The Impact of Climate Change on Agricultural Development in the Central Asian Countries: Evidence from Panel Data Analysis

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Why Is This Topic Important?

Impact of Climate Change on Central Asia's Agriculture

- Global Food Security Risk:
  - Climate change *threatens global food safety* by affecting crop production, crucial for feeding the global population and stabilizing agri-food chains (Wheeler & von Braun, 2013).
- Central Asia's Population and Agricultural Vulnerability:
  - Central Asia's population (~82.58 million, ~1% of the world population in 2024) *faces concerns* about mitigating climate change risks (Worldometer, n.d.).
  - Extreme climate events and increasing temperatures *threaten regional agriculture* (Liu et al., 2020; Saidaliyeva et al., 2024).
- Land and Climate Constraints:
  - *Only 20% of agricultural land is suitable* for crops (Babu & Djalalov, 2006; Mirzabaev, 2013; Liu et al., 2020).
  - *Average temperatures increased* by 16.7% from 1992 to 2022, while *precipitation levels remained* unchanged (World Bank, n.d.).

Why Is This Topic Important?

Agricultural Trends and Yield Increases

- Growth in Agricultural Output:
  - Despite climate challenges, *agricultural production has grown* significantly in Central Asia *over the past 27* years (FAO, n.d.; Liu et al., 2020); that is, the real value of agricultural products and crops (constant 2014-2016 USD) in 2022 increased by 2.83-fold and 3.7-fold compared to 1992, respectively.
- Crop Yields by Key Types:
  - Since 1996, *the yields of major crops* in Central Asia *have increased* by: Wheat: 1.9-fold, Potatoes: 2.2-fold, Cotton: 1.6-fold (FAO, n.d.).
- Other Factors Influencing Yields:
  - Rising temperatures generally harm crop production (Mall et al., 2017; Malhi et al., 2021; Chen et al., 2016).
  - The yield increases suggest other factors besides climate change have positively impacted agriculture.
  - Differentiating climate change effects from other agricultural drivers is essential for understanding Central Asia's agricultural development.

Novelties of the Study

Crop Simulation Modeling

- Definition:
  - Crop simulation modeling uses *mathematical models* to replicate crop growth, development, and yield under different environmental conditions.
  - Key climate variables: *temperature*, *precipitation*, *CO_2 levels* (Jones et al., 2003; White et al., 2011).
- Importance:
  - Critical for evaluating the *impacts of climate change* on crop yields.
  - Helps predict *future agricultural productivity* and informs *adaptation strategies* (Challinor et al., 2009; Rosenzweig et al., 2014).
- Disadvantages:
  - Other key *(socioeconomic) factors* such as agricultural land used for specific crops, agricultural machinery power, irrigated area, etc. *are typically ignored* (Challinor et al., 2010).

Novelties of the Study

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- Incorporating Both Climate and Socioeconomic Variables:
  - This study is one of the few that examines *both climate change* and *socioeconomic variables* as independent variables for Central Asia (Challinor et al., 2010; Ye et al., 2013; Gupta et al., 2014; Gul et al., 2022).
  - Previous studies often focused on only climate variables, excluding socioeconomic factors (Mueller et al., 2014; Sutton et al., 2013; Mirzabaev, 2013; Sommer et al., 2013).

- Treating Climate Variables as Random Terms:
  - Unlike other studies (Carter & Zhang, 1998; Mirzabaev, 2013; Thomas et al., 2021), this research treats *climate variables as random terms*, accounting for *territorial differences* that farmers may not fully comprehend (Zhou & Turvey, 2014; Sarwary et al., 2023).

Novelties of the Study

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- Nonlinear Relationships in Crop Yield:
  - This study is among the few that considers *nonlinear associations* between crop yield and climate variables (Liu et al., 2020; Mendelsohn, 2014; Wei et al., 2014; Mirzabaev, 2013).
  - Previous studies assumed *constant elasticity* of crop yield with respect to climate variables (Zhou & Turvey, 2014; Feng et al., 2021; Schierhorn et al., 2020).

- Interaction of Climate and Socioeconomic Variables:
  - It is one of the few studies to examine *interaction terms* between climate and socioeconomic factors in Central Asia (Zhou & Turvey, 2014; Xin et al., 2013).
  - Unlike this study, Zhou & Turvey (2014) assumed constant elasticity for *total value product*, and Xin et al. (2013) based their analysis on *household survey data*.

Research Questions and Aims of the Study

- Based on the covered studies, the **research questions** of this study can be written as:
  - Are there *nonlinear associations* between crop yield (of wheat, cotton, potatoes) and regressors in the Central Asia?
  - Do *elasticities v*ary across the region countries?
  - Are the crop yields *correlated with the interaction terms* between climate and other variables?

- Thus, the **aims of the study** are:
  - *To examine the nonlinear associations* between crop yields (wheat, cotton, potatoes) and relevant climate and socioeconomic variables in Central Asia.
  - *To analyze the variability of elasticities* of crop yields across different countries in Central Asia.
  - *To investigate the association between crop yields and the interaction terms* between climate variables and other factors (such as socioeconomic conditions).
  - These objectives are key in guiding *evidence-based policy-making* that enhances *agricultural sustainability* and *food security* in the face of climate change across Central Asia.

Research Methodology

Model Framework and Data Sources

- Crop Yield Function:
  - Crop yields (wheat, potatoes, cotton) are a function of *climate variables* (temperature, precipitation) and *agricultural inputs* (capital, land, labor). But there we added *other variables* as well.

- Data Collection (1992-2023):
  - Crop yield, land use, agr. machinery pwr, irrigated area, chemical fertilizer use, and agr. employment: *FAO (n.d.)* and *OWD* (Ritchie et al., 2023); Climate variables: *World Bank (n.d.)*.

Research Methodology

Model Specification and Testing Questions

- Panel Data Model:
  - $Y_{ijt} = \omega_i + \varphi_t + \alpha_1 C_{ijt} + \alpha_2 Ld_{ijt} + \alpha_3 K_{it} + \alpha_4 L_{it} + \alpha_5 C_{ijt}^2 + \alpha_6 Ld_{ijt}^2 + \alpha_7 K_{it}^2 + \alpha_8 L_{it}^2 + \alpha_9 (C_{ijt} \cdot Ld_{ijt}) + \alpha_{10} (C_{ijt} \cdot K_{it}) + \alpha_{11} (C_{ijt} \cdot L_{it}) + u_{ijt}$
    - where *Y* crop yield (in tons per hectare); *C* is a vector of climate variables (temperature and precipitation, Celsius and mm);
    - *Ld* is the crop-specific total use in 1,000 hectares;
    - *K* is the vector of capital indicators (agro machinery power (10,000 kW), fertilizer usage (1,000 ha), and irrigated area (1,000 ha);
    - *L* is the agricultural labor (10,000 persons);
    - ω_i the country-specific effects;
    - φ_t is the time-specific affects;
    - *u* the error term.
- Answering Research Questions using the model:
  - Test the individual significances of squared terms (α_5 to α_8) for *nonlinear effects* (RQ1).
  - Use *Hausman (1978)* test to determine whether to treat country and time effects as fixed or random (RQ2).
  - Test *interaction terms* (α_9 to α_{11}) between climate variables and other inputs (RQ3).

Empirical Model Results and Discussions?

- Model Types:
  - There are three types of models; *linear*, *nonlinear*, and *interaction* models.

- Some initial results obtained in the FE/RE models:
  - *Adding* squares and interactions *improved* the goodness-of-fit improved significantly, from 33% to 51-79% for wheat, 37% to 57-69% for potatoes, and 62% to 65-68% for cotton.
  - *Fixed-effects* models were *consistent in four* out of nine cases.
  - Yet, the *inclusion of interaction terms* made random-effects models more consistent.
  - The country-specific effects were needed in three models, while time-specific effects were significant in almost all models except the linear model for wheat.

Empirical Model Results and Discussions?

- The *estimations of elasticities* in the FE/RE models:

	Yield of								
	Wheat			**Potato**			**Cotton**		
	Linear	**Nonlinear**	**Interaction**	**Linear**	**Nonlinear**	**Interaction**	**Linear**	**Nonlinear**	**Interaction**
Temperature	0.073			3.634	-8.74		0.728	2.389	-17.47
Precipitation							0.784		
Land		-1.654	1.919		-0.541	-8.517			9.571
Agro machinery pwr	-0.373	-0.36		-0.329		-16.46	-0.156	-0.209	14.81
Fertilizer		-0.205		0.105	-0.147		0.115		
Irrigated area	-0.249	-6.239		0.287	3.16				
Agro employment				0.4					-11.44

(green) significant at either 1% or 5% levels

(yellow) significant at 10 level

Empirical Model Results and Discussions?

- The *turning points* and *types of nonlinear association* in the FE/RE models:

	Yield of wheat		Yield of potato		Yield of cotton	
	Turning point	Nature of correlation	Turning point	Nature of correlation	Turning point	Nature of correlation
Temperature			3.9469	U-shaped	12.7676	inverse U-shaped
Precipitation						
Land	145.76	U-shaped	79.60	U-shaped		
Agro machinery pwr	462073.04	U-shaped			0.0006	convex
Fertilizer	6.00	U-shaped	4.34	U-shaped		
Irrigated area	2256.42	U-shaped	1724.74	inverse U-shaped		
Agro employment						
	(green)	significant at either 1% or 5% levels				
	(yellow)	significant at 10 level				

Conclusion and Policy Implications

- Temperature Influences:
  - Temperature has both linear and nonlinear effects on crop yields, with significant implications for potatoes and cotton, highlighting the need for targeted *climate adaptation strategies*.
- Precipitation's Role:
  - Precipitation shows a linear relationship only with cotton yield and does not significantly affect other crops, indicating *limited impact* on overall agricultural productivity.
- Land Use Dynamics:
  - Land use does not have a direct linear impact on yields but affects wheat and potato outputs nonlinearly, suggesting the importance of *optimizing land management practices*.
- Agricultural Inputs:
  - Agricultural machinery and fertilizers play critical roles in crop yields, with both linear and nonlinear effects *necessitating careful management to maximize productivity*.
- Irrigation and Employment:
  - While irrigation has beneficial impacts on certain crop yields, agricultural employment shows limited influence, emphasizing the *need for strategic investments in irrigation infrastructure* over labor adjustments.

Thanks for Listening!

Any Questions?