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EFFECTS OF CLIMATIC AND ECONOMIC FACTORS ON CORN AND SOYBEAN YIELDS IN ONTARIO: A COUNTY LEVEL ANALYSIS

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Abstract

Climate change is the most challenging issue of our time. While climate change is often portrayed as a global phenomenon, the real impacts of climate change are felt at the local level. Changes in climatic conditions directly affect the level of precipitation which is very important for crop production in Ontario. How do changes in climate affect corn and soybean yields at the county level in Ontario? This question is addressed in this paper by estimating the effects of climatic and economic factors on yields of grain corn and soybean in three selected counties in Southwestern Ontario employing data from 1950 to 2013. The results demonstrate that the effect of precipitation during growing season on yield is positive and statistically significant and it is consistent across the selected counties. The effects of solar energy on crop yields vary across counties. Yields of both crops increase as crop price increases and decline as the price of fertilizer increases. Finally, developments in technology have a strong effect on enhancing yield for both crops. The climatic factors have a larger impact than the effects of economic factors on corn yields at the county level. The reverse, however, appears to be true for soybean production at the county level in Ontario. The policy implications of the results are also discussed.

Key Words: *Climate Change; Economic Factors; Yields, Corn; Soybean; County Level; Ontario*
Jel Codes: *Q11, Q54*

1. Introduction

Climate change is one of the most important and challenging issues faced by human civilization in the 21st Century. While climate change is a global phenomenon and requires concerted efforts by the global community to combat the most harmful aspects of climate change and slow down its pace, the effects of climate change manifest themselves locally. Since local environments differ in terms of topography, crop and animal husbandry, infrastructures and the pattern of human habitation, economic, social and political consequences of climate change are expected to vary substantially across countries and across regions/districts within a country. While the effects of climate change for broader geographical regions have been generated from global and regional simulation models and have played an important role in informing many policy choices at the United Nations, understanding the impacts of climate change at the local level is at a very early stage. This understanding, however, is very important to appreciate the effects of climate change at a local level and how they differ across local communities. A good understanding of these issues will also direct our attention towards the development of adaptation strategies suitable for local climatic conditions.

We make an attempt in this paper to further enhance such an understanding by focusing on the historical effects of climate change on the yields of two important grain crops, corn and soybean, at county level in Ontario. To the best of our knowledge, this is the first study investigating the effects of climate change on yields at county level using data from 1950 to 2013. Since economic factors also influence the yields of commercially important crops and their exclusion from the analysis will render the empirical results biased, we also used important economic variables in our analysis. Although the effects of climate change can be diverse, we pay particular attention to climate change effect on water availability as precipitation is the most important limiting factor for crop yield under rain-fed agriculture in Ontario (Kalantzis, 2013; Shifflett et al, 2014). While climate change can have dynamic impacts on crop yield, for simplicity, we consider only the direct effect of climatic and other relevant factors on the yields of two selected crops in this study. Understanding the effect of precipitation on crop yields at county levels in Ontario is also important from policy point of view. A good understanding of the effect of precipitation on crop yields at county level will aid farmers in crop choices and adapting new agronomic practices. It will also inform policy makers to develop climate friendly programs to improve crop yields in Ontario.

While the effect of precipitation on crop yields has been investigated all over the world, only in recent years the attention is focused on the fact that the effect of precipitation is location specific. Boubacar (2012) and Chen et al (2013) found positive relationship between precipitation and crop yields in Sahel and Northern China respectively. While Lobell et al (2007) found negative relationship between precipitation and crop yields in Californian, Tack et al (2012) found no statistically significant relationship in Arkansas and Mississippi, but a significant positive effect on yield in Texas. Local climatic conditions may be the main reason for variations in precipitation effects on yield. Since more precipitation might be harmful for crops in wet area but be beneficial for crops in dry areas, the precipitation effect for every location is unique and cannot be simply replicated from other locations. The effect of precipitation on crop yields in Southern Ontario has been investigated by Weersink et al (2010) and Cabas et al (2010). While the results from these studies are informative, they used data for only 26 years and incorporated economic factors in an indirect fashion. We extend the data set to 64 years, incorporate the economic and climatic variables directly in our model. Since the growing season may vary by locations and across crop types, selecting an appropriate growing season definition is important for the estimation of the crop yield functions. To this end, four different definitions of growing season (Pedlar et al, 2014) have been used in our empirical analysis.

Therefore, the second purpose of this study is to investigate the effect of precipitation on yields of grain corn and soybean in Southwestern Ontario under four alternative growing season definitions. The empirical model incorporates both climatic and economics factors. Why did we select grain corn and soybean in this study? This is because grain corn and soybean occupy about 23% and 28% of total provincial cropland area respectively and are the most important crops grown in Ontario (Agricultural Statistics for Ontario, 2011). The yield performance of these two crops is crucial for future sustainability of grain and livestock sectors in Ontario.

Section two presents a brief introduction to the production function approach used as the basis for the estimation of the yield functions. Section three describes all relevant data, key distributional features of data and their sources. The next section presents the regression model and focuses on estimation issues. Section five presents the empirical results, discuss them and bring out the implications of the results. The final section summarizes the key findings and concludes the paper.

2. Methodological Approach for the Regression Analysis

Empirical analysis of the effects of climate change on crop yield often considers climate change as a risk factor and assumes that the underlying production technology has the following Just-Pope form (Cabas et al., 2010; Holst et al., 2013; Sarker et al., 2013; Kim & Pang, 2009; Kumbhakar & Tveteras, 2003):

$$Y = f(x, z) + g(x, z) + \varepsilon,\ E(\varepsilon) = 0, and\ V(\varepsilon) = 1 \quad (1)$$

Where x is a vector of economic variables and z is a vector of climatic variables. Finally, ε is a stochastic term with mean zero and a constant variance. The first term, f(x,z) is called the mean yield function while the second term, g(x,z) represents the yield risk function.

The input vectors, x and z, are included in the yield risk function to estimate and test if a particular input is risk reducing or risk enhancing. Since we are interested to estimate the historical effects of climatic and economic factors on the yields of corn and soybean at county level in Ontario, we focus only on the estimation of the parameters of the mean yield function.

The economic factors include expected crop price, input price, and technology and climatic factors include available water and solar energy at county level. Since both corn and soybean follow particular rotation patterns in Ontario which are less likely to be influenced by substitution crop price, we decided not to include any substitution crop price in our analysis.

If the expected price of a crop is higher, farmers will attempt to increase its yield to so that more revenue from that crop can be obtained. So, the expected sign of this variable is positive. If the price of an input is higher, farmers will use less of that input. As a result, crop yield will decrease. So, the expected sign of the price of an input on yield is negative. Advances in production technology either in the form of high-yielding seeds or adoption of a new mechanical technology or both will enhance yield. Thus, the expected sign of technology variable is positive. While the expected effects of economic factors on crop yields appear to be clear, the expected effects of weather variables on crop yield are not. For example, the effect of available water and solar energy on crop yields could be either positive or negative depending on the circumstances. If there was insufficient water, crop yield increases as more water becomes available. However, in an excess water condition, crop yield would decrease with additional water. Similarly, if there is inadequate solar energy than required for optimum growth crop plants, crop yield will increase as more solar energy becomes available and vice versa, other things remaining unchanged.

As reported in previous research, the effects of precipitation and solar energy on crop yields are non-linear. Therefore, the linear functional form cannot be used to measure the historical effects of economic and climatic variables of the yield of corn and soybean. Instead, we used Quadratic and Log-Log functional forms which have been commonly used in the literature to determine the effect of water and solar energy on crop yields (Dinar *et al*, 1991; Datta *et al*, 1998; Kiani & Abbasi, 2009; Quiroga, 2011).

3. Choice of Counties

The dependent variable in this study is yield in bushels per acre and annual yield data were collected from 1950 to 2013 for grain corn and soybean which are the two of main grain crops in Ontario. Three counties - Chatham-Kent (CK), Essex, and Lambton were selected in this study because they are located in Southwestern Ontario where corn and soybean have been produced on a large scale since the 1950s. Lambton is located to the north of Chatham-Kent while Essex is located to the southwest of Chatham-Kent (Figure 1). Therefore, Lambton is expected to receive less solar energy than Chatham-Kent while Essex is expected to receive more.

Figure 1. Map of Southwestern Ontario: Location of Selected Counties

4. Empirical Model, Data and Estimation Issues

Software **R** is used to estimate the yield functions for the selected counties. Following the literature, we used both quadratic and double log functional forms to estimate the yield functions. The specifications used are as follows:

$$Yield_t = \beta_0 + \beta_1 CP_{t-1} + \beta_2 FP_t + \beta_3 TT_t + \beta_4 Pbgs_t + \beta_5 Preci_t + \beta_6 DD_t + \beta_7 CP_{t-1}^2 + \beta_8 FP_t^2 + \beta_9 TT_t^2 + \beta_{10} Pbgs_t^2 + \beta_{11} Preci_t^2 + \beta_{12} DD_t^2 + \varepsilon_t \quad (2)$$

$$\text{Ln}\,(Yield_t) = \beta_0 + \beta_1 \text{Ln}CP_{t-1} + \beta_2 \text{Ln}FP_t + \beta_3\, TT_t + \beta_4 \text{Ln}Pbgs_t + \beta_5 \text{Ln}Preci_t + \beta_6 \text{Ln}DD_t + \varepsilon_t \quad (3)$$

where t is time, CP_{t-1} is 1year lag of crop price, FP_t is current year fertilizer price, TT is centralized time trend, Pbgs is precipitation before growing season, Preci is precipitation during growing season, and DD is degree days during growing season.

Ordinary Least Square (OLS) is used to estimate Equation (2) and Equation (3). Durbin-Watson d Test is applied to determine autocorrelation problem. If autocorrelation problem shows up, then Newey-West robust variance-covariance matrix is used to correct for autocorrelation. Finally, Shapiro-Wilk Normality Test is used to test for normality.

Data were collected from four different data sources. First, yield data (bushels/acre) for grain corn and soybean at county level were obtained from Agricultural Statistics for Ontario. Second, crop price data are from Statistics Canada. Fertilizer price index in Canada from1950 to 2013 (base = 1998) is used as input price. Farm product price index in Canada during 1949-2013 (base = 2007) were collected to adjust crop and fertilizer prices for inflation. Third, climate data were obtained from Natural Resources Canada.

Precipitation during 3 months prior to the start of growing season (mm) and precipitation during growing season (mm) are collected as proxy of available moisture before growing season and during the growing season, respectively. Degree days above 10°C during the growing season were collected as proxy for solar energy during the growing season. Note that, available moisture before and during the growing season are separated to explore if they have differential effect on yields. Excess water from snow melting in the Spring may reduce the rate of seed germination, while water during growing season might have positive effect on crop yields. Furthermore, precipitation is a stochastic input and the correlation between these two variables is 0.2. So, there is no multicollinearity problem in the data. Finally, a centralized time trend is created to represent the effect of technology on crop yield.

According to Pedlar *et al* (2014), four growing season definitions in Natural Resources Canada are defined based on different critical temperature to set the start date and end date. The #1 definition is used to denote the growing season which starts when the mean daily temperature was greater than or equal to 5°C for 5 consecutive days beginning on March 1, and end when the average minimum temperature is less than -2°C beginning on August 1. The #2, #3 and #4 definitions are defined to start on the following day of last crossing of a critical daily minimum temperature (T_{crit}) in spring and end on the preceding day of the first crossing of T_{crit} in fall. The critical temperature T_{crit} are 0°C, -2.2°C, and -4.4°C respectively. Given the definitions, we can tell that the length of growing season in #2 is the shortest and the length of growing season in #4 is the longest. However, it is difficult to determine the difference between #1 definition and the other three definitions, since they are based on different standards of measurement. The #1 definition based on mean daily temperature and average minimum temperature but the other three definitions based on daily minimum temperature. But, given the data description below, we can tell that the #1 definition has the longest growing season followed by #4, #3 and #2 (i.e., length of growing season: #1 > #4 > #3 > #2). While data on precipitation before growing season is only available for growing season definition #1, to avoid a problem in regression analysis it is used in all regressions.

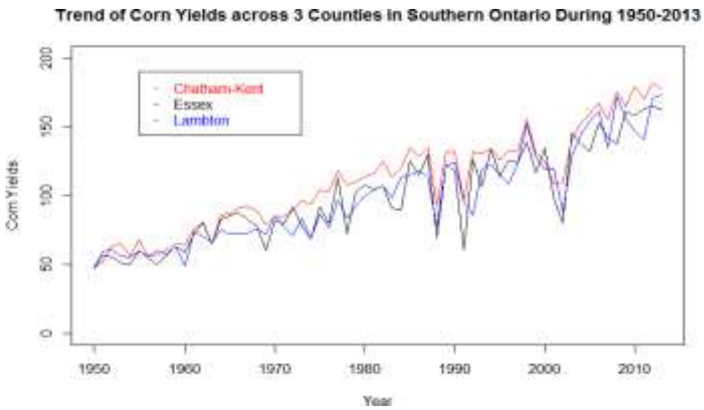

Figure 2. Historical Corn Yields in Three Selected Counties: 1950-2013

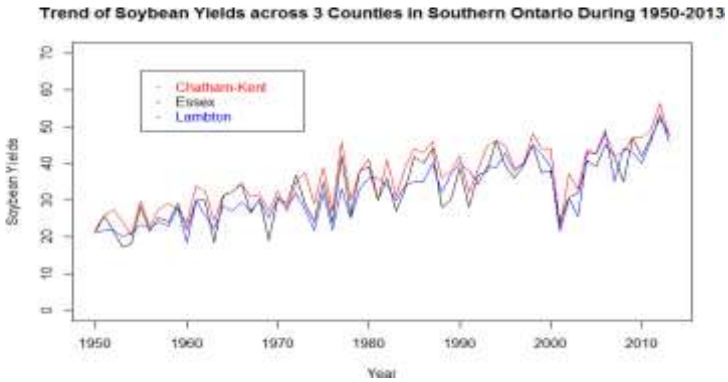

Figure 3. Soybean Yields in Three Selected Counties: 1950-2013

Table 1. Summary Statistics of Grain Corn and Soybean Yields and Real Prices

	Mean	St.d	Max	Min
Corn Yield				
Chatham-Kent	111	37	182	48
Essex	99	34	165	47
Lambton	99	34	173	48
Soybean Yield				
Chatham-Kent	36	8	56	21
Essex	33	8	52	17
Lambton	33	8	53	18
Real Prices				
Real 1-Year Lag of Corn Price	1.81	0.37	2.70	1.21
Real 1-Year Lag of Soybean Price	3.62	0.52	4.83	2.61
Real Fertilizer Price Index	1.16	0.29	2.38	0.67

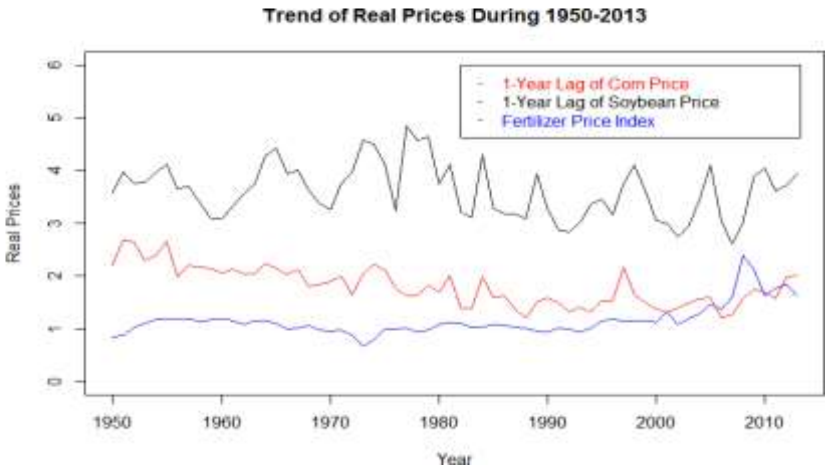

Figure 4. Real Prices of Grain Corn, Soybean and Fertilizer in Ontario: 1950-2013

Table 1 shows the summary statistics for grain corn and soybean yields and Figure 2 and Figure 3 show their trend over times. Yield of both crops are similar in Essex and Lambton while yields in Chatham-Kent are higher than those in Essex and Lambton (Table 1).

Corn yields in all three counties increased over time with notable year-to-year fluctuations. Corn yield dropped dramatically in 1988, 1991, and 2001-2002 due to serious drought conditions in Ontario (Figure 2). Soybean yields in all three counties increased over time with smaller fluctuations. Soybean yield dropped dramatically in 2001 due to soybean aphids. Soybean yields did not drop significantly in drought years compared to corn, may be due to lower moisture requirement for soybean than for corn (Norberg *et al*, 2010).

Table 1 also shows the summary statistics of the real prices for corn, soybean, and fertilizer and Figure 4 shows the trend of these real prices during the study period. While soybean price has always been higher than the price of corn, both prices declined slowly over times. However, the price of fertilizer gradually increased starting from the middle of 1990s.

Table 2. Summary Statistics of Precipitation and Degree Days: Selected Counties

Climate Variables	Mean	St.d	Max	Min
Precipitation Before Growing Season				
CK	185	50	324	58
Essex	178	47	297	59
Lambton	184	46	313	60
Precipitation During Growing Season				
CK.#1	593	119	953	348
CK.#2	410	112	762	191
CK.#3	477	102	791	315
CK.#4	534	104	773	324
Essex.#1	592	123	1019	354
Essex.#2	436	132	941	182
Essex.#3	501	112	902	286
Essex.#4	548	112	860	318
Lambton.#1	589	110	891	345
Lambton.#2	398	106	705	175
Lambton.#3	475	111	720	230
Lambton.#4	533	109	863	301
Degree Days During Growing Season				
CK.#1	2287	162	2645	1940
CK.#2	1399	135	1687	1067
CK.#3	1446	128	1737	1190
CK.#4	1460	128	1745	1193
Essex.#1	2385	169	2762	2033
Essex.#2	1486	135	1806	1232
Essex.#3	1524	135	1847	1247
Essex.#4	1532	136	1851	1254
Lambton.#1	2177	157	2549	1825
Lambton.#2	1292	128	1595	998
Lambton.#3	1352	115	1609	1099
Lambton.#4	1372	123	1632	1103

Table 2 shows the summary statistics for precipitation before growing season, precipitation during the growing season, and degree days during growing season. It can be seen from Table 2 that the length of these growing seasons can be ranked as: #1 > #4 > #3 > #2. Both precipitation and degree days in Essex were always higher than those in Chatham-Kent, and those in Lambton were always lower than those in Chatham-Kent (i.e. Essex > Chatham-Kent > Lambton).

5. Empirical Results and Discussion

Although we used quadratic and double log functional forms in this study, the results from the quadratic functional form were poor both in terms of expected signs of the estimated coefficients and their statistical significance. Therefore, we focus only on the results from the double-log functional form.

The estimated results for corn in Chatham-Kent, Essex and Lambton are presented in Tables 3, 4 and 5 respectively. While the results in Table 3 and 5 were corrected for autocorrelation using Newey-West robust variance-covariance matrix, those in Table 4 were not as there was no autocorrelation problem. Corn yield responses positively to increases in corn price but an increase in the price of fertilizer adversely affect corn yield. Both results are statistically significant only under growing season definition #2 in Chatham-Kent (Table 3). Technological developments had a positive and significant effect on corn yield in this county. While precipitation before and during growing season both yield positive coefficients, precipitation during growing season definitions #1 and #2 are statistically significant. This suggests that additional water could be used to increase corn yield in Chatham-Kent. Degree days during the growing season, irrespective of the growing season definition negatively affect corn yield but except for one coefficient, none is statistically significant. Based on the significance of the estimated coefficients and the higher value of the adjusted R-squared, #2 appears to be the most suitable growing season definition for corn in Chatham-Kent.

Table 3. Estimated Corn Yield Functions in Chatham-Kent under Four Growing Season Definitions

Variables	#1 Definition	#2 Definition	#3 Definition	#4 Definition
Intercept	5.81 *** (1.90)	4.00 *** (1.07)	6.82 *** (1.43)	6.60 *** (1.68)
1-Year Lag of Corn Price	0.147 (0.110)	0.0907 (0.0965)	0.0850 (0.104)	0.0943 (0.101)
Fertilizer Price Index	-0.106 (0.0768)	-0.153 * (0.0906)	-0.0995 (0.0736)	-0.103 (0.0836)
Trend	0.0192 *** (0.00128)	0.0184 *** (0.00128)	0.0190 *** (0.00126)	0.0191 *** (0.00124)
Precipitation Before Growing Season	0.0217 (0.0422)	0.0274 (0.0368)	0.0281 (0.0428)	0.0258 (0.0439)
Precipitation During Growing Season	0.143 * (0.0827)	0.195 *** (0.0482)	0.0561 (0.0733)	0.0527 (0.0903)
Degree Days During Growing Season	-0.292 (0.233)	-0.0957 (0.134)	-0.370 ** (0.182)	-0.337 (0.194)
Adjusted R-Squared	0.885	0.897	0.885	0.883
F-Value (Fc=2.25)	81.8	92.8	81.4	79.9
Shapiro-Wilk Normality Test (p-value)	0.0121	0.0044	0.0288	0.0335

Note: 1) the values in brackets are standard errors. 2) ***, **, and * indicate significance of coefficients at levels 0.01, 0.05, and 0.1, respectively.

Table 4. Estimated Corn Yield Functions in Essex under Four Growing Season Definitions

Variables	#1 Definition	#2 Definition	#3 Definition	#4 Definition
Intercept	5.78 ** (2.88)	4.20 ** (1.88)	6.71 *** (2.17)	6.15 *** (2.27)
1-Year Lag of Corn Price	0.181 (0.164)	0.0393 (0.156)	0.0718 (0.164)	0.0895 (0.169)
Fertilizer Price Index	0.0189 (0.127)	-0.0266 (0.120)	0.00104 (0.126)	-0.00762 (0.128)
Trend	0.0180 *** (0.00209)	0.0169 *** (0.00200)	0.0176 *** (0.00206)	0.0178 *** (0.00207)
Precipitation Before Growing Season	0.072 (0.0732)	0.0814 (0.0702)	0.0815 (0.0733)	0.0774 (0.0740)
Precipitation During Growing Season	0.258 ** (0.111)	0.237 ** (0.0702)	0.171 (0.103)	0.177 (0.113)
Degree Days During Growing Season	-0.433 (0.333)	-0.210 (0.236)	-0.505 * (0.255)	-0.432 (0.260)
Adjusted R-Squared	0.797	0.812	0.797	0.792
F-Value (Fc=2.25)	42.3	46.3	42.3	40.9
Shapito-Wilk Normality Test (p-value)	0.0038	0.0213	0.0319	0.0332

Note: 1) the values in brackets are standard errors. 2) ***, **, and * indicate significance of coefficients at levels 0.01, 0.05, and 0.1, respectively.

Table 5. Estimated Corn Yield Functions in Lambton under Four Growing Season Definitions

Variables	#1 Definition	#2 Definition	#3 Definition	#4 Definition
Intercept	1.30 (1.86)	3.14 *** (0.988)	2.07 (1.28)	3.09 ** (1.48)
1-Year Lag of Corn Price	0.208 * (0.107)	0.186 ** (0.0921)	0.177 * (0.0968)	0.201 ** (0.0971)
Fertilizer Price Index	-0.0292 (0.0941)	-0.0395 (0.0770)	-0.0455 (0.0849)	-0.0246 (0.0871)
Trend	0.0184 *** (0.00140)	0.0186 *** (0.00115)	0.0186 *** (0.00129)	0.0188 *** (0.00126)
Precipitation Before Growing Season	0.00613 (0.0413)	0.00392 (0.0413)	-0.00449 (0.0421)	0.00545 (0.0424)
Precipitation During Growing Season	0.172 * (0.101)	0.130 * (0.0669)	0.153 * (0.0869)	0.093 (0.0771)
Degree Days During Growing Season	0.261 (0.210)	0.0706 (0.145)	0.202 (0.148)	0.101 (0.184)
Adjusted R-Squared	0.887	0.888	0.889	0.881
F-Value (Fc=2.25)	83.3	84.5	85.3	78.9
Shapito-Wilk Normality Test (p-value)	0.0209	0.0062	0.0396	0.0110

Note: 1) the values in brackets are standard errors. 2) ***, **, and * indicate significance of coefficients at levels 0.01, 0.05, and 0.1, respectively.

The estimated results for corn yield in Essex county appear to be mixed. While lagged corn price yields a positive coefficient as expected, none is statistically significant. The effect of fertilizer price on corn yield is positive for #1 and #3 but negative for #2 and #4 definitions but none is significant. Irrespective of the definition of growing season, improved technology significantly enhanced corn yield in this county. The effect of precipitation during growing season is positive and statistically significant for #1 and #2 only. While the effects of degree days are all negative, only one is statistically significant at 10 percent. Overall, #2 definition appears to be the most suitable growing season definition for corn in Essex (Table 4).

In the Lambton county corn price has a positive and statistically significant effect on corn yield irrespective of the growing season definition. While fertilizer price yields a negative coefficient, none is significant. Developments in biotic and abiotic technology played an important role to increase of corn yield in Lambton as in the other two counties in our study. The effect of precipitation during growing season is positive across all definitions and all but one are significant. Unlike in the other two counties, the degree days during growing season affect corn yield in Lambton positively although none is statistically significant. Overall, #2 appears to be the most suitable growing season definition for corn in Lambton (Table 5).

Table 6. Estimated Soybean Yield Functions in Chatham-Kent under Four Growing Season Definitions

Variables	#1 Definition	#2 Definition	#3 Definition	#4 Definition
Intercept	-0.403 (2.46)	-0.430 (1.36)	1.34 (1.65)	0.685 (1.94)
1-Year Lag of Soybean Price	0.354 *** (0.126)	0.387 *** (0.110)	0.346 ** (0.132)	0.386 *** (0.134)
Fertilizer Price Index	-0.124 * (0.0736)	-0.172 ** (0.0729)	-0.138 * (0.0704)	-0.137 ** (0.0677)
Trend	0.0107 *** (0.00113)	0.0105 *** (0.000845)	0.0112 *** (0.000986)	0.0112 *** (0.000986)
Precipitation Before Growing Season	0.0378 (0.0717)	0.0245 (0.0699)	0.0243 (0.0724)	0.0264 (0.0731)
Precipitation During Growing Season	0.187 * (0.0956)	0.234 *** (0.0527)	0.140 (0.0903)	0.169 * (0.100)
Degree Days During Growing Season	0.276 (0.273)	0.275 * (0.148)	0.111 (0.187)	0.165 (0.213)
Adjusted R-Squared	0.632	0.679	0.623	0.626
F-Value (Fc=2.25)	19.03	23.19	18.37	18.54
Shapiro-Wilk Normality Test (p-value)	0.0001	0.0014	0.0007	0.0003

Note: 1) the values in brackets are standard errors. 2) ***, **, and * indicate significance of coefficients at levels 0.01, 0.05, and 0.1, respectively.

The estimated results for soybean in Chatham-Kent, Essex and Lambton are presented in Tables 6, 7 and 8 respectively. The results presented in Table 6 demonstrate that lagged soybean price, fertilizer price, and developments in technology all have expected effects on soybean yield in Chatham-Kent and all are statistically significant. Irrespective of the definition, precipitation during the growing season has a positive effect on yield and all but one is significant. The effects of degree days are all positive but only one is statistically significant. Overall, #2 appears to be the most suitable growing season definition for soybean in Chatham-Kent. Very similar results for the soybean yield function are obtained for Essex county. The only exception is that precipitation before growing season has a positive and significant effect on soybean yield irrespective of the definition. Overall, #2 appears to be the most suitable growing season definition for soybean production in Essex (Table 7). The results obtained for Lambton county reveal that all economic variables have expected signs but not all are statistically significant. Irrespective of definition, precipitation during the growing season has a positive and statistically significant effect on soybean yield. While the degree days have positive effect on soybean yield none is statistically significant. Overall, #2 appears to be the most suitable definition for soybean production in Lambton (Table 8).

Table 7. Estimated Soybean Yield Functions in Essex under Four Growing Season Definitions

Variables	#1 Definition	#2 Definition	#3 Definition	#4 Definition
Intercept	-1.32 (2.51)	-0.243 (1.68)	0.599 (1.97)	1.25 (2.18)
1-Year Lag of Soybean Price	0.394 ** (0.137)	0.351 *** (0.114)	0.407 *** (0.141)	0.369 ** (0.144)
Fertilizer Price Index	-0.0507 (0.116)	-0.0934 (0.0933)	-0.0683 (0.0925)	-0.0677 (0.102)
Trend	0.0105 *** (0.00154)	0.0109 *** (0.00143)	0.0111 *** (0.0014)	0.0114 *** (0.00163)
Precipitation Before Growing Season	0.146 ** (0.0691)	0.128 * (0.0713)	0.144 ** (0.0650)	0.135 ** (0.0644)
Precipitation During Growing Season	0.313 ** (0.120)	0.229 *** (0.0702)	0.246 ** (0.114)	0.181 (0.118)
Degree Days During Growing Season	0.199 (0.290)	0.169 (0.192)	0.0125 (0.217)	-0.0111 (0.232)
Adjusted R-Squared	0.615	0.626	0.601	0.582
F-Value (Fc=2.25)	17.8	18.6	16.8	15.6
Shapito-Wilk Normality Test (p-value)	0.0178	0.1987	0.1195	0.1363

Note: 1) the values in brackets are standard errors. 2) ***, **, and * indicate significance of coefficients at levels 0.01, 0.05, and 0.1, respectively.

Table 8 Estimated Soybean Yield Functions in Lambton under Four Growing Season Definitions

Variables	#1 Definition	#2 Definition	#3 Definition	#4 Definition
Intercept	-0.464 (1.79)	0.478 (1.53)	0.463 (1.73)	0.0903 (1.58)
1-Year Lag of Soybean Price	0.287 (0.174)	0.304 * (0.162)	0.279 (0.171)	0.327 * (0.170)
Fertilizer Price Index	-0.0295 (0.104)	-0.0659 (0.0788)	-0.0517 (0.0917)	-0.0578 (0.0907)
Trend	0.0112 *** (0.00145)	0.0116 *** (0.00137)	0.0118 *** (0.00137)	0.0117 *** (0.00139)
Precipitation Before Growing Season	0.0193 (0.0600)	0.0201 (0.0553)	0.0156 (0.0572)	0.0113 (0.059)
Precipitation During Growing Season	0.230 *** (0.0749)	0.170 *** (0.061)	0.138 ** (0.0556)	0.196 ** (0.0767)
Degree Days During Growing Season	0.259 (0.195)	0.206 (0.155)	0.237 (0.186)	0.230 (0.166)
Adjusted R-Squared	0.678	0.686	0.670	0.674
F-Value (Fc=2.25)	23.1	23.9	22.3	22.8
Shapito-Wilk Normality Test (p-value)	0	0.0001	0	0

Note: 1) the values in brackets are standard errors. 2) ***, **, and * indicate significance of coefficients at levels 0.01, 0.05, and 0.1, respectively.

5.1 Comparing Results across Counties

The most suitable growing season definition for corn and soybean production in all three counties is #2 (Tables 9 and 10). This indicates that the most suitable growing season definition in selected counties do not vary for corn and soybean. This result is not surprising as the selected counties are contiguous in Southwestern Ontario.

While the effects of economic factors on corn and soybean yields are consistent across counties, they are more revealing for Chatham-Kent than for the other two counties.

Developments in technology significantly influenced corn and soybean yields in Ontario. Thus, future development in technology is very important for sustainable production of grain corn and soybean in this province.

The availability of moisture during the growing season is very important for enhancing corn and soybean yields in Ontario (Tables 9 and 10). While the effects of precipitation before growing season for corn are all positive, none is statistically significant. Finally, the effects of degree days are negative for corn in Chatham-Kent and Essex, but positive in Lambton. As Lambton is located to the north of the other two counties, it is probable that higher solar energy is received in Chatham-Kent and Essex than in Lambton. For soybean, the effects of precipitation before and during growing season are both positive, but only the effect of precipitation during the growing season is statistically significant. The effects of degree days on soybean yield are consistently positive across counties but only one is significant. It implies that soybean do not receive excess solar energy in these counties. While farmers could obtain higher soybean yields by extending the growing season to receive more solar energy and precipitation, the requirements of planting winter wheat impedes such an extension in Ontario (Table 10).

Table 9. Corn Yield Functions in Chatham-Kent, Essex and Lambton: Most Suitable Growing Season

Variables	Chatham-Kent	Essex	Lambton
	#2 Definition	#2 Definition	#2 Definition
Intercept	4.00 *** (1.07)	4.20 ** (1.88)	3.14** (0.988)
1-Year Lag of Corn Price	0.0907 (0.0965)	0.0393 (0.156)	0.186** (0.092)
Fertilizer Price Index	-0.153 * (0.0906)	-0.0266 (0.120)	-0.0395 (0.077)
Trend	0.0184 *** (0.00128)	0.0169 *** (0.00200)	0.0186 *** (0.00115)
Precipitation Before Growing Season	0.0274 (0.0368)	0.0814 (0.0702)	0.00329 (0.0413)
Precipitation During Growing Season	0.195 *** (0.0482)	0.237 ** (0.0702)	0.130 * (0.067)
Degree Days During Growing Season	-0.0957 (0.134)	-0.210 (0.236)	0.0706 (0.145)
Adjusted R-Squared	0.897	0.812	0.888
F-Value (Fc=2.25)	92.8	46.3	84.5
Shapito-Wilk Normality Test (p-value)	0.0044	0.0213	0.0062

Note: 1) the values in brackets are standard errors. 2) ***, **, and * indicate significance of coefficients at levels 0.01, 0.05, and 0.1, respectively.

Table 10. Soybean Yield Functions in Chatham-Kent, Essex and Lambton: Most Suitable Growing Season

Variables	**Chatham-Kent**	**Essex**	**Lambton**
	#2 Definition	#2 Definition	#2 Definition
Intercept	-0.430 (1.36)	-0.243 (1.68)	0.478 (1.53)
1-Year Lag of Soybean Price	0.387 *** (0.110)	0.351 *** (0.114)	0.304 * (0.162)
Fertilizer Price Index	-0.172 ** (0.0729)	-0.0934 (0.0933)	-0.0659 (0.0788)
Trend	0.0105 *** (0.000845)	0.0109 *** (0.00143)	0.0116 *** (0.00137)
Precipitation Before Growing Season	0.0245 (0.0699)	0.128 * (0.0713)	0.0201 (0.0553)
Precipitation During Growing Season	0.234 *** (0.0527)	0.229 *** (0.0702)	0.170 *** (0.061)
Degree Days During Growing Season	0.275 * (0.148)	0.169 (0.192)	0.206 (0.155)
Adjusted R-Squared	0.679	0.626	0.686
F-Value (Fc=2.25)	23.19	18.6	23.9
Shapito-Wilk Normality Test (p-value)	0.0014	0.1987	0.0001

Note: 1) the values in brackets are standard errors. 2) ***, **, and * indicate significance of coefficients at levels 0.01, 0.05, and 0.1, respectively.

An important finding of this study is that precipitation during the growing season has positive and statistically significant effects on yields of grain corn and soybean and these effects are consistent across the selected counties. These results imply that irrigation could be applied to grain corn and soybean production to increase the yields of these crops in Ontario. However, its feasibility depends on the cost of irrigation and future prices as well as future crop insurance policy. Finally, the effects of degree days on yields are more consistent for soybeans across the counties compared to those for corn. Corn in Chatham-Kent and Essex might receive excess solar energy which reduces yield as degree days during the growing season increases. A direct implication of this result is that farmers in these two counties may need to grow hybrid corn with higher solar energy tolerance capacity in the future.

5.2 Comparing Results to Previous Studies

Comparing the results from this study to relevant studies in the past would be more meaningful, informative and thought provoking if the differences between our study and the previous studies in this area are made clear at the outset. We focus, particularly, on two previous studies, Cabas et al., (2010) and Weersink et al., (2010) because they used Ontario data and a panel estimation to determine the effects of economic, site-specific and climatic factors on crop yields in Ontario. These two studies used county level yield data for corn, winter wheat and soybean from 1981 to 2006 for Essex, Kent, Elgin, Huron, Perth, Haldimand-Norfolk, Middlesex and Lambton and used a fixed effect panel data model to estimate the results. We used data for Chatham-Kent, Essex and Lambton from 1950 to 2013 and estimated historical effects of economic and climatic factors on yields of grain corn and soybean in each of these counties. We used lagged output price and the price of fertilizer directly in our estimation while the two previous studies did not. We used two variables to explore the effects of precipitation at the county level, precipitation before and during the growing season, while the previous studies used only the precipitation during the growing season. Finally, to determine the effects of solar energy on crop yields, the two previous studies used mean temperature during the growing season while degree days during the growing season is used in this study. Despite these differences, however, our results are comparable to those in Cabas et al., (2010, Table 3, p.607).

In terms of economic variables, lagged corn price has a positive effect and fertilizer price has a negative effect on corn yield. The size and significance of the estimated coefficients vary across counties (Table 9). Advances in technology have significant positive impacts on corn yield in all counties. While this finding is consistent with those in Cabas et al., and Weersink et al., the estimated effect of technology on corn yield in this study is substantially smaller than those in two previous studies. In terms of climatic variables, precipitation has a positive and significant effect on corn yields in each county unlike those reported in two previous studies. While not directly comparable, this result is consistent with the findings of Mendelson and Reinsborough (2007) and Lobell et al., (2007). The effects of solar energy on corn yield obtained in our study are also different from those reported in two previous studies (Table 11).

Table 11. A Comparison of the Effects of Climatic Variables on Corn Yield in Ontario

Effects on Corn Yield							
Study	Study Area	Crop Type	Growing Days	Precipitation Before Growing Season	Precipitation During Growing Season	Temperatr.	Degree Days
Weersink *et al* (2010)	Southwestern Ontario	Corn	0.007 ***		-0.003 ***	-0.108 ***	
Cabas *et al* (2010)	Southwestern Ontario	Corn	0.061 ***		-0.002 ***	-0.312 ***	
Current Study	Chatham-Kent	Corn		0.0274	0.195 ***		-0.0957
	Essex			0.0814	0.237 **		-0.210
	Lambton			-0.00449	0.153 *		0.202

Note: 1) ***, **, and * indicate significance of coefficients at levels 0.01, 0.05, and 0.1, respectively.

The lagged price of soybean has a positive and significant impact on soybean yield in all counties. While the price of fertilizer has a negative effect on soybean yield, the size and significance of the effects vary across counties. While effects of technology on soybean yield is positive and significant across all counties and are consistent with those in two previous studies, the estimated effects in our study are much larger than those in Cabas et al., and in Weersink et al. The effects of precipitation during growing season on soybean yield are all positive and significant in this study. While the effects of precipitation on soybean yield reported in two previous studies are also positive, they are very small and statistically insignificant (Table 12). Similarly, the effects of solar energy on soybean yield in this study are all positive, the size and significance of the effects vary across counties.

While two previous studies also obtained positive effects of solar energy on soybean yield in Ontario, the estimated coefficients are very small and statistically insignificant (Table 12).

Table 12. A Comparison of the Effects of Climatic Variables on Soybean Yields in Ontario

Effects on Corn Yield							
Study	Study Area	Crop Type	Growing Days	Precipitation Before Growing Season	Precipitation During Growing Season	Temperatr.	Degree Days
Weersink *et al* (2010)	Southwestern Ontario	Soybean	0.003 ***		0.00015	0.010	
Cabas *et al* (2010)	Southwestern Ontario	Soybean	0.027 ***		0.0003	0.020	
Current Study	Chatham-Kent	Soybean		0.0245	0.234 ***		0.275 *
	Essex			0.128 *	0.229 ***		0.169
	Lambton			0.0201	0.170 ***		0.206

Note: 1) ***, **, and * indicate significance of coefficients at levels 0.01, 0.05, and 0.1, respectively.

Overall, the climatic variables have a larger impact on the yields of corn at the county level than the effects of economic factors. In case of soybean yields, however, economic factors have larger impacts than the climatic factors in Ontario although both sets of effects are statistically significant (Tables 9 and 10).

6. Concluding Remarks

While climate change is a global phenomenon, the effects of climate change manifest themselves locally. Despite significant research efforts drawn into global climate change and its consequences to broader geographical regions, empirical evidence of the impacts of climate change at the local level is rare. It is very important to measure and appreciate the effects of climate change at local level and how they differ across local communities. This information is critical for the development of adaptation strategies suitable for local climatic conditions. An attempt is made in this paper to further such an understanding by focusing on the historical effects of climate change on the yields of corn and soybean at county level in Ontario. Since economic factors also influence the yields of commercially important crops, we also included important economic variables directly in our analysis.

The results demonstrate that lagged corn price has a positive effect while fertilizer price has a negative effect on corn yield. The size and significance of the estimated coefficients vary across counties. Similarly, lagged price of soybean has a positive and significant impact on soybean yield. However, the price of fertilizer has a negative effect on soybean yields but the size and significance of the effects vary across counties.

Advances in technology for the production of both corn and soybean have the most consistent effect on the yields at the county level in Ontario. Precipitation has a positive and significant effect on corn and soybean yields in each county. These results differ from those reported in two previous studies in Ontario, Cabas et al., and Weersink et al. The effects of solar energy on yields of corn and soybean obtained in this study are also different from those in previous studies. Finally, the climatic variables have a larger impact on the yields of corn at the county level than the effects of economic factors. The reverse appears to be true for soybean production at the county level in Ontario.

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