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Short communication

Effect of climate variability on rubber production in Thailand

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Rising greenhouse gas emissions have intensified global warming and climate change, leading to higher temperatures and irregular rainfall that directly affect agricultural productivity—the sector most vulnerable to climate impacts (Trinh, 2018). Thailand is among the most climate-vulnerable nations (Germanwatch, 2021). Over the past four decades (1981–2020), temperatures have risen substantially, with the northern, northeastern, central, and eastern regions experiencing more rapid warming than the southern region, although there have been no substantial differences in rainfall changes. Current climate variability threatens Thailand's rain-fed agriculture, especially major crops such as rubber, rice, maize, sugarcane, and cassava, with each requiring specific water and temperature conditions that may shift under changing climates (Sdoodee, 2013).

Research studies on climate change and rubber production have been reported from different countries, including Nigeria (Mesike and Esekhade, 2014), India (Raj and Dey, 2004), Indonesia (Prasada *et al.,* 2021), and China (Shao-jun *et al.,* 2020). However, published research in Thailand remains limited, with most studies concentrating on the southern region. For example, Thaiburi *et al.,* (2021), using 1989–2019 panel data, reported that both rainfall and temperature had negatively affected yields. Makkaew and Sdoodee (2015) reported that increased rainfall days in Songkhla province had reduced rubber tapping opportunities. Thaiburi (2022) analyzed data from 2010 to 2020 across five southern provinces of Thailand, further confirming that temperature, rainfall, and their variability substantially influenced rubber production. Limsakul and Paengkaew (2014) demonstrated that rubber yield in southern coastal provinces was closely linked to ENSO, with higher yields during El Niño and lower yields during La Niña, reflecting the importance of rainfall intensity and frequency.

The present study investigated the influence of climatic factors on rubber yields across the three key rubber-cultivation regions (southern, eastern, northeastern) of Thailand. Given the growing disruptions to rainfall patterns caused by climate change, the analysis focused on rainfall variability, with temperature included as a control variable, under the hypothesis that rainfall exerts a stronger influence on rubber yields than temperature. The

Fig. 1: Major rubber cultivation regions in Thailand (orange)

study's findings should provide valuable insights for policymakers in formulating strategies to support farmers and improve water management practices, thereby enhancing the resilience of Thailand's rubber sector to climate variability.

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Table 1: Summary of variables by region

Variable	Eastern		Southern		Northeastern	
	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.
Monthly rubber production (tonnes/month)	3,925.2	4,516.7	17,457.7	15,610.0	2,169.0	3,464.2
Monthly rubber tapping area (ha/month)	34,586.8	29,468.7	135,787.8	101,309.4	20,511.1	3,808.7
Monthly average temperature (°C)	28.1	1.3	27.5	1.0	27.2	2.3
Monthly temperature variability (°C^2)	1.6	3.4	1.3	4.4	5.0	15.4
Monthly rainfall variability (mm^2)	232.8	557.6	252.9	488.0	127.8	220.7
Total monthly rainfall (mm)	187.7	232.5	210.0	199.3	121.7	

Table 2: Wald test for heteroscedasticity.

Test	Chi-square statistic	Probability
Wald test	4,526.71***	(0.0000)

The empirical analysis was conducted using panel data obtained from different Thai government organizations between 2005 and 2021 across 40 provinces divided into three regions-eastern (7 provinces), southern (14 provinces), and northeastern (19 provinces)—representing the major rubber cultivation areas of Thailand (Fig. 1). The study design followed the climate-economy framework of Dell *et al.,* (2014), combined with a Cobb-Douglas production function.

The weather data on monthly rainfall and average monthly temperature was collected from the Thai Meteorological Department (2021) for the period of 2005 to 2021. Both the monthly rainfall variability and monthly temperature variability were calculated based on their respective variances, derived from daily observations within each month. The rubber planting area and production data were collected from the Thai Office of Agricultural Economics (2022).

Monthly rainfall and temperature variability were derived from daily observations within each month. Given that the dataset included all daily records (30 or 31 days), each month was treated as a finite population of daily observations and variability was calculated using the population variance formula:

$$\sigma^2=\frac{1}{m}\sum_{d=1}^{m}(x_d-\mu)^2$$

where m is the number of days in the month, is the daily observation, and is the monthly population mean. As variance is defined as the average of squared deviations from the mean, the resulting units are expressed in squared terms (square millimeters for rainfall, degrees Celsius squared for temperature).

Empirical model

The empirical model developed incorporated rainfall variability as the primary variable of interest. In this analysis, the feasible generalized least squares (FGLS) approach was used to estimate the panel data. The empirical model is presented in Equation (1):

$$Prod_{it} = \alpha_1+\beta_1 Area_{it} +\beta_2 Ta_{it} +\beta_3 Tv_{it} +\beta_4 Rt_{it} + \beta_5 Rv_{it} + \beta_6 ERv_{it} +\beta_7 NERv_{it} + \beta_8 E_{it}+\beta_9 NE_{it} +U_{it} \quad (1)$$

where $Prod_{it}$ is the natural logarithm of the total rubber production per month (in kilograms) and $_{it}$ indicates province at *i* time *t*; $Area_{it}$ is the harvested rubber area (in rai); Ta_{it} is the average temperature per month (in degrees Celsius); Tv_{it} is the monthly temperature variability; is the total rainfall per month (in millimeters); RV_{it} is the monthly rainfall variability; ERv_{it} is the monthly rainfall variability in the eastern region (a dummy variable); $NERv_{it}$ is the monthly rainfall variability in the northeastern region (a dummy variable); E_{it} is the monthly rainfall variability in the eastern region (a dummy variable); NE_{it} is the monthly rainfall variability in the northeastern region (a dummy variable); U_{it} and is the unobservable error term for province *i* at time *t*. The descriptive statistics of the key variables are presented in Table 1.

Panel heteroscedasticity tests were conducted to assess the stationary variance of the error term by applying the Wald test. The null hypothesis was rejected as the model exhibited heteroscedasticity, indicating that the variance of the error terms was not constant (Table 2). To overcome this issue, we used the FGLS estimator, which checks the variables and provides efficient estimates in the presence of heteroscedasticity (Stock and Watson, 2020). Then, in the final step, we developed the model using effective techniques based on the estimation result.

Table 3 presents the effects of climatic factors on rubber production across 40 provinces in Thailand. The analysis revealed that climatic variables were strongly associated with production outcomes, with several variables being significant at the 99% confidence level: rubber tapping area, average temperature, temperature variability, total rainfall, and rainfall variability across the southern, eastern, and northeastern regions. Results revealed that the rubber tapping area had a significantly positive effect on production. The coefficient indicated that an increase of 1,000 ha of tapping area would raise production by 0.215%, consistent with the theory of agricultural supply.

Average temperature exerted a strong negative effect at the 99% confidence level. A 1 °C increase reduced rubber output by 39.8%. Higher temperatures impair rubber tree physiology, leading to leaf drop and reduced latex yield, as also reported by Sdoodee and Rongsawat (2012) and Thaiburi (2022). The temperature variability also had a significantly negative influence. A 1 °C² increase in temperature variability lowered production by 2.10%. This outcome reflects the detrimental role of temperature fluctuations in rubber growth, supporting the findings of Sdoodee and Rongsawat (2012), and Thaiburi (2022), who observed that climate variability disrupts tree physiology, growth, and yield potential, especially in southern Thailand.

Table 3: Rubber production function results for sample of 40 provinces in three regions (2005–2021).

Dependent variable rubber production (ln Prodit)	FGLS	Standard error
Rubber tapping area (thousands ha) (Areait)	0.0134***	0.0004206
Monthly average temperature (°C) (Tait)	-0.398***	0.0152000
Monthly temperature variability ($^oC^2$) (Tvit)	-0.0210***	0.0024400
Total monthly rainfall (100 mm) (Rtit)	0.244***	0.0251000
Monthly rainfall variability (100 mm^2) (Rvit)	-0.0872***	0.0122000
Interaction rainfall with eastern region (Rvit ×Eit)	0.0442**	0.0145000
Interaction rainfall with NE region (Rvit × NEit)	0.165***	0.0204000
Eastern: (Eit)[a]	-0.658***	0.0957000
Northeastern: (NEit)[a]	-1.850***	0.0867000
Constant	24.98***	0.4300000
Observations	8,160	
Log likelihood	-18643.18	
Probability (chi-square)	0.0000	

a indicates dummy variables representing regions, with southern region as base case;
** significant at 5%, *** significant at 1%.

Total rainfall had a significantly positive impact on yield. A 100 mm increase was associated with a 24.4% rise in production. This finding is consistent with Chaiyaphet *et al.,* (2015), who showed that rainfall positively influenced production in Nong Khai, Buriram, and Chachoengsao provinces, although negative effects were found in Surat Thani, indicating that rainfall's impact could vary by location.

Rainfall variability across three regions was examined using dummy variables, with the southern region set as the base case. This specification allowed the model to capture and compare the distinct regional effects of rainfall variability on rubber production. In the southern region, a 100 mm² increase in rainfall variability reduced production by 8.72%, consistent with Thaiburi (2022), who linked rainfall fluctuations to disease outbreaks and yield losses. In the eastern region, rainfall variability reduced production by 4.3%, corroborating earlier evidence from Thaiburi (2022) and Sdoodee and Somboonsuke (2015). In contrast, in the northeastern region, rainfall variability positively influenced production, with a 100 mm² increase raising yields by 7.78%. This outcome is consistent with Sangchanda *et al.,* (2014), who reported that higher precipitation enhanced tree girth in northeastern Thailand. In contrast, in the northeast, variability had beneficial effects, as additional rainfall improved growth (Sangchanda *et al.,* 2014).

This study analyzed the effects of rainfall variability on rubber production in Thailand's eastern, southern, and northeastern regions using a Cobb-Douglas production function and FGLS estimation. Based on the results, rainfall variability had negative impacts in the southern and eastern provinces but a positive effect in the northeast. These outcomes underscore the need for region-specific rubber variety development and targeted policy interventions. Future work should incorporate additional climatic indicators such as rainy days, humidity, and seasonal patterns, for a more comprehensive assessment.

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