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EVALUATING THE IMPACT OF CLIMATE CHANGE ON CANADIAN PRAIRIE AGRICULTURE

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Background[1]

Climate change is defined as significant and lasting changes in the mean and/or variability of climate properties like: temperature, precipitation, humidity, solar radiation, and wind speed (Schmidt and Wolfe, 2009). This phenomenon could be the result of a long-term natural cycle and human activities; however, most scientists believe that the contribution of the latter one is considerably larger than the former (George, 2011). Expanding the emission of greenhouse gases including: water vapour, carbon dioxide, methane, nitrous oxide, and CFCs is recognized as the root cause of climate change (Pachauri et al., 2007).

Since agriculture is highly sensitive to the states of climate, assessing the effect of climate change on this sector is an important topic for researchers. Many studies focused on the relationship between climate change and agriculture. Some researchers have examined the effects of agricultural activities on climate change, and some have worked on the impact of climate on agriculture — the present study belongs to the latter category. The negative effects of climate change on agriculture come through changes in the mean and variability of precipitation and temperature, water availability, and the appearance of new diseases (Fischlin et al., 2007). Climate change can affect livestock and crop productivity and consequently it affects food prices and farmland values.

Production functions were first used to examine the effects of climate change on agriculture. This approach, however, overestimated the damages of climate change since it did not take adaptations into account. In fact, faced with the climate challenges, farmers adapt to changes to alleviate the negative effects and in some cases even benefit from the new situation. Land-use switching, changing seeding times, irrigation methods, and fertilization applications are examples of adaptation that may be employed by the producers (Brklacich et al. 1997; Mendelsohn et al. 1994).

Therefore, contrary to what is expected, it is possible that not only are farmers not harmed by climate change, but they also may benefit from it. In other words, although some types of adaptations like technological development and financial management are costly at first, the benefits of such adaptations could exceed the costs in the long-term. Other reasons which make climate change beneficial include profiting from other countries faced with climate change, and benefiting from supportive government policies (Wreford et al., 2010). This argument shows the importance of including the adaptations in economic modeling to explain the actual impact of climate change.

[1] This report consists of excerpts from Hossein's MSc thesis (referred to as Ayouqi, 2013), which resides at http://circle.ubc.ca/handle/2429/45198

As expected, the effects of climate change on farmland value vary over regions. Studies in the US show that climate change will generally harm the agricultural economy while the Canadian analyses suggest a positive impact on agriculture. Although almost all research for a specific region have forecasted the same direction for climate change impacts, the magnitude of the predicted effects vary significantly across studies. For example, Reinsborough (2003) predicted a 0.9 to 1.5 million dollar benefit for the Canadian agriculture due to climate change while Weber and Hauer (2003) suggested a 5.4 billion dollar annual increase in agricultural GDP. The difference in predictions could partially be due to using dissimilar regional scale and also to using different climatic and non-climatic variables.

In the current study, an economic model is utilized to estimate the impact of climate change on Canadian Prairie agriculture. The Prairies was chosen to be the study area since it has unique and important socio-economic and agricultural characteristics. The Canadian Prairies is a vast area stretched between Ontario and British Columbia and divided into three provinces (Alberta, Manitoba, and Saskatchewan). This region has an area of 1.78 million km^2, with a population of 5.9 million in 2011, corresponding to 20% of and 18% of Canada's area and population, respectively (Census of Canada, 2011). The Prairies also represents 47% of farms, 81% of farm area and 58% of crop production in Canada. The main crops in the Prairies are wheat, canola, alfalfa, and barley which have a very large share of the Canada's production; 98% of canola, 94% of wheat, 93% of barley, and 76% of alfalfa in Canada are harvested in the Prairies (Census of Agriculture, 2011). Thus, any effects of climate change on the Prairies agriculture would be a meaningful change for all Canada.

A number of studies have predicted future climate trends for the Prairies. For example, a greater frequency of severe drought and flooding, as an extreme result of climate change, was predicted by Kharin et al. (2007). Nakicenovic et al. (2000) drew scatterplots of predicted changes in mean annual temperature, and precipitation for the 2020s, 2050s, and 2080s. Although almost all predictions suggest an increase in the mean temperature, there are different opinions about future precipitation. Barrow (2010) predicted a decrease of between 0% and 10% in the annual mean precipitation in most parts of the Prairies. This finding is in contradiction with the forecasts of Environment Canada (2010) and Nakicenovic et al. (2000), both of which predicted an increase in precipitation. To sum up, there are two main reasons for choosing the Prairies as the study area: 1) this region has a dominant share in the Canadian agriculture and agri-food system; and 2) the Prairies are known to be vulnerable to climate change.

Although climate change is undoubtedly affecting agricultural activities on the Prairies, quantifying the impacts of climate change will help decision-makers and producers implement more appropriate policies and practises to deal with the impacts. The design of national agricultural and environmental strategies should be rigorous and certainly should be based on careful predictions about the potential advantages and disadvantages of climate change for Canadian agriculture.

Problem Statement

The gold standard method of analyzing the impact of climate change on agriculture is the Ricardian model, which was developed by Mendelsohn et al. (1994). The Ricardian model has been widely used to estimate the effect of climatic and non-climatic (e.g. geographical and socio-economic) variables on the net value of agricultural production. Mendelsohn's approach is based on a hedonic modeling of farmland pricing where farmland value is defined as the dependent variable. Mendelsohn's model is well suited to take farmers' adaptation to climate change into account. Indeed, under competitive markets, farmland rent is a measure of the net profits of the best use of the land and, of course, adaptation is reflected in the best use of the land. Thus, as opposed to the traditional approaches which were based on empirical production functions, the Ricardian model considers future land management (including the adaptation to climate change) as well as present practises.

The Ricardian model, often with modifications to improve the model's predictive ability, has been applied to a variety of countries and regions to assess the agricultural impacts of climate change (Mendelsohn and Dinar 2009). The Ricardian model has delivered consistent results and it is this consistency which probably best explains the model's popularity. Several different modifications of the standard Ricardian model have been used to examine the relationship between agriculture and climate change. In the early studies, following the standard Ricardian approach, cross section data were used to estimate the climate impacts with the assumption of fixed market prices (e.g. Reinsborough, 2003 and Mendelsohn et al., 2007). More recent studies have used panel data rather than cross section data to estimate the Ricardian model (Amiraslany, 2010 and Massetti and Mendelsohn 2011). Similarly, early panel studies assumed the prices of commodities are fixed over time. In more recent studies the fixed price assumption has been relaxed (Amiraslany, 2010).

The most recent attempt to estimate the Ricardian model for the Canadian Prairies was Amiraslany (2010). This study provided an excellent advancement in the economic analysis of climate change and it is sure to be a Canadian benchmark for future research. There are several reasons why this thesis continues to examine the economic link between climate change and agriculture on the Canadian Prairies. First, more updated data is available to estimate the Ricardian model. Second, Amiraslany's (2010) list of commodities which were included in the analysis was somewhat limited. Third, although Amiraslany's (2010) relaxed the fixed price assumption, additional improvements in the way that commodity prices are incorporated into the model are possible. Finally, one particular assumption that underlies Amiraslany's (2010) econometric model is somewhat questionable and so improvements in this regard are also possible. Each of these reasons is now explained in greater detail.

With respect to using updated data, given the importance of climate change, re-estimating the model with updated data is probably sufficient justification for additional research. Indeed, as climate change progresses, and previous Canadian studies become outdated, it is highly worthwhile to re-estimate the model using the new data in order to capture the possibility of changes in the marginal effects over time due to the new adaptations against climate change. Regarding commodity coverage, Amiraslany's (2010) analysis included prices of only the two major crops — wheat and canola. Excluding the price of livestock and other agricultural commodities is likely to result in biased estimates of the model's parameters. The accuracy of the Ricardian model can likely be improved significantly by including in the econometric model the prices of a more comprehensive list of agricultural commodities from the Canadian Prairies.

With respect to fixed versus variable prices, Amiraslany (2010) showed that assuming a fixed price over time when estimating a model with panel data will typically result in biased estimates of the model's parameters. As an alternative, Amiraslany's (2010) incorporated the prevailing market prices for commodities for each census year rather than assuming a single price for each commodity across time. Although utilizing updated absolute market prices for the census years is a major improvement over the fixed price assumption, this revised approach can still result in biased estimates. Indeed, if a sharp price change happens just before a census year, the impact of commodity price on agricultural land values will certainly be misestimated. What is needed is a proxy for farmers' expectation of future commodity prices because it is these expectations which largely determine the market value of farmland.

Finally, regarding the econometric analysis of panel data, Amiraslany (2010) assumed that the climate normals have changed over 1991-2001 and therefore fixed effects regression techniques could be used to estimate the coefficients of the climate variables. Massetti and Mendelsohn (2011) used 1971-2000 climate normals for all census years because they believe that the actual change in the climate change normals over one or two decades will be essentially zero from an estimation perspective. Since in the case of time-invariant climate variables the fixed effects method is unable to estimate all coefficients, Massetti and Mendelsohn (2011) used a two-stage method (introduced by Hsiao, 2003) to estimate the coefficients of the time-invariant climate variables (this two stage method is a special type of fixed effects procedure). The two-stage model is one way to estimate the model with time-invariant climate variables; however, we will argue below that superior methods which account for spatial correlation are available and should be used.

To summarize, the previous benchmark Canadian study of climate change (Amiraslany, 2010) is currently out of date and the assumptions which have been made about which commodities to include is somewhat restrictive. Moreover, although this study made important improvements by allowing the commodity prices to vary over time when panel data is used, the inclusion of current market prices for commodities rather than a proxy measure of farmers' expected future market prices is still limiting. Finally, Amiraslany's assumption that climate change normal variables vary over time is controversial.

Study Objectives

The main goal of this study is to extend the analysis of Amiraslany (2010). Specifically, a modified Ricardian model with up-to-date and more comprehensive data and spatial econometric techniques is used to estimate the economic impact of climate change on the welfare of farmers in the Canadian Prairies. As discussed above, the standard Ricardian model is essentially a hedonic regression of farmland value on a variety of climatic and control variables. In the Ricardian model, farmland value serves as the dependent variable, since, not only does it capture the adaptations strategies against climate change but it also serves as a reasonable proxy measure for farm welfare.

Following Amiraslany (2010), we estimate the climate change impact using panel data rather than cross section data. By using panel data, we have more data points for each region and also we can consider fixed region and time effects in the estimation. This approach also captures unobservable factors that affect the dependent variable over time and across regions. Estimating the panel model with updated data is an important objective of the current analysis. Amiraslany (2010) used 1991, 1996 and 2001 census data. We have added 2006 and 2011 census data to the dataset in order to generate more up-to-date results.

Recall that Amiraslany (2010) included the prices of only wheat and canola in his dataset when estimating the Ricardian model. We include the four most cultivated grains in the Prairies: wheat, canola, alfalfa, and barley. In addition, the price of cattle is included as a representative for animal farms. Also recall that Amiraslany (2010) relaxed the fixed price assumption by including the current year commodity price rather than a singled fixed price in the panel dataset. In the present study, rather than including the current market price as an explanatory variable in the panel data, a proxy for expected price is used in the econometric model. As will be explained in greater detail below, farmers are assumed to have adaptive price expectations, as first proposed by Cagan (1956) and Nerlove (1958). This assumption implies that the current price of land will depend on both past and previous commodity prices rather than just current commodity prices.

To estimate the panel data model, three alternative econometrics approaches will be used: (1) pooled weighted least squares; (2) standard random effects estimation; and (3) spatial random effects estimation. The pooled model is common in mainstream Ricardian analysis with cross sectional data. Using the random effects assumption rather than the fixed effects assumption involves a trade-off. In general, the fixed effects method is “safer” because it automatically addresses the problem of omitted variable bias. However, it is not possible to estimate the coefficients of variables which do not vary over time using the fixed effects method. Amiraslany (2010) assumed that long term climate variables changed over time and in doing so was able to use the fixed effects method to estimate the coefficients of the long term climate variables.

The approach used in this study is to assume that long term climate variables are fixed over time. This assumption precludes the use of fixed effects estimation and so random effects estimation must be used. The random effects assumption is only appropriate if one is confident that variables omitted from the regression equation are not correlated with the climate variables. A previous study (Massetti and Mendelsohn, 2011), which was reluctant to use the random effects assumption because of a concern over omitted variable bias, chose to assume fixed effects and to use a two stage procedure to recover the coefficients of the time invariant variables, which included long term climate normal. We show that for the current analysis the random effects method is more appropriate than two-step fixed effects method because there is no evidence that omitted variables are correlated with the climate variables.

After estimating the Ricardian model by the three methods that were discussed above, we calculate the marginal effects. Knowledge of the marginal effects allows us to predict changes in the farmland value under alternative climate change and price change scenarios. To implement the climate and price change scenarios, forecasts will be borrowed from other relevant studies.

Methodology

As previously noted, the analysis in this study is based on the Ricardian model which was introduced by Mendelsohn et al. (1994). In this model, the value of farmland serving as the dependent variable is regressed on climatic and non-climatic (socio-economic and dummy) variables to estimate the impacts of the climate variables. By introducing farmland value as the response variable, the model can capture the adaptation strategies which producers utilize in response to climate change. As was explained above, the value of adaptation strategies are reflected in farmland values because farmland rent represents the net profit of the best use of the land. Moreover, because the farmland value is the capitalized stream of the future profit from the farm, we can use farmland value to measure the change in the farm welfare which can be attributed to climate change.

In addition to adding updated data in the analysis, the price of more grains (wheat, canola, alfalfa and barley) and cattle are included in the model. The farm product price index is used to calculate the market price of the representative crop in each region. Lagged prices are incorporated in the model to reflect the inclusion of adaptive price expectations.

As well as the market price, various socio-economic and dummy variables are included in the model to control for non-climatic impacts on farmland prices. The control variables in the current model are regional farm income, government transfers, population, soil type, and distance to the nearest highway and export terminal. Data on climatic variables are extracted from the 1971-2000 climate normal database. These variables include annual mean temperature and precipitation. Moreover, an evapotranspiration proxy is introduced as a climate variable to reflect the interaction between the temperature and precipitation.

To estimate the model, panel data built from five census years will be used (1991, 1996, 2001, 2006 and 2011). The spatial unit of analysis is Census Sub-Division (CSD). According to Statistics Canada, Census Subdivision (CSD) is:

> "The general term for municipalities (as determined by provincial/territorial legislation) or areas treated as municipal equivalents for statistical purposes."

There are more than 1500 CSD in the Canadian Prairies; however, only about 500 of them are rural areas which can be used in the current analysis.

The socio-economic data is extracted from Canada Census of Population which of course varies over both time and region. Dummy and CSD characteristic variables are fixed over time but they vary over regions. Since climate change is a long-term phenomenon, to obtain the climate normals for each CSD, we assume that the climate variables are fixed over the considered time interval and we use the 1971-2000 climate normals of the weather stations, which were released by Environment Canada. As the model contains time-varying variables (e.g. population and income) and time-invariant variables (e.g. climate normals), we need to employ appropriate estimation methods so that the coefficients of the both types of variables can be obtained.

Regarding the econometrics approaches, since we use panel data, two methods can be used to estimate the model. The first approach is to pool the entire data set and then estimate the model in a single stage. The second approach improves on the pooling method by explicitly accounting for the variation over time of the key variables within the model. As previously discussed, the standard random effects method is used to address the problem of estimating the model with time invariant climate variables. The formal econometric analysis concludes with a third estimation method. Specifically, we employ a spatial random effects approach in which the degree of dependency of farmland value amongst CSDs expliticly considered in the model in order to obtain a more accurate set of results.

After estimating the model, we calculate the marginal impacts of climate change and then predict the impact of the potential climate change scenarios on farmland value and farm welfare. In our analysis, we will incorporate the climate change scenario for the Canadian Prairies which was forecasted by several earlier studies. We also include the price change scenarios in our analysis in order to have a more accurate prediction regarding what lies ahead for Prairie agriculture.

Ricardian Econometric Model

The Ricardian econometric model, with the assumption of adaptive price expectations (see Ayouqi 2013 for details) can be expressed as:

$$V_t = \alpha + \beta_0 P_t + \beta_1 P_{t-1} + \cdots + \beta_n P_{t-n} + \Gamma X$$

Within this equation V_t is the price of farmland, P_t is a price index, X is the matrix of control variables other than prices and Γ is the associated coefficients vector.

The climatic variables include selected climate normals and characteristics. The non-climatic variables consist of current and lagged market prices: various regional control variables, and an assortment of regional dummies.

Census Subdivision (CSD) data for five census years (1991, 1996, 2001, 2006, and 2011) is used to estimate the model. CSD is the smallest available unit for spatial analysis since it is the lowest level of Statistics Canada Standard Geographical Classification (SGC). In the following section, all variables will be introduced and interpreted.

Dependent Variable

As discussed above, farmland value (per unit area) serves as the dependent variable in Ricardian models. In the present study, the total land and buildings market value ($CDN) are extracted from the Canada Census of Agriculture for five census years. By dividing those values (in constant 2002 CAD) in each CSD by its area (hectare), the data for average farmland value is specified in terms of $CDN/hectare. This variable is defined in its logarithm form.

Independent Variables: Climate Variables

Temperature, precipitation, and humidity are the three main climate characteristics which are included in the model. The climate data are extracted from the 1971-2000 climate normals which were published by Environment Canada. In fact, since climate change is a long term shift in the weather condition, we consider the climate variables fixed over the 5 census periods. As suggested by the literature, the climate variables which are used in the model are as follows.

- Temperature: Climate-normal average temperatures are taken for the months of January, April, July and September. Since the temperature impact on farmland value varies across seasons, the temperatures of these months are included in the model and are assumed to be representative of each season.

- Frost Free Days: The monthly mean number of days with positive temperature.

- Precipitation: Climate-normal average rainfall and snowfall for the months of January, April, July, and September.

- Evapotranspiration: This variable, which reflects the main part of water cycle, is the sum of evaporation and transpiration. Evaporation accounts for the water movement from the sources like soil and water bodies to the air; transpiration accounts for the water movement from plants to the air. Evapotranspiration is calculated by dividing the climate-normal annual average precipitation by climate-normal annual average temperature.

As the climate data are available for weather stations, we need a mechanism to calculate the climate properties of each Census Subdivision. For this purpose, only those stations which are situated less than 100km from the centre of each CSD are considered. Then, the weighted average of climate data is calculated based on the proximity of stations to each CSD.

Results

Climate Variables

The econometric results show that most of the climate variables have significant impacts on the Prairies farmland value when using the weighted least squares (WLS) method (see Ayouqi, 2013 for details). However, in the random effects models the estimates are not as significant as the WLS.

As the model is log-linear, the marginal impacts show the percentage change of farmland value for 1°C or 1 mm/year change in climate factors. The results show that a marginal increase in the January (expect in model 1), April, and September temperatures will increase the farmland value, whereas a change in the July temperature has an opposite effect. The September temperature is the most effective factor (12.5% - 65.3%) among all the variables and the January temperature is the least effective one (-2.8% - 11.5%). These results sound reasonable as September is the harvesting period for the majority of grains while there is no crop in January. Besides, as September is the last month of growing season, a warmer temperature means a longer growing season and larger productivity. A warmer July leads to more evaporation and as a result water scarcity, which can justify the negative sign of MIC for July temperature (McGinn, 2010).

The results also show that a higher annual rainfall increases the farmland value and a higher annual snowfall will decrease it. The results show that 1 unit increase in the annual rainfall and snowfall will increase and decrease the farmland value by less than one percent, respectively. The positive signs for rainfall along with the negative sign for the July temperature confirm the high dependency of the Prairies agriculture on water-related variables.

Grain and Cattle Prices

The empirical results show (see Ayouqi, 2013 for details) that the price and the lagged price variables are significant in model 1, but their significance is not considerable in model 2 and 3. The estimated parameters show that by one unit increase in the grain price index, the farmland value will increase by 9% in model 1, 0.48% in model 2, and it will decrease by 0.3% in model 3. Since we have used the number of cattle in each CSD as a weight, to obtain the marginal impact of cattle price on farmland value, the coefficient must be adjusted based on the cattle numbers. The results for the three models show an increase in the farmland value (/ha) by 1.1%, 0.09% and 0.15% per one unit increase in the cattle price index. These results can confirm that the agricultural commodity prices are an important component in determining the farmland price.

Control Variables

Control variables capture non-climatic factors which influence the farmland value. Therefore, adding control variables to the Ricardian model leads to more accurate estimations. The adjusted R-squared for the model without control variable would be 0.536 which indicate that this model is not effective in prediction of farmland value, compared to the models with control variables. Therefore, it is important to have relevant variables in the model. The control variables which are considered in this study are consistent with other Ricardian models in the literature.

The empirical results demonstrate that per capita income is positive and highly significant in all models which mean higher income causes a more expensive farmland. In fact, having wealthy residents leads to more demand for lands and as a result will push up land prices that is consistent with the economic theories. Population density has also a positive relationship with the farmland value as larger population increases the demand for farmlands.

The government transfers are the other positive and significant variable in our model. In fact, one of the purposes of the government payments is reducing the financial risk for farmers against unpredictable and undesirable environmental and economic conditions. Clearly, with a lower risk more people tend to have a farmland and again the market will face larger demand and then the price will surge.

The coefficients of elevation and longitude variables have different signs in the models. The coefficient of elevation is significant and negative in model 2 and 3 which is consistent with the literature. Based on the Canadian studies, higher longitude has a positive impact on farmland since the price goes up from Manitoba to Alberta, therefore, the estimation of random effects models are reasonable in this case.

The last two control variables in Table 5.2 are the distance to the closest highway and export terminal. Being close to a highway is a considerable advantage for a farmland since the owner has easy access to big cities and markets. So, the negative and significant association of this factor with land price is logical. The distance to the closest export terminal was expected to have a negative relationship with farmland value since being close to an export terminal means low transportation cost. However, the sign of the estimated coefficient does not follow the expectations. It can show the presence of omitted variable bias. In other words, the distance to port is related to an omitted variable that is positively related to the farmland value. The air quality might be the omitted variable that has a positive relationship with farmland value and also relates to the distance to export terminal since export terminals are close to big cities (e.g. Calgary and Winnipeg) which are relatively polluted.

Dummy Control Variables

The soil type can capture the productivity difference among census subdivisions. Most of soil dummies are significant in the models. The black, dark brown and dark gray soil zones are positively associated with farmland value which is reasonable, since these types of soils are the most productive soils in the Canadian Prairies (Ecological Framework of Canada). The lower productivity for the regions with brown and gray soils is confirmed by the negative sign for these dummies. Therefore, the soil zones dummies successfully show their influence on the dependent variable in the model.

The year dummies are supposed to capture both observed and unobserved year fixed effects (that could be economic and environmental conditions), new rules, and all effects that vary over time. For example, the significant negative 1996 fixed effects can be a sign for occurrence of something special in this year (e.g. new rule or low economic growth) which is unobservable or is not included in our model.

Spatial Lag

The spatial autoregressive coefficient is estimated as 0.073 which is significant at the 0.001 level. The significant spatial lag term demonstrates that farmland value can be partly explained by neighboring farmland values, and the positive coefficient indicates that higher farmland value in neighbor area promotes farmland value in other area that seems reasonable. This result confirms the necessity of incorporating spatial lag into the Ricardian model.

Climate Change Scenarios

As the climate normals are calculated for a 30-year period, the climate change scenarios are defined for such length of time too. The climate scenarios have a baseline that the potential changes are simulated base on that. For this study, the baseline is 1971-2000 climate normals.

Before explaining the scenarios, note that we examine uniform temperature and precipitation scenarios for the Canadian Prairies which means every census subdivision is exposed to the same climate change. Therefore, different predictions for CSDs are the result of different sensitivities (not different scenarios).

There are 24 international modelling centres that use different models to simulate the future climate. For example, Bjerknes Centre for Climate in Norway, Centre National de Recherches Meteorologiques in France, and Canadian Centre for Climate Modelling and Analysis (CCCma) in Canada develop BCM, CNRMCM and CGCM models, respectively, to predict the future climate of all points on the earth. These models run based on different emission scenarios.

To be consistent with the previous Canadian studies, we choose CGCM model to get the appropriate scenarios for the Canadian Prairies. One of the specifications of climate models is their ability to retrieve scenarios for every single point on the earth as well as a selected area. Thus, we select the Prairies area to get a uniform climate change scenario for this region.

Choosing the model and selecting the region of interest are done in the Canadian Climate Change Scenarios Network (CCCSN) website. To retrieve the scenarios, we use CGCM3T47 which is the last version of CGCM model. Each model can be run with different assessments and SRES scenarios. For the current study, we choose the fourth assessment report (AR4 2007), which is the latest one, and SRES A2 emissions scenario.

The forecasts say that the average annual temperature will increase by 1.3, 2.6 and 4.1 °C, and the annual precipitation will increase by 5%, 12% and 17%. The monthly temperature scenarios demonstrate an increase for all months where January and April will face the most and the least increases in temperature, respectively. The CCCSN website shows the modelled monthly and annual temperatures and precipitation from 2011 to 2099 by year using CGCM3T47 model.

As was mentioned earlier, the present model is capable of assessing the impact of the change in market price on farmland value as well as the impact of climate change. Therefore, we need price change scenarios for the mentioned three periods There are several research in which the impact of climate change on agricultural commodity productions and prices are evaluated—Parry et al. (1999 and 2005), Darwin et al. (1995) and Adams et al., (1998). All these studies indicate that global warming will decrease the production of agricultural commodities and as a result will increase the prices. Parry et al. (1999) has predicted that output prices will rise between 3% in 2020 and 32% in 2080 due to the climate change. Following Amiraslany (2010), we consider 5%, 15% and 25% increases in the prices for the three periods.

Evaluating the Impact on Farmland Value

After preparation of the required information (i.e. model estimates and climate change scenarios), we can calculate the annual change in farmland values under the three different scenarios. In fact, each scenario gives us a new set of values for climate (i.e. temperature and precipitation) and price variables. Then, by plugging the new and old values into the estimated equation we can calculate the changes in the farmland values because of climate change.

The following table shows the predicted percentage and per hectare annual change in the Canadian Prairies' farmland values using the three mentioned models and scenarios. According to this table, under the medium climate change, the farmland value will change 21-31 CAD/ha. These changes are 36-51 and 35-77 CAD/ha for the strong and extreme climate change, respectively.

Average Annual Change in the Prairies Farmland Value

	Model 1	**Model 2**	**Model 3**
Scenario 1 (Medium)	1.32% 31.33 CAD/ha	0.9% 21.57 CAD/ha	1.5% 30.98 CAD/ha
Scenario 2 (Strong)	1.6% 38.19 CAD/ha	1.71% 36.02 CAD/ha	2.54% 51.65 CAD/ha
Scenario 3 (Extreme)	1.44% 35.53 CAD/ha	2.5% 51.54 CAD/ha	3.87% 77.75 CAD/ha

The total annual change in farmland values in the Canadian Prairies (which can be interpreted as farm welfare) can also be calculated using the total farmland area in this region. The next table shows that the farmland values of the Prairies increase between 1.14-1.65 billion Canadian Dollar annually for the medium scenario. The gain in farmland value can reach $1.87-$4.1 billion for the extreme scenario. These amounts of increases are considerable compared to the annual Prairies' crop and animal GDP ($11.67 billion in 2011, 2002 prices).

Although all models predict that farmland value will increase by climate change, the intensity of increasing is not the same for the models. Random effects model gives us the lowest amount in the medium and strong scenarios. The pooled model estimates the largest change in scenario 1, while in scenario 2 and 3 the largest prediction belongs to the spatial random effects model which is the result of the difference in the curvature of the models.

To show the effect of incorporating price in the Ricardian model, we can do the prediction without the price change which is consistent with the approach of most Ricardian Analysis. The following pair of tables show the predictions of change in agricultural land value with fixed prices.

Annual Change in the Prairies' Farmland Values (Farm Welfare), (Billions of Canadian Dollar, 2002 Prices)

	Model 1	**Model 2**	**Model 3**

Scenario 1 (Medium)	1.65	1.14	1.63
Scenario 2 (Strong)	2.01	1.9	2.7
Scenario 3 (Extreme)	1.87	2.71	4.1

Comparing the results of the next table with the previous two tables shows the predicted percentage and per hectare annual change in the Canadian Prairies' farmland values using the three mentioned models and scenarios. According to this table, under the medium climate change, the farmland value will change 9-31 CAD/ha. This change is 4-51 and -2-77CAD/ha for the strong and extreme climate change, respectively. These results demonstrate a big change in the prediction of the pooled model, whereas the other models do not show a considerable change. The big marginal impact of prices in model 1 with respect to the other models is the reason of this change. Hence, in the new prediction the pooled model gives the smallest increase under the medium and strong scenarios, and interestingly a decrease under the extreme scenario in the farmland values.

Average Annual Change in the Prairies Farmland Value (No Price Change)

	Model 1	**Model 2**	**Model 3**
Scenario 1 (Medium)	0.31% 8.89 CAD/ha	0.93% 20.21 CAD/ha	1.51% 30.79 CAD/ha
Scenario 2 (Strong)	0.08% 4.53 CAD/ha	1.63% 33.98 CAD/ha	2.55% 51.36 CAD/ha
Scenario 3 (Extreme)	-0.25% -1.87 CAD/ha	2.40% 49.27 CAD/ha	3.88% 77.44 CAD/ha

Annual Change in the Prairies' Farmland Values (Farm Welfare), No Price Change (Billions of Canadian Dollar, 2002 Prices)

	Model 1	**Model 2**	**Model 3**
Scenario 1 (Medium)	0.47	1.06	1.62
Scenario 2 (Strong)	0.24	1.79	2.71

Scenario 3 (Extreme)	-0.10	2.60	4.08

Conclusions

Climate change is a lasting change in the average or/and variability of climate normals that can affect many aspects of human life like health and food. Thus, this phenomenon has become a serious concern for lots of people and some governments. Clearly, one of the most vulnerable sectors against climate conditions is agriculture. Temperature, precipitation, flood, and drought are parts of climate-related factors that can highly influence agricultural production.

As for the importance of the relationship between climate and agriculture, the main goal of this study is quantifying the impact of climate change in the Canadian Prairies. The Prairies is chosen as the study region, since this area has a remarkable share in the Canadian agriculture. Moreover, it is vulnerable to climate change because of high risk associated with flooding and drought.

The most common method to evaluate how climate change might affect the agricultural economy is the Ricardian model. Prior to this model, researchers had been using a production function to calculate the effect of change in climate on agricultural production. This method, however, did not consider the adaptation to climate change. The Ricardian model, in fact, could deal with this problem by introducing farmland value as the response variable (instead of production) and regressing it on climatic and non-climatic variables.

After introducing the Ricardian model, a considerable number of scholars have tried to apply it in a variety of regions and also to modify the model. For example, fixed market price, which was one of the main assumptions of the Ricardian model, got relaxed by Amiraslany (2010). By evaluating the approach of including the price in the Ricardian model, we showed that the farmland value depends not only on the current market price but also the lagged prices. Hence, we added previous prices as well as current prices into the model. Furthermore, more commodity prices, compared to the Amiraslany's analysis, were incorporated to the model.

The other significant contribution of the present study to the literature is: using random effects and spatial random effects method to estimate the model. In the previous panel data studies, the fixed effects model had been employed to solve the Ricardian model. However, one of the requirements of using this model is that the variables of interest must be time-varying. Since the climate factors are the most important variables and as these variables are time-invariant, the fixed effects approach does not seem to be an appropriate econometrics method to estimate the model. Thus, the random effects method was used for this study. Moreover, by using spatial econometrics method, the spatial interactions between CSDs are considered which could give us a more accurate result.

Therefore, three econometrics methods have been used to estimate the Prairies Ricardian model — pooled WLS, random effects, and spatial panel data estimations. At first, by running two pooled WLS (one with lagged prices and the other one without them); we showed that the added lagged prices are significantly associated with the farmland value. Then, the model was estimated by the two random effects approach. Among the econometrics methods, the regular random effects had the largest R-square; however, the estimates of WLS for climate variables were more significant.

The marginal impacts of climate factors show that the January, April, and September temperatures and rainfall have a positive marginal effect on the land value, whereas this relationship is negative for the July's temperature, snowfall, and evapotranspiration. These results can confirm that the Prairies' agriculture is sensitive to water supplies; high July temperature leads to water scarcity, because of more evaporation during summer and as a result it has a negative effect on farmland value.

The main finding of the current analysis is that climate change is beneficial for the majority of regions in the Canadian Prairies. To obtain this result, three different climate change scenarios were applied to the estimated model. Except for the north part of Saskatchewan and the west part of Alberta in the medium climate change scenario, all other cases show increase in the farmland value. According to the results of this study, the farmlands of Canadian Prairies will gain a value between $1.14 and $4.1 billion annually (based on the estimation model and scenario).

The positive association between climate change and the Prairies farmland values are consistent with the previous Canadian studies. The estimated value of gains, however, are not the same among the different analyses, which can be because of using different spatial unit, data, scenarios and econometrics methods.

Although this study shows that climate change is not a threat for the economy of Prairies agriculture, this phenomenon can be harmful if inappropriate adaptation strategies are adopted. Therefore, the agricultural policies have to be made to encourage farmers to utilize proper strategies and practices against climate change. These policies should help farmers to: develop better irrigation methods, choose appropriate crops, and deal with water scarcity.

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