Climate change and agricultural trade in central Asia: evidence from Kazakhstan
Xiaohua Yu, Hengrong Luo, Hanjie Wang and Jan-Henning Feil
Department of Agricultural Economics and Rural Development, University of Göttingen, Göttingen, Germany

ABSTRACT
Agriculture in Central Asia faces tremendous challenges due to climate change. International agricultural trade is seen in the literature as a potential adaption to climate change. However, little attention has been paid to the effect of climate change on cereal trade in Central Asia. This study takes Kazakhstan as an example to empirically analyze the effect of climate change on cereal trade by including them as determinants in the gravity model. Our results show that climatic changes in Kazakhstan, measured by precipitation and temperature, could increase the export of wheat and rice and the import of maize, and decrease the import of wheat. Specifically, as a major crop in Kazakhstan, increasing precipitation by 1 millimeter during the major cropping season from May to August, will significantly enhance export of wheat by 0.7% and reduce the import by 1.7%; increasing temperature by 1°C during the same cropping season will significantly increase export of wheat by 21.9% and reduce the import by 49.4%. As an important cereal trade country in the world, the dramatic adjustments of cereal trade patterns resulting from climate change in Kazakhstan might affect global food security.

Introduction
It is widely known that climate plays a vital role in agricultural production (Brown and Funk 2008; Crost et al. 2018; Holst, Yu, and Gruen 2013). According to the OECD-FAO Agricultural Outlook (2016–2025), the global cereal use will grow by 14%, reaching 2818 Mt by 2025. Given the fundamental function of agriculture in food security, there is a growing concern on the potential effect of climate change on agricultural productivity (Adams et al. 1998; Olesen and Bindi 2002; Baldos and Hertel 2014). Specifically, climate change would certainly change the natural conditions of crop growth, such as temperature and precipitation (Rosenzweig and Parry 1994; Huang, von Lampe, and van Tongeren 2011; Zhang, Zhang, and Chen 2017). In order to project the effect of climate change on crop yield scientifically, a series of crop-simulation models, including the SOYGRO model, the CERES-wheat model, and the CERES-maize model, are well-developed (Raj Singh, Shekhar, and Mani 2010; Ahmed et al. 2016). In general, the mainstream findings have not reached a general conclusion on the effect of climate change on agricultural production, which is the main determinant of trade.

Central Asia, an important partner of the Belt and Road Initiative (BRI), its agriculture development faces tremendous challenges to climate change. Although agriculture sector is one of the most important sectors of the five Central Asian countries,1 accounting for 10% to 45% of their GDP, employing 20% to 50% of total employment (Hamidov, Helming, and Balla 2016), the natural environment of Central Asia might not be ideal for agricultural production. Explicitly, most of the agricultural land in Central Asia is desert. For example, the share of deserts of Turkmenistan and Uzbekistan is up to 80–90%. Likewise, the shortage of water for agricultural production is a critical challenge in Central Asia. According to the estimation of the European Parliamentary Research Service, four of the five Central Asian countries are under water-stress.2 In particular, most of the agricultural land of Kazakhstan, nearly 35 million hectares, is rain-fed, while only 6% is irrigated ( Mizina et al. 1999). This makes agricultural production in Central Asia vulnerable to climate change. Consequently, climate change would certainly increase natural risk and uncertainty in agriculture sectors. Using SRES scenarios from IPCCAR4, 23 models, the Intergovernmental Panel on Climate Change (IPCC) points out that projected increases in temperature could exacerbate the water shortage in Central Asia.3 Thus, how to cope with climate change is prior of policy agenda in Central Asia.

Theoretically, adaption is one of the effective approaches that respond to climate change in the
agriculture sector (Chen et al. 2015). Extensive studies show that climate change would be problematic for agricultural production without adaption, while the vulnerability of agricultural production could be alleviated with adaption (Mendelsohn, Nordhaus, and Shaw 1994; Wheaton and Maciver 1999; Burke and Emerick 2016). In practice, numerous agricultural adaption options coping with climate change have been proposed, ranging from technical, financial, political, and also managerial approaches (Chen et al. 2015; Schwan and Yu 2018). For example, U.S. has undertaken several new agricultural adaptive approaches, such as the development of resilient agricultural production systems, the connection between climate knowledge and decision-making by farmers, and technical advisors (Walthall et al. 2013). Schwan and Yu (2018) find that migration is another adaptive strategy for climate change. However, the five Central Asian countries, all developing countries, are more vulnerable to climate change, as they lack financial and technical capability coping with increased variability (Barrios, Ouattara, and Strobl 2008; Khasay and Hansen 2016).

While a large body of literature generally discusses a series of adaptations, only a few studies evaluate the potential of international agriculture trade. Huang, von Lampe, and van Tongeren (2011) point out that a well-functioning agriculture trade system could be a supportive adaptation to climate change. Although the effect of climate change on agricultural production is significant, it varies among different regions. Generally, the consensus is that low latitudes, tropical regions, facing extreme temperatures, would experience a reduction of crop yield. Such a scenario, international agriculture trade, accompanying the transfer of virtual water, could be an effective adaptation to reduce climate-induced environmental stress (Konar et al. 2011). Nevertheless, international agriculture trade would also increase climate-induced vulnerability, as some regions are specialized in producing certain agricultural products in which they have a comparative advantage (Ouraich et al. 2019).

Although a few studies have realized the potential adaptation of agriculture trade, to the best of our knowledge, far too little attention has been paid to the effect of climate change on cereal trade in Central Asia. Given the importance of the potential adaptation of international agriculture trade, it is necessary to understand how climate change affects the agriculture trade patterns in Central Asia. Particularly, agriculture plays an important role in their livelihood, but food production particularly suffered from political and economic turmoil after the collapse of the Soviet Union even though these countries traditionally had a favorable endowment of natural resources and well-organized facilities for agricultural production. How to incorporate themselves into the global food trade system, particularly after the transition from a planned economy to a market system, has not been well studied.

Thus, the main contribution of this study is that we use the gravity model, a widely used trade model in the field of international trade (Hasiner and Yu 2019), to empirically reveal the relationship between climate change and cereal trade, which provide the empirical evidence for the effect of climate change on cereal trade. Furthermore, Kazakhstan, a dominant economy in Central Asia, more than 70% of its land is occupied by agriculture, and its agricultural trade ranks first among the five Central Asian countries, though the share of agriculture in total GDP is only 5%. This paper hence takes Kazakhstan as an example to analyze how climate change affects cereal trade in Central Asia.

### Background: cereal trade and climate change in Kazakhstan

Cereal is one of the most important agricultural products in Kazakhstan. According to the Ministry of Agriculture of Kazakhstan, the total crop area is up to 19 million hectares, in which cereal crops occupy 14.5 million hectares. The country’s major cereal crops include wheat, rice, and maize. In particular, wheat production is officially estimated at 14 million tonnes, accounting for 70% of the total cereal production. In terms of cereal trade, Kazakhstan, a major global wheat producer, exports cereal products to over 70 countries, ranked in the top 10 grain exporters. For instance, in 2018, wheat exports of Kazakhstan were valued at 965.4 USD million, accounting for 2.3% of the global total.

Nevertheless, sustainable cereal productivity in Kazakhstan is increasingly challenged by climate change, which might affect cereal trade. According to the UNDP, nearly 75% of the territory in Kazakhstan is under high-risk ecological destabilization. Additionally, the country’s agricultural production is facing a series of climate change risks, including water shortage, increased aridity, and also extreme weather events. Worse still, climate trends in Kazakhstan are expected to exacerbate these risks. For instance, the temperature rose approximately by 2°C from 1936 to 2005 in Kazakhstan, double the global average. Since 2000, the temperature increased by 0.31°C in ten years. Moreover, heavy precipitation and redistribution of precipitation also contribute to the vulnerability of agriculture in Kazakhstan, though it is possible that increasing precipitation could somehow benefit agricultural production.

Considering the vital role of wheat exports in Kazakhstan, we show the trend of wheat production,

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*Source: FAO, Global Information and Early Warning System (GEWS).*

*https://www.adaptation-undp.org/explore/central-asia/kazakhstan.*
wheat trade, and climate change. In particular, climate change related to cereal production in this study mainly refers to the change of precipitation and temperature. Figure 1 depicts the trends of precipitation, wheat production, and wheat exports in Kazakhstan from 2001 to 2017, while Figure 2 captures the trends of temperature, wheat production, and wheat exports. It is clear that wheat production and exports show similar trends with the variation of precipitation. However, the relationship between temperature, wheat production, and wheat exports is rather complicated as it manifests both positive and negative correlations. It is possible that crop yields have a non-linear relationship with temperature (Holst, Yu, and Gruen 2013). Figures 1 and 2 cannot mirror the accurate quantitative relationship between them, which will be studied by the gravity model in the rest of the paper.

**Data and descriptive statistics**

To empirically reveal the effect of climate change on cereal trade in Kazakhstan, this study employs a panel dataset of 158 countries from 2001 to 2017. As discussed above, the major cereals produced in Kazakhstan mainly include wheat, rice, and maize. For this reason, we define the cereal trade as imports and exports of wheat, rice, and maize, which come from the FAO (Food and Agriculture Organization of the United Nations) database.²

Regarding climate variables in Kazakhstan, we use the following two proxies in this study: precipitation and temperature. It is widely admitted that water and temperature are the essential conditions for cereal production (Holst, Yu, and Gruen 2013). Specifically, the precipitation data, measured by millimeter per hour (mm/hr), is available from the GPM (Global Precipitation Measurement) data products. The GPM, an international network of satellites initiated by NASA (the National Aeronautics and Space Administration) and JAXA (the Japan Aerospace Exploration Agency), provides the global observations of raining. The “Core” satellite of GPM carries advanced radar (radiometer system), having the extended capability to measure light rain (< 0.5 mm/hr). Besides, the temperature data, defined as land surface temperature, is obtained

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²Source: http://www.fao.org/faostat/en/#data/TM.
from the MERRA2 (the second Modern-Era Retrospective analysis for Research and Applications). The MERRA2, a NASA atmospheric reanalysis, provides remote sensing data beginning in 1980. It uses GEOS-5, which equipped with the newer microwave sounders and hyperspectral infrared radiance instruments. Importantly, according to the crop calendar of Kazakhstan reported by FAO-GIEWS, the cultivating and growing period of cereal mainly takes place from May to August. Thus, it would be reasonable to use the precipitation and temperature data of this period, which is consistent with the growth of cereal in Kazakhstan. Specifically, we use the total precipitation (Millimeters) and average temperature (°C) during these four months as the climate measures.

Additionally, in order to fit the gravity model consistently, the empirical study further includes some other variables. For example, the GDP (constant 2010 US$) and the land under the cereal production of exporters and importers come from the World Development Indicators database of the World Bank. While the distance variable, measured by the great circle distance between two capitals, is taken from CEPII. Besides, we also access two proxies for bilateral covariates from CEPII: common language and contiguous border, which are measured by dummy variables. These three variables are widely used as economic distance variables in the literature (Hasiner and Yu 2016; 2019). Table 1 presents the detailed definition of variables, and Table 2 reports the descriptive statistics.

Gravity model and econometric approach

The gravity model of international trade, inspired by Newton’s gravity equation, relates bilateral trade flows to the economic size and distance of two trade partners. This model was first proposed by Isard (1954) in the field of economics. The basic model for two partners’ trade can be formulated by the following equation:

\[ Y_{ij} = C \frac{E_{ij}}{D_{ij}} \]  

(1)

Where \( Y_{ij} \) denotes trade flows (export or import) from country \( i \) to country \( j \); \( E_{ij} \) and \( E_{ji} \) denote the economic size of two countries respectively, measured by their GDP’s; \( D_{ij} \) is the geographical distance between the two countries; and \( C \) is constant. Theoretically, this model indicates that trade flows are determined by the exporter’s productivity, the importer’s purchasing power, and also the trade cost measured by geographical and economic distance. In addition, Linnemann (1967), Bergstrand (1985), and Tian and Yu (2017) further consider a set of bilateral trade covariates as trade costs, mainly including contiguous border, common language, and so on. Empirically, for the sake of econometric analyses, we can easily transfer the gravity model to a linear form by taking logarithms, that is:

\[ \ln Y_{ij} = \alpha + \beta_1 \ln E_{ij} + \beta_2 \ln E_{ji} + \beta_3 \ln D_{ij} + \varepsilon_{ij} \]  

(2)

Regarding the estimation strategies for the gravity model, some disputes exist. Traditionally, OLS could be a feasible way to estimate Equation (2) as it has been transferred to linear form, which is based on the homoscedasticity assumption. However, this approach has been subjected to considerable criticism due to its several limitations. First, Silva and Tenreyro (2006) argue that the parameter of the gravity equation estimated by OLS would be biased under heteroskedasticity, and they suggest that nonlinear estimation would perform better. The second challenge is the problem of zero values, as there are always some countries do not trade all products with their partners (Haveman and Hummels 2004). Gómez-Herrera (2013) points out that the econometric models that do not consider the zero values would perform worse than others. In practice, given the theoretical foundation of firm heterogeneity (Chaney 2008), Helpman, Melitz, and Rubinstein (2008) employ the two-stage Heckman sample selection model to avoid inconsistent estimation. However, the disadvantage of the Heckman sample selection model is that it might be difficult to find an identification

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**Table 1. Variables definition.**

| Variable                   | Definition                                                                 |
|----------------------------|---------------------------------------------------------------------------|
| Precipitation              | Total precipitation during major crop season (May-August) (mm)            |
| Temperature                | Land surface temperature (°C)                                             |
| Wheat trade                | Exports and imports of wheat (1000 MT), log                              |
| Rice trade                 | Exports and imports of rice (1000 MT), log                                |
| Maize trade                | Exports and imports of maize (1000 MT), log                              |
| GDP of Kazakhstan          | Constant 2010 US$, log                                                   |
| GDP of trade partners      | Constant 2010 US$, log                                                   |
| Land of Kazakhstan         | Land under cereal production (hectares), log                             |
| Land of trade partners     | Land under cereal production (hectares), log                             |
| Distance                   | Distance between two capitals (kilometer), log                           |
| Common language            | Trading partners share a common language, dummy                          |
| Contiguous border          | Trading partners share a common border, dummy                            |

**Table 2. Descriptive statistics.**

| Variable                   | Mean   | SD     | Min    | Max    |
|----------------------------|--------|--------|--------|--------|
| Precipitation              | 117.155| 24.809 | 80.980 | 170.264|
| Temperature                | 23.106 | 0.718  | 21.991 | 24.332 |
| Wheat export               | 1.515  | 3.761  | 0      | 14.340 |
| Wheat import               | 0.108  | 0.891  | 0      | 14.720 |
| Rice export                | 0.263  | 1.404  | 0      | 10.460 |
| Rice import                | 0.113  | 0.932  | 0      | 10.460 |
| Maize export               | 0.138  | 0.764  | 0      | 9.641  |
| Maize import               | 0.138  | 0.764  | 0      | 9.641  |
| GDP of Kazakhstan          | 25.630 | 0.294  | 25.050 | 26.000 |
| GDP of trade partners      | 24.500 | 2.179  | 18.620 | 30.480 |
| Land of Kazakhstan         | 16.301 | 0.059  | 16.383 | 16.623 |
| Land of trade partners     | 13.337 | 2.582  | 3.332  | 18.473 |
| Distance                   | 8.693  | 0.586  | 6.857  | 9.7160 |
| Common language            | 0.028  | 0.166  | 0      | 1      |
| Contiguous border          | 0.023  | 0.149  | 0      | 1      |
restriction (Gómez-Herrera 2013). In this paper, we use the PPML (Poisson Pseudo Maximum Likelihood) to estimate the gravity model. Compared with other econometric methods, the advantage of PPML is that it cannot only deal with the problem of zero trade flows but also obtain unbiased estimation under heteroskedasticity (Silva and Tenreyro 2006; An and Puttitanun 2009; Prehn, Brümmer, and Glauben 2016). The third challenge for a gravity model is the identification problem. GDP could be endogeneity. However, as the share of agriculture in total GDP is less than 5% in Kazakhstan, and export value for a single cereal is far less than 1% in GDP. GDP, which measures the economic scale, can therefore be regarded as exogenous. Endogeneity could also be caused by the unchanged heterogeneity in the error terms, such as scale and institution, and we use a fixed-effects model to control for it.

In the last few decades, the gravity model is widely used in international trade researches. For instance, Anderson and Marcouiller (2002) employ a gravity model and corruption data to study the effect of institutional weakness on trade. And their results show that institutional weakness dramatically reduces international trade. Hasiner and Yu (2016) and Hasiner and Yu (2019) also draw a conclusion that the institutions of exporters have a significant positive effect on meat exports to China. Besides, some literature pays more attention to the trade partnerships and trade barriers, including Regional Trade Agreement (TRA) (Tian and Yu 2017), Non-Tariff Barriers to Trade (NTB) (Fontagné, Mayer and Zignago 2005), cost of border (Anderson and Van Wincoop 2003), single currency on trade (Frankel and Rose 2000), trade patterns (Fontagné, Freudenberg, and Périody 1998), and so on.

Nevertheless, to the best of our knowledge, although a few studies realize the importance of agricultural trade in climate change, little attention has been paid to the effect of climate change on cereal trade empirically by employing gravity model. Climate variables could be regarded as essential resource variables that significantly affect agricultural productivity (Holst, Yu, and Gruen 2013). Of course, it is an important determinant of agricultural trade. Given the dramatic trend of climate change and the importance of food security, this paper empirically studies the potential effect of climate change on cereal trade in Kazakhstan by incorporating the climate variables in the gravity model. Moreover, as the proxies for climate change are strictly exogenous, we could simply construct the econometric model as follow:

\[
\ln T_{ij} = \alpha + \beta_1 \ln C_{mi} + \beta_2 \ln GDP_i + \beta_3 \ln GDP_j + \beta_4 \ln Z_{ij} + \epsilon_{ij}
\]

(3)

Where \( T_{ij} \) denotes the cereal trade between Kazakhstan and other countries, \( C_{mi} \) denotes the precipitation and land surface temperature of Kazakhstan, \( GDP_i \) denotes the GDP of Kazakhstan while \( GDP_j \) denotes the GDP of trade partners, \( Z_{ij} \) stands for bilateral covariates, including the distance of two capitals, land under cereal production, common language, and contiguous border. Note that we did not take logs for the climate variables so that the coefficient will be explained as the percentage of trade volume (export or import) in response to one unit increase in climate variables.

**Results and discussion**

In order to tackle zero trade flows, we adopt the Poisson Pseudo Maximum Likelihood (PPML) to estimate the gravity model of Equation (3). As aforementioned, the proxies for climate change in this study include precipitation and land surface temperature, while cereal trade is defined as cereal exports and imports, which are estimated separately below.

**Climate change and cereal exports in Kazakhstan**

Table 3 reports the effect of climate change on cereal exports. Specifically, we mainly discuss three major crops in Kazakhstan: wheat, rice, and maize. In column (1), column (3), and column (5) of Table 3, we present the estimated results of the basic gravity model incorporating climate variables for the purpose of comparison, while column (2), column (4), and column (6) are the results of the full gravity model incorporating climate change and control variables as well (Equation (3)). It is clear that the estimated results are robust.

Overall, the coefficients of precipitation and temperature are positive, although the effect of climate change on maize exports is not significant. The general conclusions indicate that a marginal increase in precipitation would significantly increase exports of wheat and rice but has no significant impact on the export of maize. Specifically, increasing precipitation by one millimeter during the major cropping season from May to August will significantly promote the export of wheat and rice by 0.7% and 0.5%, respectively, in the full model. A marginal increase in temperature only significantly increase the export of wheat, while no significant impact is found for rice and maize. The marginal effect of temperature for wheat is 0.219 in the full model. It indicates that a 1°C increase would lead to 21.9% more export of wheat.

A possible explanation for this might be that marginally increasing precipitation and temperature are likely to result in cereal production increase as the climate becomes milder for grain production, which is consequently transmitted to trade. Also, it indicates that the decreasing precipitation might reduce the wheat export in Kazakhstan. Landscape in Kazakhstan is characterized by mountain and desert areas in the
whole nation except in the north and northwest regions. Water shortage is one of the main challenges to agricultural production in Kazakhstan. Specifically, most of the agricultural land of Kazakhstan, nearly 35 million hectares, is rain-fed, while only 6% is irrigated (Mizina et al. 1999). Hence, the increase of precipitation might increase cereal production so as to promote cereal exports, which is consistent with the trend we depict in Figure 1. Nevertheless, the maize plant is highly sensitive to moisture surplus and deficit (Rashid and Rasul 2011). As a result, the effect of climate change on maize export is not significant.

Besides, the coefficients of the GDP of Kazakhstan are almost negative and statistically significant, while the coefficients are positive regarding the importers. It is comprehensible that economic growth would demand more food domestically and could lead to less export of food. Furthermore, the distance plays a negative effect on cereal exports, which is consistent with the basic assumption of the gravity model.

### Climate change and cereal imports in Kazakhstan

Now we look at the effect of climate change on cereal imports. Many countries simultaneously import and export certain products, such as cereal products. Table 4 reports the effect of climate change on cereal imports. Specifically, column (1), (3), and (5) of Table 4 are the estimation results of Equation (2) with climate variables, while column (2), (4), and (6) for Equation (3)

| Variables | Wheat | Wheat | Rice | Rice | Maize | Maize |
|-----------|-------|-------|------|------|-------|-------|
| Precipitation | 0.005*** | 0.007*** | 0.004* | 0.005** | 0.000 | −0.001 |
| (0.001) | (0.001) | (0.002) | (0.002) | (0.003) | (0.000) |
| Temperature | 0.120*** | 0.219*** | 0.052 | 0.128 | −0.156 | −0.237 |
| (0.030) | (0.033) | (0.072) | (0.079) | (0.110) | (0.131) |
| GDP_Kaz | −0.891*** | −1.296*** | −0.155 | −0.443 | −2.362*** | −2.106*** |
| (0.071) | (0.100) | (0.229) | (0.281) | (0.480) | (0.597) |
| GDP_Par | 0.514*** | 0.503*** | 1.625*** | 1.669*** | 2.407*** | 2.471*** |
| (0.071) | (0.077) | (0.225) | (0.270) | (0.481) | (0.504) |
| Distance | −2.895*** | −2.980*** | −10.644*** | −11.212*** | −21.483*** | −20.489*** |
| (0.297) | (0.319) | (1.745) | (1.839) | (5.061) | (4.477) |
| Land_Kaz | 2.450*** | 1.969* | 0.895 | (1.529) | (0.392) | (0.072) |
| (1.34) | (1.931) | (0.372) | (2.97) | (0.039) |
| Language | 0.043 | 0.011 | −0.354 | (0.039) | (0.392) | (0.072) |
| (1.085) | (2.043) | (1.72) |
| Border | −2.895*** | −2.980*** | −10.644*** | −11.212*** | −21.483*** | −20.489*** |
| (0.297) | (0.319) | (1.745) | (1.839) | (5.061) | (4.477) |
| Constant | 30.815*** | −1.234 | 45.878*** | 22.247 | 166.380*** | 187.464*** |
| (2.869) | (5.988) | (14.098) | (19.154) | (38.517) | (37.888) |

### Table 4. The effect of climate change on cereal exports.

| Variables | Wheat | Wheat | Rice | Rice | Maize | Maize |
|-----------|-------|-------|------|------|-------|-------|
| Precipitation | −0.016*** | −0.017*** | 0.001 | 0.002 | 0.007*** | 0.006** |
| (0.003) | (0.003) | (0.002) | (0.002) | (0.003) | (0.003) |
| Temperature | −0.398*** | −0.494*** | −0.057 | 0.016 | 0.151 | 0.091 |
| (0.114) | (0.131) | (0.071) | (0.080) | (0.100) | (0.111) |
| GDP_Kaz | −0.107 | 0.383 | −0.374** | −0.474** | 1.016*** | 1.379*** |
| (0.233) | (0.312) | (0.150) | (0.217) | (0.217) | (0.274) |
| GDP_Par | 0.896*** | 0.653*** | 0.432*** | 0.187 | 0.822*** | 0.491** |
| (0.211) | (0.220) | (0.103) | (0.120) | (0.209) | (0.242) |
| Distance | −2.639*** | −2.008*** | −1.586*** | −1.323*** | −2.156*** | −1.589*** |
| (0.633) | (0.709) | (0.366) | (0.355) | (0.559) | (0.642) |
| Land_Kaz | −2.336 | (1.429) | 1.729* | (1.907) | (1.313) |
| (0.384) | (0.215) | (0.124) | (0.275) |
| Language | 3.173** | 0.137 | 3.958 | (1.801) | (4.286) |
| (1.574) | (1.801) | (1.801) |
| Border | −0.382 | 0.691 | −3.184 | (1.672) | (1.632) | (3.905) |
| Constant | 9.836 | 33.122 | 11.401*** | −18.101 | −35.327*** | −21.831*** |
| (7.149) | (21.069) | (4.610) | (13.058) | (6.658) | (20.328) |

| Country | Y | Y | Y | Y | Y | Y |
| Observations | 2627 | 2627 | 2627 | 2627 | 2627 | 2627 |
are the results for the full model. In column (2) of Table 4, we can find that the coefficients of precipitation and temperature are negative and statistically significant, suggesting that an increase in precipitation would reduce wheat imports. The coefficients are −0.017 and −0.494, respectively. It implies that increasing precipitation by one millimeter during the period from May to August will reduce the import of wheat by 1.7%, while a 1°C increase will reduce the import of wheat by 49.4%.

This result is consistent with those of the export function and might be due to the fact that the increase of precipitation and temperature promote wheat production, reducing wheat imports from other countries. Similarly, corresponding to earlier findings, the coefficient of precipitation of column (6) is 0.006 and statistically significant, indicating that increasing precipitation by one millimeter during the period from May to August could increase the maize imports by 0.6% in Kazakhstan. This might be due to the reason that the variation of climate change decreases maize production in Kazakhstan. The most likely cause is the flood caused by increased precipitation deteriorates the growing environment of maize. Consequently, to cope with the impact of climate change on maize production, maize trade is a feasible adaption. However, the coefficients of climate variables are not significant in terms of rice imports.

Likewise, the GDP of Kazakhstan plays a negative effect on cereal imports except for maize imports, while the GDP of exporters plays a positive effect. In addition, the increase in distance between importers and exporters significantly decreases the cereal imports of Kazakhstan. The results are consistent with the existing literature.

### Robustness check

Considering the fact that some variables are constant across entities but vary over time, this study further controls the time fixed effect to check the robustness of estimation results. The results of Tables 5 and 6 show that, after controlling the year fixed effect, the major conclusions of this study remain unchanged. It indicates that our econometric results are robust.

### Conclusions and implications

International agricultural trade is a potential adaption to climate change. Given the background of increasing challenges of climate change on agricultural production in Central Asia, international agricultural trade should be taken into consideration for coping with climate change. However, little attention has been paid to the relationship between climate change and cereal trade. In light of this, this study takes Kazakhstan as an example to empirically analyze the effect of climate change on cereal trade in Central Asia by employing the gravity model incorporating PPML (Poisson Pseudo Maximum Likelihood) approach.

Generally, the empirical results show that climate change in Kazakhstan plays a significant effect on cereal trade. On the one hand, the precipitation and temperature in Kazakhstan significantly increase wheat and rice exports, while such an effect is not significant in terms of maize exports. Specifically, increasing precipitation by one millimeter during the period from May to August will significantly promote the export of wheat and rice by 0.7% and 0.5%, respectively. Considering the water shortage situation in Kazakhstan, it is comprehensible that the

### Table 5. Robustness check of cereal exports.

| Variables       | Wheat | Wheat | Rice  | Rice  | Maize | Maize |
|-----------------|-------|-------|-------|-------|-------|-------|
| Precipitation   | 0.008*** | 0.008*** | 0.004** | 0.005** | 0.000 | −0.001 |
| (0.001)         | (0.001) | (0.002) | (0.002) | (0.003) | (0.003) | |
| Temperature     | 0.098*** | 0.095*** | 0.041  | 0.112  | −0.157| −0.318**|
| (0.029)         | (0.036) | (0.072) | (0.089) | (0.110) | (0.142) | |
| GDP_Kaz         | 1.935*** | 2.106*** | 1.007  | −0.050 | −2.095**| −0.165 |
| (0.286)         | (0.404) | (0.712) | (1.053) | (0.974) | (1.433) | |
| GDP_Par         | 0.567*** | 0.551*** | 1.677*** | 1.662*** | 2.479***| 2.765***|
| (0.073)         | (0.079) | (0.233) | (0.273) | (0.537) | (0.557) | |
| Distance        | −2.926*** | −3.012*** | −10.916*** | −11.274*** | −21.948***| −22.219***|
| (0.296)         | (0.319) | (1.800) | (1.855) | (5.358) | (4.868) | |
| Land_Kaz        | −0.127 | −0.267 | −1.653 | −3.473* | −1.895*| −0.433 |
| (0.493)         | (1.212) | (2.722) | (4.246) | (4.416) | (4.416) | |
| Land_Par        | 0.044  | 0.008  | 0.649  | 3.252  | 3.428 |
| (0.073)         | (0.272) | (0.649) | (3.428) | (0.416) | |
| Language        | 0.267  | 0.139  | 9.388  | 3.428  | 3.428 |
| (1.139)         | (1.938) | (3.428) | (3.428) | (3.428) | |
| Border          | −1.116 | −3.086 | 0.983  | 4.868  | 4.868 |
| (1.073)         | (2.054) | (2.166) | (4.868) | (4.868) | |
| Constant        | 313.135*** | 328.898*** | 156.370** | 59.922 | 202.355*| 412.183***|
| (27.768)        | (38.357) | (65.451) | (99.059) | (120.713) | (156.132) | |
| Country         | Y     | Y     | Y     | Y     | Y     | Y     |
| Year            | Y     | Y     | Y     | Y     | Y     | Y     |
| Observations    | 2627  | 2627  | 2627  | 2627  | 2627  | 2627  |
increase of precipitation could positively affect wheat and rice production. On the other hand, the increase in precipitation and temperature in Kazakhstan reduce wheat imports significantly, while the increase in precipitation significantly increases maize imports.

Overall, our conclusions indicate that under the increased challenges of climate change, international cereal trade could be an effective adaption to ensuring food supply in Kazakhstan. Thus, a well-functioning international cereal trade system should be taken into consideration so as to support the adaption to climate change. Nevertheless, as an important cereal trade country around the world, the dramatic adjustments of cereal trade patterns resulting from climate change in Kazakhstan might affect global food security. For this reason, it is necessary to integrate international food trade into the other climate change adaption approaches in the future.

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No potential conflict of interest was reported by the authors.

ORCID
Xiaohua Yu http://orcid.org/0000-0003-4257-8081

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Table 6. Robustness check of cereal imports.

| Variables | (1) | (2) | (3) | (4) | (5) | (6) |
|-----------|-----|-----|-----|-----|-----|-----|
| Precipitation | −0.018*** | −0.018*** | 0.002 | 0.002 | 0.005* | 0.006** |
| Temperature | −0.380*** | −0.397*** | −0.069 | −0.048 | 0.199* | 0.336*** |
| GDP_Kaz | −2.558*** | −2.106 | 1.379*** | 1.222 | −2.463*** | −4.330*** |
| GDP_Par | 0.916*** | 0.668*** | 0.451*** | 0.198 | 0.823*** | 0.490** |
| Distance | −2.671*** | −2.017*** | −1.573*** | −1.321*** | −2.163*** | −1.589*** |
| Land_Kaz | −0.369 | (0.159) | 0.426 | (1.159) | 3.264* | (1.803) |
| Land_Par | 0.370* | (0.213) | 0.390*** | (0.124) | 3.613** | (0.273) |
| Language | 3.148** | (1.574) | 0.150 | (1.804) | 3.942 | (4.275) |
| Border | −0.375 | (1.671) | 0.676 | (1.634) | −3.176 | (3.894) |
| Constant | −220.065*** | −199.350 | 181.630*** | 143.811 | −345.085*** | −548.137*** |
| Country | Y | Y | Y | Y | Y | Y |
| Year | Y | Y | Y | Y | Y | Y |
| Observations | 2627 | 2627 | 2627 | 2627 | 2627 | 2627 |
