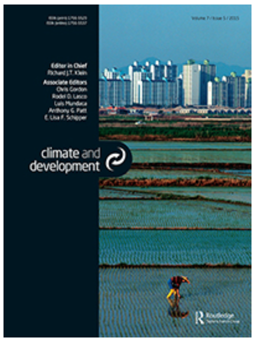

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RESEARCH ARTICLE

Measuring the economic impact of climate change on agriculture: a Ricardian analysis of farmlands in Tajikistan

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We apply the Ricardian approach to analyse the economic impact of climate change on agriculture using the 2007 World Bank Tajikistan Living Standards Survey. The study analyses data of 2557 farm households in 166 villages across the 10 agro-ecological country zones. In general, the results indicated that increasing temperature and precipitation will both be damaging to Tajikistan agriculture and consequently to the net revenue (NR) of farmers in the medium and long term. Regressing NR on climate parameters, household and soil variables showed that these variables have a significant impact on the farmers' NR per hectare. We examined the impact of the current climate on farmers' NR per hectare, and how that is affected by future climate scenarios: one +2.9°C warming and one 4.6°C warming scenarios. Although the analysis did not incorporate variables such as the carbon fertilization effect, the role of technology or the change in prices in the future, significant information for policy-making can be extracted. Tajikistan has very diverse regions in terms of geography, population density and socio-economic situation; our results will help policy-makers to anticipate the adaptation effort needed in different locations of the country.

Keywords: agriculture; climate change; economic impact; sensitivity; Tajikistan

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1. Introduction

Climate models show that Central Asian countries will significantly warm and face more frequent droughts and heat waves (IPCC, 2007; World Bank, 2009). These changes would have profound impacts on agriculture, biodiversity, population health, ecology and the overall economy. Climate change is an intricate problem mainly because of uncertainty. Indeed, substantial uncertainty exists about extreme events (e.g. droughts and floods) or local impacts of global warming. According to the vulnerability index of Fay and Hrishi (2008),[1] Tajikistan has very low adaptive capacity and so has the highest vulnerability to climate change in the Europe and Central Asian Region (World Bank, 2009).

A small mountainous country of less than seven million people, Tajikistan is the poorest country of the region and more than half of the population depends on agriculture for their livelihood. The agriculture sector represents more than 20% of the GDP and 30% of exports (World Bank, 2009). Furthermore, Tajikistan is highly dependent on food imports, which also make it vulnerable to external shocks (Akramov & Shreedhar, 2012). According to the International Fund of Agricultural Development (IFAD), more than half of the population is poor and 80% of the poor live in rural areas. Non-governmental organizations and international organizations also point out food insecurity in the country, underscoring the importance of the agricultural sector in tackling poverty and achieving rural development.

At the same time, agriculture appears to be one of the most vulnerable sectors to climate change because of its sensitivity to direct effects of changes in climate such as temperature, rainfall and carbon dioxide (CO_2) and indirect effects through water or soil. Indeed, climate is one of the main determinants of agriculture productivity, and climate change could have important consequences for food security and economy of this agricultural country. Tajikistan particularly needs to adapt to climate and this requires information about the future. However, the literature that estimates the economic impact of climate change in Tajikistan is still incomplete.

Globally, a large body of literature on climate change impacts on agriculture has developed. The world impact of climate change on agriculture has been estimated in numerous studies (Antle, 1995; IFPRI, 2009; Mendelsohn, 2000; Watson, Zinyoera, & Moss, 1997). Different kinds of

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economic modelling are used in the literature, including crop simulation (Sommer, Glazirina, & Yuldashev, 2012), agro-economic modelling, bio-economic modelling (Bobojonov & Aw-Hassan, 2013; Kaul, 2007) or econometric analysis (Isik & Devadoss, 2007). The econometric cross-sectional approach, also known as the Ricardian approach, which analyses relationships between land value or net revenue (NR) and agro-climatic variables, has the advantage of using existing survey data and taking into account adjustments that a farmer can make in response to the environment. This model takes into account the direct impact of climate on yield and the indirect substitution of inputs, activities or any potential adaptation to different climate. Due to the lower cost of such analysis, Ricardian models have been largely used to estimate the cost of climate change in the developing world (Deressa, 2006; Gbetibouo & Hassan, 2005; Kurukulasuriya & Ajwad, 2007; Liu, Li, Fischer, & Sun, 2004; Mano & Nhemachena, 2007; Molua & Lambi, 2007; Seo & Mendelsohn, 2008b; Seo, Mendelsohn, Dinar, Hassan, & Kurukulasuriya, 2009). Indeed, the developing world is often highlighted to suffer the most from climate change. For instance, Mendelsohn, Nordhaus, and Shaw (1996) have examined the impacts of the climate change on agriculture for all countries in the world between 1960 and 2000. For the analysis, cross-sectional model, experimental (crop simulation) model and response functions for temperature, precipitation and carbon dioxide are used. In the results, temperature and precipitation have the effect from a loss of 0.05% to a gain of 0.9% of global agricultural GDP. When carbon fertilization is included in the models, historic climate change increases the global agriculture production from 2% to 4%. The interesting finding is that the climate change impacts vary by locations. The results suggest that the positive effect is larger in the mid-to-high latitude countries while is smaller in the low latitude countries. Mendelshon stresses that most developed countries lay on the mid-to-high latitudes while most less-developed and developing countries are located in the low latitudes.

Mendelsohn and Dinar (1999) have also analysed the impacts of climate change on agriculture in developing countries such as India and Brazil. They used three different methods for the analysis, which are the Ricardian method, agro-economic model and agro-ecological zone (AEZ) analysis. Farm performance, land value or net income was regressed on a set of environmental factors, traditional economic inputs which are land and labour, and support systems such as infrastructure in the models. Unlike most studies, this analysis pointed out the importance of the farmers' adaptation. They argue that farmers will adapt to new conditions for instance due to climate change by making production decisions which are in their own best interests. Crop choice is one of the examples of farmers' adaptation to warmer weather in the paper. Wheat, corn and rice are three crops as examples since the regions they grow depend on the temperature. As temperature gets warmer, wheat farmers switch wheat to corn for making profits. Later, if temperature gets warmer again, farmers adapt to warmer weather by switching to rice from corn. The results of the Ricardian method, agro-economic model and AEZ analysis showed that an increase in temperature will decrease the crop production especially the crops grown in cool areas such as wheat. However, the authors argue that the result of the Ricardian method suggests that farmers' ability to adapt to new condition will mitigate the impacts of climate change in the long run, while the agro-economic model and AEZ analysis would be more suitable for short-run analysis since the adaptation is not included in the models.

Many other studies have studied the climate change impact on agriculture in developing countries. For instance, Seo, Mendelsohn, and Munasinghe (2005) examined the climate change impacts on Sri Lankan agriculture using the Ricardian method and five AOGCM experimental models. The model analysed the NR per hectare of the four most important crops (rice, coconut, rubber and tea) in the country. Both the Ricardian method and five AOGCM experimental models showed that the effects of increase in precipitation are predicted to be beneficial to all crops tested and the benefit ranges from 11% to 122% of the current NR of the crops in the model. On the other hand, the impacts of increase in temperature are predicted to be harmful to the nation and the loss ranges from −18% to −50% of the current agricultural productivity.

More recently, Deressa and Hassan (2007) have analysed the economic impact of climate change on crop production in Ethiopia by using the Ricardian method. For the estimation, county-level survey data are used and the net crop revenue was regressed on climate (rainfall and temperature), household and soil variables. They analysed the seasonal marginal impact of climate variables, which are temperature and precipitation on the crop NR. The analysis indicates that a marginal increase in temperature during summer and winter has a negative significant effect on net crop revenue per hectare and marginal increase in precipitation during spring has a positive significant effect on net crop revenue per hectare.

Studies using a Ricardian analysis also highlight the uncertainty of climate change impacts depending on climate scenarios, geography and AEZ. However, dry and hot regions are expected to suffer more from the coming climate change. For example, in a dry country such as Israel, agricultural NR is expected to drop by 60–390% by 2100, depending on climate scenarios (Fleisher, Lichtman, & Mendelsohn, 2007).

Given this, the objective of this study is to investigate local impact of climate change on the rural economy and how the impacts vary across the different agro-ecosystems in Tajikistan. The differential impacts are important to

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target adaptation measures to the most vulnerable regions. According to previous international studies and the specific climate and geography of Tajikistan (Bobojonov & Aw-Hassan, 2013), we suppose an average negative impact of climate change on Tajikistan's agriculture, with differences of magnitude across regions.

This study focuses on modelling the sensitivity of agriculture to climate using a Ricardian model, which then allows the estimation of the economic impact of climate change on Tajikistan agriculture. Tajikistan has very diverse regions in terms of geography, population density and socio-economic situation. For a better understanding of how climate change impacts will vary across the country, we disaggregated our results by AEZ and by province. These results can help to anticipate the priorities of adaptation efforts needed in different regions. Section 2 briefly reviews the assumptions of the Ricardian model. In Section 3, we present the methodology and the data. Section 4 presents and discusses the results while Section 5 concludes.

2. Theoretical background

In recent decades, many studies have analysed the consequence of climate change on the agricultural sector. The methods adopted to calculate the effects of climate change on the agricultural sector can be classified into two approaches: structural and spatial (McCarl, Adams, & Hurd, 2001; Molua & Lambi, 2007; Schimmelpfennig, Lewandrowski, Reilly, Tsigas, & Parry, 1996). The first combines the physical responses of crops with the economic responses of agricultural producers, while the second is characterized by analysing agricultural production and the climate of the different regions, and then the differences are estimated.

The structural approach uses interdisciplinary models to simulate crop response and, based on the estimated effects, production changes are simulated. The advantage of this methodological approach is that it allows detailed information to be obtained regarding physical, biological and economic responses, as well as possible adjustments. Nevertheless, among its disadvantages is the need to make multiple inferences from relatively few sites and crops in relation to large extensions of land and a variety of production systems (Schimmelpfennig et al., 1996). The greatest difficulty that this methodological approach faces is incorporating farmer adaptation into the models to reduce the possible overestimation of negative aspects (Adams, Hurd, Lenhart, & Leary, 1998; Ramírez, Ordaz, Mora, Acosta, & Serna, 2013).

The second approach uses the spatial approach methodology. In this approach, the effects of climate change on the agricultural sector can be determined through the differences between the type of land, agricultural production and other regional variables that relate the climate to the sector. The models that characterize this approach use statistical or programming methods to analyse changes in spatial production standards; the models used include Ricardian (Mendelsohn, Nordhaus, & Shaw, 1994), computable general equilibrium and geographic information system (GIS) models. The spatial approach models identify production standards using a statistical technique. One hypothesis states that producers are willing and able to adopt new crop systems and crops from other regions. Another is the idea that the physical and economic adjustments needed for crops and by farmers are carried out automatically. The latter hypothesis makes it unnecessary to model the adaptation behaviours of farmers related to adjustment costs in the short and medium terms. The models included in the spatial approach have the disadvantage of being highly dependent on the availability of information (Ramírez et al., 2013).

In this study, we based our analysis on the Ricardian model (Mendelsohn et al., 1994). The Ricardian approach is a cross-sectional model applied to agricultural production. It explains how variations in climate change affect NR or land value. This model is based on the assumption of a direct cause and effect relationship between climate events and land productivity or farm value. The Ricardian approach is developed to correct the bias of the production function model that tends to overestimate damage. In theory, the use of economic data on land value corrects the bias. Indeed, this approach does not study yields of specific crops, but examines how climate in different places affects the NR or value of farm land. By regressing NR or land value on environmental variables, one can measure the marginal contribution of each input to farm income. This sensitivity of the agriculture sector to local climate is estimated using cross-sectional data. Based on this estimation, we predict the change in NR due to climate change.

This model takes into account the direct impact of climate on yield and the indirect substitution of inputs, activities or any potential adaptation to different climates. This methodology takes into account adjustments that an economist makes in response to the environment. We assume that the production function is a continuously differentiable function (Molua & Lambi, 2007). The farm output function is specified as follows:

$$Q_i = Q(x_i, E) + \varepsilon_i,$$

where Q_i is the output, x_i is the input with values x_i ($i = 1, 2, \ldots N$) and N is the number of data points. E is a set of exogenous environmental inputs such as precipitation, temperature or soil characteristics. ε_i are model errors assumed independently and normally distributed with mean zero and constant variance. Thus, agricultural productivity (Q) is assumed to depend on exogenous climate, soil and socio-economic factors. The farmer's

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objective is thus to maximize returns based on critical output x^*, say, and environmental factor (E)

$$\text{Maximize } \pi_i(x^*, E) = P_q Q(x^*, E) - P_x x^*,$$

where P_q is price of output Q and P_x is price of the input.

If we assume that the change of environment from E_0 to E_1 will leave market prices of input and output unchanged, then climate effects on farm returns can be given as follows:

$$\Delta W = \pi_i(x_1^*, E_1) - \pi_i(x_0^*, E_0),$$

In the literature, ΔW is estimated using either land value or annual NR depending on whether data are available. Different studies adopt models to data availability and country characteristics. Some studies use farm-level data while others use district-level data.

As for any conceptual model, Ricardian analysis has caveats and cannot replace other kinds of analyses but rather complements other studies. In previous literature concerning Ricardian models, the absence of irrigation variables was criticized (Darwin, 1999); however, since then this question has been carefully addressed (Seo & Mendelsohn, 2008a). For example, Kurukulasuriya and Mendelsohn (2006) considered irrigation as endogenous and used a modified Heckman selection model. The Ricardian model has been recently modified and improved but it still has a number of weaknesses. First, the model does not integrate CO_2 fertilization in the analysis. Second, price is assumed constant, which could lead to some bias (Cline, 1996). However, in the context of great disparities in the climate change effects at a global level, we can rightfully consider that international crop will remain unchanged: while some region will decrease some of their crop production others will be able to increase it. Third, the model does not measure the transition cost, and finally it reflects current technology and current agricultural policies. However, despite these limitations, the Ricardian technique has been demonstrated as a practical tool for predicting the agricultural consequences of global climate change (Timminns, 2006).

3. Empirical model

3.1. *Data sources and statistical analysis*

We apply the Ricardian model to the 2007 World Bank Tajikistan Living Standards Survey (TLSS, 2007). We rely on De Pauw (2008) and the GIS Unit at the International Center for Agricultural Research in the Dry Areas (ICARDA) for climate data and future climate scenarios, and on the Food and Agriculture Organization (FAO) soil map for soil data (FAO-UNESCO, 1995).

The TLSS provides household data covering the five main administrative zones (four oblasts and Dushanbe) and was designed using 270 clusters. We excluded urban locations (all the urban districts; for example the four districts of Dushanbe) and we kept 166 rural locations. Our data covered all Tajikistan provinces and all AEZs as defined by Heltberg and Bonch-Osmolovskiy (2011). Data distribution across Tajikistan provinces is presented in Appendix 1.

In Appendix 2, the table shows the share of agriculture variables across the four provinces (oblasts), the gross agricultural output (GAO), agricultural land, sown area and population. The Soghd province is one of the four administrative divisions of Tajikistan. Agriculture represents 25% of its gross regional product and it is also the province where cotton production is concentrated (Tsimpo Nkengne, 2010).

The Regions of Republican Subordination (RSS) is the province in which Dushanbe is located. RSS has an extremely harsh climate, where snow starts in fall (October). Khatlon is the most populous of the four provinces, with 39% of Tajikistan's population, and most people mainly engaged in agriculture, especially cotton. The last region, Gorno-Badakhshan Autonomous Province (GBAO), is an autonomous, mountainous province in the east of Tajikistan. It is located in the Pamir Mountains and represents17% of the land area of the country but only 4% of the population. The summary statistics for variables used in the empirical analysis (Appendix 3) show some differences in NR per hectare across regions.

3.2. *The climate change data*

Climate change, due to the emission of greenhouse gases, is generally expected to increase temperature and precipitation (Deschênes & Greenstone, 2007; IPCC, 2007). Nevertheless, the climate data provided by the ICARDA GIS Unit, from a downscaling climate model (De Pauw, 2008), gave a much more accurate picture. Therefore, we used predicted climate change for each of the 166 locations. In a small country such as Tajikistan, but very varied in terms of topography and climate, these more accurate data allow more consistent results. In this study, two scenarios of climate change were employed: an average 2.9° warming scenario and an average 4.6°C warming scenario. These forecasts can be seen as a high change but they are still consistent with the highest scenario of IPCC (2013), for which the mean global temperature change in 2100 is estimated at +3.7° (IPCC, 2013).

Table 1 displays the average predicted change in temperature and rainfall by oblast in our study. This table displays the average forecast of our 166 villages' downscaling forecast. Current climate data were used in our Ricardian regression, and we used these climate scenarios to calculate change in future agricultural revenue. Temperature is the average temperature in °C and rainfall is in mm per month. Under the 2.9° warming scenario,

Table 1. Current climate and climate change scenarios for Tajikistan and its provinces.

		Soghd		Khatlon		RSS		GBAO		Tajikistan	
		°C	Rainfall per month (mm)	°C	Rainfall Per Month (mm)	°C	Rainfall per month	°C	Rainfall per month	°C	Rainfall per month
Summer	Current climate	20.56	18.23	23.49	18.86	20.71	33.58	12.57	19.56	20.04	22.68
	Scenario 1	+2.9°	−2.90%	+3°	5.10%	+3°	2%	+3.1°	−9.20%	+3°	0.20%
	Scenario 2	+4.5°	−3.20%	+4.7°	10,20%	+4.6°	2.40%	+4.8°	−7.50%	+4.7°	2%
Winter	Current climate	4.71	37.35	8.03	55.54	5.79	85.37	−3.83	39.86	4.46	56.31
	Scenario 1	+2.5°	4.6%	+2.7°	2.70%	+2.6°	3.50%	+2.9°	5%	+2.7°	3.60%
	Scenario 2	+4.4°	5.90%	+4.6°	2.50%	+4.5°	3.90%	+4.9°	6%	+4.6°	4.10%

Source: Authors' calculations using data ICARDA GIS Unit.

temperature will increase by 3°C in summer and around 2.6°C in winter with very few differences between regions. However, the changes in rainfall are very different between them. The data predict a decrease in rainfall in the Soghd and GBAO regions and an increase in Khatlon and RSS. In winter, rainfall is expected to increase in all regions. There was a similar expected trends across the different AEZs (Appendix 4) with expected increases in temperatures as well as winter precipitation in every AEZ. Summer precipitation is expected to rise in the majority of AEZs, but in GBAO, Khatlon hills, RSS Mountains and Soghd lowlands, precipitation is expected to decrease by less than 1 mm per month in summer and by less than4.5 mm per month in winter. In the 4.6°C warming scenario, temperatures should rise by around 5°C in winter and summer. Rainfall does not follow the same trend and should remain more or less stable under the 2.9°C warming and 4.6°C warming scenarios.

3.3. *Empirical specification*

The empirical study is divided into two parts. In the first part, annual NR per hectare of the farm is regressed on current climate, soil, community and socio-economic variables. In the second part, climate change impacts are simulated using the estimated parameters from the Ricardian regression. We estimated the changes in agriculture revenue based on two climate scenarios.

We explored several empirical specifications of the model to test the robustness of the model. We chose a non-linear two seasons' specification model using average temperature (T) and precipitation per month (P) for winter (November–April) and summer (May–October) and added climate interaction terms between temperature and precipitation. Based on the TLSS data (TLSS, 2007), the crop NR is calculated for each farm at local prices (in Somoni). The analysis did not take into account livestock for which data were not sufficiently accurate. We consider this to be an important gap given the important role that livestock can play in climate adaptation – efforts to fill this gap should be a priority in future data collection in Tajikistan. For climate variables, we assumed a nonlinear effect of climate on yield. Temperature and rainfall are known for each village and we used the average rainfall and temperature per season. Thus, we avoided multi-collinearity that we would face using monthly climate variables.

The model was explored at two different levels of analysis: the household level and the village level. In the two models (Equations (1) and (2)), we added dummy variables for each of the four administrative regions (D_{Oblast})

$$\begin{aligned} \mathrm{NR}_{ij} = \beta_0 &+ \sum_{s=1,2}\left[\beta_1 T_j + \beta_2 T_j^2 + \beta_3 P_j + \beta_4 P_j^2 + \beta_5 (T_j * P_j)\right] \\ &+ \beta_6 S_j + \beta_7 C_j + \beta_8 Z_{ij} + \beta_9 D_{\text{Oblast}} + \varepsilon_{ij}, \end{aligned} \tag{1}$$

$$\begin{aligned} \mathrm{NR}_{j} = \beta_0 &+ \sum_{s=1,2}\left[\beta_1 T_j + \beta_2 T_j^2 + \beta_3 P_j + \beta_4 P_j^2 + \beta_5 (T_j * P_j)\right] \\ &+ \beta_6 S_j + \beta_7 C_j + \beta_9 D_{\text{Oblast}} + \varepsilon_{j}. \end{aligned} \tag{2}$$

The dependent variable is annual NR per hectare denoted by NR. NR per hectare is the value of the output (including own consumption) calculated using the median price for each location (j). For each crop, we calculated the value of the harvest based on the median price of the location. All the prices are calculated based on the declaration of farmers from their sell, if there is no local average price we use the national one. To calculated the farmer's NR, we subtract the value of input from the total value of harvest. NR_{ij} in Equation (1) is the NR for each farm ($i = 2557$). Following Equation (2), we will also present the results of a model where the unit of analysis is the village ($j = 166$; Appendix 5). In this regression we aggregate farm NR by village. The dependent variable, the crop NR per hectare, is defined as the average crop NR per hectare in the village. In the two models, we excluded negative NR and outliners. While negative revenue is possible as

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any farmer can occasionally experience a bad year, we remove it from our study due to missing data. Negative revenues in our database are mostly due to missing data in the harvest section and thus can be considered as outliners. We estimated the NR on climate data and we included other explanatory variables.

We include socio-economic explanatory variables such as household and farm characteristics (Z_{ij}: farmer's age, ethnicity and farm size), socio-economic C_j and soil S_j variables for each village. These variables include the distance from the village to the capital Dushanbe and two other dummy variables. "Watercentral" is a dummy equal to 1 if there is centralized water supply in the village, and 0 otherwise. "Clay" is a dummy equal to 1 if the soil contains more than 35% clay and 0 otherwise. Statistical descriptive table of explanatory variable is displayed in Appendix 6.

In Equation (2), we kept socio-economic (C_j) and soil (S_j) variables from Equation (1) and added two of the previous farm characteristics that we first aggregated by village: ethnicity and farm size variables. In this regression, "land_area" is defined as the average farm size in the village and "uzbek" the proportion of Uzbek farmers in the village. The empirical results of the first equation are presented in Table 2 and the results of Equation (2) in Appendix 5.

In the second part of our analysis, we used the estimated parameters from previous regressions to predict climate change impacts on agricultural NR as follows:

$$\Delta \mathrm{NR}_{ij} = \mathrm{NR}_{ij}^{\text{after CC}} - \mathrm{NR}_{ij}^{\text{today}}. \quad (3)$$

Based on the marginal effects of climate on NR per hectare, we calculated the effects of climate change scenarios on future NR per hectare. Results are shown in Section 4.2 where we calculated the percentage of change for Tajikistan and for each of the four administrative regions using the model below.

3.4. *Model*

Using the estimated parameters from Equation (1), we first calculated marginal impact of precipitation (ME^{P}) and temperature (ME^{T}) on NR:

$$\mathrm{ME}_j^{\mathrm{T}} = \frac{\partial NR}{\partial T}(T = T_j) = \beta_1 + 2\beta_2 T_j + \beta_5 P_j, \quad (4)$$

$$\mathrm{ME}_j^{\mathrm{P}} = \frac{\partial NR}{\partial P}(P = P_j) = \beta_3 + 2\beta_4 P_j + \beta_5 T_j. \quad (5)$$

For each village, we calculated marginal effects of summer and winter precipitation and of summer and winter temperature. Then, using these marginal impacts we calculated NR change for the 2.9°C warming scenario (S1) and the 4.6°C warming scenario (S2), and for each village, as shown in the following equations

$$\Delta \mathrm{NR}_j^{\mathrm{S1}} = \mathrm{ME}^{\mathrm{Ts}} \Delta \mathrm{Ts}_j^{\mathrm{S1}} + \mathrm{ME}^{\mathrm{Tw}} \Delta \mathrm{Tw}_j^{\mathrm{S1}} + \mathrm{ME}^{\mathrm{Ps}} \Delta \mathrm{Ps}_j^{\mathrm{S1}} + \mathrm{ME}^{\mathrm{Pw}} \Delta \mathrm{Pw}_j^{\mathrm{S1}}, \quad (6)$$

$$\Delta \mathrm{NR}_j^{\mathrm{S2}} = \mathrm{ME}^{\mathrm{Ts}} \Delta \mathrm{Ts}_j^{\mathrm{S2}} + \mathrm{ME}^{\mathrm{Tw}} \Delta \mathrm{Tw}_j^{\mathrm{S2}} + \mathrm{ME}^{\mathrm{Ps}} \Delta \mathrm{Ps}_j^{\mathrm{S2}} + \mathrm{ME}^{\mathrm{Pw}} \Delta \mathrm{Pw}_j^{\mathrm{S2}}, \quad (7)$$

where ME is the marginal effect, Ts is the summer temperature, Tw is the winter temperature and Pw and Ps are, respectively, winter and summer precipitation. The variations of precipitation and temperature (ΔT and ΔP) in S1 and S2 were provided by the ICARDA GIS Unit.

4. Results and discussion

4.1. *Regression results*

Regressions at household level are shown in Table 2 and at village level in Appendix 5. Regressions are run in local currency (Somoni). The adjusted R^2 values indicate that explanatory variables explained less than 15% of variation in farm revenue (Table 2). These models do not completely explain variation between households; indeed, R^2 was quite low and few of the household-level explanatory variables were significant. The significant variables for households' characteristics were age (age_head) and ethnicity (Uzbek) of household head and farm size (area_land).

To confirm the robustness of our results, we estimated Equation (2) at the village level (Appendix 5). Econometric testing, using likelihood ratio, failed to rank our models. In both tables, Column (1) shows regression with only climate data, in Column (2) control variables are added without location dummies while Column (3) displays the final model including oblast dummies. The explanatory variables are similar for all models. In regressions presented in Table 2, the unit of analysis is the farm ($N = 2557$), while our empirical regression results at the village level are displayed in Appendix 5. A statistical description of our explanatory variables is displayed in Appendix 6.

The empirical finding in Table 2 indicates that most climate data were highly significant for all estimated specifications. The comparison between models highlights the robustness of climate parameters to different specifications. Linear, squared terms and the interaction terms were significant. This confirms our assumption that climate had a nonlinear effect on NR. Winter precipitation seemed irrelevant in the analysis, the summer precipitation and temperature had bell-shaped relationships with NR and winter temperature had a U-shaped relationship. We dropped the squared term of winter rainfall as well as the altitude variable, which were not significant and not relevant in our analysis.

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Many of the control variables were significant (Table 2). Farm area reduced the value per hectare of farms at a decreasing rate – that is, small farms were more productive on a per hectare basis. Soil characteristics also mattered – as the high proportion of clay increased productivity. Finally, being further from the capital also had a positive impact on NR of farms. This is explained by the fact that soil fertility and climatic conditions are better for farms further from the capital. As shown above, these results were robust for the different specifications.

In order to interpret the climate coefficients, we calculated the marginal impacts of a change in each climate variable evaluated for the mean climate of each region. The marginal values depend on the regression equation used

Table 2. Regressions explaining farm NR in Somoni (1 USD = 0.21 Somoni) calculated at household level.

Explanatory variables	(Model 1)	(Model 2)	(Model 3)
temp_winter2	−8.244***	−8.988***	−6.874***
	(1.651)	(1.664)	(1.587)
temp_winter2sq	431.5***	376.9***	210.7**
	(80.61)	(89.43)	(85.85)
prec_winter2	−191.4	−324.3***	−90.57
	(125.6)	(85.95)	(92.74)
prec_winter2sq	−0.454		
	(0.792)		
precxtemp_winter	47.93***	64.17***	41.94***
	(13.12)	(13.19)	(13.12)
temp_summer2	32.853***	30.074***	22.637***
	(5.394)	(5.606)	(5.393)
temp_summer2sq	−642.4***	−564.0***	−402.1***
	(108.0)	(116.9)	(113.7)
prec_summer2	6.219***	6.182***	5.306***
	(1.092)	(1.070)	(1.004)
prec_summer2sq	−17.64***	−14.35***	−21.33***
	(5.060)	(3.414)	(4.051)
precxtemp_summer	−265.4***	−271.2***	−232.4***
	(47.18)	(47.60)	(45.99)
clay		2.288**	2.547***
		(1.002)	(984.4)
age_head		38.15**	36.36*
		(18.70)	(18.58)
uzbek		1.335**	1.169*
		(671.6)	(689.2)
area_land		−147.3***	−146.5***
		(13.48)	(13.53)
area_landsq		0.321***	0.319***
		(0.0418)	(0.0425)
watercentral		1.655**	805.8
		(668.5)	(671.9)
dist_cap		−5.030	11.02***
		(3.225)	(3.696)
Khatlon			3.541**
			(1.532)
RSS			9.674***
			(1.712)
GBAO			−3.382**
			(1.534)
Constant	−372.165***	−340.610***	−268.900***
	(62.188)	(63.007)	(60.243)
Observations	2.557	2.553	2.553
R^2	0.077	0.124	0.141
Adjusted R^2	0.0734	0.118	0.134
F	14.00	20.99	20.15

Source: Authors' calculations using data from TLSS (2007).
Notes: Values in parentheses are standard errors.
*$p < .1$.
**$p < .05$.
***$p < .01$.

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Table 3. Marginal impact of temperature and precipitation on annual NR: temperature in °C, precipitation in mm/month and NR in US$ per hectare.

	Sogd	Khatlon	RRS	GBAO	Total
Winter temperature	−697.43	−243.57	−178.81	−1431.09	−552.94
Winter precipitation	22.49	51.72	32.01	−52.73	20.25
Summer precipitation	−1148.35	−1264.67	−1282.64	−750.49	−1145.71
Summer temperature	392.17	−133.63	−382.56	1675.55	262.22

Source: Authors' calculations using data from TLSS (2007) and ICARDA GIS Unit.

and the climate evaluated. Table 3 displays the results using parameters from the third column regressions of Table 2 and converted into US dollars (1 Somoni = US$0.21). An increase in average temperature of 1°C in summer is expected to increase NR in Soghd and GBAO and decrease it in RSS. Winter temperature increase is expected to decrease NR; however, a marginal increase in average monthly summer precipitation is expected to decrease NR in every region and AEZ.

The results should be assessed while considering the key assumptions of the Ricardian approach and also some specific caveats of our analysis. First, the study is based on crop and ignores livestock. During the period 1990–2009, the livestock sector's share in gross agricultural product decreased from one-third in 1990 to 10% in 2009 (Akramov & Shreedhar, 2012). However, if livestock represents less than 10% of the agricultural sector, livestock could be a good agricultural activity to increase Tajikistan's agriculture resilience to climate change. Seo et al. (2009) found a higher resilience of Africa to climate change than previous studies and assigned these results to livestock activities being taken into account unlike previous studies. Livestock is heat-tolerant and would help farmers to decrease their vulnerability (Seo & Mendelsohn, 2008a). Second, our model did not include a hydrological model that would allow us to integrate hydrological change (e.g. runoff and water flows). As highlighted by Akramov and Shreedhar (2012), water management can have important implications in climate change adaptation in Tajikistan. Finally, our model did not account for the increased probability of extreme events (e.g. drought and floods), disasters or pests and diseases.

4.2. *Predicted impact of climate change scenarios*

Based on the calculated marginal effect of climate on NR, we estimated the effect of climate change on farm revenue under different scenarios. We calculated the average percentage of change for Tajikistan and each of its four administrative regions (Table 4), and for each AEZ (Table 5).

The above empirical results (Table 2) indicate that Tajikistan's agriculture is very sensitive to climate change. In this section, we use the regression results and the climate scenarios to project the impact of global warming on Tajikistan agriculture. Using the estimated regression coefficients, we first calculate the marginal impact of climate on crop agriculture. Then, based on these marginal impacts, we estimate the impact of climate scenarios on agriculture revenue for Tajikistan.

The estimated results display the predicted impact of climate change on agricultural economic revenue in S1 and S2 (Table 4) based on Regression (3) of Table 2 and Appendix 5. The changes are calculated on percentage change from the baseline. The third column shows results using different methods of calculation of marginal impact. Results in Column (3) were estimated based on marginal impact that were calculated per oblast using average climate of the oblast as displayed in Table 3. The two first columns use marginal impact calculated for each village using average temperature and rainfall of the village defined in Equations (4) and (5).

The marginal impacts displayed in Column (1) (Table 4) were calculated using the parameter from Equation (1), while Column (2) shows results using the parameter from Equation (2). Results for Tajikistan were weighted using

Table 4. Climate change impacts by oblast and by scenario (% change from baseline).

	Baseline annual NR per hectare (US$)	+2.9 Scenario (S1)			+4.6 Scenario (S2)		
Oblast		1	2	3	1	2	3
Soghd	2166.9	−3	1	1	−33	−26	−26
Khatlon	1620.4	−135	−128	−136	−177	−166	−254
RSS	2463.5	−104	−100	−97	−143	−137	−142
GBAO	1680.0	147	150	136	147	153	120
Total	1947.7	**−84**	**−79**	**−82**	**−122**	**−113**	**−157**

Source: Authors' calculations using data from TLSS (2007).

Table 5. Climate change impact on agricultural NR for S1 and S2 (in %) by AEZs.

	AEZs	Average NR/ha (US$)	Population	% Change MT	% Change LT
1	North Soghd lowlands	2235.8	994 648	4%	−30%
2	South Soghd hills, Pedhzkent-Shakhristan-Ganchi	2010.7	297270	−56%	−77%
3	RSS-Soghd: Varzob-Zarafshan-Surkhob	2567.0	332803	8%	−41%
4	West RSS lowland, Tursunzade-Shakrinav-Gissar	2887.9	392001	−138%	−161%
5	West RSS hills, Rudaki-Vakhdat	1486.1	426660	−251%	−310%
6	South Khatlon lowlands	1972.9	1080409	−136%	−165%
7	South-east Khatlon hills	921.5	536901	−203%	−298%
8	Northeast Khatlonhills	629.8	148201	202%	37%
9	East RSS mountains	3126.4	116528	107%	73%
10	GBAO	1601.5	152041	146%	153%
	Rural Tajikistan	1958.6	4477462	−48%	−80%

Source: Authors' calculations using data from TLSS (2007) and Heltberg and Bonch-Osmolovskiy (2011).

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the sown area. Figure 1 shows results from Column (1) for S1 and S2.

Climate change will have a profound negative impact on three of the four regions of Tajikistan, but a positive impact on agriculture in the GBAO region. These negative impacts of climate change do not include the possibility of a reduction in water flow. With nearly 80% of farms in Tajikistan being irrigated, a reduction in water flow could widely increase the impact of climate change.

Based on the marginal impact (Table 3) and on climate scenario (Table 1), we conclude that Khatlon and RSS will lose the most from climate change and that GBAO will actually gain. Under the model assumptions, agricultural NR of Khalton and RSS provinces will decrease while that of GBAO will increase. The increase in summer precipitation for Khatlon in our climate change scenario is the main reason for the huge negative impact on agricultural NR in Khatlon. Similarly, the combined effects of increases in summer temperature and summer precipitation are the main reason for the drop by nearly 100% in the RSS province. By contrast, the GBAO province will benefit from increased summer temperatures and decreased precipitation.

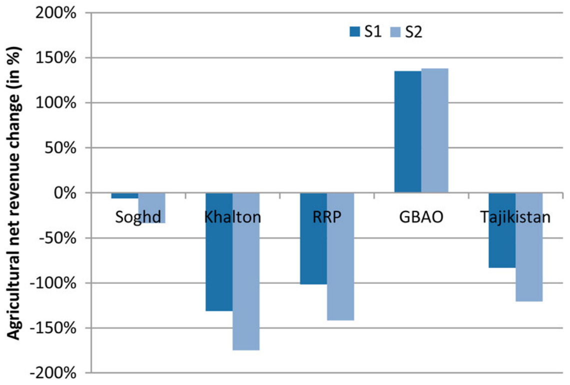

Figure 1. Climate change impact on agricultural NR for 2.9°C warming (S1) and 4.6°C warming (S2) scenarios (in %) by oblast and for the country.
Source: Authors' calculations using data from TLSS (2007).

Understanding the beneficial effect of increased summer temperatures and decreased summer precipitation on agriculture in GBAO province is difficult. However, these results can easily be understood with regard to the actual characteristics and climate of the region. It is a mountainous cold region in which an increase in temperature will increase the agriculture possibility. Increases in temperature and CO_2 can benefit some crops in this region. However, to realize these benefits, nutrient levels, soil moisture, water availability and other conditions must also be met. In any case, the effect of increased temperature will depend on the crop's optimal temperature for growth and reproduction.

Regarding the benefit from decreased precipitation, it is important to indicate that summer average rainfall may tend to decrease in this region. Where average rainfall increases, there is likely to be more extremely wet summers, and where average annual rainfall decreases more droughts are anticipated. However, in the specific case of mountainous region, heavy rain can be harmless due to the soil erosion caused by it.

A more disaggregated picture is shown in the impact of climate change by AEZ (Table 5). We classified villages in AEZs as defined in Heltberg and Bonch-Osmolovskiy (2011) and divided the country into 10 AEZs. These AEZ are based on the cluster that the World Food Program have used in their food security survey in 2004 in Tajikistan (WFP, 2005), AEZs have been defined based on elevation and land cover. We calculated the average change for each of the AEZ. Results for Tajikistan in Table 5 were weighted using the population because sown area by AEZ was not available and population by AEZ was used as a proxy. Tajikistan agricultural NR is expected to decrease around 48% in case of S1 and around 80% in case of S2.

Some AEZs will gain from climate change while the majority will lose (Figure 2). The results suggest an average negative impact on Tajikistan, but also indicate

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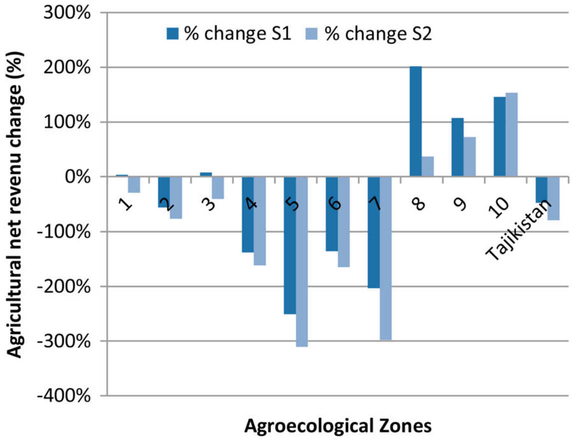

Figure 2. Climate change impact on agricultural NR for 2.9°C warming (S1) and 4.6°C warming (S2) (%) by AEZs and for the country.
Source: Authors' calculations using data from TLSS (2007).

that some regions will likely gain from climate change. Within the same oblast, the situation can be diverse. While RSS lowland (AEZ 4) and hills (AEZ 5) will lose from increased temperature, the cold and humid RSS east mountain (AEZ 9) will gain. In Khatlon, the humid North east hills (AEZ 8) will gain from increased temperatures and decreased rainfall, while agriculture in the Khatlon lowlands (AEZ 6) and south-east hills (AEZ 7) will lose. The agricultural sector in the GBAO province could also possibly benefit from future climate change. Indeed, the cold GBAO (AEZ 10) will gain from increased summer temperatures and also benefit from decreased summer rainfall, while the majority of Tajikistan AEZs will greatly suffer from increased summer temperatures associated with increased rainfall.

In light of these results, the main challenge will be to design policy in order to improve the resilience of farmers and agriculture of the country. In this challenge, the sensitivity and the exposure do not determine the future, but the adaptation to these changes is the most important. Our study focuses on agriculture as a whole and so hides challenges and opportunities.

In the medium term, seven AEZs that represent nearly 60% of the rural population are expected to lose revenue due to climate change (Table 5). The populous Khatlon lowlands as well as the south-east Khatlon and the RSS lowland region will be affected by climate change; however, according to Heltberg and Bonch-Osmolovskiy (2011) these three regions have quite strong adaptive capacities due to above average levels of income diversification and education. In contrast, West RSS hills, which will also be highly affected by climate change, has the lowest adaptive capacity (Heltberg & Bonch-Osmolovskiy, 2011) of the 10 AEZs and thus will probably suffer more from climate change.

The three AEZs expected to gain revenue from climate change are located on the east mountainous side of Tajikistan. For example, GBAO agriculture is expected to gain from climate change but it must be considered that it is also one of the most exposed to natural disaster (Heltberg & Bonch-Osmolovskiy, 2011). Currently, GBAO agricultural gross output is 4% of the national agricultural output; however, with 17% of Tajik agricultural land, the positive effect on GBAO climate could be an opportunity to develop agriculture, including heat-tolerant livestock, in this region.

In the long term, the impact of climate on agriculture is expected to be even stronger than in the medium term. All of the regions already projected to lose revenue in S1 are expected to increase their losses if S2 happened. For the five AEZ that previously gained, two will see their revenue decrease in the longer term. The only AEZ expected to benefit from climate change in S2 are the mountainous regions.

5. Concluding remarks and policy implications

This study conducted a Ricardian analysis on 2557 farm households in 166 villages across the 10 AEZs of Tajikistan. Annual crop NR was regressed on seasonal climate and other control variables. Different specifications were used and the empirical results were robust. This study makes two main contributions. First, we estimated the impact of climate on the smallholder sector. Climate had a nonlinear effect on revenue and explained 8% of the variation in NR across farms. Adding variables of households, soil and community characteristics increased the explanatory power of the first model to 14%. To confirm the results, we also designed a model at the village level using average NR per village. Climate explained 24% of the variation in the farm NR per hectare across villages – while adding variables of community, soil characteristics and farm size increased the explanatory power of the village model to 36%.

Second, we applied the Ricardian framework using climate change disaggregated data, which allowed us to better understand the variation in climate change impact across regions and AEZs in Tajikistan. The findings confirmed that Tajikistan agriculture is highly vulnerable to climate change. Tajikistan will suffer from a huge average negative impact (−80 to −157%) of climate change on agricultural revenue. However, regional disaggregated estimation shows a more nuanced picture. The strong negative impact of temperature increase in the hot and populous Khatlon lowlands (−165%) could become a great concern for public policies; however, the results also show a surprisingly positive impact in some mountainous parts of the country.

The caveats of the model and the possibility for Tajikistan agriculture to adapt to a new climate must be

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considered. This scenario was based on the current agricultural policies and technology. Adaptation policy could change the agricultural path of the country. Adaptation will be the key to improve Tajikistan's resilience to climate change and to ensure sustainability of the agriculture sector. In this framework, livestock and water management could be keys for a better future and could be interesting research in the context of climate change adaptation in Tajikistan. Because water is a key factor of agriculture and, despite a current high level of irrigation (80%), water management will be important in any adaptation (MIWMRT, UNDP, and IFSAS 2006). Indeed, irrigation needs to be more efficient, but the renovation of the irrigation system has to be coupled with river flow and water use management. An integrated water management policy could be an important measure to ensure sustainability and a fair allocation of water resources. At the same time, the development of a heat-tolerant livestock sector (IFAD, 2009) could be another opportunity to develop Tajikistan's agriculture.

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Note

1. Fay and Hrishi (2008) define a simple index of vulnerability to climate change as a function of exposure, sensitivity and adaptive capacity.

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Appendix 1

Distribution of numbers of districts, households and share of households across provinces (oblasts) in the sample (%).

	Number of districts	Number of households	Percentage
Soghd	12	685	21.97
Khatlon	21	1026	32.95
RSS	12	810	26.01
GBAO	7	594	19.08

Source: TLSS (2007).
Note: RSS – Regions of Republican Subordination; GBAO – Gorno-Badakhshan Autonomous Province.

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Appendix 2

Shares (%) of agricultural indicators across Tajikistan's provinces (2006 data).

	Soghd	Khatlon	RSS	GBAO	Total
GAO	25	45	26	4	100
Agricultural land	24	33	26	17	100
Sown area	32	49	18	1	100
Population	33	39	24	4	100

Source: Lerman and Sedik (2008).

Appendix 3

Sample statistical description: average value by oblast.

	Tajikistan	Soghd	Khatlon	RSS	GBAO
Annual NR per ha in US$	1947.7	2166.9	1620.4	2463.5	1680.0
Farm size (ha)	23.4	14.8	24.4	26.7	27.6
Proportion of irrigated farm (%)	80.0	84.0	69.7	81.3	94.1
Proportion of Tajiks in the data set population (%)	77.0	65.6	72	78	100

Source: Authors' calculations using data from TLSS (2007).
Note: 1 Somoni = US$0.21 (average 2012).

Appendix 4

Current climate and future climate scenarios by AEZ (temperature in °C, rainfall is in mm per month).

			Summer			Winter		
			Current	S1	S2	Current	S1	S2
1	North Soghd lowlands	°C	21.4	2.9	4.5	5.1	2.6	4.4
		Rainfall	15.8	−4.7%	−4.0%	32.6	5.4%	6.7%
2	South Soghd hills, Pedhzkent-Shakhristan-Ganchi	°C	19.1	2.9	4.5	4.4	2.4	4.1
		Rainfall	23.9	2.9%	2.9%	53.9	3.2%	4.6%
3	RSS-Soghd: Varzob-Zarafshan-Surkhob	°C	17.8	3	4.6	2.6	2.7	4.6
		Rainfall	40.8	−4.5%	−3.0%	88.1	4.0%	4.6%
4	West RSS lowland, Tursunzade-Shakrinav-Gissar	°C	21.7	3	4.6	7.1	2.5	4.3
		Rainfall	28.7	8.0%	6.6%	80.8	3.1%	3.5%
5	West RSS hills, Rudaki-Vakhdat	°C	22.1	3	4.6	7.3	2.6	4.5
		Rainfall	31.4	5.4%	6.5%	86.7	3.0%	3.3%
6	South Khatlon lowlands	°C	24.2	3	4.7	8.6	2.6	4.5
		Rainfall	13.4	11.4%	15.2%	41.7	2.3%	2.0%
7	South-east Khatlon hills	°C	22.4	3	4.7	7.3	2.8	4.7
		Rainfall	28.3	1.3%	7.1%	80.1	3.1%	3.0%
8	North EastKhatlon hills	°C	20.1	3	4.7	5.1	2.8	4.8
		Rainfall	37.9	−6.1%	1.5%	101.1	3.4%	3.4%
9	East RSS mountains	°C	15.8	3	4.7	0.5	2.8	4.9
		Rainfall	38.1	−11.7%	−10.6%	78.2	5.1%	5.8%
10	GBAO	°C	12.1	3.1	4.8	−4.5	2.9	4.9
		Rainfall	16.9	−8.6%	−7.4%	32.9	5.3%	6.4%
	Tajikistan	°C	20.1	3	4.6	4.5	2.7	4.6
		Rainfall	22.8	0.2%	1.9%	56.4	3.5%	4.1%

Source: Authors' calculations using data from TLSS (2007).

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Appendix 5

Regressions explaining farm NR in Somoni (1 USD = 0.21 Somoni) calculated at village level.

Explanatory variables	(Model 1)	(Model 2)	(Model 3)
temp_winter2	−8.280**	−8.618**	−6.417**
	(3.403)	(3.483)	(2.983)
temp_winter2sq	431.0***	365.9**	203.9
	(156.4)	(174.9)	(165.8)
prec_winter2	−206.4	−296.5*	−83.16
	(201.0)	(159.5)	(147.3)
prec_winter2sq	−0.287		
	(1.284)		
precxtemp_winter	50.85**	59.88**	38.33*
	(25.46)	(24.22)	(21.08)
temp_summer2	32.809***	29.440**	21.959**
	(10.974)	(11.600)	(10.656)
temp_summer2sq	−641.4***	−554.4**	−390.8*
	(214.2)	(236.1)	(225.1)
prec_summer2	6.223***	6.073***	5.215***
	(2.185)	(2.194)	(1.875)
prec_summer2sq	−16.50*	−15.49**	−21.58***
	(9.349)	(6.754)	(7.102)
precxtemp_summer	−271.2***	−262.8***	−224.2***
	(96.48)	(96.92)	(84.05)
clay		2.642	3.017
		(1.866)	(1.833)
uzbek		1.903	1.508
		(1.562)	(1.544)
area_land		−70.62***	−69.46***
		(21.81)	(21.35)
watercentral		2.050	1.091
		(1.259)	(1.223)
dist_cap		−4.179	12.11*
		(5.260)	(6.344)
Khatlon			2.948
			(2.705)
RSS			9.341***
			(3.006)
GBAO			−2.582
			(3.051)
Constant	−370.575***	−333.938**	−262.548**
	(127.740)	(132.663)	(119.643)
Observations	167	167	167
R^2	0.239	0.300	0.359
Adjusted R^2	0.190	0.235	0.286
F	3.319	4.984	5.584

Source: Authors' calculations using data from TLSS (2007).
Note: The values in parentheses are standard errors.
*$p < .1$.
**$p < .05$.
***$p < .01$.

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Appendix 6

Descriptive statistics of regression variables.

	(1)	(2)	(3)	(4)	(5)
Variables	No. of observations	Mean	Std. dev.	Min.	Max.
area_land	3114	20.26	47.13	0	1.049
clay	3114	0.179	0.384	0	1
area_landsq	3114	2,630	28,548	0	1.100e+06
temp_winter2	3078	4.486	5.072	−16.63	9.004
temp_summer2	3078	20.06	4.788	−0.164	24.88
prec_winter2	3078	56.41	27.88	7.167	128.3
prec_summer2	3078	22.73	10.88	8.500	50.06
temp_winter2sq	3078	45.84	35.80	0.0211	276.7
prec_summer2sq	3078	634.9	581.9	72.25	2.506
temp_summer2sq	3078	425.3	159.0	0.0270	619.0
precxtemp_winter	3078	277.0	298.4	−1,227	664.3
precxtemp_summer	3078	443.8	214.4	−5.454	914.4
age_head	3110	52.42	13.75	17	96
uzbek	3110	0.217	0.413	0	1
dist_cap	3114	250.9	203.8	1	1.095
watercentral	3114	0.312	0.463	0	1

Source: Authors’ calculations using data from TLSS (2007).