.77	2.11	3.15	1.85	2.85
Case III	2.79	4.10	2.22	3.39	1.95	3.06
Case IV	2.93	4.06	2.38	3.41	2.13	3.09
Case V	3.15	4.43	2.55	3.68	2.26	3.34

373 Note: Bounds (F-statistic) tests refer to Pesaran et al. (2001).

374 **Table 4** The results of long-run and short-run effects using PMG estimation

Variable	Model: lnY			Model: ln $e^2$		
	Coefficient	t-statistic	p-value	Coefficient	t-statistic	p-value
<b>Long-run coefficient</b>						
lnA	0.120	0.842	0.399	0.128	4.187	<0.001
lnL	0.335	2.054	0.040	-0.094	-3.189	0.001
lnAverT	9.144	1.921	0.054	-2.565	-1.972	0.048
lnMinT	-6.223	-2.837	0.004	0.913	1.648	0.099
lnMaxT	-6.238	-2.237	0.025	1.501	1.853	0.064
lnRf	2.491	13.398	<0.001	-0.031	-1.224	0.221
lnRfd	-0.944	-4.977	<0.001	-0.023	-0.661	0.508
<b>Short-run coefficient</b>						
ECT <sub>it-1</sub>	-0.063	-10.414	<0.001	-0.248	-9.651	<0.001
$\Delta$ lnA	0.222	0.781	0.434	0.017	0.047	0.962
$\Delta$ lnL	-0.087	-1.779	0.075	0.297	3.007	0.002
$\Delta$ lnAverT	1.470	2.249	0.024	1.955	1.695	0.090
$\Delta$ lnMinT	-0.139	-0.368	0.712	-1.078	-2.023	0.043
$\Delta$ lnMaxT	-0.230	-0.534	0.593	-0.455	-0.588	0.556
$\Delta$ lnRf	0.066	2.533	0.011	0.172	1.806	0.071
$\Delta$ lnRfd	-0.096	-3.817	<0.001	-0.100	-1.762	0.078
No. of province	76			76		
No. of observations	1900			1900		

375  $\Delta$  is the first order of integration.

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386

## 387 **Declarations**

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