CLIMATIC SENSITIVITY OF AGRICULTURE IN EURASIA: IDENTIFYING CLIMATE EFFECTS USING WEATHER OBSERVATIONS

Abstract: We study the impacts of climate change on agricultural sector productivity in three major grain producing and exporting countries in Eurasia: Kazakhstan, Ukraine, and Russia (KUR). We employ a panel data model that enables consistent identification of climate effects by using, in addition to within unit variation, between group variation, specifically variation between groups of regions located in zones with similar climates. Our dataset covers 62 regions in Russia, 22 regions in Ukraine and 8 regions in Kazakhstan, and spans the period 2000–2020. Our preliminary results indicate that climate change negatively affects the agricultural sector performance only in regions situated in climatic zones known for relatively moderate past summer temperatures. In contrast to regions with warmer climates, these regions still specialize in growing spring cereals. We also find empirical evidence for a slight positive effect of climate change on farm economic performance in high-latitude regions in Russia due to warmer autumns.

Introduction

Political and economic reforms of the 1990s induced in the first two decades of the 21st century a notable agricultural sector productivity growth in Central and Eastern European countries (CEECs) and 15 post-Soviet states (PSS), including Kazakhstan, Ukraine, and Russia (KUR) – three important grain producing and exporting nations in Eurasia (Swinnen et al., 2009; Fugli, 2015; USDA ERS, 2023).

Swinnen et al. (2009) provide a profound discussion of main factors explaining agricultural productivity growth and different trends in its evolution across CEESs and PSS. This subject also has been extensively studied in several empirical investigations in the recent decade. For KUR, the literature refers to weather shocks as an important factor of crop harvest volatility (Lioubimtseva and Henebry, 2012; Bokusheva and Hockmann, 2006, Liefert, 2002). However, the effect of climatic variability and weather shocks on the recent agricultural productivity trends in KUR remains rather unstudied. The identification of the impacts of climate change on an economic outcome variable requires the availability of long-term observations on both, the economic performance and weather. While reliable weather data have been available for KUR for the periods before the 1990s, meaningful indicators of farm economic performance exist for the region only for the period after the transition to a market economy. Indeed, it is well known that farm decisions in the Soviet era were not driven by market forces but made within the Soviet economic planning system.

Furthermore, the Russia's war against Ukraine seriously affected the Ukrainian economy[1] and the Russian economic policy.[2] It very likely has caused structural breaks in agricultural time series for both countries.[3] Therefore, using data for the period 2000–2020 is the only option to draw consistent inferences about the economic impacts of climate change on agriculture in KUR. In this context, our study presents a unique quasi-natural experiment that allows consistent identification of the impacts of climate change on agricultural productivity in KUR in the presence of farm adaptation actions.

Methodology and data

We identify climatic sensitivity of agricultural production in KUR following the identification strategy proposed by Hsiang (2016). In that, the climate affects the economic output Y in two ways: firstly, the climate in a location determines the weather (variation) in that location $\mathbf{c} \in \mathbf{C}$ which has a direct effect on Y; secondly, farmers' beliefs over the structure of climate, $\mathbf{b}$, may influence their actions and, hence, also their production outcome viz.:

$$Y(\mathbf{C}) = Y[\mathbf{c}(\mathbf{C}), \mathbf{b}(\mathbf{C})], \tag{1}$$

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[1] Since the outbreak of the war, Ukrainian farmers must permanently adjust their operations and processes due to disruptions in value chains, and direct and indirect impacts of military actions taking place on the territory of the country.

[2] The current economic regime in Russia is characterized by government's extensive interventions aimed at import substitution, a restricted access to international markets due to economic sanctions against Russia applied by the EU, the U.S., and some other countries, and, finally, also Russia's countersanctions such as bans on the export of several agricultural and other commodities.

[3] Though Kazakhstani farmers are comparatively less affected by the war in Ukraine, a low number of administrative regions in the country sets constraints on the application of panel data approaches for Kazakhstan.

where $\mathbf{C}$ can be defined as a vector of selected climatologies, such as long-term averages of selected weather variables. Accordingly, the farmer optimization problem can be formulated as follows:

$$Y(\mathbf{C}) = [\mathbf{b}^{*}(\mathbf{C}), \mathbf{c}(\mathbf{C})] = \max_{b \in R^{N}} z\,[\mathbf{b}, \mathbf{c}(\mathbf{C})], \tag{2}$$

where $\mathbf{b}^{*}(\mathbf{C})$ $(b = 1, 2, .., N)$ is the vector of actions maximizing producer's value function z under climate $\mathbf{C}$ (Hsiang, 2016, p. 54).

In this setting, farm adaptation efforts may vary across locations with different climates. However, given that farmers' adaptation actions are guided by economic considerations, the net effect of adaptation decisions can be expected to be zero in any climate because any marginal benefits are offset by additional marginal costs by the Envelope Theorem.

Therefore, given that in each climate farms undertake actions allowing them to maximize z under the current climate, it is rationale to expect that any difference in the optimized outcomes between two farms situated in slightly different climates is associated with the effect of slightly different climates. Consequently, for a sample of farms situated in different climates, the impact of climate can be identified by conditioning an economic outcome variable on both location-specific climates $(\mathbf{C})$ and period-specific weather observations $\mathbf{c}(\mathbf{C})$.[4] This implies a procedure that draws inferences using both within variation in unit time series and between variation across respective climatic intervals. This approach is particularly beneficial for studying the effects of climate change over large territories covering diverse climatic zone, as applies to KUR.

We conduct our empirical analysis using the data on gross regional products from agriculture, arable land, and other indicators for 62 regions in Russia, 22 regions in Ukraine, and 8 regions in Kazakhstan for the period 2000–2020[5] (Ukrstat, 2000-2021; Rosstat, 2000-2021; Qazstat, 2000-2021). To derive relevant weather indicators, we use the ERA5 LAND reanalysis data and weight them with MODIS Land Cover data on agricultural land for the period 1970–2020. We define season-specific climatic intervals (CIs) by computing for each region-year observation 30-year rolling averages of respective season's temperatures. In a next step, we split the corresponding distributions into 5 equal intervals using the quintiles of the seasonal temperature climatology distributions in the period 1991–2020. For each season, the interval with the highest climatology is referred to as CI1 and set to the reference interval, while the interval with the lowest seasonal climatology is called CI5.

We employ a reduced-form economic output response model akin to that by Gammans et al. (2022):

$$\ln y_{it} = \alpha_i + \boldsymbol{\beta}\boldsymbol{e}_{sit}(i,t)\boldsymbol{x}_{it} + f_g(t) + \varphi \boldsymbol{h}_{\mathrm{it}} + \varepsilon_{it}\ , \tag{3}$$

where y_{it} is the gross regional product from agriculture per hectare of arable land in region i $(i = 1, 2, .., N = 92)$ and period t $(t = 1, 2, .., T = 21)$, α_i are region fixed effects, $\boldsymbol{x}_{it}$ is a M–element vector of weather variables, $f_g(t)$ is time trend for groups of regions with similar trends in economic and technological development, $\boldsymbol{e}_{sit}(i,t)$ is a vector of dummy variables indicating for each season s the climatic interval where region i is located in period t. $\boldsymbol{h}_{\mathrm{it}}$ refers to a vector of control variables and ε_{it} are Conley-HAC standard errors adjusted for spatial and serial correlation (Conley 1999; Hsiang 2010).

Results

We estimate model (3) using seasonal temperature and precipitation variables. Our preliminary results indicate that climate change has a significant and negative impact on agricultural sector productivity in the regions situated in summer CIs 3 and 4 (Fig. 1). An increase in summer temperatures by 1 degree C in these CIs is associated with an average decline in the dependent variable of 1.3 and 2.2%, respectively.

Although these two CIs are associated with relatively moderate summer temperatures (with the long-term average summer temperatures of 18.6–19.7 and 17.6–18.6 degrees C, respectively), agricultural productivity in these CIs appears to be affected by global warming stronger than in regions with hotter

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[4] By definition, interannual weather variation does not cause changes in climate, and respectively should not induce any changes in farmers' beliefs about climate; concurrently, as some parts of weather distribution in a climate mimic climate in nearby locations, interannual weather variation allows to identify differences in expected optimized outcomes associated with cross-sectional differences in climate.

[5] We do not consider the regions Luhansk, Donetsk, and Crimea in our study as agricultural statistics were missing/incomplete for these regions since 2014.

climates, summer CI1 and CI2 (with the long-term average summer temperatures above 21.0 and 19.7–21.0 degrees C, respectively). An explanation for this outcome is that regions in summer CI1 and CI2 grow predominantly winter grains that may help them to reduce their exposure to extreme summer temperatures. In contrast, regions situated in summer CI3 and CI4 still predominantly produce spring grains that are generally more sensitive to extreme summer temperatures.

By increasing autumn and winter temperatures in the regions situated in higher latitudes of Eurasia and known for rather cold autumns and winters, global warming is expected to improve climatic conditions for agricultural production in these regions. According to our model estimates, the effects of autumn and winter temperatures is not found to be significant except for the regions in the autumn CI with coldest temperatures (autumn CI5), where warmer autumns were found to have a slightly positive effect on farms' economic performance.

Fig.1: Climatic intervals derived using summer temperature climatologies: 1991–2020.

Note: Black contours correspond with countries' borders, whereas white contours show regional boundaries. Countries and region borders are presented according to FAO (2023).

We intend to conduct robustness checks of our preliminary results using alternative formulations of climatic intervals, an alternative set of weather variables including degree-days measures, and an alternative estimator.

Conclusions

Our preliminary results indicate that climate change did not significantly affect agricultural productivity in most productive agricultural regions of Ukraine and Russia over the period 2000–2020. However, high summer temperatures affected productivity of agriculture in all main grain-producing regions of Kazakhstan, 12 Ukrainian regions situated in the Northwest of the country, and in several Russian regions specializing in production of spring grains. These findings suggest that either farms in these regions may have not well adapted their production to climate change or significantly stronger increases in autumn and/or winter temperatures are required to make winter grains' production profitable in these locations.

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