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A Ricardian analysis of US and Canadian farmland

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Abstract In this analysis, we undertake a comparative Ricardian analysis of agriculture between Canada and the United States. We find that the climate responses of the two countries are similar but statistically different despite the fact that the two countries are neighbors. Comparing the marginal impacts of climate change, we find that Canadian agriculture is unaffected by warmer temperatures but would benefit from more precipitation. US farms are much more sensitive to higher temperatures and benefit relatively less from increased precipitation. These marginal results were anticipated given that Canadian farms are generally cooler and drier than American farms.

1 Introduction

The Ricardian technique is a well-known approach to measure the effects of climate on the value of cropland (Mendelsohn et al. 1994, 1999, 2001). The market value per hectare of cropland is regressed on climate and other exogenous variables to reveal the role climate plays in explaining farm value. These climate relationships can then be used to predict the agricultural impact of future changes in climate. Recently, the technique has been independently applied to both the United States (Mendelsohn and Dinar 2003) and Canada (Reinsborough 2003). Despite the proximity of the two countries, the two papers yielded quite different results. The Canadian regressions implied that warmer temperatures would lead to little effect in Canada. However, if one used the American regressions to infer what would happen in Canada, they suggested warming would be beneficial in Canada.

In this analysis, we extend this research by combining the data sets of the two countries to estimate a new overarching relationship between climate and land value. In the first model,

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we assume that the climate coefficients are the same for the two countries. In the second model, we allow the climate coefficients to vary between the two countries. Because one explanation of the different results is irrigation, we estimate a third model that repeats the second experiment but uses only dryland farms. By combining the data from Canada and the US, we are able to get a much wider range of climate variation and thus better climate estimates. Further, by comparing the results of the different regressions, we can formally test whether farmland values have the same response to climate in both countries. For all three models, we compare the marginal sensitivity of farmland values to climate in each country.

2 Theory

The Ricardian method is a cross-sectional approach to studying agricultural production. The method was named after Ricardo because of his original observation that land rents would reflect the net productivity of farmland. Farmland value (V) reflects the present value of future rents, which are tied to future net productivity. This principle is captured in the following equation:

$$V = \int P_{\mathrm{LE}} e^{-\varphi t}\, dt = \int [\Sigma P_i Q_i(X, Z) - \Sigma RX]\, e^{-\varphi t}\, dt \tag{1}$$

where P_{LE} is the net revenue or rent per hectare, P_i is the market price of crop i, Q_i is output of crop i, X is a vector of purchased inputs (other than land), Z is a set of exogenous variables tied to the farm such as soils, climate, and economic variables, R is a vector of input prices, t is time, and φ is the discount rate (see Mendelsohn et al. 1994). The farmer is assumed to choose X to maximize net revenues given the characteristics of the farm and market prices. The Ricardian model is a reduced form model that examines how a set of exogenous variables, Z, affects farm value.

The standard Ricardian model relies on a quadratic formulation of climate:

$$V = B_0 + B_1 T + B_2 T^2 + B_3 P + B_4 P^2 + B_5 Z + u \tag{2}$$

where T is a vector of seasonal temperatures, P is a vector of seasonal precipitation, Z is a vector of exogenous variables, and u is an error term. Both a linear and a quadratic term for temperature and precipitation are introduced. In this paper, we add interaction terms between temperature and precipitation:

$$V = B_0 + B_1 T + B_2 T^2 + B_3 P + B_4 P^2 + B_5 T^* P + B_6 Z + u \tag{3}$$

The marginal influence of temperature on farm value in a country with mean climate, $E[T]$, is:

$$E[dV/dT] = B_1 + 2{*}B_2{*}E[T] + B_5{*}E[P] \tag{4}$$

And the elasticity of farm value with respect to temperature is:

$$\varepsilon_T = (B_1 + 2{*}B_2{*}E[T] + B_5{*}E[P]){*}(E[T]/E[V]) \tag{5}$$

The marginal value of precipitation is:

$$E[dV/dP] = B_3 + 2{*}B_4{*}E[P] + B_5{*}E[T] \quad (6)$$

And the elasticity of farm value with respect to precipitation is:

$$\varepsilon_P = (B_3 + 2{*}B_4{*}E[P] + B_5{*}E[T]){*}(E[P]/E[V]) \quad (7)$$

Note that the marginal effect and climate elasticities in the two countries can be different because they have different climate coefficients and because the two countries have different mean climates.

The quadratic term reflects the nonlinear shape of the climate impact response function (Equation (2)). When the quadratic term is positive, the net revenue function is U-shaped and when the quadratic term is negative, the function is hill-shaped. We expect, based on agronomic research and previous cross-sectional analyses, that farm value will have a hill-shaped relationship with annual temperature. For each crop, there is a known temperature where that crop grows best across the seasons. Crops consistently exhibit a hill-shaped relationship with annual temperature, although the maximum of that hill and the seasonal impacts vary with each crop.

3 Data and empirical specifications

In order to examine the Ricardian model across both the United States and Canada, it was important to define all variables using consistent units. The American farm data comes from the 1997 US Census of Agriculture (USDA 1997). The Canadian farm data come from the 1996 Canadian Census of Agriculture (Statistics Canada 1996). The data is consequently one year apart. However, because the analysis focuses on the market value of farms, which are relatively stable, this difference should not be problematic. Canadian economic measures have been converted to US dollars using the exchange rate. The most important economic variable in the Ricardian method is farm value. These values come from self-reported estimates by every farmer surveyed in the Canadian and US Censuses. Farmers were asked to estimate the market value of their farms. The reported value in both countries includes the land and buildings.

Additional data were found from other sources. The Census of Population in 1990 in the US and the Census of Population in 1996 in Canada were used to obtain population density, population change, and income. Soils data for the US were obtained from the National Resource Inventory and soils data for Canada come from the National Ecological Framework.

Climate data for both countries reflect average measures of monthly temperature and precipitation from 1961–1990 at nearby weather stations. These long run climate measures are stable and so should pertain to the period of study. The mean climate values for farmland in each country are displayed in Table 1. The climates in each county or division are weighted by farmland so that they represent the climates farmers actually face. Note that by restricting the sample to farmland, vast areas of northern Canada are excluded. The important insight of Table 1 is that the two countries do not have the same mean climate conditions. Canada is distinctly colder and drier than the US.

The regression models are estimated using weighted OLS. The areas (counties in the US and Census Divisions in Canada) were weighted by aggregate farmland in order to give more weight to counties with more farmland. The weights also control for urban areas with only

Table 1 Mean climate of farmland in Canada and the United States

	Temperature °C		Precipitation cm/mo	
	Canada	US	Canada	US
January	−14.7	−1.7	3.0	3.9
April	3.8	11.6	3.2	6.2
July	17.9	24.2	6.8	7.0
October	5.3	13.2	3.1	4.8

Values are weighted by farmland

a small amount of land in farmland but very high values due to urban proximity. The land value per hectare is regressed on climate, soils, and socioeconomic variables.

4 Results

In order to compare impacts in Canada and the United States, we estimate three regressions with the combined US and Canadian data. In the first regression in Table 2, we estimate a single climate response function for both countries. That is, we introduce only one set of climate coefficients for the sample. In the second regression in Table 2, we include both an American and a Canadian set of climate variables. The second model allows the climate coefficients to vary for each country. We then test whether the climate coefficients for the two countries are significantly different. In the third model, we repeat the second experiment but examine only dryland. In all cases, we use the same variables for each regression.

The agricultural policies of Canada and the United States are not the same. Farmers in the United States receive relatively large government subsidies whereas Canadian farmers have large cooperatives that purchase output. We control for these differences using a dummy variable for Canada and by including the size of the government subsidies per hectare of farmland in each county in the US.

The climate coefficients in the first column in Table 2 reveal that farmland value is indeed sensitive to both temperature and precipitation. The climate coefficients change over the seasons as expected. The quadratic terms are significant indicating that the response function is nonlinear. The squared terms for temperature in each season have offsetting signs implying a mixture of hill-shaped and U shaped responses. The squared terms for precipitation are positive implying a U shaped response function.

The exogenous variables behave largely as expected. Higher income and population growth increase farm value per hectare. Higher population density increases farm value but at a decreasing rate. Surprisingly, higher altitude also increases farm value. The dummy variable for Canada is not significant. However, the American subsidies/ha are very significant. They imply that American farm values increase $0.29 for every dollar of annual subsidy to that county. In general, it is surprising that the increase in farm value is so small for such a large annual government payment. It implies that farmers do not expect the subsidy to last or that the subsidies are concentrated on unproductive farms.

The second model in Table 2 contains some variables that are common to the entire data set and climate variables specific to each country. Thus, the second and third columns of climate coefficients in Table 2 reflect the US and Canadian response to climate. These climate variables were created by introducing a dummy variable for each country and multiplying that dummy variable times each climate variable. The temperature coefficients appear to be quite different between the two countries. Most of the Canadian precipitation coefficients are not significantly different from the American coefficients but that is largely due to their

Table 2 Ricardian regressions across the United States and Canada

Independent variables	Same climate response	Different climate response		Different climate response-dryland	
	US+Canada	US	Canada	US	Canada
January	−87*	−197*	−874*	−48	111
Temperature	(2.57)	(4.97)	(1.96)	(1.26)	(0.25)
April	986*	1140*	−615*	667*	−404
Temperature	(12.01)	(9.24)	(1.96)	(5.64)	(1.52)
July	527*	518*	4750*	616*	531
Temperature	(2.79)	(2.28)	(2.71)	(2.65)	(0.36)
October	−684*	−1060*	53	−475*	−248
Temperature	(4.74)	(5.49)	(0.09)	(2.40)	(0.49)
January squared	1.2	5.0*	−19.1	−1.3	2.6
Temperature	(0.83)	(2.87)	(1.59)	(0.82)	(0.22)
April squared	−31.9*	−36.5*	84.8*	−18.7*	−18.5
Temperature	(10.40)	(8.55)	(3.43)	(4.38)	(0.86)
July squared	−11.9*	−13.3*	−132.6*	−15.5*	−19.1
Temperature	(2.81)	(2.70)	(2.83)	(3.06)	(0.47)
October squared	34.9*	56.1*	−4.5	21.0*	57.9
Temperature	(5.98)	(7.97)	(0.09)	(2.83)	(1.30)
January	208*	233*	426.	82*	134
Precipitation	(6.23)	(6.95)	(0.71)	(2.26)	(0.23)
April	615*	462*	272.	295*	387
Precipitation	(8.94)	(6.38)	(0.52)	(4.35)	(0.86)
July	377*	676*	574	719*	−468
Precipitation	(5.02)	(6.88)	(0.54)	(7.55)	(0.52)
October	−17.	23	674	−90.9	−184.4
Precipitation	(0.23)	(0.24)	(1.77)	(0.92)	(0.57)
January squared	−4.7*	−3.7*	28.6	3.0	9.2
Precipitation	(3.28)	(2.56)	(1.29)	(1.75)	(0.41)
April squared	−10.9*	−15.2*	−28.4	−4.5	−93.9*
Precipitation	(3.20)	(4.36)	(0.78)	(1.38)	(2.96)
July squared	19.9*	21.8*	37.1	10.5*	6.5
Precipitation	(9.27)	(10.04)	(1.24)	(4.87)	(0.23)
October squared	36.7*	43.4*	−56.8*	14.8*	5.0
Precipitation	(10.60)	(8.60)	(3.85)	(2.68)	(0.36)
January	7.4*	3.9	83.1*	−3.8	12.0
Temp*Prec	(2.38)	(1.22)	(2.27)	(1.16)	(0.34)
April	−20.2*	−7.7	140.5*	−8.6	69.4
Temp*Prec	(4.51)	(1.58)	(2.53)	(1.79)	(1.46)
July	−31.2*	−42.9*	−58.3	−34.6*	35.7
Temp*Prec	(9.10)	(9.85)	(1.27)	(8.05)	(0.93)
October	−23.7*	−34.9*	14.4	2.0	15.9
Temp*Prec	(5.36)	(6.03)	(0.26)	(0.33)	(0.35)
Canada	115	...	−42500*	...	5740
	(0.84)		(2.32)		

(Continued on next page)

Table 2 *(Continued)*

Independent variables	Same climate response US+Canada	Different climate response US	Different climate response Canada	Different climate response-dryland All
Income	189*	200*		226*
	(13.72)	(15.14)		(19.52)
Population	1330*	1240*		1030*
Density	(22.17)	(21.55)		(20.56)
Population	−38.7*	−35.3*		−27.4*
Density squared	(9.70)	(9.35)		(8.65)
Population	199*	161*		146*
Change %	(2.90)	(2.46)		(2.67)
Altitude	487*	519*		−7*
	(3.78)	(3.99)		(0.05)
Subsidy/ha	0.29*	0.28*		0.26*
	(12.77)	(12.69)		(11.82)
Constant	−10700*	−9510*		−10100*
	(5.78)	(4.14)		(4.20)
R^2	0.61	0.66		0.64
# Observations	3195	3195		2822

The *t*-statistics are in parentheses

large standard errors. Curiously, the coefficients of the temperature-precipitation interaction are quite different in each country. The Canadian coefficients are positive and significant for January and April. The American coefficients are negative and significant for July and October.

Testing for whether the two sets of climate coefficients are the same, we find the climate coefficients of the two countries are significantly different ($F = 20.8$). Specifically, the Canadian coefficients for April and July temperature, October precipitation, and the January and April interaction terms are significantly different. The differences are complex, however. For example, the Canadian coefficient for the linear temperature term in April is negative rather than positive but the coefficient on the squared term is positive rather than negative. The Canadian coefficient on the linear temperature term in July is positive rather than negative and the squared term is more negative.

Allowing the climate coefficients to vary between the US and Canada has little effect on the control variables. However, the dummy variable for Canada becomes significant and quite negative in the second regression.

The fact that the climate responses are different is disconcerting. Ideally, one would want the climate response function to fit smoothly over the two adjacent countries. There are at least two explanations for this puzzling result. First, the climate surface could be more complicated than the quadratic model, requiring higher order terms. However, the introduction of third order terms does not make the climate coefficients in the two countries identical. A more complicated form may be required. Second, important control variables may be omitted. For example, the Canadian data set has only a limited description of soils. The Canadian Shield sweeps down from the northwest to the southeast of Canada. There is no soil variable in the Canadian dataset to reflect this outcropping of forbidding bedrock. If the Canadian Shield is spatially correlated with climate in Canada, it would lead to some Canadian specific climate coefficients. Another key variable that is not available in this study is climate variability.

Table 3 Marginal climate impacts

	One climate response		Different climate responses		Different climate responses-dryland	
	Canada	US	Canada	US	Canada	US
Temperature	−109	−551*	87	−102	−51	−168
	(−0.3)	(−2.8)*	(0.2)	(−0.5)	(−0.1)	(−0.8)
Precipitation	716*	330*	428	307*	249	358*
	(2.2)*	(0.8)*	(1.3)	(0.7)*	(0.6)	(0.8)*

Marginal effects are the change in USD/ha per °C or mm/month evaluated at the mean annual climate for farmland in each country. Elasticities are in parentheses. Significant effects are starred

The final two columns in Table 2 explore a similar model except that the sample is limited to dryland farms (irrigation is less than 10% of cropland). Eliminating many of the counties reduces the significance of the coefficients. The Canadian model is barely statistically different from zero. The coefficients also change. Many of the climate coefficients are different between the second and third model, especially the temperature coefficients. Altitude also has a different coefficient between the models. These changes suggest that dryland does not have the same climate response as irrigated land as noted by Mendelsohn and Dinar (2003) and Schlenker et al. (2005). Although we could not test this hypothesis because there are so few irrigated divisions in Canada, it is likely that irrigated models differ across countries too.

Because the linear and squared coefficients are difficult to interpret in raw form, we calculate the marginal effects of annual temperature and precipitation in Table 3. For each country, we calculate the marginal effect of temperature and precipitation evaluated at the mean temperature and precipitation level of farmland in each country (see Table 1). Using the coefficients of the single climate response function, we find that the marginal impacts are quite different for each country. Increasing temperature reduces American farm values substantially but Canadian farm values only slightly. Specifically, the temperature elasticities are much higher for the American farms. Given the overall hill shaped relationship between farm values and temperature, this is an expected outcome. American farms are warmer and much closer to the top of the hill from which they will fall. Canadian farms are much colder and to the left of optimal temperatures. Warming is expected to be more beneficial. Increasing precipitation increases Canadian farm values almost twice as much as American farm values. Again this was expected given that Canadian farms are generally drier. The Canadian precipitation elasticities are almost 3 times higher.

When the climate coefficients for the two countries are allowed to vary, the climate responses of the two countries change. The model has trouble distinguishing detailed climate surfaces for each country. However, the temperature response for Canada becomes positive whereas the American response remains negative. The Canadian precipitation response becomes smaller but it remains larger than the American response.

The third set of results in Table 3 concern the dryland-only experiments. Shrinking the sample leads to many insignificant coefficients in the dryland model. Compared to the results for the full sample, though, there are some interesting changes in the marginal effects and elasticities. The dryland farms are more sensitive to temperature in both Canada and the US. This implies that the dryland farms are more sensitive than irrigated farms to temperature. In Canada, the dryland farms are less sensitive to precipitation than all farms. This finding was not repeated in the US. The full sample in Canada, because it captures switching between dryland and irrigation, is actually more sensitive to precipitation than just looking at dryland farms alone. In the US, irrigated farms are less sensitive to precipitation, which overwhelms the switching effect.

5 Conclusion

This paper examines a set of Ricardian models estimated across both American and Canadian data. The models predict that both temperature and precipitation will have different effects on Canada and the US because Canada is cooler and drier to begin with. In general, warmer temperatures will have ambiguous effects in Canadian farms but increased (decreased) precipitation will clearly increase (decrease) farm values. American farms have a similar though more muted reaction to precipitation but will be more likely harmed with warmer temperatures.

Combining the data in adjacent countries can improve both the accuracy and the shape of the overall estimates. In general, the wider the distribution of climate in the sample, the better a cross-sectional approach such as the Ricardian method will perform. The combined sample regressions were able to estimate a more sophisticated climate response function across both countries.

However, allowing the climate response functions to differ between the two countries reveals a perplexing outcome: the Canadian and American temperature response functions are significantly different. This raises questions about the universality of the climate response function. Perhaps the quadratic functional form is not capturing all the shapes a global function must reflect. Alternatively, the model may be plagued with insufficient controls (omitted variables). In cross-sectional studies, such as this one, it is important that there be adequate controls for other important variables that might vary across the landscape. For example, missing from the data is a more complete representation of geological and soil characteristics in Canada, which one would expect to be very relevant for Canada and its varied geography. There may also be an important role here for climate variability as well.

These results suggest that midlatitude countries are more vulnerable to warming than polar countries. Drier countries will be more vulnerable to any reductions in precipitation. However, to determine exactly what will happen to any country, it is helpful to do an empirical analysis that actually includes data from that country. Even neighboring countries can have different climate response functions.

There are a number of other caveats to keep in mind as well. First, the research suggests that seasonal temperatures and precipitation are important. Climate responses are very complex. Other climatic variables may also be important such as shifts in climate variance or extremes. Projections must also take into account carbon fertilization. Finally, the analysis in this paper is examining long run responses to climate. Short run responses by farmers to transient climate change may lead to very different outcomes. Although farmers have shown a remarkable ability to adjust quickly to changes in prices and government incentives, short run changes in climate are likely to be more difficult to detect and more difficult to respond to than long run changes.

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