How Does Climate Change Affect Rice Production in Thailand? Assessing the Role of Financial Development

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Abstract

The study aims to examine the impacts of climate change (CC) and financial development (FD) on rice production (RP) in Thailand from the period 1969 to 2016 by using the ARDL and VECM framework. The empirical results revealed that in the long- run (LR) and short- run (SR) there is a reduction in rice production as temperature increase. The carbon dioxide (CO₂) positively affects rice production in the (LR), while this connection is negative in the SR. The empirical results further confirmed that in the LR and SR domestic credit provided by the financial sector positively and significantly improved rice production, while domestic credit to private sector by banks negatively affect rice production. The important input factors including cultivated area, fertilizers use and labor force positively and significantly contributed to rice production in both LR and SR. The LR causal link of all variables with rice production is validated. The SR causal association is unidirectional among temperature, CO₂ emissions, financial development, labor force and rice production. Additionally, the IRF and VDM outcomes also confirm that both climate change and socioeconomic development are crucial for rice production in Thailand. The study offers important policy implications to improve rice production with the help of improved financial system and climate controls.

Keywords: Climate change, Financial development, Rice production, ARDL, VECM framework

Introduction

Attention given to the factors aimed at improving economic growth, specifically, agriculture development to enhance food security, is essential. The reason being that without proper measures to alleviate food insecurity, the world will experience severe hunger (FAO 2017, Pickson & Boateng 2021). Agriculture is one of the critical components that can help enhance the world's food insecurity alleviation agenda (Chandio et al. 2021a, FAO 2013, Issahaku & Abdulai 2020, Pickson et al. 2021). Therefore, interventions and policies to promote agriculture growth need critical thoughtfulness. In Thailand, rice consumption is on the rise, making it a significant contributors of economic development and food security assurance. About 18% of Thailand's arable land is used for producing rice, i.e., approximately 9.38 million hectares are utilized for rice production (OAE 2018). In 2017, the nation recorded 25.24 million tons of rice, significantly contributing to Thailand's economic growth (OAE 2018). The largest rice field (63% of the rice field area) in Thailand can be found in the Northeast region. The suitable climate and geographical variations in the Northeast region have made it a favorable place for rice production, including the Thai Jasmine ("Kao Dok Mali 105" or "KDML105") rice variety, which covers about 66% of the Northeast region rice field area (RD 2016). However, as Thailand's population grows, demand for food, including rice is likely to increase. Therefore, if serious interventions are not made to curtail some challenges (e.g., climate change) distorting Thailand's agriculture production (e.g., rice production), the nation will be threatened with food insecurity due to failure to satisfy domestic rice demand (OAE 2018), which may also affect the nation's economic growth.

75 Climate change, which means a change in climatic conditions resulting from individual
76 and non-human, has been highlighted as a major element detrimentally affecting the
77 agricultural sector (Ali 2021, Challinor et al. 2007, Chandio et al. 2021b, Limantol et al.
78 2016). The story is not different in the case of Thailand's agricultural sector (Arunrat et al.
79 2017). Changes in climatic conditions can vary rainfall patterns, cause agricultural water
80 reduction, frequent droughts, and overall temperature increment (Chandio et al. 2021a,
81 Chandio et al. 2020a, Roul et al. 2017). Several studies projected that Thailand would
82 continue to experience severe climatic changes due to temperature and rainfall variations
83 in the future which will cause a fall in food production (Boonwichai et al. 2019, Chinvanho
84 et al. 2013). The studies of Shrestha et al. (2017) and Babel et al. (Babel et al. 2011) show
85 that the productivity of rice in northeast Thailand is likely to fall due to the fluctuations in
86 climatic conditions. Due to climatic variations, the lower Makong basin may record
87 variations in rainfed rice production (Mainuddin et al. 2013). Most studies in Thailand have
88 reported a high tendency of rice production reduction in the future as temperature and
89 rainfall fluctuate (Arunrat & Pumijumnong 2015, Boonwichai et al. 2019, Felkner et al.
90 2009, Shrestha et al. 2017). Again, the demand for crop irrigation water in the nation, which
91 is difficult to come by, increases as rainfall (temperature) reduces (rises); hence, rice
92 production is affected negatively (Chiarawipa & SDOODEE 2020, Mainuddin et al. 2012).
93 According to the IPCC fifth evaluation report, there is a high expectation that the mean
94 surface temperatures will increase up to 4.8°C globally by the close of the 21st century.
95 They also predicted that global precipitation might experience an increase or a decrease
96 depending on latitudes (IPCC 2014). All these reports about climate change above serve as

97 call to the government and policymakers of the nations around the world to provide several
98 initiatives that can promote the agricultural sector, the hardest hit of climatic variations.
99 Although the adverse effect of climate change on agriculture is highly unacceptable,
100 financial development can be considered an effective tool to remedy this menace to
101 enhance the agriculture sector. Therefore, to improve Thailand's rice production and the
102 agriculture sector as a whole, financial development must be given the maximum attention
103 (Boonwichai et al. 2019). Saqib et al. (2016) and Raifu and Aminu (2019) studies have
104 argued that credit can be a better element for financial development, implying that financial
105 development through agriculture credit can boost agriculture productivity and encourage
106 farmers' participation and agriculture transformation. According to prior studies (Churchill
107 & Marisetty 2020, Twumasi et al. 2019a), credit supply and accessibility can strengthen
108 economic growth, improve the adoption of technologies, and reduce poverty. While the
109 study of Chandio et al. (2018), the long-term (LT) and short-term (ST) loans impact on the
110 production of wheat in Pakistan, showed that credit increases wheat productivity, Ahmad
111 et al. (2020) revealed that Pakistan's agrarian sector rises in both short-and long-term
112 periods through Chinese FDI. Wheat production effect of credit distribution by commercial,
113 financial institutions in Pakistan has been explored by (Bashir & Mehmood 2010). The
114 study documented that wheat production increment is influenced by agricultural credit.
115 Thus, the wheat yield of credit receivers is 1.21 times higher than their counterparts who
116 are did not receive credit. In the context of Thailand, Boonwichai et al. (2019) showed that
117 credit is a crucial element to help rice farmers in their climate change adaptation measures;
118 hence, reducing climate change challenges to empower rice productivity. In the case of
119 Ghana, Twumasi et al. (2019b) studied the influence of saving mobilized on credit

accessibility and farm household productivity. The found out that farmers savings played a significant role in their production. Again, the result revealed that savers were more likely to obtained credit, indicating that peasants will be better-off through their savings and credit received from the financial market. Looking at the imperative advantages of financial development on agricultural growth, we analyze its impact on Thailand's rice production. This present study adds to the current literature by using the annual time-series data and the ARDL model to explore the robust LR and SR impacts of climate change and financial development on Thailand's rice production from the period, 1969 to 2016. Several studies (Arunrat et al. 2017, Boonwichai et al. 2019, Mainuddin et al. 2012, 2013) have focused on how changes in the climate and its adaptation measures affect rice production in Thailand rather than financial development. To our knowledge, this is first investigation that assess both LR and SR impacts of climate change and financial development on rice production in the context of Thailand. Also, we employed several econometric techniques such as the A.D.F and P.P conventional unit root testing, the ARDL model, the Johansen co-integration testing, and VECM approaches to achieve the study's main objective. In addition, several diagnostic tests to stabilize the model are applied in this study. The outcomes are particularly significant for policymakers, bringing to the forefront how financial development can improve agricultural productivity (e.g., rice production) in this climate change era as they try to design policies to enhance the nation's agricultural sector. The study's organization is as follows; literature review of financial development, climate change, and rice production nexus together with the study's hypotheses are discussed in section 2. Data and methodology of the study are reported in section 3, while section 4 provides the empirical outcomes. Last section provides the conclusion of the study.

Literature review and Hypotheses formulation

This section offers a conceptual analysis of how climate change as well as financial development can potentially influence rice production.

Climate change and rice production nexus

The harmful emission of carbon dioxide resulting from environmental pollution, climate change, and global warming effect on the agricultural-environmental system is significantly positive, according to previous studies. Climate change is causing land degradation (e.g., soil erosion, loss of soil natural fertility and nutrient), flooding, storms, loss of soil biodiversity, reduction in forests and rural land conversion, and health crisis, making future cultivation more vulnerable (Ojo & Baiyegunhi 2020, Okwala et al. 2020).

Many previous empirical studies inspected the effects of climate change on cereal yields/production in agrarian countries. For example, Guntukula (2020) studied the effects of variations in climate on primary food yield (e.g., wheat, rice, groundnut) in India. After using time-series dataset ranging from 1961 to 2017, the study concluded that climate change has a significant adverse association with food crops. The study, therefore, suggested that policies should be provided to mitigate the adverse effects of climatic variations on crop harvests in the nation, which will enhance food and nutritional security.

Also, using temperature patterns, carbon dioxide emissions, and rainfall patterns as a proxy for climate change, Chandio et al. (2020b) investigated how climate change affects the production of cereals in Turkey within the period 1968 to 2014. The study showed that the cereal harvest effect of, carbon dioxide emissions and the yearly mean temperature is negative. However, in the long-run, cereal production increases as the annual mean rainfall increases. The study revealed a prevailing long-run equipoise interconnection among

166 carbon dioxide emissions, moderate temperature, and rainfall patterns, as well as cereal
167 crop yield. The study suggested that policies related to adaptation strategies should be
168 encouraged to improve the nation's cereal production.

169 The study of Yu et al. (2010) established that the Consultative Group for International
170 Agricultural Research (CGIAR) has revealed that Bangladesh agricultural production is
171 likely to reduce due to climate change. This indicates that food insecurity is inevitable,
172 making the country victimize to the high risk of hunger due to poor climatic conditions.

173 Another study endorsed that Bangladesh rice production will be the hardest hit (reduction
174 in rice production by 7.4% annually with the period of 2005-2050) if climate change
175 adaption strategies are ignored or given less attention (Islam et al. 2020). Moreover,
176 Attiaoui and Boufateh (2019) assessed the climate alteration impact on cereal cultivation
177 in the case of Tunisia from 1975 to 2014, depicted that climate change (low rainfall) has
178 an adverse impact on cereal production. In the case of Thailand, Babel et al. (2011) and
179 Boonwichai et al. (Boonwichai et al. 2019) also showed that temperature rise and shortage
180 in rainfall reduced rice output. Compared to previous years, in 2012/13 cultivated paddy
181 area and production declined by 7.2% and 11.3%, respectively in Nepal due to unfavorable
182 climatic conditions (Khanal et al. 2018). The study furthermore revealed that Nepal's
183 paddy crop production is suffering from severe drought, and it is essential to provide
184 policies aimed at climate change alleviation and farmers' production improvement.

185 In the same manner, Sarkar et al. (2020) used annual average temperature (AAT) as a proxy
186 for climate variation and investigated Malaysian oil palm production and climate change
187 nexus from 1980 to 2010. The result mirrored previous studies' findings; thus, AAT

detrimentally affects palm oil production. Based on the above literature of climate change and cereal production, the study proposed the following hypothesis.

H1: Climate change negatively affects rice production in the case of Thailand.

Financial development and rice production nexus

As revealed in the previous section, the role of financial development in economic development through agriculture growth is undisputed since it may provide opportunities to unblock development prospects for disadvantaged segments of the population and depresses income inequality (Park & MERCADO JR 2018). Poor climate change mitigation and adaptation strategies, pest and disease control, irrigation technology, low-quality seeds, outmoded technology utilization, and many social and economic factors detrimentally affecting agriculture productivity can be curb if farmers are not financially excluded (Bogan et al. 2015). Several empirical scholars have investigated the role of financial development in the rural economy. For example, the study of Shahbaz et al. (2013), which used the Cobb-Douglas function to assess the long-term empirical connections between development in the agrarian sector and financial development from 1971 to 2011 showed that the bidirectional causality between development in the agrarian sector and financial development is profound.

Similarly, Zakaria et al. (2019) investigation of financial growth and agricultural production-nexus in South Asia from 1973 to 2015 showed an inverted U-shaped exist between these two indicators. However, other determinants of agricultural production including per capita income, industrialization and trade openness significantly enhanced agricultural production, while agricultural labor and CO₂ emissions significantly declined agricultural output.

In Pakistan, cereal production impact of climate variation, financial growth, and technical advancement, including fertilizers used and improved seeds, over the period 1977 to 2014 has been examined by Chandio et al. (2021b). The study applied the ARDL methodology to analyze the variables' long-term interconnections. Outcomes from the study discovered that the production of cereal increases as financial development enhances, which will help in achieving the country's food security agenda domestically.

Chandio et al. (2018) explored the credit (an attribute of financial development) effect on Pakistan's agricultural growth using primary data. The study reported that credit pushes farmers to adopt modern technologies and empowered them to be resource-efficient. Similarly, Anetor et al. (2016) advocated that policies to encourage the supply of loans at lower interest rates by the commercial banks are essential after a study in Nigeria showed a positive relationship between macro-economic development and commercial bank loans. An empirical study in Ghana also showed that credit accessibility improves youths' intensity of agriculture participation because credit can improve farm productivity by purchasing required inputs and adopting new technologies (Twumasi et al. 2019a). In terms of rice production, Omoregie et al. (2018) study, which analyzed the credit supply impact of Nigeria's rice production output from the period 1981 to 2016, reported that rice production output increases as credit supply grows. Given these scenarios of financial development and crop production, we proposed the following hypothesis.

H2: Financial development positively improves rice production in the case of Thailand.

Empirical Strategy and Data

Model Specification

Following the empirical recent works of Ahsan et al. (2020), Ahmad et al. (2020), Pickson et al. (2020) and Warsame et al. (2021), this study examines the short-and long-term (SLT) effects of climate warming (CW) and financial developments (FD) on rice production (RP) in the case of Thailand, the functional form can be expressed as follows:

$$\text{Rice production} = f(AT, CO_2, AR, FD1, FD2, FC, LF) \quad (1)$$

Applying several econometric techniques requires the same order of integration in the dataset. Therefore, we transformed all the study variables such as rice production, average temperature, CO₂ emissions, cultivated area, financial development (i.e., FD1 and FD2), fertilizer consumption, and labour force into logarithm. Hence, Eqn (1) can be rewritten as follows:

$$\begin{aligned} LRP_t = & Y_0 + Y_1 LAT_t + Y_2 LCO_{2t} + Y_3 LAR_t + Y_4 LFD1_t + Y_5 LFD2_t + Y_6 LFC_t + Y_7 LLF_t \\ & + \varepsilon_t \end{aligned} \quad (2)$$

where $LRP, LAT, LCO_2, LAR, LFD1, LFD2, LFC$ and LF represent the natural log of rice production, natural log of average temperature, natural log of CO₂ emissions, natural log of cultivated area, natural log of financial development proxy 1, natural log of financial development proxy 2, natural log of fertilizer use, and natural log of labor force. The parameters $Y_1, Y_2, Y_3, Y_4, Y_5, Y_6$ and Y_7 denote the long-run (LR) elasticity estimates, t denotes the time period, and ε_t is the white noise error term.

Empirical Model

During the empirical investigation, the empirical analysis's initial step is to test whether or not all the study variables are stationary. In this regard, we used the Augmented Dickey-Fuller (ADF) and PP unit root testing to discover the stationarity of the variables. After

confirming the order of integration of the selected variables, we applied the ARDL bounds testing methodology established by (Pesaran et al. 2001) to scrutinize the LT co-integration relationships between rice production, temperature, CO₂ emissions, cultivated area, financial developments, fertilizer use, and labor force. The J-J cointegration approach is employed for checking the robustness of co-integration amid the study variables. As compared to conventional cointegration approaches, the ARDL bounds testing approach is more appropriate. This method is appropriate concerning the study variables' stationary attributes. The ARDL approach turns to be appropriate when the study variables are integrated at the I(1) or I(0). This method also gives effective and efficient scientific backing for inadequate sample size (Pesaran et al. 2001, Shahbaz et al. 2013) as seen in Thailand. The ARDL method instantaneously discovers the SLT parameters. Hence by following (Raifu & Aminu 2019, Yazdi & Khanalizadeh 2014), the present study carry-out the bounds test based on the following equations:

$$\begin{aligned} \Delta LRP_t = & \Omega_0 + \sum_{i=1}^p \Omega_1 \Delta LRP_{t-i} + \sum_{i=1}^q \Omega_2 \Delta LAT_{t-i} + \sum_{i=1}^q \Omega_3 \Delta LCO_{2t-i} + \sum_{i=1}^q \Omega_4 \Delta LAR_{t-i} \\ & + \sum_{i=1}^q \Omega_5 \Delta LFD1_{t-i} + \sum_{i=1}^q \Omega_6 \Delta LFD2_{t-i} + \sum_{i=1}^q \Omega_7 \Delta LFC_{t-i} + \sum_{i=1}^q \Omega_8 \Delta LLF_{t-i} \\ & + \beta_1 LRP_{t-1} + \beta_2 LAT_{t-1} + \beta_3 LCO_{2t-1} + \beta_4 LAR_{t-1} + \beta_5 LFD1_{t-1} \\ & + \beta_6 LFD2_{t-1} + \beta_7 LFC_{t-1} + \beta_8 LLF_{t-1} \\ & + \varepsilon_t \end{aligned} \quad (3)$$

$$\begin{aligned} \Delta LAT_t = & \Omega_0 + \sum_{i=1}^p \Omega_1 \Delta LAT_{t-i} + \sum_{i=1}^q \Omega_2 \Delta LRP_{t-i} + \sum_{i=1}^q \Omega_3 \Delta LCO_{2t-i} + \sum_{i=1}^q \Omega_4 \Delta LAR_{t-i} \\ & + \sum_{i=1}^q \Omega_5 \Delta LFD1_{t-i} + \sum_{i=1}^q \Omega_6 \Delta LFD2_{t-i} + \sum_{i=1}^q \Omega_7 \Delta LFC_{t-i} + \sum_{i=1}^q \Omega_8 \Delta LLF_{t-i} \\ & + \beta_1 LAT_{t-1} + \beta_2 LRP_{t-1} + \beta_3 LCO_{2t-1} + \beta_4 LAR_{t-1} + \beta_5 LFD1_{t-1} \\ & + \beta_6 LFD2_{t-1} + \beta_7 LFC_{t-1} + \beta_8 LLF_{t-1} \\ & + \varepsilon_t \end{aligned} \quad (4)$$

279

$$\begin{aligned}
280 \quad \Delta LCO_{2t} = & \Omega_0 + \sum_{i=1}^p \Omega_1 \Delta LCO_{2t-i} + \sum_{i=1}^q \Omega_2 \Delta LAT_{t-i} + \sum_{i=1}^q \Omega_3 \Delta LRP_{t-i} + \sum_{i=1}^q \Omega_4 \Delta LAR_{t-i} \\
281 \quad & + \sum_{i=1}^q \Omega_5 \Delta LFD1_{t-i} + \sum_{i=1}^q \Omega_6 \Delta LFD2_{t-i} + \sum_{i=1}^q \Omega_7 \Delta LFC_{t-i} + \sum_{i=1}^q \Omega_8 \Delta LLF_{t-i} \\
282 \quad & + \beta_1 LCO_{2t-1} + \beta_2 LAT_{t-1} + \beta_3 LRP_{t-1} + \beta_4 LAR_{t-1} + \beta_5 LFD1_{t-1} \\
283 \quad & + \beta_6 LFD2_{t-1} + \beta_7 LFC_{t-1} + \beta_8 LLF_{t-1} \\
284 \quad & + \varepsilon_t
\end{aligned} \tag{5}$$

285

$$\begin{aligned}
286 \quad \Delta LAR_t = & \Omega_0 + \sum_{i=1}^p \Omega_1 \Delta LAR_{t-i} + \sum_{i=1}^q \Omega_2 \Delta LCO_{2t-i} + \sum_{i=1}^q \Omega_3 \Delta LAT_{t-i} + \sum_{i=1}^q \Omega_4 \Delta LRP_{t-i} \\
287 \quad & + \sum_{i=1}^q \Omega_5 \Delta LFD1_{t-i} + \sum_{i=1}^q \Omega_6 \Delta LFD2_{t-i} + \sum_{i=1}^q \Omega_7 \Delta LFC_{t-i} + \sum_{i=1}^q \Omega_8 \Delta LLF_{t-i} \\
288 \quad & + \beta_1 LAR_{t-1} + \beta_2 LCO_{2t-1} + \beta_3 LAT_{t-1} + \beta_4 LRP_{t-1} + \beta_5 LFD1_{t-1} \\
289 \quad & + \beta_6 LFD2_{t-1} + \beta_7 LFC_{t-1} + \beta_8 LLF_{t-1} \\
290 \quad & + \varepsilon_t
\end{aligned} \tag{6}$$

291

$$\begin{aligned}
292 \quad \Delta LFD1_t = & \Omega_0 + \sum_{i=1}^p \Omega_1 \Delta LFD1_{t-i} + \sum_{i=1}^q \Omega_2 \Delta LAR_{t-i} + \sum_{i=1}^q \Omega_3 \Delta LCO_{2t-i} + \sum_{i=1}^q \Omega_4 \Delta LAT_{t-i} \\
293 \quad & + \sum_{i=1}^q \Omega_5 \Delta LRP_{t-i} + \sum_{i=1}^q \Omega_6 \Delta LFD2_{t-i} + \sum_{i=1}^q \Omega_7 \Delta LFC_{t-i} + \sum_{i=1}^q \Omega_8 \Delta LLF_{t-i} \\
294 \quad & + \beta_1 LFD1_{t-1} + \beta_2 LAR_{t-1} + \beta_3 LCO_{2t-1} + \beta_4 LAT_{t-1} + \beta_5 LRP_{t-1} \\
295 \quad & + \beta_6 LFD2_{t-1} + \beta_7 LFC_{t-1} + \beta_8 LLF_{t-1} \\
296 \quad & + \varepsilon_t
\end{aligned} \tag{7}$$

297

$$\begin{aligned}
298 \quad \Delta LFD2_t = & \Omega_0 + \sum_{i=1}^p \Omega_1 \Delta LFD2_{t-i} + \sum_{i=1}^q \Omega_2 \Delta LFD1_{t-i} + \sum_{i=1}^q \Omega_3 \Delta LAR_{t-i} + \sum_{i=1}^q \Omega_4 \Delta LCO_{2t-i} \\
299 \quad & + \sum_{i=1}^q \Omega_5 \Delta LAT_{t-i} + \sum_{i=1}^q \Omega_6 \Delta LRP_{t-i} + \sum_{i=1}^q \Omega_7 \Delta LFC_{t-i} + \sum_{i=1}^q \Omega_8 \Delta LLF_{t-i} \\
300 \quad & + \beta_1 LFD2_{t-1} + \beta_2 LFD1_{t-1} + \beta_3 LAR_{t-1} + \beta_4 LCO_{2t-1} + \beta_5 LAT_{t-1} \\
301 \quad & + \beta_6 LRP_{t-1} + \beta_7 LFC_{t-1} + \beta_8 LLF_{t-1} \\
302 \quad & + \varepsilon_t
\end{aligned} \tag{8}$$

303

$$\begin{aligned}
\Delta LFC_t &= \Omega_0 + \sum_{i=1}^p \Omega_1 \Delta LFC_{t-i} + \sum_{i=1}^q \Omega_2 \Delta LFD2_{t-i} + \sum_{i=1}^q \Omega_3 \Delta LFD1_{t-i} + \sum_{i=1}^q \Omega_4 \Delta LAR_{t-i} \\
&+ \sum_{i=1}^q \Omega_5 \Delta LCO_{2t-i} + \sum_{i=1}^q \Omega_6 \Delta LAT_{t-i} + \sum_{i=1}^q \Omega_7 \Delta LRP_{t-i} + \sum_{i=1}^q \Omega_8 \Delta LLF_{t-i} \\
&+ \beta_1 LFC_{t-1} + \beta_2 LFD2_{t-1} + \beta_3 LFD1_{t-1} + \beta_4 LAR_{t-1} + \beta_5 LCO_{2t-1} \\
&+ \beta_6 LAT_{t-1} + \beta_7 LRP_{t-1} + \beta_8 LLF_{t-1} \\
&+ \varepsilon_t
\end{aligned} \tag{9}$$

$$\begin{aligned}
\Delta LLF_t &= \Omega_0 + \sum_{i=1}^p \Omega_1 \Delta LLF_{t-i} + \sum_{i=1}^q \Omega_2 \Delta LFC_{t-i} + \sum_{i=1}^q \Omega_3 \Delta LFD2_{t-i} + \sum_{i=1}^q \Omega_4 \Delta LFD1_{t-i} \\
&+ \sum_{i=1}^q \Omega_5 \Delta LAR_{t-i} + \sum_{i=1}^q \Omega_6 \Delta LCO_{2t-i} + \sum_{i=1}^q \Omega_7 \Delta LAT_{t-i} + \sum_{i=1}^q \Omega_8 \Delta LRP_{t-i} \\
&+ \beta_1 LLF_{t-1} + \beta_2 LFC_{t-1} + \beta_3 LFD2_{t-1} + \beta_4 LFD1_{t-1} + \beta_5 LAR_{t-1} \\
&+ \beta_6 LCO_{2t-1} + \beta_7 LAT_{t-1} + \beta_8 LRP_{t-1} \\
&+ \varepsilon_t
\end{aligned} \tag{10}$$

The parameters $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7$, and β_8 represent the long-run (LR) elasticity estimates while $\Omega_1, \Omega_2, \Omega_3, \Omega_4, \Omega_5, \Omega_6, \Omega_7$, and Ω_8 denote the short-run (SR) dynamics, the 1st differential operator is denoted by Δ , and ε_t is the error term. The F-statistics posit by Pesaran et al. (2001) assesses the mutual significant of the lagged level coefficient of the variables. This study investigates the long-term (LT) cointegration relationships among the variables based on the following hypothesis:

$$H_0 = \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = \beta_8 = 0 \text{ (No long-term cointegration)}$$

$$H_0 \neq \beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 \neq \beta_7 \neq \beta_8 \neq 0 \text{ (Exist a long-term cointegration)}$$

Pesaran et al. (2001) provided dual important asymptotic values, including the lower critical bound (LCB) and upper critical bound (UCB). The LCB and UCB help to analyze if there exists a long-term (LT) cointegration relationships between the variables or not. When all the study variables are stationarity and integrated at $I(0)$, the LCB could be

utilized to determine cointegration; then, using the UCB is needed. Where the calculated F-statistic is profound compared to UCB, the long-term (LT) cointegration connections between the series persists. The long-term (LT) cointegration interactions among the variables become meaningless until the computed F-statistic's LCB is realized. The calculated F-statistic lines in the mist of LCB and UCB, cointegration outcomes are doubtful.

Data Sources

This study used the annual time-series data from the period 1969 to 2016 for Thailand. Table 1 reports a list of selected variables used in our empirical estimations and their measurements. All the study variables are carefully selected based on their usage in the previous literature. Data for rice production, cultivated area, and fertilizer use are sourced from the FAO while data for temperature, CO₂ emissions, financial developments, and labor force are sourced from the WDI. Figure 1 presents the trend in LRP, LAT, LCO₂, LAR, LFD1, FD2, LFC, and LLF in the case of Thailand over the study period.

Table 1. Measurements of the study variables

Variable(s)	Measurements
RP	Rice production (tons)
AT	Average annual temperature
CO ₂	CO ₂ emissions (kt)
AR	Cultivated area (hectares)
FD1	Domestic credit provided by financial sector (% of GDP)
FD2	Domestic credit to private sector by banks (% of GDP)
FC	Fertilizer consumption (tons)
LF	Rural population (% of total population)

Figure 1. Trend of study variables over the period.

Analysis and Discussion

Figure 2 shows the the summary statistics of the study variables from 1969 to 2016 through box plots. In Table 2, we report the descriptive statistics and pair-wise correlation. The

outcomes confirmed the normal distribution for the series of rice production, temperature, CO₂ emissions, cultivated area, and FD1. According to the pair-wise correlation results, temperature, CO₂ emissions, cultivated area, financial development (i.e., FD1 and FD2), and fertilizer use have a strong relationship with rice production in a positive way, and labor force has a negative relationship with rice production. Both descriptive statistics and pair-wise correlation provide some preliminary information about the relation amid variables. However, several robustness econometric methods will be applied to obtain more valid findings about the interaction amid study variables.

The stationarity and order of integration of all variables should be tested before proceeding to cointegration investigation. In a time-series study with non-stationary series, false estimation problems arise. In order to apply the A.R.D.L method, the series must be stationary/integrated maximum at the first-order. For this purpose, firstly, the stationarity test was carried out with the help of conventional approaches such as A.D.F and P.P unit root testing. The outcomes of both conventional approaches are given in Table 3. Both tests reveal that all variables have unit roots in their levels. However, after taking first difference all variables become stationary. Since all variables are integrated of same order and findings confirmed that we can apply A.R.D.L approach to explore a long-term (LT) relationship amid the variables.

371 **Figure 2:** Box-plot summary statistics of **A** LRP, **B** LAT, **C** LCO₂, **D** LRA, **E** FD1, **F** FD2, **G** LFC, and **H** LLF.

372

373 **Table 2.** Descriptive statistics and correlation estimates

	LRP	LAT	LCO ₂	LRA	LFD1	LFD2	LFC	LLF
Mean	16.8943	3.2742	11.4102	16.0501	4.5066	4.2086	12.9968	4.2146
Median	16.8530	3.2734	11.6632	16.0550	4.6313	4.4807	13.4015	4.2506
Maximum	17.4558	3.3100	12.5680	16.2968	5.1841	5.1150	14.3131	4.3736
Minimum	16.3342	3.2304	9.5861	15.7294	3.2404	2.8250	10.6572	3.9425
Std. Dev.	0.3178	0.0181	0.9548	0.1357	0.5182	0.6163	1.1331	0.1208
Skewness	0.0946	-0.0578	-0.3557	-0.4600	-0.7068	-0.7296	-0.6075	-0.8759
Kurtosis	1.9329	2.6748	1.6698	3.2343	2.4981	2.4586	2.0330	2.6639
Jarque-Bera	2.3491	0.2381	4.5513	1.8031	4.5003	4.8455	4.8223	6.3641
Probability	0.3089	0.8877	0.1027	0.4059	0.1053	0.0886	0.0897	0.0414
Sum	810.9262	157.1662	547.6910	770.4064	216.3175	202.0132	623.8490	202.3050
Sum Sq. Dev.	4.7483	0.0154	42.8486	0.8659	12.6254	17.8544	60.3518	0.6866
Observations	48	48	48	48	48	48	48	48
LRP	1.0000							
LAT	0.2927**	1.0000						
LCO ₂	0.9275***	0.3926***	1.0000					
LRA	0.9107***	0.1583	0.8149***	1.0000				
LFD1	0.8429***	0.3193**	0.9472***	0.8037***	1.0000			
LFD2	0.7760***	0.3298**	0.9197***	0.7510***	0.9786***	1.0000		
LFC	0.9172***	0.3763***	0.9847***	0.8503***	0.9598***	0.9356***	1.0000	
LLF	-0.8851***	-0.3534**	-0.8574***	-0.7612***	-0.7654***	-0.6613***	-0.8338***	1.0000

374 **Note:** ***, and ** shows the level of significance at the 1% and 5%.

Table 3. Results of unit root testing

Variable(s)	A.D.F.		P.P.	
	Level	1st difference	Level	1st difference
LRP	-2.4314 (0.3594)	-9.0042*** (0.0000)	-2.6163 (0.2753)	-8.9460*** (0.0000)
LAT	0.739834 (0.8708)	-9.1485*** (0.0000)	0.2594 (0.7571)	-7.9094*** (0.0000)
LCO ₂	-1.0206 (0.9309)	-4.9111*** (0.0013)	-0.2626 (0.9895)	-4.8598*** (0.0015)
LRA	-1.3169 (0.8714)	-8.2019*** (0.0000)	-1.3169 (0.8714)	-8.1035*** (0.0000)
LFD1	-2.0318 (0.5688)	-4.7580*** (0.0020)	-2.2395 (0.4575)	-4.6412*** (0.0028)
LFD2	-1.6536 (0.7555)	-3.3973* (0.0642)	-1.4449 (0.8342)	-3.5076* (0.0503)
LFC	-1.1175 (0.9151)	-5.8657*** (0.0001)	-0.5806 (0.9756)	-16.1794 (0.0000)
LLF	-2.0980 (0.5331)	-11.9892*** (0.0000)	0.0934 (0.9963)	-8.9987*** (0.0000)

Note: null hypothesis = H_0 : there is no stationarity. ***, **, and * indicates the level of significance at the 1%, 5%, and, 10%.

Lag order selection and Long-run (LR) equilibrium relationship

After the assessment of integration level of the variables, in the following stage, the LR equilibrium connections amid the variables was evaluated by utilizing the A.R.D.L bounds testing method which is recommended by several authors (Abdul-Rahaman et al. , Ahsan et al. 2020, Anh et al. 2020, Zhai et al. 2017). A suitable lag length for the A.R.D.L. bounds testing method was also determined by applying the V.A.R model. The A.I.C., S.I.C., and H.Q.C information criterion were used to determine a suitable lag order. The outcomes of the tests for lag length are reported in Table 4. This study used the optimal lag length 2 based on the A.I.C.

Table 4. Lag order selection criteria

Lags	Log.L.	L.R.	F.P.E.	A.I.C.	H.Q.C.	S.I.C.
Lag = 0	362.9939	NA	5.20e-17	-14.7914	-14.6735	-14.4795
Lag = 1	790.7564	695.1141	1.41e-23	-29.9481	-28.8874	-27.1413*
Lag = 2	883.5668	119.8801*	5.30e-24*	-31.1486*	-29.1450*	-25.8468

Note: $L.R$ = sequential modified LR test statistic (each test at 5% level), $F.P.E$ = Final prediction error, $A.I.C$ = Akaike information criterion, $H.I.Q$ = Hannan-Quinn information criterion, and $S.I.C.$ = Schwarz information criterion. * shows lag order selected by the criterion.

Following the determination of a suitable lag order, the long-term cointegration association amid the study variables was explored. Table 5 shows the long-term cointegration test results. As depicted in Table 5, the calculated F statistic value (4.06**) of the model F_{LRP} (LRP/ LAT, LCO₂, LAR, LFD1, LFD2, LFC, LLF) is prominent compared with the critical of the upper bound $I(1)$ value at the 5% significance level. This means a long-term relationship was found amid the study variables. Likewise, the calculated F statistic values (10.35***, 4.77***) for the models F_{LAT} (LAT/ LRP, LCO₂, LAR, LFD1, LFD2, LFC, LLF) and F_{LCO_2} (LCO₂/LAT, LRP, LAR, LFD1, LFD2, LFC, LLF) are greater than the $I(1)$ critical value bound at the 1% significance level. Suggesting that there exists a long-term interaction between the variables. In contrast, the calculated F statistic values (1.59, 3.09, 1.88) for the models F_{LAR} (LAR/LCO₂, LAT, LRP, LFD1, LFD2, LFC, LLF), F_{LFD2} (LFD2/LFD1, LAR, LCO₂, LAT, LRP, LFC, LLF), and F_{LFC} (LFC/LFD2, LFD1, LAR, LCO₂, LAT, LRP, LLF) are not exceeds the $I(1)$ critical value bound at all levels of significance. Suggesting that no cointegration for these models. In addition, the calculated F statistic values (5.00***, 9.58***) for the models F_{LFD1} (LFD1/LAR, LCO₂, LAT, LRP, LFD2, LFC, LLF) and F_{LLF} (LLF/LFC, LFD2, LFD1, LAR, LCO₂, LAT, LRP) exceeds the $I(1)$ critical value bound at the 1% significance level.

Table 5. Results of A.R.D.L cointegrating

Estimated model(s)	F value	Cointegration
F_{LRP} (LRP/LAT, LCO ₂ , LAR, LFD1, LFD2, LFC, LLF)	4.06**	Yes
F_{LTA} (LTA/LRP, LCO ₂ , LAR, LFD1, LFD2, LFC, LLF)	10.35***	Yes
F_{LCO_2} (LCO ₂ /LAT, LRP, LAR, LFD1, LFD2, LFC, LLF)	4.77***	Yes
F_{LAR} (LAR/LCO ₂ , LAT, LRP, LFD1, LFD2, LFC, LLF)	1.59	No
F_{LFD1} (LFD1/LAR, LCO ₂ , LAT, LRP, LFD2, LFC, LLF)	5.00***	Yes
F_{LFD2} (LFD2/LFD1, LAR, LCO ₂ , LAT, LRP, LFC, LLF)	3.09	No

F_{LFC} (LFC/LFD2, LFD1, LAR, LCO ₂ , LAT, LRP, LLF)	1.88	No
F_{LLF} (LLF/LFC, LFD2, LFD1, LAR, LCO ₂ , LAT, LRP)	9.58***	Yes
Significance	I(0)	I(1)
10%	2.03	3.13
5%	2.32	3.50
1%	2.96	4.26

Note: null hypothesis = H_0 : there is no long-term cointegration . ***, and ** means 1%, and 5% level of significance.

Johnson cointegration tests

Additionally, to verify whether or not there exists a long-term (LT) association amid the study variables, we applied the Johansen's (1992) cointegration method, examined both trace, and maximum eigen statistics. Based on significant p-values of both statistics such as trace and maximum eigen, we established a long-term (LT) connections between the study variables. The Johansen cointegration test outcomes given in Table 6 confirmed three cointegration for both trace and maximum eigen statistics.

Table 6. Johanson cointegration

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.
None	0.8174	238.6283***	159.5297	0.0000
At most 1	0.7221	160.3862***	125.6154	0.0001
At most 2	0.6152	101.4810**	95.7536	0.0190
At most 3	0.4267	57.54785	69.8188	0.3183
At most 4	0.3055	31.95564	47.8561	0.6146
At most 5	0.2071	15.18392	29.7970	0.7680
At most 6	0.0904	4.508000	15.4947	0.8586
At most 7	0.0032	0.148216	3.8414	0.7002
Maximum Eigenvalue				
None	0.8174	78.2421***	52.3626	0.0000
At most 1	0.7221	58.9051**	46.2314	0.0014
At most 2	0.6152	43.9332**	40.0775	0.0175
At most 3	0.4267	25.5922	33.8768	0.3461
At most 4	0.3055	16.7717	27.5843	0.5996
At most 5	0.2071	10.6759	21.1316	0.6795
At most 6	0.0904	4.3597	14.2646	0.8196
At most 7	0.0032	0.1482	3.8414	0.7002

Note: null hypothesis = H_0 : there is no long-term cointegration . ***, and ** means 1%, and 5% level of significance.

Long- and short-run (LSR) estimations

Table 7 displays the long-and short-run (LSR) results. The findings of long-and short-run (LSR) imply that the interconnection between average temperature and rice production is negative but an insignificant, which indicates a one per cent increase in temperature decreases rice production with -0.0138% and -0.0111% in the both cases. This finding mirrors Ahmad et al. (2020) Guntukula (2020), and Pickson et al. (2020) studies, who revealed that maximum temperature declines the cereal production.

The LR results reveal that CO₂e has a positive relationship with rice production but an insignificant in the case of Thailand. This means CO₂e has no adverse effect on rice production. However, the SR results disclose that CO₂e-rice production nexus is negative, where a one per cent increase in atmospheric CO₂e concentration decreases rice production with -0.0236. These results mirror past literature (Ahmad et al. 2020, Chandio et al. 2020b, Pickson et al. 2020, Qureshi et al. 2016, Warsame et al. 2021). In the context of Pakistan, evidence provided by Qureshi et al. (2016) reported that CO₂e and GHGe affect rice production detrimentally.

The nexus of cultivated area and rice production has exposed a significant positive relationship in the LSR. This relationship suggests that an increase in cultivated area by a per cent improves rice production with 0.6403% and 1.1694% in the LSR. The study results are referring to the findings of Bashir and Mehmood (2010); Omoregie et al. (2018); Guntukula (2020); and Rayamajhee et al. (2020), who specified that the increase in the cultivated area had increased rice production.

Similarly, the LSR results indicate that the financial development (FD1) and rice production nexus are significantly positive, suggesting that a one percent increase in

447 financial development (FD1) enhances rice production 0.5727% and 0.4605%. Rural
448 households in Thailand boost their household income through rice crop cultivation. The
449 present evidence verified that financial development improves the livelihoods of rural
450 households by increasing rice production. The empirical results support the findings of
451 Afrin et al. (2017); Anh et al. (2020); Chandio et al. (2021b); and Zakaria et al. (2019),
452 who found that increase in financial development has improved rice production as well
453 agricultural growth.

454 When we use financial development (FD2), the results revealed that there is a significant
455 negative association between financial development (FD2) and rice production in the the
456 LSR. This provides an indication towards the characteristics of credit supplied by banks in
457 Thailand. Mostly, the lending procedure as well as time periods of formal credit is not
458 flexible compared to informal credit, which can be adjusted to match the crop production
459 progress. This result implies that a one per cent decrease in financial development (FD2)
460 declines rice production with -0.7609% and -0.2403% in both periods. Therefore, banking
461 sector credit process and the ultimate distribution needs substantial improvements for
462 increased rice productivity.

463 In addition, turning to other an important inputs (fertilizers use and labor force); the results
464 revealed the positive and significant relationship with rice production in the the LSR. The
465 contribution of both an important inputs to rice production is boosting and have positive,
466 beneficial impacts. Thus, it declares that a one per cent increase in fertilizers use and labor
467 force helps to increase rice production with 0.2672% and 0.8384% in the LR. The empirical
468 results mirror the results of Rehman et al. (2019); Rayamajhee et al. (2020); and Zhai et al.
469 (2017), Hamid et al (2021), who reported that fertilizers use and labor force, both input

factors significantly contributed to rice production. Lastly, we confirmed the robustness of the ARDL model by testing with various diagnostic assessments including the heteroscedasticity, normality, serial correlation LM, and Ramsey, respectively. The stability of LSR estimations is verified by CUSUM and CUSUMsq techniques. The results of both the CUSUM and CUSUMsq techniques are exhibited in the Figs. 3 and 4 confirmed that the model is stable. The outcomes of the stability test of coefficients are exhibited in the Fig. 5. As we can see from the Fig.5, according to the test results assessed parameters are robustness and stable over the period.

Table 7. Long-run (LR) and Short-run (SR) estimations

Variable(s)	Coefficient	Std. error	t-statistic	Prob.
Long-run estimation				
LAT	-0.0138	0.6025	-0.0229	0.9819
LCO ₂	0.1687	0.1051	1.6059	0.1181
LRA	0.6403**	0.2347	2.7279	0.0103
LFD1	0.5727***	0.1735	3.2994	0.0024
LFD2	-0.7609***	0.1530	-4.9708	0.0000
LFC	0.2672**	0.0998	2.6758	0.0117
LLF	0.8384**	0.3524	2.3787	0.0235
Constant	-1.5971	5.3598	-0.2979	0.7676
Short-run estimation				
DLRP(-1)	0.1959	0.1404	1.3952	0.1725
DLAT	-0.0111	0.4848	-0.0228	0.9819
DLCO ₂	-0.0236	0.1294	-0.1828	0.8561
DLCO ₂ (-1)	-0.0446	0.1486	-0.3005	0.7657
DLCO ₂ (-2)	0.2040**	0.0896	2.2771	0.0296
DLRA	1.1694***	0.1401	8.3433	0.0000
DLRA(-1)	-0.3313	0.2484	-1.3333	0.1918
DLRA(-2)	-0.3232*	0.1837	-1.7588	0.0882
DLFD1	0.4605***	0.1373	3.3525	0.0021
DLFD2	-0.2403**	0.1080	-2.2245	0.0333
DLFD2(-1)	-0.3714***	0.1337	-2.7780	0.0091
DLFC	-0.0855	0.0533	-1.6044	0.1184
DLFC(-1)	0.0472	0.0686	0.6878	0.4965
DLFC(-2)	0.2531***	0.0584	4.3292	0.0001
DLLF	0.6741**	0.2867	2.3507	0.0251
CointEq(-1)	-0.8040***	0.1404	-5.7240	0.0000
Diagnostic tests				
R-squared	0.9881			

Adjusted R ²	0.9826
F-stat	178.1149***
χ^2 HETERO	2.6432 (0.1110)
χ^2 NORMAL	1.3024 (0.5214)
χ^2 SERIAL	1.0658 (0.3571)
χ^2 RESET	0.7659 (0.4495)

Note: ***, **, and * means 1%, 5% and 10% level of significance.

Figure 3: Outcomes of CUSUM test

Figure 4: Outcomes of CUSUMsq test

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Figure 5: Outcomes of stability test of the Model's coefficients

Granger causality in the VECM framework

This study applied the VECM Granger causality approach to explore the direction of causality amid the variables, and this approach is appropriate for vital policy implications. Table 8 reports the VECM estimated findings. The causality connections of all factors with rice production confirm long-run (LR) links of all variables with rice production. The short-run (SR) causal association is unidirectional between temperature and rice production. Furthermore, CO₂ emissions, financial development and labor force are also affecting productivity level in the SR. The temperature is also linked with other factors in the LR and CO₂ emissions and temperature have a unidirectional link in the SR. Similarly, cultivated areas, financial development and labor also share unidirectional causality with rice production. The CO₂ emissions and remaining factors share a LR causal association. The one-way SR causal relationship is valid among rice production, labor, temperature, area, fertilizers, and emissions in the SR. The cultivation area has no LR connection with all factors; however, temperature, CO₂ emissions, financial development and labor share a SR relationship with cultivation area. Likewise, both proxies of financial development have a significant LR impact on rice production and cultivation area as well as labor force is also associated with financial development in the SR. All factors are not associated with fertilizers in the LR. The only significant connection in the SR is running from CO₂ emissions to fertilizers. Finally, LR association of all factors with labor force is also not significant, but a SR unidirectional link is valid from rice production, area, temperature and financial development to labor force. In short, climatic factors and financial development significantly affects rice production in LSR. The outcomes of Shahbaz et al. showed that the bidirectional causality between agricultural progress and financial improvement is

514 positive. Omoregie et al. (2018) reported a significant and positive connection between
515 credit supply and paddy crop production. Likewise, Chandio et al. (2020b) confirmed that
516 annual average temperature and CO₂ emissions negatively affects yields of cereal, while
517 the increment in yearly average rainfall positively influence yields of cereal in the LR. Thus,
518 the outcomes are consistent with literature and validate long-run impact of climatic factors
519 on rice productivity.

520

521 **Table 8.** VECM Granger-causality results.

Variables	Wald-statistic (Short-run causality)								Long-run causality
	LRP	LAT	LCO ₂	LRA	LFD1	LFD2	LFC	LLF	ECT(-1)
LRP	—	2.8689* (0.0903)	2.3383 (0.1262)	0.7838 (0.3760)	0.0918 (0.7618)	1.7866 (0.1813)	1.0373 (0.3084)	0.5319 (0.4658)	-0.6804*** (0.0035)
LAT	0.0074 (0.9310)	—	4.8855** (0.0271)	0.0009 (0.9756)	0.5640 (0.4526)	1.1817 (0.2770)	1.4912 (0.2220)	1.7418 (0.1869)	-0.2942*** (0.0014)
LCO ₂	3.8915** (0.0485)	2.7599 (0.0967)	—	0.8671 (0.3517)	0.2690 (0.6040)	0.0002 (0.9867)	0.0048 (0.9444)	12.0477*** (0.0005)	-0.1025*** (0.0004)
LRA	2.5154 (0.1127)	5.1900** (0.0227)	6.2871** (0.0122)	—	2.9299* (0.0869)	5.9443** (0.0148)	0.0019 (0.9648)	1.8423 (0.1747)	-0.0816 (0.6356)
LFD1	0.6032 (0.4373)	1.8431 (0.1746)	0.3416 (0.5589)	0.2266 (0.6340)	—	8.7624*** (0.0031)	0.1508 (0.6977)	0.1154 (0.7340)	-0.2268* (0.0646)
LFD2	4.6314** (0.0314)	3.8860** (0.0487)	0.2010 (0.6539)	1.6187 (0.2033)	17.6060*** (0.0000)	—	1.0859 (0.2974)	15.3033*** (0.0001)	-0.6511* (0.0667)
LFC	2.2029 (0.1377)	0.0063 (0.9364)	17.5403*** (0.0000)	0.9229 (0.3367)	0.4660 (0.4948)	0.6639 (0.4152)	—	1.7834 (0.1817)	0.2483 (0.3249)
LLF	3.2979* (0.0694)	3.9362** (0.0473)	0.4324 (0.5108)	3.8847** (0.0487)	9.6304*** (0.0019)	2.3903 (0.1221)	0.0084 (0.9266)	—	-0.0001 (0.5180)

522 *Note: ***, **, and * means 1%, 5% and 10% level of significance.*

523 ***Results of the IRF and VDM***

524 The outcomes are rechecked with Impulse Response Function (IRF) and Variance
525 Decomposition Method (VDM) after the specified time. The IRF of rice production stated
526 that temperature has negative impact but this impact decreases gradually in long run. The
527 connection between CO₂ emission and rice productivity is relatively stable and positive
528 during all periods. The association between cultivation area and rice production
529 experienced a significant decrease and became stable after few periods. The link between
530 two variables remains positive till end. The association of both financial development
531 proxies with rice production is different. The impact of domestic credit to private sector is
532 positive and the affiliation of banking credit is negative. However, this negative association
533 has been improving with the passage of time and turned positive at the end. The impact of
534 fertilizers on rice productivity is stable and positive in the long run but labor force indicates
535 a negative association that improves as time passes and touches the positive note in the
536 long run (see Figure 6).

Figure 6: Impulse Response Function

Additionally, the outcomes of VDM in Table 9 indicate that the impact of financial development and climate change factors improves in the long run. The most prominent impact comes from emissions, financial development, fertilizers, and cultivation area. These outcomes also validate the ultimate long-run association of financial development and climatic factors on rice production in the long run. Thus, both climate change and socioeconomic development is crucial for rice production in Thailand, especially in the long-run.

Table 9. Variance Decomposition of LNRP

Period	S.E.	LRP	LAT	LCO ₂	LRA	LFD1	LFD2	LFC	LLF
1	0.082	100.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.097	90.578	0.010	1.758	2.366	0.221	3.103	1.942	0.017
3	0.108	82.123	0.094	3.292	3.002	0.229	6.600	4.603	0.053
4	0.118	75.843	0.287	4.393	2.861	0.195	9.378	6.938	0.102
5	0.126	71.352	0.476	5.225	2.571	0.222	11.255	8.7371	0.159
6	0.133	68.145	0.612	5.933	2.318	0.311	12.355	10.102	0.221
7	0.139	65.804	0.689	6.603	2.125	0.438	12.867	11.184	0.286
8	0.144	64.029	0.716	7.279	1.982	0.577	12.964	12.094	0.356
9	0.149	62.607	0.707	7.979	1.881	0.714	12.782	12.899	0.428
10	0.152	61.384	0.679	8.705	1.824	0.839	12.430	13.632	0.503
11	0.156	60.248	0.652	9.447	1.820	0.948	11.996	14.304	0.581
12	0.159	59.109	0.645	10.191	1.885	1.040	11.555	14.912	0.660
13	0.161	57.899	0.679	10.916	2.037	1.112	11.170	15.443	0.739
14	0.164	56.567	0.773	11.601	2.296	1.165	10.895	15.882	0.817
15	0.167	55.078	0.943	12.223	2.675	1.199	10.772	16.214	0.892

Conclusion and policy implications

In Thailand, as in many other Asian countries where rice is a staple food crop, and it is major source of income for the vast majority of rural households. Several studies have shown that climate change significantly affected crops yield in developing regions. To address the climate variability issue and financial development nexus, we examined the SR and LR rice production impact of climate change and financial growth using Thailand as a case study. The data used was from the period 1969 to 2016. Other important rice production determinants incorporated in the study include cultivated area, fertilizer use, and agrarian labor force. The ARDL model was employed to explore the LSR dynamics relationship between the study variables. The VECM based Granger causality test was also applied to analyze the data for causal connections.

The ARDL model results show that the study variables are cointegrated; in other words, the variables exhibited a long-term association among themselves. The findings confirmed that average temperature exerts an inverse effect on rice production in both the SR and LR.

CO₂e exerts a profound impact on rice production in the LR, while the SR exerts a negative effect indicating that the agricultural sector is extremely vulnerable to climate change, resulting in food insecurity, which directly affects rural households' livelihoods in developing countries. In addition, financial development (FD1) positively and statistically improves rice production in both cases indicating that financial development is crucial for improving the production of cereal crop and ensuring food security and reducing poverty in rural areas of developing nations. In contrast, banks' domestic credit to private sector as proxy of financial development (FD2) negatively influenced rice production in both short and long-run. This shows that domestic credit to the private sector by banks with inappropriate lending procedures may have adverse impacts on rice production and needs further improvements. In addition, cultivated area, fertilizers use and labor force positively and statistically contributed to rice production in the long-and short-run. These findings suggest that cultivated area, fertilizers use and labor force are important determinants of rice production and played a vital role to enhanced rice production in the case of Thailand. The causality connections of all factors with rice production confirm long run links of all variables with rice production. The short-run causal association is unidirectional between temperature and rice production. Furthermore, CO₂ emissions, financial development, and labor force are also affecting productivity level in short-run. Finally, the IRF and VDM outcomes also confirmed that both climate change and socioeconomic development are crucial for rice production in Thailand, especially in long-run. The study suggests that Thailand's banking sector should engage with more profound financial activities related to agriculture, especially short and medium-term loans should be provided to the farming community. This will enhance the banking sector's contribution and turn the negative

585 impact of banking credit into positive in the long run. On the same note, climate change
586 and primary factors of agriculture including fertilizers, cultivation area, and labor should
587 be monitored for increased productivity of rice in both long and short run. Therefore,
588 Thailand Government should reform the financial banking sector and expand the credit
589 supply to farming communities based on flexible procedure. To cope with climate change
590 and improve rice production, there is need to launch climate financing scheme through
591 banking sector and grant credit to farmers' at easy instalments.

592 **Authors' contributions**

593 **Abbas Ali Chandio** has accomplished the conception and design of the study, data
594 collection and analysis, drafting the work, and validation of the outcomes.

595 **Martinson Ankrah Twumasi** has contributed to writing the literature section.

596 **Fayyaz Ahmad** has contributed to data analysis and interpreted the results.

597 **Ghulam Raza Sargani** has reviewed and edited the manuscript.

598 **Yuansheng Jiang** has contributed to proofreading and final approval.

599 **Data availability**

600 The data will be available on request.

601 **Conflict of interest**

602 The authors declare that they have no conflict of interest.

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