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Assessing the Economic Impact of Climate Change on Agriculture in Central Asia

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Abstract

Climate change has the potential to exact a significant toll on global economic output, and agriculture in Central Asia is one sector that will inevitably be affected. This paper measures the economic impact of climate change on Central Asian agriculture by employing the Ricardian method. The study is conducted on five countries in Central Asia: Kazakhstan, Kyrgyzstan, Turkmenistan, Tajikistan and Uzbekistan. The findings suggest that agriculture in Central Asia is sensitive to climate change, and the impacts are more acute from increases in temperature. Results indicate that every degree Celsius increase in annual temperature has resulted in a modest benefit of $4/hectare increase in agricultural net revenue, which amounts to $117 million in total agricultural benefits across Central Asia. The estimation of future climate change scenario, however, suggests a far more conservative outcome. Results of the future climate scenario indicate that changes in the pattern of rainfall and temperature by 2040 will result in approximately $66 million net welfare loss from agriculture to Central Asia. The net welfare loss from agriculture will be largest in Kazakhstan at $50 million loss, while Tajikistan will have the least welfare loss at $1.6 million. From a policy perceptive, the results in this study highlight the need for governments in countries like Tajikistan, Turkmenistan and Uzbekistan to implement regulations that allow private ownership of farmlands; for the government in Kazakhstan to invest in novel technologies such as drip irrigation systems, climate smart agriculture, and canals for rainwater harvesting; while the government in Kyrgyzstan needs to ensure that farming populations in the country can easily alter their farm types or even switch between owning crops and livestock that are suited for the dryer conditions in the country.

Keywords: Agricultural Net Revenue, Central Asia, Climate Change, Ricardian Analysis, Environmental Valuation.

JEL Classification: Q54, Q51, Q15

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Motivation and Background

Climate change is emerging as a significant environmental problem facing modern society. There is substantial evidence that anthropogenic actions have led to increases in greenhouse gases such as carbon dioxide, methane, and nitrous oxide, which are all considered to be a major contributor to climate change. More than 200 billion tons of carbon dioxide has been added to the atmosphere in the last 150 years, and half of it has occurred in the past 30 years itself (Intergovernmental Panel on Climate Change (IPCC), 2014). The consequences of such changes in the natural atmospheric greenhouse gases could be devastating, and we are enduring some of the costs. The global temperature has risen by approximately 1-degree Celsius since 1880s, and the trend of the earth warming up has been accelerating with each passing decade (IPCC, 2014). For the large part of the 1900s, the average temperature on every decade has increased by 0.065-degree Celsius, whereas the temperature since the 1990s has been increasing by 0.136-degree every decade (NOAA-NCEI, 2016). As the earth continues to heat up, the impact of the warming will become more frequent and severe; precipitation patterns will begin to alter and the frequency of extreme weathers events such as cold snaps, heat waves, tidal flooding, droughts, wildfires, and monster storms will become more frequent (NOAA-NCEI, 2016).

Climate change has the potential to exact an enormous toll on the global economic output too. It is expected that increases in average global temperature by only 0.04-degrees Celsius per year will reduce world real gross domestic product (GDP) per capita by 7.22% by 2100 (Kahn et al., 2019). The variability in the patterns of temperature and precipitation coupled with extreme weather events could be devastating to every facet of our society ranging from the destruction of critical infrastructures and properties to declining human health and productivity to a distressing impact on ecosystems, land and water resources, and agricultural, forestry, fishery and the tourism industries. Agriculture is one sector that is perhaps the most vulnerable to climate change. Climate change will adversely impact agrarian productivity at local, regional, and even global scale, and it will have a profound impact on the farm and the farming communities as they struggle to satisfy the global demand for food production. The Food and Agricultural Organization (FAO) estimates that with the current trend of income and consumption growth, agricultural production in 2050 will have to rise by 60 percent to satisfy the expected demands for food and feed (Alexandratos and Bruinsma, 2012).

One region that is largely dependent on agriculture and highly vulnerable to climate change impacts is Central Asia. The countries in Central Asia include Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. Most of Central Asia is a dryland region covered with grasslands, rangelands, deserts, and woodlands and falls within arid and semi-arid zones. Central Asia is highly agrarian, and agriculture remains an important economic sector and a source of livelihood and income for many people. Approximately, 45% of the total population in these countries are employed in the agricultural sector and about 60% of the population (other than in Kazakhstan) reside in the rural areas (Abdullaev, 2014; Bobojonov and Aw-Hassan, 2014). Agriculture is a major source of livelihood activity for the majority of the households, and this sector contributes to 5.2% of GDP in Kazakhstan; 7.5% in Turkmenistan; 18.5% in Uzbekistan; 20.8% in Kyrgyzstan; and 23.3% in Tajikistan (Abdullaev, 2014; Bobojonov and Aw-Hassan, 2014).

Central Asia is one of the largest semi-arid regions in the world and is argued to be a hot spot for climate change (Girorgi, 2006). As such, climate change will inevitably alter agricultural production and affect food security in Central Asia. The potential climate change stressors in the region could come from changes in temperature and precipitation patterns, and surges in extreme weather events that could result in a myriad of issues on the agricultural sector. Past studies have suggested that the temperature in Central Asia has been increasing more than the global mean, whereas precipitation only shows a minor increase (Zhang et al., 2019). The impact of climate change on the agricultural sector in Central Asia could be felt in the form of reduced crop yields; deteriorating rate of desertification; increased demand for irrigation water; decline in the amount of precipitation and water availability during vegetation periods; rise in pest outbreaks and spread of infectious diseases; and increase in soil salinity, all of which will inevitably result in substantial damages and losses. The impoverished rural farming population in Central Asia will perhaps be the hardest hit group as they have limited assets and access to resources, knowledge, use of technologies, and financial services, which are vital to smoothly adapt their production systems to the changing climate.

Given the vast population that relies on agriculture in Central Asia, the implication of climate change on food security in the region will be enormous. Despite the well-understood concerns of climate change, there have only been a handful of studies that look at the impact of climate change on agriculture in the Central Asia, and even fewer have incorporated the economic dimensions of climate and agriculture. In fact, to our knowledge, there has only been one study by Mirzabaev (2013) that has investigated the economic impact of climate change on net agricultural revenues in Central Asia. Without adequate studies that have quantified the impact of climate change on agriculture, the policies that get adopted in Central Asia will neither be effective nor efficient. This study aims to fill in an important research gap in the literature of economic impact of climate change on agriculture, which has entirely been missing in the context of Central Asia. As such, this study provides methodical and evidence-based research finding with policy suggestions that can be valuable to regional decision-makers on understanding the potential impacts and the adaptation actions they could incorporate to safeguard the farming communities from the impending consequences of climate change. Central Asia is also a fascinating region to study because of the high degree of heterogeneity between and within the different states. The wide variation in topography from mountainous terrains to rolling deserts can produce significant differences on the economic impacts between these different countries, which might result in drastically varying regional policy implications. Hence, the findings and policy suggestions from this study can also be transferable to topographies in other parts of the world.

This paper examines the impact of climate change on agriculture in Central Asia by employing the Ricardian method. The result suggests that the value of agricultural production is indeed affected by the climate in the region. In particular, we find the economic impact of climate change on agriculture was more pronounced during the summer season, where precipitation and temperature both had a concave relationship with the agricultural revenues. Additionally, we find that winter precipitation and summer temperature also affected the net agricultural revenues. The estimates of annual marginal impacts in Central Asia suggest that temperature has contributed to a modest positive benefit, while the impact of rainfall was not found to be significant. The marginal impact of every degree Celsius increase in temperature was about $4/hectare (ha) increase in agricultural net revenues. Overall, the direct monetary impact of climate change on Central Asia has been approximately $117 million in benefit to the agricultural sector. The result from future projection of climate scenarios based on the *RCP 2.6* and *RCP 8.5* models indicate that changes in temperature will produce lower benefits in the future and the farming population stands to lose as much as $64 - $66 million between 2020-2040. The net loss to agricultural revenue will be highest in Kazakhstan at $49 million, while Kyrgyzstan will face up to $29 million in loss; Uzbekistan will lose $7.7 million; Turkmenistan will lose $4.4 million and Tajikistan will lose up to $1.6 million from future climate change scenarios.

The findings from this study have significant policy implications for regional policymakers. The threat of climate change on the income and livelihood of the farming population will ultimately depend on the measures the government implements to help these populations adapt and prepare for it. The findings presented in this study provides a guide for governments in Central Asia to proactively think about the risks and the possible mitigation strategies so farming households can become more resilient and cope with the imminent effect of climate change on their income and livelihood. Our policy suggestion can be categorized into three broad components: (i) The government in nations like

Tajikistan, Turkmenistan and Uzbekistan can prepare the country for climate adaptations by passing regulations that support privatizations of farmlands by allocating proper property right structures to farm land owners as it would enable small farms to operate profitably and more efficiently (ii) The second category of policy the government needs to focus on is to invest in agricultural infrastructures such as building canals for rainwater harvesting, water storage and conveyance; introducing drip irrigation and climate-smart agriculture approaches; increasing investment in technologies to improve crop varieties and fertilizer applications; and also to invest on implementing novel forms of climate insurance programs to the vulnerable populations. (iii) The third category of policy that will be fundamental to mitigate the consequences of climate change is to increase investment in research and development that leads to novel ways to produce crops and livestock that are more suited for dryer conditions that Central Asia experiences. This kind of policy might be particularly suitable to countries like Kyrgyzstan, where farmers generally own a mix of crops and livestock in their portfolio.

This paper is organized as follows. In section 2, we review the existing literature on the various applications of climate change on agricultural production that employ the Ricardian method. Section 3 highlights our study area, where we describe the climate characteristics and present agricultural statistics and relevant current policies in Central Asia. In section 4, we briefly explain the theory and the empirical specification behind the Ricardian analysis to assess the economic impact of climate change on agriculture. Section 5 presents information on the data and the variable used in the study. In section 6, the empirical findings, as well as measures of the impact of future climate scenarios based on *RCP 2.6* and *RCP 8.5* models, are presented. The paper then concludes with a summary of the results, policy implications, and the limitations of the study. Tables and graphs are given in the appendix section.

Literature Review

The widely adopted literature on estimating the impact of climate change on agriculture follows two main methodologies: *the production function approach* and *the Ricardian approach*. The production function approach is a crop-specific analysis where the agronomic relationship between specific crops and climate is estimated by varying one or a few input variables like temperature, precipitation, carbon dioxide levels etc. The major criticism with the crop-specific analysis approach is its inability to capture the farmer's behavior, particularly with regards to the numerous adaptation strategies that farmers might make in response to changing climatic conditions.

The other methodology to analyze the impact of climate change on agriculture is based on the Ricardian approach, which was first introduced by Mendelsohn, Nordhaus, and Shaw in 1994. Mendelsohn et al. (1994) argued that the bias in the production-function approach tends to overestimate the damages from climate change as it does not, and cannot, take into account the infinite variety of substitutions and adaptations that farmers may make to displace the activities that are not advantageous as the climate changes. To overcome the problem of the production function approach, the Ricardian approach allows for the full range of compensatory behaviors of the farmers by examining how climate in different places affects the net value of farmland instead of just studying yields of specific crops. The Ricardian model is based on two assumptions: A perfectly competitive market for both outputs and inputs; and an equal amount of interest rate, rate of capital gains and capital per acre for all plots of land.

There are a considerable number of Ricardian studies that have been implemented to investigate the economic impacts of climate change on agriculture in various parts of the world. Van Passel et al., (2017) employed a continental scale Ricardian analysis to estimate the impact of climate on European agriculture using data from 41,030 farms across Western Europe. Their findings indicate that European farms are sensitive to seasonal climatic variables. The marginal effect of an increase in temperature was an 8-percentage increase in farmland value, while a marginal increase in precipitation would result in a 2-percentage increase in farmland value. Their findings further indicated that warmer temperature and precipitation by 2100 would be detrimental to European agriculture. Huong et al. (2019) investigated the impact of climate change on northwest Vietnam and found a non-linear seasonal relationship between climate and farmlands with net revenues expected to decrease and temperature expected to increase in the dry season. The impact of future climate change was a 17.7% decline in agriculture net revenues by 2050, although they argue the loss in revenue could be far more conservative at only 0.37% if the farmers can adapt to the changing climatic situations.

Kurukulasuriya and Mendelsohn (2007) developed a choice model of irrigation in the context of a Ricardian model of cropland and applied it to African farmlands. They looked at how climate affects the decision to employ irrigation and how climate affects the net revenues of dryland and irrigated land. Their findings suggest that African agriculture is sensitive to climate change. In particular, they find that a 10-percent increase in temperature would lead to an 8.2-percent decline in net revenue per hectare, while a reduction in precipitation was found to be especially deleterious to dryland farmers. Schlenker et al. (2005) employed the Ricardian model to estimate the potential impact of climate change on farmlands in the United States. They find that a 5-degree Fahrenheit increase in temperature and 8-percent rise in precipitation would result in an annual loss of $5 to $5.3 billion in the agricultural sector. Mendelsohn and Dinar (2003) employed the Ricardian model to explore the interaction between climate, water, and agriculture by quantifying the role of irrigation in adapting to unfavorable climate conditions. They find that surface water withdrawals were able to explain the variation on farmland values, which prompted them to highlight the role of irrigation as a potential mitigation option to help adapt agriculture to global warming. Other notable studies that have employed the Ricardian method to look at climate change impacts on agriculture include those by Seo and Mendelsohn (2007) on South American farmlands; Liperty and Aurbacher (2009) on farmlands in Germany; and Kunwar and Bohara (2019) on Nepalese farmlands.

Although there have been several studies that investigate the economic impact of climate change on agriculture in many countries, there are only a handful of studies available on agro-ecosystems in Central Asia. Even the few available studies that have focused on Central Asia have largely failed to include any economic component of climate change impact on agriculture. For instance, Bobojonov and Aw-Hassan, (2016) employed a bio-economic farm model (BEFM) as an ex-ante assessment of climate change impacts at sub-national levels in Central Asia. Their result suggested large differences in climate change impacts across the studied farming systems. Some earlier studies that have tried to incorporate an economic component in the context of Central Asia was by Bobojonov (2011) and Nelson et al. (2010). These studies broadly demonstrate that the impact of climate change would vary across the different crops and the various regions in Central Asia. They show that rainfed wheat, irrigated maize, and the potato will have positive yield gains in the future, whereas cotton yields will be negatively impacted in the long-term (2040-2070). However, one caveat of these aforementioned studies on Central Asia is that they are all based on the integrated assessment method and not the Ricardian approach. As such, these studies fail to take the full set of adaptive actions that farm holders might take against climate change impacts, which could produce downwardly biased estimates (i.e., their negative impacts will be exaggerated).

Although the economic analysis of climate change on agriculture in Central Asia are limited, there have been some Ricardian analyses that investigate the economic impacts at a global level where Central Asia was also incorporated (e.g., Cline 2007; Nelson et al., 2009, 2010). The only study to solely focus on Central Asia that has employed the Ricardian method to our knowledge is by Mirzabaev (2013). The study was conducted to investigate the impact of climate change for the period of 1990-2010. Their result suggests that the net average effect of weather variability was less than 1% of the total crop production revenues. This study adds upon the findings of Mirzabaev (2013) by presenting a precise economic analysis of climate change by employing the Ricardian method, which is currently missing in the context of Central Asia.

Study Area

Figure-1 presents the map of our study area that covers five countries in Central Asia: Kazakhstan, Tajikistan, Turkmenistan, Uzbekistan, and Kyrgyzstan. These countries are located between a latitude of 35 – 55^0 N, the longitude of 46 – 87^0 E, and span an area of approximately 400 million hectares, with 65 million people residing between them (Lal, 2007). These countries stretch from Russia in the north to Afghanistan, Iran and Pakistan in the south, China in the east and the Caspian Sea to the west. Of the 400 million hectares of total land, about 32.6 million hectares is arable land area, which represents a per-capita arable land area of 0.55 ha (Lal, 2007).

Central Asia has a wide-ranging geographic topology that contributes to a considerable variation in climate. For instance, the Kyrgyz Republic and Tajikistan are primarily mountainous countries, whereas the desert covers a large part of Kazakhstan, Turkmenistan, and Uzbekistan. The desert area as a percent of total land area in Central Asia is about 27.5% in Kazakhstan, 35.4% in Kyrgyzstan, 17.5% in Tajikistan, 79.3% in Turkmenistan, and 55.7% in Uzbekistan (Lal, 2007). The topography of these countries has a significant impact on the weather. The Kyrgyz Republic is considered to lie in a moderate climate zone and the annual average temperature in the country over the past 100 years has been about 2.1-degree Celsius (World Bank, 2018). The majority of the land area (about 70%) that lies at an elevation above 2000 meters in the Kyrgyz Republic receives heavy rainfall, while the remaining land area is fairly prone to droughts as well. Likewise, Tajikistan, where almost 93% of the terrain is mountainous, has a sub-tropical and arid climate with significant inter-annual variability. The annual average temperature in the past 100 years in the country was 3.3-degree Celsius, and the annual average rainfall was 480.3 mm during that period (World Bank, 2018).

Kazakhstan is situated in north-central Eurasia, where the terrain is diverse, and the country is located in four climatic zones: forest-steppe; steppe; semi-desert and desert. The country experiences a continental climate with long, hot summers and cold winters. The average annual temperature in the last 100 years was 5.8-degrees Celsius, and the average annual precipitation was 251.5 mm (World Bank, 2018). Turkmenistan is predominantly an arid country where 80% of the territory is characterized by desert and oases, although the country also has mountainous zones along the southern borders. Turkmenistan experiences a continental climate, and the average annual temperature in the past 100 years has was 15.1-degree Celsius, and the average precipitation was about 149.9 mm (World Bank, 2018). Similar to Kazakhstan and Turkmenistan, Uzbekistan's terrain is mostly flat-to-rolling sandy desert, with desert forests accounting for nearly 78% of the country's total land area. The country experiences an arid and continental climate that is characterized by cold winters, hot summers, and low precipitation across most of the country. The annual average temperature in the past 100 years in Uzbekistan was 12.2-degree Celsius, while the annual average precipitation was 190.0 mm (World Bank, 2018).

Agriculture plays a central role in the economy of Central Asia, and as such, these countries are highly vulnerable to climate change impacts. The primary agricultural commodities in the Central Asian region include cotton, wheat, tobacco, cereals, fruits, and vegetables (Hamidov et al., 2016). Agricultural land is the predominant land use in Central Asia and covers more than 70% (approximately 280 million ha) of the total land area. Next to agricultural lands, rangelands occupy 63% (250 million ha) of the land area; and croplands occupy 7% (30 million ha) of the land area, of which only 34% (10.3

million ha) is irrigated (Lal, 2007). Excluding Kazakhstan[1], almost 80% of the arable land in Central Asia is irrigated, and the irrigated land area has been drastically expanding since the 1950s.

The agricultural sector in Central Asia has gone through significant reorganization ever since the collapse of the Soviet Union. According to Lerman (2013), the five countries in our study area, all part of the former Soviet Union, have made considerable strides in their effort to reform the farming structure from command economy structure to a model that is closer to market principles. While the farming structure in Central Asia during the Soviet era was dominated by large agricultural enterprises, new changes were implemented during the early 1990s, which saw household plots substantially enlarged from additional land allocations. In particular, countries like Kazakhstan and Kyrgyzstan now recognize private ownership of lands; Tajikistan allows land market transactions, although the ownership of the land still belongs to the state; while Uzbekistan and Turkmenistan have state-controlled non-transferable land, but they now allow small leaseholders in leu of large collective farms.

In addition to the farmland restructuring, there have been significant reforms in agricultural production strategies as well. During the Soviet era, the agricultural production of each country was rather strategic with each country specializing in certain specific crops only. For instance, Kazakhstan specialized in grain production; Kyrgyzstan in alfalfa, maize, and sheep production; while Tajikistan, Turkmenistan and Uzbekistan mostly focused on the production of irrigated cotton and karakul sheep (Suleimenov, 2014). With the collapse of the Soviet Union, agro-industries that specialize in crop production began to emerge, and the landscape of agricultural production has changed with it. Kazakhstan saw a significant decline in cropland area during the transition which led to rapid increase in the production of monoculture wheat, dry peas, and chickpeas in the country. Kyrgyzstan also saw a huge increase in wheat production, and dry beans are now also being increasingly produced in the country. The most significant change in the other three countries has been in the cropping patterns, with cotton being largely substituted by wheat production. For instance, the wheat area in Tajikistan has more than doubled since the collapse of the Soviet Union; Turkmenistan has seen a rapid increase in bread what grain production; while in Uzbekistan, increase in bread wheat grain production has been the major outcome of agricultural restructuring (Suleimenov, 2014; Hamidov and Balla, 2016). Along with farmland and agricultural production restructuring, there have also been price and trade policy reforms that have collectively resulted in a vast reduction of wasteful resources in the agricultural sector and thus improved the productivity in these nations.

Theoretical and Empirical Model

The empirical analysis to investigate the economic impact of climate change on agriculture is based on the theoretical framework of the Ricardian approach. The Ricardian method is a cross-sectional approach of examining agricultural production using the relationship between climatic variables and farm performance. Farm performance is typically measured using agricultural net revenue or farmland value in the Ricardian analysis. Mendelsohn et al. (1994) argued that the then standard method used to measure the impacts of climate change on agriculture, the traditional production function approach, tends to overestimate the effects since it is based on a crop-specific analysis. To overcome the limitation of the production function approach, the Ricardian approach was developed which assumes the following specification:

$$V = \int P_{LE} e^{-\rho t} \partial t = \int (\sum P_i Q_i(X, F, Z) - \sum RX)\ e^{-\rho t} \partial t \tag{1}$$

[1] Only about 7% of arable land in Kazakhstan in irrigated (Lerman & Stanchin, 200

Where, farmland value (V) reflects the present value of future net productivity from a parcel of land; P_{LE} is the net revenue per hectare; P_i is the market price of the crop i, Q_i is the output of the crop i; *F* is a vector of climatic variables; *Z* is a vector of soil and socio-economic variables; *X* is a vector of purchased inputs (excluding land); *R* is a vector of input prices; t is the time and ρ is the discount rate. Differentiating Equation (1) with respect to each input identifies the set of inputs that maximize net revenues.

The Ricardian model is based on the assumption of a perfectly competitive market for both outputs and inputs; and the interest rate, rate of capital gains, and capital per acre equal for all plots of land (Mendelsohn et al., 1994). These assumptions allow for the reduction of the profit maximization function to a cross-sectional analysis. Assuming a farmer that wishes to maximize their land value by choosing *X* given the characteristics of the firm and market prices, the Ricardian method is a reduced form model of the endogenous variables (*F* and *Z*) that examines their impact on the farm value. The standard Ricardian model hypothesizes a quadratic relationship between the land value (net revenue) and climate variables. The rationale behind the non-linear relationship between farmland value and climatic variables is because experiments with crops in laboratory settings have suggested a hill-shaped response function with respect to climate, particularly with regards to temperature (Morison and Morecroft, 2008). The empirical specification of the Ricardian model can be expressed as:

$$V = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \varepsilon \qquad (2)$$

Where, ε is an error term. As stated above, the linear and a quadratic term for temperature and precipitation are introduced to capture the known non-linearities of the climate response function to crop production. A positive quadratic term signifies a U-shaped net revenue function while a negative term implies that the function is hill shaped. The original Ricardian literature was carried out in the context of United States and it predicted a hill-shaped relationship between annual temperature and agricultural net revenues (Mendelsohn et al., 1994). In this study, we employ an alternative log-linear functional form for the Ricardian model which is given by:

$$ln\, V_i = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \varepsilon \qquad (3)$$

The estimates of the climate coefficients derived from the regression can be used to compute the marginal effects of climate change. In the log-linear Ricardian form, differentiating the above equation (equation 3) with respect to a climate component (such as spring precipitation or winter temperature), yields the marginal impact of climate change given by:

$$\frac{dV}{df_i} = V * (b_{1i} + 2 * b_{1i} * f_i) \qquad (4)$$

The marginal impact of climate change as shown in equation (4) depends on the value of the climate component, f_i as well as the other variables that determine the farmland net revenue.

Data and Variables

The data for the empirical analysis comprises of information on agricultural activities and the climate in Central Asia. We use the data on agricultural activities and climate from all the provinces in Kazakhstan, Kyrgyzstan, and Uzbekistan, while we rely on country-level information for Tajikistan and Turkmenistan due to the limited data availability at province level in the latter two countries. The climate data in this study includes monthly temperature and precipitation between 1991 – 2016 and was obtained from the World Bank Climate Data Portal (World Bank, 2018). For the empirical analysis, the temperature and precipitation data have been converted into four seasonal averages: Spring (January – March); Summer (April – June); Fall (July – September); and Winter (October – December). We use linear and quadratic specification of the climatic variables to capture the potential non-linear impacts of climate change on agriculture. The empirical analysis also uses elevation (meters) as a control variable, and it was constructed based on the latitude and longitude of the centroids of the provinces and the countries in the study area.

The widely used dependent variable in the Ricardian analysis is net revenue per hectare of farmland. In our analysis, the net revenue variable was constructed by using the data on '*Total Agricultural Revenue*' and '*Total Cultivable Land Area'*. The data on agricultural activities in Central Asia comes from the Food and Agricultural Organization (FAOSTAT, 2016), and from the Statistics Committee of Kazakhstan, Uzbekistan and Kyrgyzstan. The ratio of the '*Total agricultural revenue*' and '*Total cultivable land area*' was used to construct the net revenue per hectare variable for the empirical analysis. Table 1 presents the variables, the measurement units and the data source for the variables employed in the study.

Figure-2a presents the total revenue from agriculture in Central Asia, and Figures-(2b – 2d) presents the total agricultural revenue on the different provinces in Kazakhstan, Kyrgyzstan and Uzbekistan. The country with the largest agricultural revenue in Central Asia was Uzbekistan with an annual revenue of almost $18 billion in 2018, while Tajikistan had the lowest agricultural revenue at $1.2 billion in 2018. The province-level data (Figure 2b-2d) shows that the largest agricultural revenue in Kazakhstan comes from the Almaty province; the Samarkand province in Uzbekistan; and from the Chui province in the Kyrgyz Republic.

Table 2 presents the summary statistics of the variables in our study. The total value of agricultural production in 2018 between the five countries in Central Asia ranged from $1.26 billion to $11.8 billion per year. The total area of land available for cultivation ranged from 715,000 hectares to 22.3 million hectares. The dependent variable in our analysis, *net revenue per hectare*, has an average value of $2,174/ha. The average annual rainfall since 1991-2016 in the five countries ranged from 12mm to 43mm, while the range of average temperature in the last 25 years goes from a low of 3-degree Celsius to a maximum of 15-degree Celsius. Table 2 also presents the summary statistics of climate and agricultural activities for all the provinces in Kazakhstan, Uzbekistan and Kyrgyzstan. The mean agricultural net revenue at the province-level data is $4,375/ha, and the value ranges from $125/ha to $24,571/ha.

Table 3 presents some additional detail on the agricultural characteristics on the provinces in Kazakhstan, Uzbekistan and Kyrgyzstan. When we isolate the agricultural information of these countries at province-level, several noteworthy information begins to emerge. The maximum amount of cultivable land area in Kazakhstan belongs to the Kostanai province; but the highest share of agricultural revenue comes from the Almaty province and North Kazakhstan. On the other hand, the largest net revenue per hectare belongs to farmlands in Almaty city and Nur Sultan, even though both these regions have a meager share in agricultural revenue or on the available cultivable land area in Kazakhstan. In the case of Uzbekistan, Samarkand province has the biggest share of agricultural revenue in the country, while Kashkardarya province has the maximum amount of cultivable land area. In terms of the net revenue per hectare, Andijan followed by Navoi are the two provinces that have a higher value than any other provinces in Uzbekistan. Finally, when we look at Kyrgyzstan, the data suggests that the Chui province has both the highest share of agricultural revenue and also the cultivable land area in the country. The province with the highest agricultural net revenue in Kyrgyzstan, however, belongs to Bishkek city.

Results and Discussion

The empirical analysis was conducted using a linear regression analysis. The dependent variable is the agricultural net revenue per hectare, and the independent variable considered are the linear and the quadratic specification of average seasonal temperature and precipitation. We control for the elevation of the provinces in the regression analysis since elevation has been shown to be an important control in past Ricardian studies (Seo et al., 2005). The dependent variable of the study, *agricultural net revenue per hectare*, is defined as:

$$Net\ revenue\ per\ hectare = \frac{Total\ net\ revenue\ of\ the\ province}{Area\ of\ cropland\ in\ hectares\ of\ the\ province} \quad (5)$$

Figure-3 presents the histogram of the dependent variable (i.e., net revenue per hectare) as well as the logarithm of the dependent variable. The logarithm of the net revenue is used as the dependent variable in the empirical analysis since the logged value is relatively more normally distributed. Table 4 presents the outcome of the regression estimates, and the result generally indicates that climate change does impact the agricultural revenue in Central Asia. In particular, the findings reveal that the summer and the winter precipitation had an impact on the net revenues from agriculture; while the spring and fall precipitation does not suggest any significant relationship. Similarly, the spring, summer and the fall temperature all had a significant impact on the agricultural net revenues in Central Asia. The regression model shows a modest degree of fit with a r-square value of 0.53.

The significant quadratic terms on some seasons for the climatic variables suggest that climate and agricultural revenues in Central Asia have a non-linear relationship, which is consistent with the hypothesis of the Ricardian approach (Mendelsohn et al., 1994). The summer precipitation and temperature both have a quadrative and convex relationship with net revenues, which indicates that there is a minimally productive level of temperature and precipitation during the summer season and either more or less amount of temperature and/or precipitation would result in an increase in agricultural net revenues. The minimal productive level of temperature and precipitation during the summer season occurs at 18.73-degree Celsius and 30 mm respectively.

The winter precipitation and the fall temperature show a concave relationship, which indicates that there is an optimal level of climate variable from which the value function decreases in both directions (Mendelsohn et al. 1994). The optimal temperature and precipitation for agricultural net revenues during the fall and the winter season occurs at 21.76-degree Celsius and 45mm, respectively. While the findings of this study indicate a relationship between climate and agriculture in certain seasons, it is difficult to relate the results with other similar studies since there have not been adequate economic impact studies of climate change on agriculture in Central Asia. Mirzabaev (2013) is one of the only studies that investigates the economic impact of climate change on agricultural profits, and that study employs a longitudinal data on the different provinces in Central Asia to carry out their analysis. Their findings also suggest a non-linear quadratic relationship between climate and agricultural profits in Central Asia. More specifically, Mirzabaev (2013) find that temperature in winter, summer and fall had a convex relationship with crop production revenues while spring temperature had a concave relationship.

To get a clearer understanding of the impact of climate change on the agricultural net revenues, Table 5 presents the marginal effects of climate change estimated from the results in Table 4. The impact of annual precipitation marginal is not significant, but the annual temperature marginal implies that moderate warming is beneficial to agriculture in Central Asia. Moderate increases in temperature has been established to be beneficial to agricultural revenues in some other studies as well. For instance, Van Passel et al. (2017) find that temperature increases has resulted in an 8-percentage increase in the value of farmlands in Western Europe; Massetti and Mendelsohn (2011) find that moderate increase in temperature has been beneficial to US agriculture; and Birthal et al. (2014) find increases in minimum temperature was beneficial to *Kharif* and *Rabi* crop yields in India. The results from the marginal impacts in Table 5 suggest that every degree increase in annual temperature has contributed to about $4/ha increase in agricultural net revenue in Central Asia.

We also estimate the impact of future climate change scenarios (2020-2040) on agricultural net revenues to explore the aggregate welfare impacts in Central Asia. The analysis of future climate change impacts is based on two climate projections from the Representative Concentration Pathways (RCP) scenario which is adopted by the IPCC. The first scenario we estimate is based on *RCP 2.6* projection which represents a stringent mitigation scenario or low greenhouse gas (GHG) emissions trajectory in the future. The second scenario we estimate is based on *RCP 8.5* projection and it represents a scenario with high GHG emissions trajectory. The projection of the future climate data based on *RCP 2.6* and *RCP 8.5* scenario was constructed using the World Bank Climate Change Knowledge Portal (World Bank, 2019).

The outcome of the future climate impacts (based on the *RCP 2.6* and *RCP 8.5* scenario) on agriculture is presented in Table 6, and the sign and significance of the variables are pretty similar between both the scenarios. In either of the two models in Table 6, the result suggests that the future temperature might have a more pronounced impact of agriculture with the summer and fall temperature being significant in both the scenarios. The rain fall has a convex relationship with the net revenues in the *RCP 2.6* scenario, while the winter rain is significant in the *RCP 8.5* scenario. Table 7 presents the marginal impacts from the two RCP climate projections, and it is evident that while temperature will still have a favorable impact on the agricultural net revenues in the future, the positive impacts will be sharply diminished when compared to the historical climate impacts presented in Table 5.

The marginal impacts of precipitation were not significant in both the *RCP 2.6* and *RCP 8.5* scenarios, but the estimates of annual temperature change suggest that the gain in agricultural revenues in the future will fall down to $1.75/ha - $1.81/ha as compared to $4/ha that Central Asia has been witnessing based on historical trends. The findings of future climate change impacts presented in this study are relatively in line with other studies in the region. Mirzabaev (2013) argue that the overall effect of future climate change scenario (for the year 2039) on crop revenues in the would be modest. They find that in the pessimistic case, the welfare would decline by 1.43%, or about $210 million relative to 2010 levels. Bobojonov and Aw-Hassan (2014) argue that agricultural revenues between 2070-2100 will decline in Central Asia due to increasing temperature and increasing risk of water deficit. They also note that impacts on agricultural systems in Central Asia will be diverse and some farmers in different regions of the Central Asia might benefit too.

Based on the marginal estimates from Table 5 and Table 7, we present the total aggregate welfare changes from climate change in Central Asia in Table 8. These estimates are calculated using the current total available cultivable land area in the five countries. The net benefits of a marginal increase in temperature in Kazakhstan historically has been approximately $88 million; $5 million In Kyrgyzstan;

$2.8 million in Tajikistan; $7.8 million in Turkmenistan and $13 million in Uzbekistan. The results from Table 8 suggests these benefits will be reduced in the next 20 years in either of the two climate scenarios, *RCP 2.6* and *RCP 8.5*. While the current aggregate benefits to Central Asian agriculture from climate change seems to be about $117 million, these benefits will be reduced by almost half to $51 million under the *RCP 8.5* scenario and $53 million under the *RCP 2.6* scenario. The net welfare loss to the farming communities in these countries is going to be significant. Kazakhstan will lose as much as $49 million; Kyrgyzstan, about $29 million; Tajikistan about $1.6 million; Turkmenistan about $4.4 million; and Uzbekistan stands to lose as much as $7.7 million from the future climate change scenarios.

Conclusion and Policy Implications

Climate change is emerging as a serious concern in our modern society, and agriculture is one area that could be gravely affected. As the global temperature continues to rise and precipitation patterns become even more erratic, the impact on food security and crop yields is already being felt acutely, and this trend will only worsen over time. Central Asia has an average temperature that is warming faster than the global average (Maas et al., 2011), and the region is heavily dependent on agriculture. The ramifications of climate change to the agricultural sector and the overall economy of Central Asia can be huge if proper policies are not implemented to mitigate the potential impacts of climate change.

This paper used an application of the Ricardian approach to demonstrate the impact of climate change on agriculture in Central Asia. The empirical analysis is conducted on five countries: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, by investigating the relationship between seasonal rainfall and precipitation on net agricultural revenues per hectare. The findings suggest that agriculture in Central Asia is indeed sensitive to changes in climate, and in particular to changes in temperature during certain seasons. We find a convex relationship with the summer precipitation and temperature, and a concave relationship between the fall temperature and winter precipitation with the net revenues from agriculture in Central Asia. The marginal impacts of climate change suggest that every degree Celsius increase in annual temperature has resulted in a modest benefit of $4/ha increase in net agricultural revenue in Central Asia. The total impact of climate change on net agricultural revenues in Central Asia is estimated to be about $117 million in benefits. We also present the impact of future climate change scenarios on agriculture in Central Asia, and the results are more conservative in the future scenarios. While the results from both the *RCP 2.6* and *RCP 8.5* models suggest that agriculture would still be sensitive to changes in temperature, the marginal impact of future increases in temperature only results in about $1.75/ha - $1.81/ha benefits to Central Asian agriculture. The loss of agricultural revenues from climate change in Central Asia is estimated to be as much as $66 million by 2040. The country that stands to lose the most is Kazakhstan where the losses will be about $50 million, while the loss to Tajikistan will be the least in Central Asia at $1.7 million.

Agricultural production is one of the major means of livelihood for a vast majority of the households in Central Asia, and as such, the results from this paper indicates there is a dire need to implement corrective policies to protect the livelihood of these vulnerable populations and also to mitigate any disruption in the economy from potential climate change impacts in the future. The policies should be directed with the aim to ensure that farming communities in Central Asia are able to adapt early to the unintended consequences of climate change. There are several paths the government could take to implement such policies. One approach that is relevant to the Central Asian economies is for the government to actively implement regulations that support privatization of farmlands. Implementing proper property right structures in regard to farmland ownership can enable small farms to operate profitably and efficiently. This policy might particularly be relevant to countries like Tajikistan, Turkmenistan, and Uzbekistan, where land rights are still state-controlled and non-transferable.

Allocating property rights to private farmland-owners is likely to be important for climate adaptations too since farmers can only pursue adaptation measures by themselves if they have secure ownership of their land and water. Studies have shown that farmers with private rights will make investments in the adaptation that farmers with insecure rights will not (Deininger and Jin, 2006).

The second policy government should target to increase its investment budget into bringing new agricultural infrastructures in the region. For instance, investment into novel irrigation technologies like drip irrigation could be one adaptation action that would be useful in regions where water is available. Incorporating innovative irrigation technologies would not only increase net revenues from agriculture, it would also the resilience of agriculture to climate change. This policy might be particularly relevant in countries like Kazakhstan, where only 7% of the total arable land is irrigated (Lerman and Stanchin, 2006). Likewise, investment in infrastructures and canals for rainwater harvesting, water storage, and conveyance would make Central Asia more resilient to climate change. Similarly, investment into other technologies to improve crop varieties and fertilizer applications should also be considered. The agricultural system in Central Asia could also be extended to incorporate agricultural extensions, finances, and services in place.

The third category of policy that could be implemented to defend from climate change scenarios is towards investment in research and development (R&D) activities that lead to novel ways to produce crops and livestock more suited for dryer conditions that Central Asia experiences. Past studies have suggested that farmers might adapt better to climate change by altering farm types; by adding or removing livestock from their portfolio; or even by switching species (Mendelsohn and Dinar, 2009). This kind of approach might be suitable in Kyrgyzstan, where farmers have a mix of crops and livestock in their portfolio. In addition to R&D, governments can also help strengthen outreach and dissemination programs that provide farmers with advice about alternatives more suitable for changing climates. Additionally, they can implement programs to provide credit to help farmers invest in their land and farming operations. Finally, the government should also invest heavily into integrating approaches like climate smart agriculture (CSA), which is an integrative approach to address the complex and interrelated challenges of food security, development and climate change. On a related note to investment in R&D for the production of crops and livestock, it is also imperative that the governments in Central Asia promote transparency and collaboration from research centers and universities from around the world to ensure cutting edge studies are being produced to investigate the relationship between climate change and agriculture in Central Asia. It is also vital that the government should carry out regular household surveys to gather data in the region, and also incentivize the collection of economic data from third parties by providing grants so scientific studies can be conducted easily.

Finally, while this paper quantified the economic impacts of climate change on agricultural revenue in Central Asia, the result presented in this study should be taken with caution, and further research is warranted to get a more robust understanding of climate change impacts in Central Asia. The major limitation of this study comes from the nature of the data availability in Central Asia, which is extremely difficult to get hold of. The bulk of Ricardian studies to investigate climate change impacts on agriculture are carried out using household-level data, while our analysis employed province-level data on three countries and country-level data for two countries. A more robust result would have been possible with access to either a household level data or at least district-level data across these countries. A richer dataset would have made it possible to provide a robust assessment of the impacts on each district in Central Asia, and that would equip policymakers with detailed information to devise targeted policies based on a methodical approach.

The other issue with our study is that we have not accounted for household, institutional, agro-ecological, and production factors that could also impact the net agricultural profits, which was again due to data unavailability in Central Asia. Excluding such control variables will not allow the empirical model to fully capture the variations thereby producing biased estimates. Some examples of variables that have been used in other Ricardian studies include soil quality, access to irrigation, household income, literacy rate, population density, household size, access to electricity, all of which could affect farm performance and have been used as controls in other Ricardian studies (Mendelsohn and Dinar, 2009). The final limitation of the study is with our use of climate variables as well. While we have used the seasonal climate normals to capture the weather, past studies have indicated that climate variance (diurnal variance and interannual variance) could also be significant factors that affect farm performance (Mendelsohn and Dinar, 2009). In addition to climate variance, plant physiology literature suggests that extreme weather events could have a more severe effect on crop yields and agriculture in general (Rosenzweig, 2001), and as such, incorporating indices to capture extreme temperature and rainfall could provide more robust findings. A recent study by Kunwar and Bohara (2017) in Nepal found that extreme weather events like the count of warmer days and excessive precipitation also affected farm performance; while another study by Zhang et al. (2017) highlighted that incorporating additional climatic variables like humidity, wind speed, sunshine duration and evaporation was able to give a better estimation of the climate change impact on agriculture in China. However, disregarding these limitations, this study provides clear evidence that agriculture in Central Asia in sensitive to climate change and these impacts are going to be accentuated in the future, thereby warranting proper policies to be put in place to mitigate the adverse impacts of climate change.

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Appendix: Tables and Figures

Figure1: Map of the study area in Central Asia

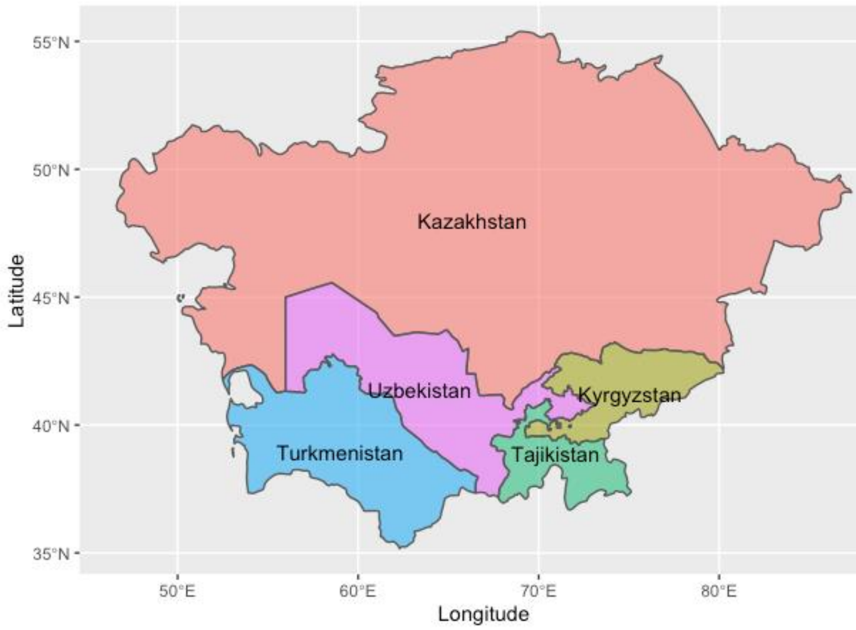

Figure 2a: Total Revnue from Agriculture in Central Asia

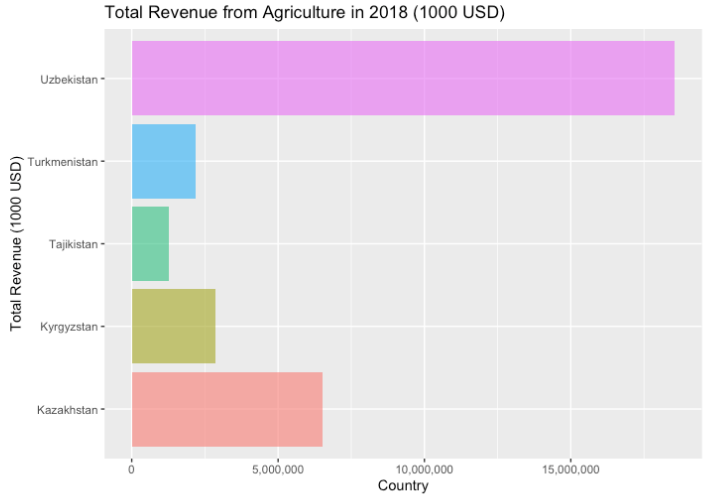

Figure 2b: Total Revnue from Agriculture in Kazakhstan

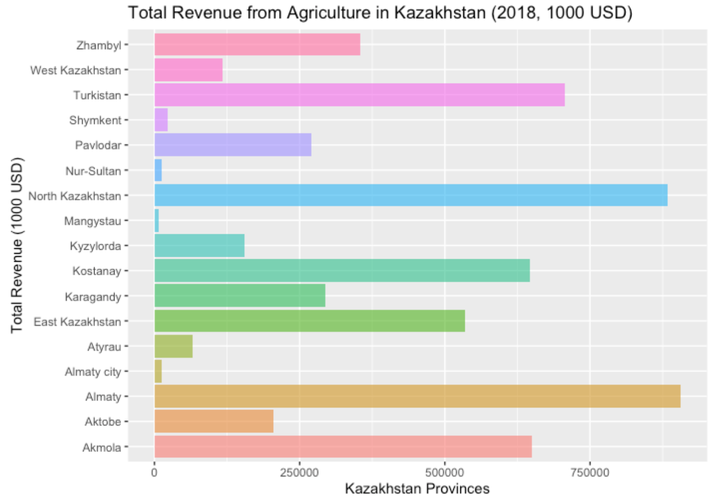

Figure 2c: Total Revenue from Agriculture in Kyrgyzstan

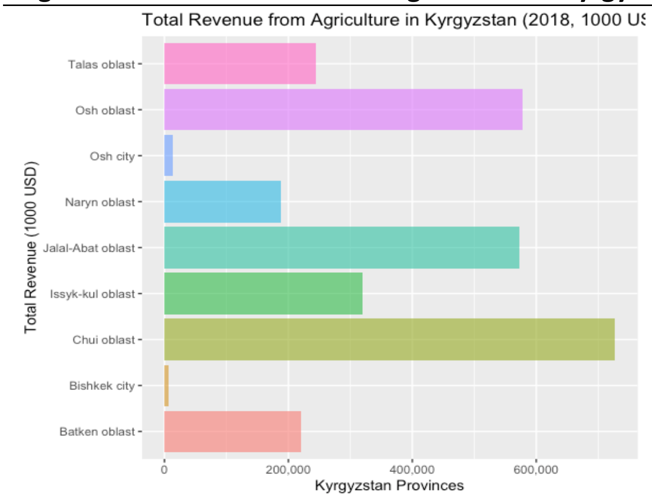

Figure 2d: Total Revnue from Agriculture in Uzbekistan

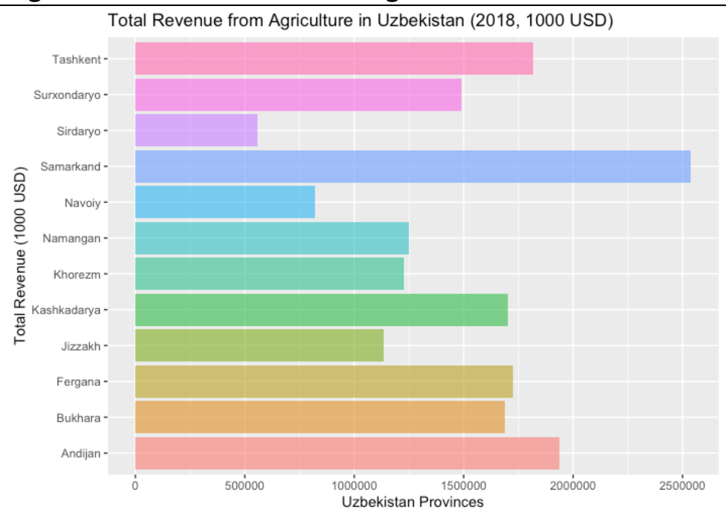

Figure 3: Histogram of net revenue per hectare (left) and log of net revenue per hectare (right)

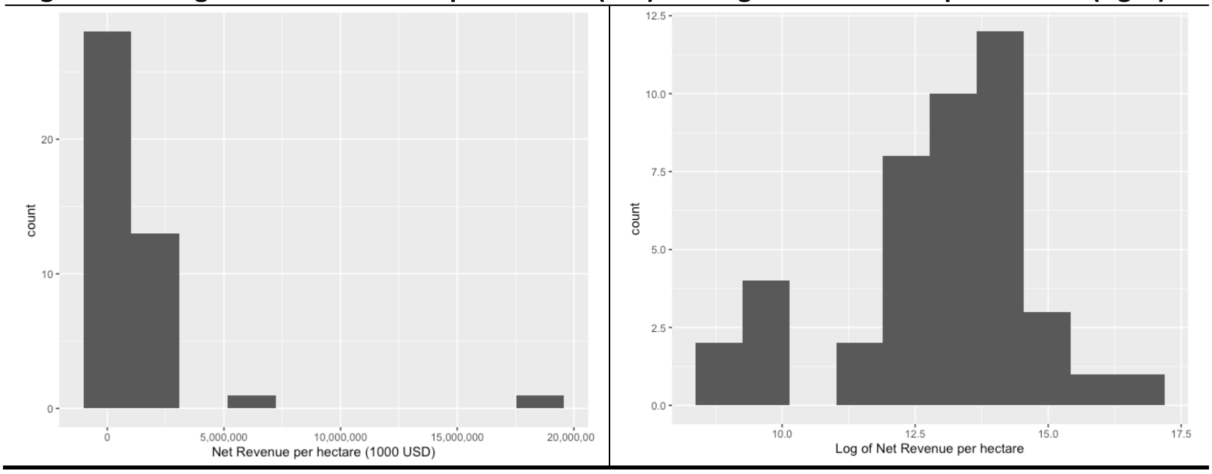

Table 1: Variable information and the data source for the variables in the study

Variable	Measurement unit	Source
Average Seasonal Temperature (seasonal mean for spring, summer fall and winter seasons between 1990 – 2016)	Degree Celsius	World Bank Climate Change Portal
Average Seasonal Precipitation (seasonal mean for spring, summer fall and winter seasons between 1990 – 2016)	Millimeters (mm)	World Bank Climate Change Portal
Total Value of Agricultural Production (2018)	US $ (1000 USD)	Food and Agriculture Organization (FAO) & Statistical Committee of Kazakhstan, Kyrgyzstan and Uzbekistan
Total Cultivable Land Area	Hectare (Ha) (1000 Ha)	JICA Report on Agriculture, FAO & Statistics Committee of Kazakhstan, Kyrgyzstan and Uzbekistan
Elevation	Elevation of the province and/or country's centroid in meters	Extracted from the Latitude and Longitude coordinates acquired from Work Bank climate change portal.

Table 2: Summary Statistics for the 5 countries and the provinces of Kazakhstan and Uzbekistan

Variable	Obs	Mean	Std.Dev.	Min	Max
Country-Level					
Net Revenue (ha)	5	2174.781	1976.314	297.816	5463.82
Total value of agriculture (1000 USD)	5	6280000	7150000	1260000	1.86e+07
Total cultivable land (1000 ha)	5	5847.783	9028.685	715.7	21899.41
Mean Spring Rain (mm)	5	33.759	20.188	17.679	68.244
Mean Summer Rain (mm)	5	32.333	18.34	12.436	53.282
Mean Fall Rain (mm)	5	8.862	8.588	1.949	20.423
Mean Winter Rain (mm)	5	26.826	13.993	12.41	47.564
Mean Spring Temperature (degree Celsius)	5	-2.9	5.658	-7.641	4.769
Mean Summer Temperature (degree Celsius)	5	14.808	6.305	8.09	21.859
Mean Fall Temperature (degree Celsius)	5	19.585	5.829	13.756	26.423
Mean Winter Temperature (degree Celsius)	5	2.015	4.927	-2.692	8.885
Mean Annual Rain (mm)	5	25.445	12.689	12.208	43.304
Mean Annual Temperature (degree Celsius)	5	8.377	5.509	3.048	15.484
Elevation (m)	5	1366.8	1561.737	110	3782
(Province-Level)					
Net Revenue (ha)	38	4345.745	5549.499	125.565	24751.79
Total value of agriculture (1000 USD)	38	700000	662000	6668.2	2540000
Total cultivable land (1000 ha)	38	705.573	1256.864	.478	5143.327
Mean Spring Rain (mm)	38	34.438	16.161	12.283	64.238
Mean Summer Rain (mm)	38	36.263	14.237	10.763	64.592
Mean Fall Rain (mm)	38	14.363	11.893	.524	38.642
Mean Winter Rain (mm)	38	30.82	11.393	9.688	59.814
Mean Spring Temperature (degree Celsius)	38	-2.371	6.648	-12.762	7.044
Mean Summer Temperature (degree Celsius)	38	16.781	4.772	3.777	23.282
Mean Fall Temperature (degree Celsius)	38	21.025	4.346	10.019	26.676
Mean Winter Temperature (degree Celsius)	38	2.746	5.226	-6.014	10.632
Elevation (m)	38	727.895	910.381	-24	4404

Table 3: Agricultural characteristics of the provinces in Kazakhstan, Uzbekistan and Kyrgyzstan

Country	Provinces	Share in the total national agricultural revenue (%)	Share of the national cropped area (%)	Net Revenue per hectare (USD)
Kazakhstan	Akmola	9.95	22.32	132.76
	Aktobe	3.15	3.37	278.66
	Almaty City	0.18	0.01	24,057.62
	Almaty	13.89	4.35	949.78
	Atyrau	1.00	0.002	8119.01
	West Kazakhstan	1.79	2.36	225.86
	Karagandy	4.51	5.24	256.63
	Kostanai	9.90	23.48	125.56
	Kyzylorda	2.37	0.81	865.60
	Mangistau	0.11	0.004	7988.32
	Nur Sultan	0.18	0.002	24,751.79
	Pavlodar	4.14	5.80	212.69
	East Kazakhstan	8.19	6.01	405.61
	Shymkent	0.33	0.12	851.83
	North Kazakhstan	13.53	19.31	208.66
	Turkistan	10.82	3.71	867.57
	Zhambyl	5.43	3.02	535.68
Uzbekistan	Andijan	10.45	6.77	8428.83
	Bukhara	9.09	7.08	7016.25
	Fergana	9.30	8.52	5964.02
	Jizzakh	6.10	11.66	2859.50
	Kashkadarya	9.17	14.73	3401.49
	Khorezm	6.62	6.82	5304.55
	Namangan	6.73	6.58	5589.44
	Navoi	4.42	3.03	7977.27
	Samarkand	13.67	10.72	6967.93
	Surkhandarya	8.02	8.33	5255.32
	Syrdarya	3.01	6.85	2401.88
	Tashkent	9.78	10.39	5142.00
Kyrgyzstan	Batken	7.65	7.81	2184.30
	Jalal-Abad	19.94	14.49	3066.35
	Issyk-Kul	11.13	16.83	1473.65
	Naryn	6.56	4.19	3484.07
	Osh	20.13	17.80	2519.00
	Talas	8.49	8.04	2351.64
	Chui	25.35	44.08	1281.38
	Bishkek City	0.23	0.60	8593.04
	Osh City	0.49	0.36	3042.63

Table 4: Linear regression estimates

Log (Net Revenue/ha)	Coef.	St.Err.	t-value	Sig
Spring Rain	-0.508	0.424	-1.20	
Spring Rain Sq	0.004	0.004	0.94	
Summer Rain	-0.243	0.015	-16.47	***
Summer Rain Sq	0.004	0.001	3.27	**
Fall Rain	-0.332	0.182	-1.83	
Fall Rain Sq	0.006	0.003	1.79	
Winter Rain	0.631	0.243	2.60	*
Winter Rain Sq	-0.007	0.003	-2.45	*
Spring Temperature	1.480	0.602	2.46	*
Spring Temperature Sq	0.052	0.041	1.26	
Summer Temperature	-3.796	1.172	-3.24	**
Summer Temperature Sq	0.103	0.027	3.73	**
Fall Temperature	7.487	2.772	2.70	*
Fall Temperature Sq	-0.172	0.055	-3.11	**
Winter Temperature	-1.139	0.736	-1.55	
Winter Temperature Sq	-0.015	0.034	-0.45	
Elevation	0.000	0.000	-0.04	
Constant	-27.210	17.693	-1.54	
Number of obs		40.000		
R-squared		0.536		
Akaike crit. (AIC)		96.738		
Bayesian crit. (BIC)		103.288		

**** p<0.01, ** p<0.05, * p<0.1 (Robust Standard Errors)*

Table 5: Marginal effects of climate change

	Marginal Impact		Marginal Impact
Rainfall ($/ha/mm)		**Temperature ($/ha/^{0}C)**	
Spring Rain	-0.508 (0.42)	Spring Temperature	1.479** (0.60)
Summer Rain	-0.243*** (0.01)	Summer Temperature	-3.796*** (1.17)
Fall Rain	-0.332** (0.18)	Fall Temperature	7.487*** (2.77)
Winter Rain	0.631*** (0.24)	Winter Temperature	-1.138 (0.73)
Total Rainfall		**Total Temperature**	
Rainfall	-0.452 (0.33)	Temperature	4.032*** (1.43)

Note: Standard Errors in parenthesis

Table 6: Linear regression estimates of future climate change scenarios

	RCP 2.6 scenario (low GHG emissions)		RPC 8.5 scenario (High GHG emissions)	
Log (Net Revenue/ha)	Coef.	St.Err.	Coef.	St.Err.
Spring Rain	-0.039	0.126	-0.203	0.127
Spring Rain Sq	0.001	0.001	0.002	0.001
Summer Rain	0.158	0.125	0.229	0.124
Summer Rain Sq	-0.001	0.001	-0.001	0.001
Fall Rain	0.216*	0.101	0.068	0.085
Fall Rain Sq	-0.003**	0.001	-0.001	0.001
Winter Rain	-0.060	0.195	0.153	0.184
Winter Rain Sq	-0.002	0.002	-0.004*	0.002
Spring Temperature	-2.171	1.483	-1.846	0.962
Spring Temperature Sq	-0.042	0.029	-0.003	0.028
Summer Temperature	-7.920*	3.392	-7.540*	3.021
Summer Temperature Sq	0.245*	0.119	0.222*	0.092
Fall Temperature	8.650*	3.375	7.776*	3.031
Fall Temperature Sq	-0.209*	0.093	-0.180*	0.073
Winter Temperature	3.253	2.369	3.370	1.790
Winter Temperature Sq	-0.015	0.053	-0.067	0.054
Elevation	0.000	0.000	0.000	0.000
Constant	-30.948	17.100	-26.207	14.105
Number of obs		40.000		40.000
R-squared		0.610		0.616
Akaike crit. (AIC)		119.297		118.610
Bayesian crit. (BIC)		128.103		127.416

**** p<0.01, ** p<0.05, * p<0.1 (Robust Standard Errors)*

Table 7: Marginal effects of future climate change scenarios

Rainfall ($/ha/mm)			**Temperature ($/ha/^{0}C)**		
	RPC 2.6	**RPC 8.5**		**RPC 2.6**	**RPC 8.5**
Spring Rain	-0.038 (0.12)	0.203* (0.127)	Spring Temperature	-2.171 (1.48)	-1.845* (0.962)
Summer Rain	-0.157 (0.12)	0.228* (0.123)	Summer Temperature	-7.920** (3.39)	-7.540 **(3.021)
Fall Rain	-0.216** (0.11)	0.067 (0.084)	Fall Temperature	8.650** (3.37)	7.775** (3.031)
Winter Rain	0.059 (0.19)	0.153 (0.184)	Winter Temperature	3.252 (2.36)	3.370 (1.789)
Total Rainfall			**Total Temperature**		
Rainfall	-0.275 (0.22)	0.246 (0.170)	Temperature	1.811* (0.05)	1.759* (0.925)

Note: Standard Errors in parenthesis

Table 8: Aggregate welfare impacts of climate change in Central Asia

Country	Climate change impacts (1990 – 2016) (1000 UDS)	Future climate impacts (2020-2040): RPC 2.6 (1000 USD)	Future climate impacts (2020-2040): RPC 8.5 (1000 USD)	Net Welfare Loss
Kazakhstan	$88,298.4211	$39,659.8315	$38,521.0622	(-$48,638.5896, -$49,777.3589)
Kyrgyzstan	$5,192.4096	$2,332.2058	$2,265.2402	(-$28,60.2038, -$29,27.1694)
Tajikistan	$2,885.7024	$1,296.1327	$1,258.9163	(-$1,589.5697, -$1,626.7861)
Turkmenistan	$7,822.08	$3,513.34	$3,412.46	(-$4,308.74, -$4,409.62)
Uzbekistan	$13,692.672	$6,150.156	$5,973.564	(-$7,542.516, -$7,719.108)
Total Impact	**$117,891.285**	**$52,951.666**	**$51,431.2427**	**(-$64,939.6191, -$66,460.0424)**