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The Economic Impact of Climate Change on Cash Crop Farms in Québec and Ontario

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ABSTRACT

This paper examines the economic impact of alternative climate change scenarios on representative cash crop farms in Quebec and Ontario. Mixed Integer Dynamic Linear Programming models are used to determine the annual optimal land and labor allocations over a 30 year time horizon. In the modeling process, five climate scenarios are modeled, along with different combinations of CO_2 enhancement and water limitation. Parameters, such as crop prices, costs of production, and crop yields, are simulated and projected into the future using various methods, such as Monte Carlo simulation, Crystal Ball Predictor and DSSAT cropping system model. Rotation and diversification constraints, as well as participation in public risk management programs are also incorporated into the optimization procedures. The results show that the economic impact of climate change varies by scenario, with the CO_2 effect and water limitation having a more significant effect than the specific climate scenarios. Technology development, as well as the public insurance programs can contribute to the reduction of economic vulnerability.

INTRODUCTION

Defined as a change in the state of the climate, climate change can be continually identified by shifts in the mean or variability of temperature and precipitation (Chen 2011). And this change is predicted to affect every economic sector (Parry et al. 2007) and alter people's behaviour in various ways. Given that climate change and weather conditions will result in more externalities and uncertainties (Tol 2009), especially in agricultural production, it is essential to be aware of what has happened in the past and potentially what will happen in the future.

Records would indicate that the global surface has been warmed by GHGs since pre-industrial times (Alexandrov et al. 2002). This process is widely agreed by scientists as a poleward shift of the thermal limits of agriculture which will favour the northern regions, assuming suitable soil and water is available to grow crops there. Unbalanced precipitation, accompanied by higher temperatures, accelerates the hydrological cycle and thus results in inefficient use of water resources (Fleischer et al. 2008). Christensen et al (2007) demonstrated that almost all of the North American continent would experience an increase in precipitation except the south-western U.S. Faced with more heat units, a longer growing season and different soil moisture availability, farmers in Canada will have to modify their variety choices and management strategies according to specific changes happening on their land, as well as to prevent exacerbated environmental problems like soil erosion or salinization, chemical runoff and water contamination from happening (Herrington et al. 2010).

Climate change has also been predicted to increase the frequency and intensity of extreme weather events, resulting from the interaction among atmosphere, ocean and land, which may make our climate unstable and increase the risk to agriculture production. Risks in agriculture arise from the inherent uncertainties associated with climate change, and the fluctuation in the Canadian dollar which makes input costs and market prices difficult to predict. But risk is inevitable when pursuing opportunities for development. There exists tremendous potential for the agriculture industry to benefit if the decision-makers can shift from unplanned and ad hoc reactions to proactive, systematic and integrated risk management strategies when confronting various scenarios. Hence, risk management tools, such as improved information and technology, crop insurance programs, and cultivation diversification, can be adopted to not only cushion damages, but also increase opportunities. But difficulties rise when farmers try to obtain sufficient and reliable information regarding weather and market conditions, to predict how crops will respond to these conditions, as well as to evaluate the potential loss and benefits of adopting new management strategies. The cost of risk management is immediate and observable, the benefits which are less visible tend to be underestimated. If farmers fail to understand and adapt to the stochastic state due to a lack of resources or cognitive failures, they will suffer not only the negative effects on their production and marketing, but also the opportunity costs from potential benefits.

Agriculture has changed over the past decades, but it remains the backbone of the economy, and farmers remain a vulnerable community facing climate change. Rural communities in Québec and Ontario that rely on the agriculture sector will also be subject to vulnerability from climate change because of the decreased economic activity in their region. On the other hand, farming has become more technically sophisticated. Along with technology development, such as more advanced varieties, machinery and land management practices are available to increase yield. However, most of the existed studies have focused on the average conditions or scenarios using a static or partial equilibrium approach (van Zon and Yetkiner 2003 , Schlenker and Roberts 2009 , Kokoski and Smith 1987), which may exclude indirect and general equilibrium effects, including market prices and interdependence (Arndt et al. 2012). Previous studies often provide only global or regional assessments and ignore the potential benefits from adaptation policies implemented by a higher institutional level (Lobell et al. 2008). Thus, a systematic and dynamic assessment of the uncertainty associated with climate change on representative cash crop farmers is essential in order to evaluate farmers' economic vulnerability under different scenarios, as well as the economic effects resulting from technology development and institutional adaptations.

In this study, three specific sites, Ste-Martine and St-Sébastien in Québec and North Dundas in Ontario, are selected to address the above issues by evaluating both physical and economic impacts of projected climate scenarios and weather conditions focusing on four cash crop production, i.e. corn, wheat, barley and soybean. A Mixed Integer Dynamic Linear Programming (MIDLP) model was developed to optimize farm net returns and corresponding resource allocation, as well as to see the number of years when negative farm income occurs under each climate scenario. The impact of technology will be analyzed by comparing the results of models using only existing crop varieties and those using both existing and improved varieties. The present study also investigates how institutional change affects returns through modeling both existing and modified crop insurance programs into the mathematical model.

PREVIOUS RESEARCH

Influence of Climate Change

The causes and consequences of global warming are very diverse (Tol 2009). Risks faced by farmers can be divided into two main categories, namely the risks during production process and those in the market (Antón et al. 2011). Taking production into consideration first, it can be demonstrated that crop yield changes due to climate change are likely to vary according to different climate scenarios, crop varieties (Hareau et al. 1999) and agricultural region (Brassard and Singh 2008). But in general, the main causative factors controlling crop yield tends to be the same. One is the direct CO_2 fertilization effect (Alexandrov et al. 2002), which would benefit C_4 cereal crops, such as corn and sorghum, from climate change(El Maayar et al. 1997). The other is the indirect CO_2 effects, causing an increase in temperature which accelerates crop maturation, the changes in soil moisture and nitrogen supply, and thus the farm performance (Brassard and Singh 2008). Factors that affect crop yield related to climate change are usually interdependent and it is difficult to isolate and recognize their individual components. This phenomenon will lead to a dilution of the effects of climate change to some extent, or even cancel the impact of some individual factors out (Brassard and Singh 2008).

Apart from the above mentioned technical effects resulting from climate change, climate change variables will also cause changes in food system assets, production activities, storage, processing, distributing, and consumption patterns (Wilcock et al. 2008), as well as policy making processes at the institutional or political level. For example, climate-driven environmental changes, together with local economic conditions, will result in significant changes in future land-use (Reilly 1999) and risk management tools used by farmers. Supply and demand of other production inputs, such as labour, water, equipment, energy, etc., will also be affected (Seyoum-Edjigu 2008), and leads to an adjustment or reallocation according to comparative advantage (Rosenzweig and Hillel 2007). Furthermore, increased uncertainty will strengthen the development of international markets (Fleischer et al. 2008), while some economic costs should be expected if adaptation to climate change occurs. On the other hand, it is not the average conditions or merely temperature and precipitation that affect crop yield. "Uncertainty pervades the behaviour of ecological systems, ensuring that we cannot know in advance whether some system is or is not resilient" (Perman et al. 2003, p.94), thus it is the "inter-annual and intra-annual variation" and extreme events, along with the complexity of agriculture, which determines the critical climatic threshold and should be accounted for in risk averse models (Bryant et al. 2000).

Economic Approach

Apart from the modeling of physical and biological processes of agriculture, social-economic parameters representing human behaviour and cognition should be identified (Andersen and Mostue 2012 , Just 2001). Optimization models that maximize the farmer's profits are often used and can integrate crop growth model information into an economic decision model (Lehmann et al. 2013). This technique can be used in a parametric analysis to examine the impact of climate change (Roshani et al. 2012), which not only concerns optimizing profits, but also reflects the production risks and management decisions on a field scale (Lehmann et al. 2013). In some cases, it can carry out a sensitivity analysis, if data is adequate, and incorporate a large number of farm specific variables and constraints.

John et al. (2005) used a whole-farm linear programming model to explore the consequences of several climate scenarios based on discrete stochastic programming (DSP). DSP has the advantage of being a sequential decision framework that can incorporate risks which makes it well-suited to a variety of firm-level problems. But its usage is strictly limited by the cost of model construction and the availability of data (Apland and Hauer 1993). A Mixed Integer Dynamic Linear Programming (MIDLP) model was used by Seyoum-Edjigu (2008) to investigate the economic impact of climate scenarios on producers' gross margin. This model included a long planning horizon and a large number of stochastic variables. Crop selection and acreage decisions were based on optimizing the farmers' net income.

Adaptation Strategies

Mitigation and adaptation can be mutually reinforcing (Johnston et al. 2012), especially in a situation of increasing climate variability (Rosenzweig and Hillel 2007). Adaptive strategies are needed in order to protect local food supplies, assets and livelihoods, avoid damage to farmers' income, and protect the ecosystems (Wilcock et al. 2008). The way towards adaptation are diverse (Adger et al. 2005). A global solution is a necessity, however, a polycentric system where enterprises at multiple, smaller scales may complement each other can start the process of mitigation (Ostrom 2010). Generally speaking, a systematic approach to agricultural risk management towards climate change should be structured around three layers of risk that require differentiated responses: normal (frequent) risks coped with at the farm level, market intermediate risks retained by market tools, and catastrophic risks requiring government assistance (Antón et al. 2011). Whichever strategies are selected, they should be integrated together so as to guarantee the sustainability and resilience of agriculture in the context of an uncertain future challenged by climate change.

At the farm level, the existing technology that will likely be used when coping with a warmer climate includes irrigation, cover, and early market products (Fleischer et al. 2008). Shorter-maturing varieties and wide-spread use of grain drying technology are two major developments in corn production, both of which can be employed to reduce the risk of losses due to early frost (Reilly et al. 2003). Other strategies such as changes in the timing of operations, as well as land and irrigation management could also be feasible (Easterling 1996) given the past experience of agricultural research applied to production (Hareau et al. 1999). Diversification and rotation are other strategies that are likely to occur when coping with climate variation from year to year. These strategies would reduce the risks of pests and diseases in crop production, and make crops less vulnerable (Alexandrov et al. 2002). These strategies can offset either partially or completely the loss of productivity caused by climate change (Easterling 1996).

Farmers' net returns depend not only on the biophysical conditions and thus crop yield changes that results from climate change, but also on the cost of production and products' market prices (Lobell et al. 2008). The economies of scale has led to an overall expansion tendency in agricultural production (Easterling 1996), which can benefit from lower costs of production, potentially more access to information and policy-making processes, as well as regional market power when faced with climate change. A mild increase in temperature is beneficial only when the markets for farm products are well-developed (Fleischer et al. 2008), either regional or international. Thus, economic adaptation strategies such as investment should not only be in new technologies and infrastructure construction, but can also be used to develop the input and output markets (Easterling 1996).

Changes in institutional structures and relationships can be used to reduce climate change risks and thus agricultural vulnerability (Antón et al. 2011). Adaptation at this level does not aim at achieving a welfare optima, but maintaining and enhancing welfare under a changing environment by continuously influencing the decision-making processes at the economic level (Ciriacy-Wantrup and Bishop 1975), which enhances the social environment for the other systems to function and provides direct support to vulnerable people (World Bank 2013). Existing institutional adaptation frameworks include several interrelated steps, which assess the fundamental goals and resilience of individuals in the face of adverse events, understanding the internal and external risks and opportunities associated with the environment, considering the potential risk management tools at different levels of society and assessing the resources and obstacles they have (World Bank 2013). The insurance system has been the primary risk governance tool for industrialized society thus far (Phelan et al. 2011). Both the UN Climate Convention and the Kyoto Protocol have included the provision of insurance as a mechanism of risk reduction, which deals with the risk of natural disaster and manages the events following disasters (Antón et al. 2011). Owing to the risky nature of agriculture and the unpredictable uncertainties brought about by climate change, it is appropriate to encourage or even subsidize farmers to insure their crops and bring their interests and concerns to the attention of policymakers (Schmitz et al. 2010).

"Successful climate change adaptation requires careful consideration of technical and social dimensions" (Costello et al. 2010, p.8). Adaptation research is an action-oriented undertaking where mutual learning among participants is required at the farm, economic and institutional levels (Jones and Preston 2011). In addition, an understanding of cross-level interactions (Phelan et al. 2011) are important, while trade-offs and synergies can take place among collective actions. As their financial losses are limited by government policies, farmers may show increased willingness to accept yield losses, and thus shift from risk-averse to risk-seeking behaviour (Reilly et al. 2003). Some individual farmers, for example may have perceived the risks and opportunities in biophysical factors associated with climate change and made technical improvements in their operations. Climate change, however, should be regarded as a long-term phenomenon and it should be carefully coped with not only at the farm level, but also at the institutional and political levels, so as to reach our target of reducing agricultural vulnerability (Bryant et al. 2000). Meantime, government failure, which is defined as its limited ability to maintain long-term policies, if it occurs, will increase the associated agricultural uncertainties and farmers' costs (Schmitz et al. 2010). Hence, the potential significant co-benefits to adaptation and mitigation strategies (Kenny 2011) resulting from collaborative adaptive co-management(May and Plummer 2011) makes it necessary to maintain a more diverse and sustainable adaptation structure (Pukkala and Kellomäki 2012).

RESEARCH DESIGN AND DATA DESCRIPTION

Four major cash crops are assumed to be cultivated on the representative farms in the selected sites. They are grain corn, wheat, barley and soybean. And there are two cultivars for each crop being simulated for a 30 year time horizon over the period 2010 to 2039. One is called the reference cultivar, which is currently being grown and their performance and yields have been validated by comparing the simulated values with the observed values. The other is an improved cultivar. It is a result of plant breeding which make them resistant to disease, insects and other pests as well as resistant to some climatic conditions, such as drought, heat, frost, shattering, etc. As for the cultivation practices, conventional tillage is the predominant tillage practice in these regions. Thus, conventional tillage, with its corresponding cost, was the cultivation practice assumed in this study.

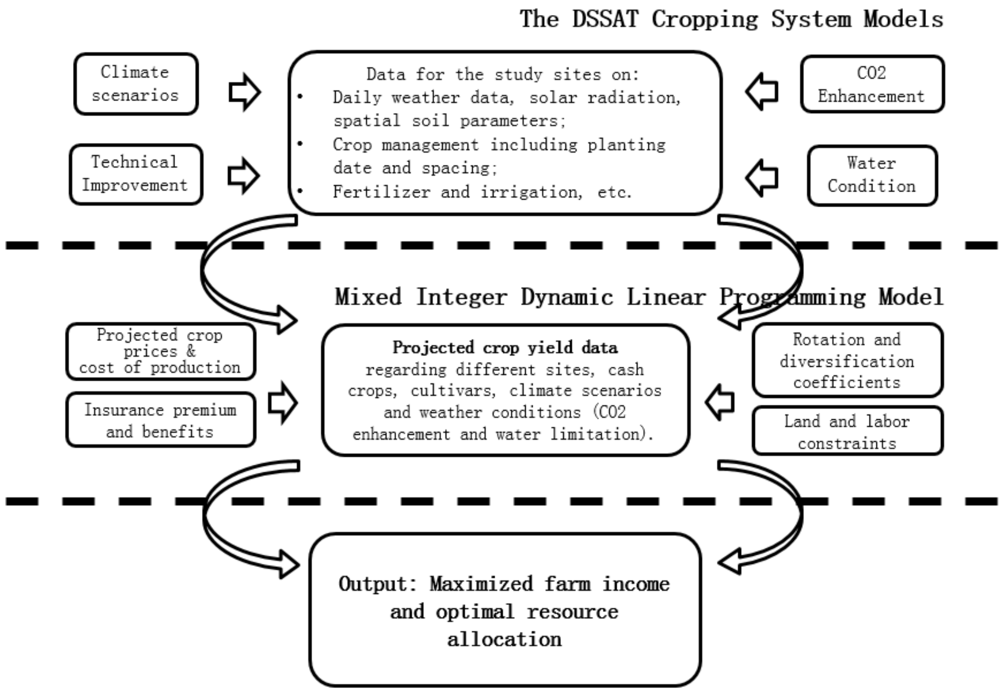
Given the uncertainties associated with the direction and magnitude of future climate change, five climate scenarios were considered. This allows a better understanding of the potential threats and opportunities under each scenario and encourages related adaptation strategies to be applied. The five scenarios selected were: 1) hot and dry; 2) hot and humid; 3) median; 4) cold and dry; 5) cold and humid[1]. In addition, these five scenarios were modified to include with and without CO_2 enhancement, with and without water limitation. Given these combinations there are 20 different climate scenarios and conditions considered for each site. Given the uncertainty associated with climate change, climatologists were unable to provide a probability for any one scenario, so it was assumed that each scenario had an equal probability of occurring over the planning horizon. Once a scenario was selected, it was not subject to

[1] They were chosen to represent differentiate agro-climatic indices by climatologists in OURANOS based on their understanding of representative climate scenarios in the future 30 years. For example, hot and dry scenario means a scenario with increase in temperature and decrease in the precipitation pattern.

change over the time period being analyzed. For example, if the producer is facing Hot & Dry with CO_2 enhancement and water limitation in the first year, then this will last over the following projected 29 years.

The Decision Support System for Agro-Technology Transfer (DSSAT) model was used by the Geography Department of the University of Montreal to simulate future crop yields for all scenarios, sites and crop varieties. And the output from this model is an input into the mathematical programming models which were used to analyse the economic impact of climate change and agricultural vulnerability. A brief structure of the process of analysis for this study is described in Figure 1.

Figure 1: Structure of the Analysis Process



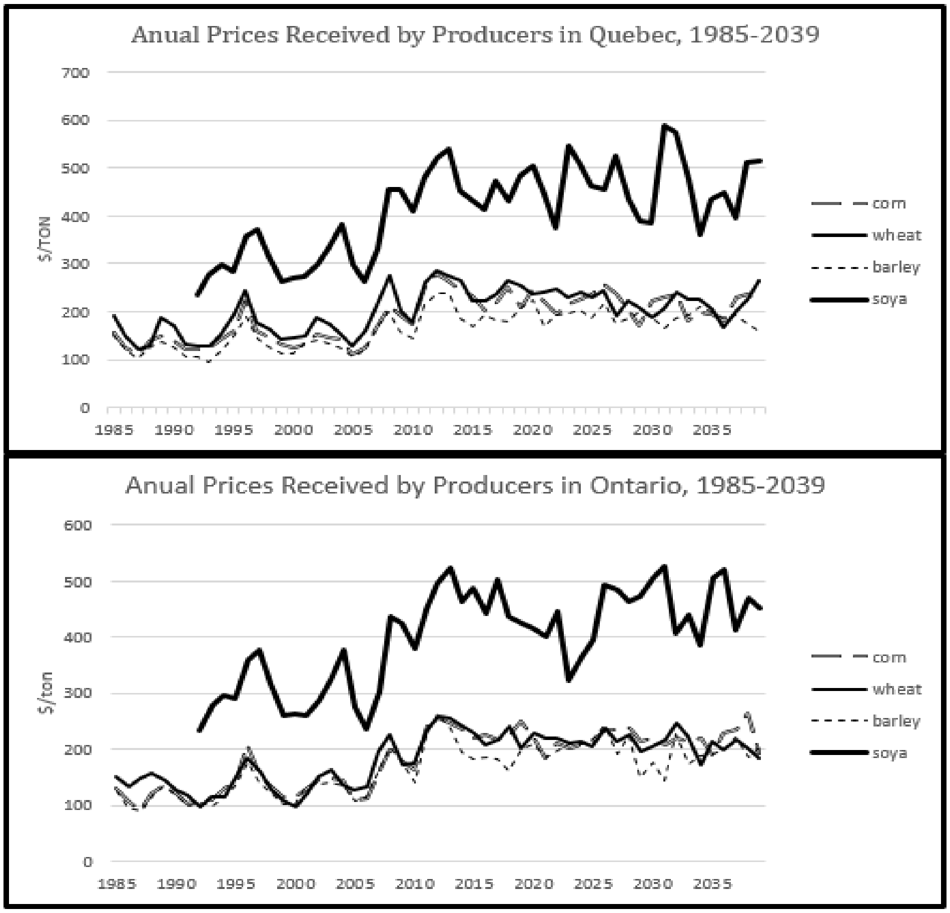
Data Prepared

Projected Prices and Costs

It is assumed that each producer's influence on crop markets was not great enough to significantly impact the national market, i.e. a small supplier assumption and thus price takers. The annual crop prices received by Ontario and Québec producers were used to project future prices. Several individuals confirmed that there was no significant difference between the provincial and regional prices (St-Pierre 2013). In order to capture the trend and variability of crop prices and project them into the planning horizon of the model, a series of monthly historical price data were selected for each crop. Historical prices for grain corn, wheat and barley are over the period 1985 to 2010 while price for soybean started from 1989 to 2010, all of which have a cycle of 6 years. Crystal Ball's CB Predictor (v.11.1.2.2) (Werchman and Crosswhite 2006) and Monte Carlo (MC) simulations were used to predict the prices into the future until 2039. CB Predictor uses time-series methods to analyze the underlying structure of the historical data, including Single Moving Average, Seasonal Additive, Double Exp Smoothing, and Holt-Winters' Multiplicative, etc. so as to see which one provides the best goodness-of-fit and uses it to forecast into the future. Using the error measure methods, such as RMSE, MAD and MAPE, it projects the trends and patterns to predict future values providing a confidence interval at 5% and 95% as default indicating the degree of uncertainty around the forecast. The forecasted values are then evaluated and validated with statistics, such as Theil's U and Durbin-Watson (DW). It was assumed that no widespread extreme events occurred in either the historical or future time periods. The trends and variability of the crop prices in both provinces are summarized in Figure 2.

CB Predictor and Monte Carlo simulations were also used to simulate the cost of production (COP). The budget for each crop into the future was modified using time-based data. Provincial COP numbers from La Financière Agricole du Québec since 1999 were used to reflect the budgets at the Ste-Martine and St-Sébastien sites, after adjusted by regional numbers from Centre d'Expertise en Gestion Agricole (Tremblay 2013). In North Dundas, it is the Field Crop Budgets from Ministry of Agriculture, Food and Rural Affairs (OMAFRA 2013) and Ontario Farm Input Price Index (Statistics Canada 2013) since 1971 that were used to make projection. In this study, the cost per hectare for each of the four crops includes both fixed cost and variable costs. The insurance expenses and salaries were excluded because they were analyzed separately in other parts of the mathematical programming model. For example, the need for labour was unequally distributed throughout the growing season. Labour demand was broken down into 6 periods (mostly monthly) in each growing season according to major agricultural activities including seeding, harvesting, sales, etc.

Figure 2: Historical and Projected Crop Prices in Québec and Ontario, 1985-2039.



Source**:** Fédération des producteurs de cultures commerciales du Québec (FPCCQ), Ontario Ministry of Agriculture and Food (OMAFRA), and Statistics Canada

The hourly wage was assumed to start at $15 in 2010 and increases at a minimum rate of 2% per year. Land and machinery rental expenses were not included in the budget because it was assumed that this capital was owned by producers. Machinery depreciation was captured and zero residual was assumed at the end of the planning horizon while maintenance costs were still counted.

In order to increase the precision, the annual cost of production was obtained by separately projecting the cost for each input and then combining together. And according to the simulation results from the DSSAT cropping models, the new improved cultivar shows a significant higher yield than the reference cultivar for each crop under most of the scenarios, conditions and sites (Table 1). Producers in Ste-Martine were better off by using the improved cultivars, especially under the condition of no water limitation. Barley was the crop with the greatest increase in yield among the four crops, especially in the median scenario and coupled with no CO2 enhancement or water limitation. Soybean was hardly affected by the technology improvement and even suffered from losses in St-Sébastien. Crops in Québec may expect much higher yield improvements when the improved cultivar was adopted, especially in St-Sébastien. These large increases in yield would result in higher expenses for pesticides, drying, storage, fuel and electricity, etc. Therefore, based on the projected cost of production for the reference cultivar, adjustments were made for the improved cultivar depending on different sites and crops.

Table 1: Average Yield Increase Due to Cultivar Improvement

	North Dundas	Ste-Martine	St-Sebastien
corn	10.49%	38.56%	62.03%
wheat	39.18%	77.93%	178.61%
barley	42.95%	121.32%	200.65%
soya	16.23%	2.30%	-17.54%

Crop Insurance Programs

There was a reported 50 percent increase in insured crop area in Montérégie West between 2000 and 2010, and grain corn alone represents 62 percent of the total insured area in 2010 (La Financière Agricole du Québec 2010). In the present study, the producers were assumed to be risk neutral and their objective was to maximize their net returns. In order to achieve this goal, four major types of crop insurance offered by La Financière agricole du

Québec and Agricorp were contained in the model. The Individual Crop Insurance in Québec (La Financière Agricole du Québec 2013), and the Production Insurance in Ontario (Agricorp 2013), protects producers from yield reductions caused by factors beyond their control at various levels. In order to account for producers' commitment to this program, their costs of production were initially adjusted on a per hectare basis using corresponding premiums and compensations depending on the difference between simulated yield and covered probable yield, which is the average projected yield of the previous five-year period times coverage rate.

The Farm Income Stabilization Insurance (ASRA) program (La Financière Agricole du Québec 2013), similar to Risk Management Program (RMP) in Ontario (Agricorp 2013), provides protection against adverse market price fluctuations. If the projected selling price is lower than the stabilized income, which is based on the cost of production, producers would receive a payment from their provincial government.

The AgriStability program is based on the principle that governments share with the individual the cost of stabilizing annual income with the participating producer (La Financière Agricole du Québec 2013 , Agricorp 2013). As long as the margin[2] drops by more than 30 percent in relation to the reference margin[3] for a given participation year, the decline would be partially offset (70%) by the federal and provincial governments. Binary variables (1 or 0) are used to obtain the results where the margin reduction level of each year over the planning horizon (2010-2039) can be placed into one of three categories: <30% reduction, 30%-100%

[2] Generally speaking, the production margin corresponds to the difference between the participating producers' farming revenue and costs (La Financiere Agricole du Québec).
[3] The reference margin corresponds to the Olympic average of the margin in previous five years, which excludes the highest and lowest years.

reduction, or >100% reduction. Producers will receive only one payment from ASRA or RMP and AgriStability whichever is higher.

The AgriInvest program can also be taken advantage of without influencing the marginal benefits per hectare of land (La Financière Agricole du Québec 2013 , Agricorp 2013). It allows participants to make an annual deposit into an account of up to 1.0 percent of their operation's adjusted net sales (Parry et al.) of allowable products and to receive a matching government contribution, as well as the interests. Therefore, to maximize their net return, the producer would deposit as much as they can into the AgriInvest program whenever possible and keep it until the end of the planning horizon. These insurance programs were modeled in order to create a dynamic platform which links the average income and yield of previous years with the future, and can be also used as an indication of the economic vulnerability under different scenarios. Most of the insurance programs, except Individual Crop Insurance and Production Insurance, are not in the optimization procedures, but their risk aversion capability will be evaluated based on the annual optimal farm performance.

Rotation and Diversification

Apart from the technological improvement in cultivars, rotation and diversification also can be effective short-term adaptation tools to reduce production and price risks caused by unfavorable climate conditions or markets. A corn-soybean rotation was adopted in the modeling process for all sites. In the corn year, the cropland of grain corn is allowed on a maximum of 80% of the total cultivated land allocated to these four crops while soybean can be grown on up to 60%, and vice versa. In terms of wheat and barley, the model allowed a maximum of 25% and 30% of crop area to be allocated to them respectively. These limits were set slightly higher than their actual shares so as to give the model more flexibility in choosing the most desirable annual production bundle. Also, a minimum requirement of acreage for each crop was not set in the model because if the production of one crop was no longer profitable in the future, the model would not select it.

Mixed Integer Dynamic Linear Programming Model

Producers need to make a great many decisions at the same time involving technical agricultural and economic activities, so as to maximize their profit every year. For example, producers have to make rotation and diversification plans, decide the seeding area for each crop, the amount of hired labour, insurance coverage, etc. In addition, most of the variables he or she needs to decide are subject to some limits. Seeding area is limited by the total cultivable land while hired labour is dependent on how many labour hours are available in the market in a particular period. Insurance participation is also constrained by some qualification requirements set by certain institutions. One method that is often used to solve such complex decision problems and provide for an optimal solution is a mathematical method called Linear Programming (LP). Its models take the following forms:

$$\text{Maximize} \quad Z = p_n^T S_n - c_n^T X_n - w_n l^T X_n \text{ , } n=1, 2, \ldots, 30 \tag{1}$$

$$\text{Subject to} \quad X_n I \le b \tag{2}$$

$$l^T X_n \le d \tag{3}$$

$$X_n \circ Y_n \ge S_n \tag{4}$$

$$X_{ij} \le \mathrm{a} X_n I \tag{5}$$

$$\text{And} \quad X_n, S_n \ge 0 \tag{6}$$

Where in the objective function (1), Z is the net return that needs to be maximized. X_n is the cultivation area for each crop with different Individual Crop Insurance coverage at year n, S_n

is the sale for each crop at year n[4]. p_n, c_n and w_n represent the correspondent crop prices, cost of production (including the net payment to the Individual Crop Insurance) and hourly wage to hired labor. And l is the coefficients regarding periodical labor requirement for each unit of cropland. Formula (2) and (3) are the land and labor constraints where b and d represent the total land and labor available for the representative farm, which are 350 ha and 4,725[5] h respectively. In formula (4), Y_n is the yield per unit for each crop and the yearly sale is necessarily smaller than the total output. Formula (5) is the rotation and diversification constraint, where the maximum acreage is set for each crop at different rotation years. Through randomly adjusting the value of all variables subjected to all the constraints and the non-negative requirement (6), an optimized objective value can be estimated. In this case, some of the unknown variables like land allocation and contract labour hours are required to be integers.

RESULTS

The average climate condition and its variability tends to change due to global warming, thus increasing the vulnerability of the agriculture sector because it relies heavily on climate variables as an input into production. On one hand, their production process needs to be consistent with the historical record and experience, which might be the result of their risk management behaviours. But this could also contribute to building into the model a rigid management situation, which will shift the focus from actually improving profitability to compliance with requirements (Andersen and Mostue 2012). On the other hand, adaptation strategies must be designed to increase both their agronomic and economic resilience against this unpredictable variability. A balance between compliance and resilience is needed.

[4] A minimum of five percent of the total output for each crop will be stored for farm consumption according to historical data.

[5] This number was obtained from Centre d'études sur les coûts de production en agriculture.

Economic Vulnerability

The results in Table 2 indicate that income varies more due to variation in weather conditions, i.e. CO_2 concentration and water availability, rather than climate scenarios. Results from the reference cultivar model indicate that producers were very vulnerable to marginal reductions under all scenarios, but at different magnitudes depending on their location and weather conditions. Generally speaking, North Dundas was the best site for producers. The results from the reference model for this site would suggest they experience fewer marginal reductions and the magnitudes were smaller. For example, losses of between 30 to 100 percent only occur in approximately 7 of the 30 years with less variability among weather conditions. It was followed by St-Sébastien and then Ste-Martine. Water resources can have a substantial effect on producers' income vulnerability. Producers at each site would suffer the largest losses when water limitations existed, particularly coupled with a lack of CO_2 enhancement. This was a serious situation in Ste-Martine, where the model would indicate that producers would suffer moderate losses (30-100% reduction) in 3 of the 30 years, but extremely large losses (>100% reduction) in 11 of 30 years. Losses of this magnitude and frequency leaves these producers vulnerable to bankruptcy.

Adopting the improved cultivar does not guarantee that the improved cultivar will always be selected in all cases, or the possibility of suffering large losses will be eliminated, but it does help decrease the magnitude and frequency under all scenarios. It should be noted that this technical improvement has enhanced the resilience of all producers to climate change; the magnitude of this resiliency varies with water availability and CO_2 enhancement. Under favorable conditions, where CO_2 and water were adequate, the producer can be much better off when they adopt the improved cultivars. Technological change, i.e. cultivar improvements, can ameliorate some of the negative effects of adverse weather conditions, i.e. no CO_2 enhancement and water limitations, and the different climate scenarios, thus building resilience in the farming community. The large losses (>100% reduction) in Ste-Martine still occur when there was negative weather conditions. Farms in the region were susceptible to bankruptcy if these large losses occur in successive years.

Table 2: Numbers of Years with Margin Reduction under Optimal Decisions

Site	CO2 and Water Conditions	Reference Cultivar			Improved Cultivar		
		0-30%	30%-100%	>100%	0-30%	30%-100%	>100%
SMT	CO2 & No Water Limit	24.2	5.8	0	28.8	1.2	0
	CO2 & Water Limit	16.6	9.4	4	16.8	13.2	0
	No CO2 & No Water Limit	22.4	7.6	0	27.8	2.2	0
	No CO2 & Water Limit	15.4	3.2	11.4	14.6	8.4	7
SSB	CO2 & No Water Limit	22.6	7.4	0	28.4	1.6	0
	CO2 & Water Limit	21.4	8.6	0	26.2	3.8	0
	No CO2 & No Water Limit	21.4	8.6	0	27.2	2.8	0
	No CO2 & Water Limit	20.8	9.2	0	23.2	6.8	0
D_N	CO2 & No Water Limit	23.8	6.2	0	26	4	0
	CO2 & Water Limit	22.8	7.2	0	22.8	7.2	0
	No CO2 & No Water Limit	23	7	0	24.8	5.2	0
	No CO2 & Water Limit	22.4	7.6	0	23.4	6.6	0

Insurance Participation Rate

In the last subsection, the coverage rate of the AgriStability insurance program was used as an indicator to estimate the impact of climate change on producers' margins. But producers who are worried about their production and thus margin might change their insurance behaviour as it relates to weather conditions or uncontrollable natural disasters. As a result, producers may want to adopt different risk management tools to avoid this loss. The Individual Crop Insurance (ICI) or Production Insurance (PI) plans are often considered as production safety programs when different coverage levels are being selected for various crops and regions (Lehmann et al.). Thus producers' enrolment level in these two programs can be considered as an indicator of how they perceive the risk of climate change. The adaptation of different risk management tools is an institutional strategy to address climate change. Table 3 provides the optimal average percentage of annual cultivation land enrollment in either ICI or PI programs for each site and condition in terms of both reference and improved cultivar models. The higher the participation proportion, the more variable the potential yield is.

The results from both the reference and improved cultivar models would indicate that the optimal choice for producers for all sites, scenarios and conditions was to be covered by either the maximum coverage or not enroll in these insurance programs. Thus, this study only compares the proportion of land which is insured with the maximum coverage. In the reference cultivar model, wheat was the crop that had the most coverage and the highest participation proportion in these production safety insurance programs. In North Dundas, the portion participating can be as high as 90 percent. This would indicate that wheat yield per ha was subject to wide variations from year to year in the future under all scenarios. Barley and soybeans were insured less in the Montérégie, particularly when water limitations did not apply. Again, producers tended to insure more for each crop when there were water limitations, especially when CO_2 enhancement was absent. It is interesting to note that a higher average participation proportion can be found in the Hot & Dry scenario for the Montérégie region, and decreases as the scenarios move towards the Median and finally Cold & Dry. The opposite results were found in North Dundas. From a regional perspective, North Dundas has the highest participation rate for all crops except barley, which was not very profitable to plant in this area, followed by Ste-Martine, and St-Sébastien at a much lower level under all conditions.

In the case of the improved cultivar model, crop insurance participation was much lower for all sites and scenarios. Wheat participation had decreased by approximately 45% in Montérégie and 80% in North Dundas, while barley insurance participation increased by approximately 10% in Montérégie under all scenarios and conditions. Contrary to the results with the reference cultivar model, but in accordance with the situation in North Dundas, the highest participation can be found with the Cold & Dry scenario and decreases towards the Hot & Dry scenario in Montérégie. CO_2 alone does not play an important role when the improved cultivar was used, but its absence can exacerbate the vulnerable conditions when water was not available. As a C_4 crop, grain corn does not have better performance for any site or cultivar under the Hot & Dry scenario as was expected. Looking back at the economic vulnerability analysis in the last subsection, it is interesting to note that producers who were economically vulnerable, from either climate risks or market shocks, tended to take precautionary measures by increasing their insurance participation, so as to protect themselves from shocks or benefits more from potential opportunities.

	Site	CO2 and Water Conditions	Hot & Dry				Hot & Humid				Median				Cold & Dry				Cold & Humid			
			corn	wheat	barley	soya	corn	wheat	barley	soya	corn	wheat	barley	soya	corn	wheat	barley	soya	corn	wheat	barley	soya
Ref	SMT	CO2 & No Water Limit	0.0%	83.3%	0.0%	0.0%	0.0%	79.1%	0.0%	0.0%	0.0%	87.4%	0.0%	0.0%	0.0%	72.3%	0.0%	0.0%	0.0%	82.4%	0.0%	0.0%
		CO2 & Water Limit	45.0%	93.2%	35.5%	36.7%	9.2%	71.6%	26.4%	30.2%	28.1%	63.0%	26.9%	29.3%	27.4%	61.4%	33.7%	27.6%	24.0%	73.8%	21.3%	26.9%
		No CO2 & No Water Limit	0.0%	86.0%	0.0%	0.0%	18.3%	79.0%	0.0%	0.0%	0.0%	87.2%	0.0%	0.0%	0.0%	84.9%	0.0%	0.0%	0.0%	83.3%	0.0%	0.0%
		No CO2 & Water Limit	91.9%	66.1%	22.4%	18.7%	66.8%	64.3%	27.2%	20.6%	26.2%	63.2%	18.5%	19.8%	33.8%	53.1%	24.8%	17.9%	24.5%	64.4%	0.2%	25.5%
	SSB	CO2 & No Water Limit	14.2%	16.1%	0.0%	0.0%	12.7%	17.1%	0.0%	0.0%	8.3%	13.3%	0.0%	3.0%	6.1%	17.7%	0.0%	3.0%	5.1%	13.3%	3.0%	0.0%
		CO2 & Water Limit	26.4%	50.0%	27.3%	0.0%	31.5%	45.2%	24.8%	0.0%	25.5%	50.0%	32.4%	3.2%	20.0%	46.3%	8.9%	0.0%	11.1%	46.3%	11.6%	0.0%
		No CO2 & No Water Limit	15.0%	16.7%	0.0%	0.0%	24.9%	11.1%	0.0%	0.0%	8.0%	12.9%	0.0%	0.0%	10.7%	18.2%	0.0%	3.1%	4.2%	16.7%	3.0%	0.0%
		No CO2 & Water Limit	36.7%	50.0%	33.7%	0.0%	26.8%	41.7%	28.2%	0.0%	28.4%	52.8%	30.0%	0.0%	7.1%	51.0%	13.8%	0.0%	9.4%	52.9%	11.8%	0.0%
	D_N	CO2 & No Water Limit	18.2%	90.9%	-	36.7%	19.6%	88.8%	-	37.6%	25.1%	88.8%	-	37.1%	27.6%	90.9%	-	37.5%	22.9%	91.6%	-	36.5%
		CO2 & Water Limit	20.5%	90.7%	-	38.2%	19.7%	90.3%	-	38.5%	26.7%	89.1%	-	37.1%	29.5%	91.5%	-	37.5%	23.0%	92.0%	-	36.5%
		No CO2 & No Water Limit	17.0%	89.6%	-	36.8%	22.2%	87.8%	-	37.4%	25.0%	88.2%	-	37.1%	27.9%	84.6%	-	37.4%	24.2%	91.0%	-	36.4%
		No CO2 & Water Limit	21.5%	87.9%	-	39.1%	19.6%	89.4%	-	38.5%	28.1%	89.3%	-	37.1%	29.6%	89.1%	-	37.5%	23.5%	90.7%	-	36.4%
Imp	SMT	CO2 & No Water Limit	3.0%	0.0%	8.5%	0.0%	4.6%	0.0%	8.7%	0.0%	2.8%	0.0%	4.2%	0.0%	2.9%	0.0%	10.7%	0.1%	2.7%	0.0%	4.2%	0.0%
		CO2 & Water Limit	5.3%	39.6%	38.9%	28.6%	7.4%	22.4%	34.5%	22.4%	13.4%	19.5%	45.0%	31.1%	0.1%	8.1%	41.5%	28.8%	3.0%	9.2%	46.0%	29.0%
		No CO2 & No Water Limit	2.9%	0.0%	8.5%	0.0%	0.0%	0.0%	11.6%	0.0%	2.6%	0.0%	4.4%	0.0%	2.6%	0.0%	10.6%	1.4%	2.5%	0.0%	4.1%	0.0%
		No CO2 & Water Limit	12.2%	33.3%	42.6%	26.7%	0.0%	9.0%	37.7%	2.7%	10.7%	8.2%	36.0%	30.2%	0.3%	9.9%	40.1%	30.8%	0.0%	9.1%	40.2%	30.4%
	SSB	CO2 & No Water Limit	0.0%	3.3%	8.1%	0.0%	0.0%	7.3%	17.1%	0.0%	0.0%	0.0%	10.9%	0.0%	0.0%	0.0%	13.5%	0.0%	0.0%	0.0%	11.0%	0.0%
		CO2 & Water Limit	14.8%	34.6%	27.2%	-	14.1%	11.8%	28.1%	0.0%	15.6%	27.3%	28.3%	0.0%	2.5%	23.5%	27.0%	0.0%	4.2%	29.6%	35.0%	-
		No CO2 & No Water Limit	0.0%	3.3%	10.1%	0.0%	1.6%	3.0%	16.3%	0.0%	0.0%	0.0%	13.7%	0.0%	0.0%	0.0%	13.5%	0.2%	0.0%	3.3%	13.0%	0.0%
		No CO2 & Water Limit	19.5%	40.0%	28.7%	-	11.6%	22.2%	26.8%	0.0%	10.1%	44.4%	33.7%	0.0%	5.3%	42.9%	30.8%	0.0%	5.7%	46.4%	38.6%	0.0%
	D_N	CO2 & No Water Limit	15.4%	8.3%	0.0%	36.7%	16.9%	7.3%	0.0%	37.2%	24.9%	10.0%	-	37.1%	23.4%	6.8%	-	37.5%	20.0%	6.8%	0.0%	36.5%
		CO2 & Water Limit	6.5%	6.2%	44.4%	36.3%	15.2%	7.4%	0.0%	37.8%	26.2%	9.1%	0.0%	36.9%	23.9%	7.3%	0.0%	37.5%	-	6.7%	0.0%	37.1%
		No CO2 & No Water Limit	14.6%	9.7%	-	36.6%	17.0%	7.0%	-	37.4%	25.1%	10.6%	-	37.1%	24.7%	8.1%	-	37.7%	21.2%	7.6%	-	36.2%
		No CO2 & Water Limit	15.3%	6.2%	-	36.8%	16.0%	6.3%	-	21.5%	25.0%	8.0%	-	37.1%	23.9%	5.2%	-	36.2%	5.3%	6.1%	-	36.8%

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Effects of Institutional Adaptations

It is the complex interaction among a great many climatic and institutional factors that ultimately influences agricultural production and financial management. Most of the research in Canada is on the potential impact of crop yields and agricultural production, however, the role of humans in the decision-making process should not be neglected (Bryant et al. 2000). From this point of view, the adaptation of agriculture to climate variability is multifaceted and should not only focus its attention on technical and economic aspects, but also on institutional strategies. In this study, four kinds of institutional adaptations have been considered and modeled mathematically into the optimization model. Individual Crop Insurance (or Production Insurance), AgriStability and ASRA (or Risk Management Program) have been modeled either in the calculation of the cost of production, or as a constraint. They are all functioning on a dynamic platform by linking producers' previous performance with future benefit.

Net Institutional Benefits

It was assumed that the institutional policies of these insurance programs, including the coverage, premium and compensation rate, remain unchanged over the planning period of the model. Since only one kind of compensation from either ASRA (or RMP) or AgriStability, whichever is higher, can be obtained by the producer, it is worth comparing the net benefits brought by them. The results for the reference and improved cultivar models are presented in Table 4.

The results should be interpreted with caution since the compensation happens only after the losses have taken place. This is especially the case with AgriStability, since government payments occur only when there exists a margin reduction larger than 30 percent. The higher the net benefit observed, the larger the loss is. The specific amounts of net benefit coming from the insurance programs is not what the producer will actually receive, since these programs are subject to change periodically. Recently, a large number of changes have occurred in a relatively short time period. As a result, they might be better used to give us an indication concerning margin reductions, or the relationship between stabilised income and market crop prices.

The results from the reference cultivar model indicate that water limitation was the main driver for insurance compensations. Water limitations put producers into a very vulnerable situation economically. In Ste-Martine, the Cold & Dry scenario was the worst scenario for producers to be involved in agricultural production under favorable conditions where water was available. With water limitation, the Median scenario would surpass the Cold & Dry scenario as the most unfavorable scenario at this site. A similar situation can be observed in St-Sébastien where the top two worst scenarios were Hot & Humid and Median. On average, producers at this site were compensated by the ASRA insurance program due to the increased cost of production and fluctuating crop prices. Agriculture activity in North Dundas had a much better performance with an average negative RMP benefit. AgriStability compensation was higher under the Hot & Humid scenario. As climate change heads to a warmer future, it might favor Ste-Martine more than St-Sébastien or North Dundas.

	Site	CO2 and Water Conditions	Hot & Dry			Hot & Humid			Median			Cold & Dry			Cold & Humid		
			AgriStability	ASRA	AgriInvest	AgriStability	ASRA	AgriInvest	AgriStability	ASRA	AgriInvest	AgriStability	ASRA	AgriInvest	AgriStability	ASRA	AgriInvest
			(in dollars)														
Ref	SMT	CO2 & No Water Limit	9349.0	3177.2	8870.5	9308.1	3299.0	8142.5	9837.0	2392.0	8611.4	11507.0	3707.5	7355.5	10113.3	1817.7	8361.4
		CO2 & Water Limit	14904.4	10422.3	2116.3	18280.6	14498.5	3813.5	20252.1	12786.4	4017.8	16249.7	14862.7	3238.6	20398.3	11795.4	3791.4
		No CO2 & No Water Limit	10405.9	4328.1	6309.9	10046.5	3910.6	5637.5	10894.6	5251.7	6077.2	11812.1	3464.5	5029.1	11518.6	2834.1	5879.5
		No CO2 & Water Limit	12490.4	11730.7	1766.8	14717.2	14467.8	2051.8	15648.6	12568.1	1927.6	10148.9	11994.3	1390.3	14821.4	15440.8	1874.2
	SSB	CO2 & No Water Limit	12395.0	13023.4	8592.3	14756.0	13174.5	8051.1	13220.4	12701.9	8590.1	4258.1	12324.3	7468.8	14464.9	11201.4	8219.3
		CO2 & Water Limit	12454.2	21151.5	8195.4	13508.2	21402.7	8566.6	13653.2	21768.1	8162.2	14146.7	22548.4	7315.9	14038.6	21381.5	7808.3
		No CO2 & No Water Limit	12325.8	15226.9	5742.3	13532.9	15173.4	5302.7	12759.8	15395.7	5732.4	13039.1	15224.9	4796.3	13521.0	13900.0	5421.0
		No CO2 & Water Limit	12961.4	26004.7	5271.1	14336.4	26776.5	5515.4	13886.4	26629.3	5283.2	16473.8	27449.2	4514.9	14048.4	26629.3	4906.6
	D_N	CO2 & No Water Limit	3135.0	-199.6	13240.7	6576.0	-233.1	11743.9	3936.3	-182.9	13969.3	2288.6	-239.8	12659.2	4406.5	-216.4	13337.2
		CO2 & Water Limit	4489.1	-215.9	11697.9	7097.7	-197.1	12192.6	4387.2	-204.6	12559.0	4075.0	-212.2	12772.2	4516.3	-193.3	14073.4
		No CO2 & No Water Limit	5168.5	-283.3	9897.6	6659.4	-300.0	9200.1	5623.6	-269.9	10710.3	3365.6	-306.7	10074.4	6316.8	-293.3	10540.9
		No CO2 & Water Limit	6561.3	-264.9	9498.3	8256.7	-257.4	9860.8	5473.2	-261.2	10119.2	5880.7	-268.7	10222.0	5832.4	-257.4	11583.6
Imp	SMT	CO2 & No Water Limit	-543.3	-2166.7	18040.0	-477.5	-2783.4	16298.6	142.0	-3008.2	18384.7	631.0	2326.2	16512.2	-1070.8	-3087.9	17893.4
		CO2 & Water Limit	15538.2	23747.6	6531.5	11559.5	21196.4	6024.8	13302.2	14303.3	6855.5	10243.6	18017.0	5331.4	13741.5	17858.4	5993.3
		No CO2 & No Water Limit	56.4	-1748.4	15645.6	-707.4	-2122.5	13723.1	688.0	-3013.8	16031.1	2303.3	2317.1	14360.0	229.7	-3126.5	15618.7
		No CO2 & Water Limit	19206.6	12828.3	3371.9	17129.7	11549.1	3166.2	19772.7	13029.9	3719.8	14359.6	6199.4	2849.7	17525.8	9279.5	3387.7
	SSB	CO2 & No Water Limit	537.2	-1820.3	15932.3	959.2	-1160.7	14924.9	-306.3	-1623.7	16010.0	280.2	-22.6	15199.3	-694.3	-1804.7	15710.7
		CO2 & Water Limit	1461.9	4020.4	11474.7	1288.9	4757.7	11559.8	2058.8	7232.3	11275.0	1411.3	1840.0	10329.4	2040.3	2539.5	10870.8
		No CO2 & No Water Limit	732.7	-1996.1	13110.7	2856.3	-746.7	12070.3	308.7	449.0	13258.0	429.3	30.9	12411.4	109.0	-1911.6	13036.3
		No CO2 & Water Limit	3234.3	7136.9	8001.8	2295.0	6864.2	7959.3	4174.8	10480.4	7950.1	5508.3	4045.5	7254.0	4414.9	5482.7	7519.7
	D_N	CO2 & No Water Limit	1068.3	4322.1	17986.2	3933.3	5879.7	16152.2	1808.9	5165.9	18882.1	1314.4	5082.2	17157.0	2141.6	4135.2	18027.3
		CO2 & Water Limit	26739.1	6622.4	11341.3	6354.0	8669.5	13445.5	2615.3	7463.9	15796.0	2658.2	7536.8	14273.6	4074.2	5550.3	15234.3
		No CO2 & No Water Limit	2435.7	10973.2	13850.5	4752.0	13360.2	13001.8	3426.4	12075.4	14852.1	1918.3	9651.9	13924.5	3132.9	8169.9	14515.3
		No CO2 & Water Limit	4520.4	16132.1	11356.8	6877.3	17122.6	10697.4	4594.4	16374.7	12161.8	3369.6	13608.3	11366.7	5187.4	12153.3	11944.9

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In the Improved Cultivar model, water limitation was still a problem for producers in St-Sébastien, but they were much better off and obtained much less compensation from either ASRA or AgriStability. In Ste-Martine, producers participating in these two insurance programs had a balance of payment in the long run under favorable conditions. When a water limitation was applied, however, they received more compensation when the improved cultivar was planted. A similar situation was found in North Dundas. This again confirms that climate scenarios and weather conditions, which were reflected in variable yields, were not the only factors contributing to producers' economic vulnerability. Economic variables, including input costs and market prices, individual insurance portfolios and their interaction can all contribute to a producer' vulnerability or their flexibility to adjust to climate change.

Adaptations at Different Levels

The optimal net benefit that the producer could obtain from each insurance program separately was investigated in the subsection above, however, this study also investigated how these programs performed either individually or cooperatively on farmers' net returns from their agricultural activities. The aggregation of these four types of insurance programs does not mean that the compensation paid would be equal to the sum of all these net benefits after registration. However, as introduced before, the producer could only benefit from one of ASRA (or RMP) and AgriStability, whichever had the higher net benefit. The compensation from these two programs also assists producers' in their ability to contribute more to their saving accounts in the AgriInvest program. Table 5 investigated how the adoption of different levels of coverage contribute to an improvement in a producer's net return in all scenarios for both the reference and improved cultivar models respectively.

The crop production safety program, i.e. the Individual Crop Insurance program and the Production Insurance program, has been incorporated into the economic modelling process by including the premium in the cost of production; it is the adoption of the other three insurance programs that are investigated. The first column of each group, $Adapt^1$, stands for the average annual net return when all ASRA (or RMP), AgriStability and AgriInvest were included. $Adapt^2$ excludes the involvement of AgriInvest and $Adapt^3$ represents the net return when only ASRA is used. The last column of each group indicates the average net return that can be obtained over 30 years if the producer participates in none of the insurance programs. For all sites, scenarios, conditions and cultivars, the highest net return can be found when the producer adopts all of the financial risk management tools in the study, particularly when AgriInvest was involved. It was also advantageous to register for both AgriStability and ASRA (RMP) insurance programs so as to get the higher compensation, since differences exist, even though they were not significant. CO_2 enhancement with no water limitation would again be the best condition. In this case, the optimal average annual net returns from agricultural activities were the highest in both models. In the reference cultivar model, the highest annual net return was found with the Hot & Dry scenario for producers in Ste-Martine without water limitation, while the Median scenario would be better if water was limited. But large differences exist mainly between weather conditions rather than climate scenarios. This was the same case for St-Sébastien, farm performance was only slightly better in the Hot & Dry and Median scenarios, but CO_2 enhancement played an essential role that resulted in an approximate doubling of the annual net return. This corresponds to the situation in North Dundas, where CO_2 enhancement can improve the operation performance more than any other situation. The Median and Cold & Humid scenarios provided the highest net returns to producers at this site if the reference cultivar model was used. The results indicate that farming in North Dundas was more profitable than in

Montérégie, however, since the site models used different methods to estimate the cost of production, for example a different array of variable costs. Therefore, comparisons between net returns at different sites need to be interpreted with care.

Using the improved cultivar model can substantially increase farm net returns for all sites, scenarios and conditions. In Ste-Martine, the results from the improved cultivar model indicates that the net returns were almost doubled under all conditions, but producers were still financially vulnerable in conditions where water was limited. CO_2 enhancement and the climate scenarios play a less important role at this site. When all financial risk management tools were applied, the optimal average net farm return under the most favorable conditions, no water limitation combined with CO_2 enhancement, varies from $461,814.52 under the Median scenario to $410,978.17 under the Hot & Humid scenario. However, if water was limited and CO_2 enhancement was not available, it can be as low as $76,853.63 under the Cold & Dry scenario even when the farm business was involved with all the insurance programs. Although the Hot & Dry scenario was not the best scenario for Ste-Martine, it remains better than the others. The financial performance of the agricultural activities in St-Sébastien and North Dundas were similar when using the improved cultivar model. CO_2 was no longer the essential influencing factor at these two sites, but water availability was. The optimal average net returns were similar at Ste-Martine under the condition of no water limitation. The Median scenario was again the best scenario followed by Hot & Dry, and Cold & Dry was the worst. Under unfavorable conditions, the net return that a producer in St-Sébastien could obtain every year was greater than those in Ste-Martine. It was approximately $200,000 in St-Sébastien and $280,000 in North Dundas.

In both the reference and improved cultivar models, financial risk management strategies, such as insurance, can only help cushion the impact of climate change or market risks faced by the producers. These programs cannot eliminate the losses, especially as a medium-term or long-term adaptation option. Even though producers in the worst situation, such as producers in Ste-Martine under water limitation, can get the most benefit from insurance programs every year over the planning horizon, a sound market with a transparent and credible system, will decrease these benefits over time.

	Site	CO_2 and Water Conditions	Hot & Dry				Hot & Humid				Median				Cold & Dry				Cold & Humid			
			Adapt[1]	Adapt[2]	Adapt[3]	No Adapt	Adapt[1]	Adapt[2]	Adapt[3]	No Adapt	Adapt[1]	Adapt[2]	Adapt[3]	No Adapt	Adapt[1]	Adapt[2]	Adapt[3]	No Adapt	Adapt[1]	Adapt[2]	Adapt[3]	No Adapt
			(in thousands of dollars)																			
Ref	SMT	CO2 & No Water Limit	224.0	215.1	213.5	210.1	207.1	198.9	196.7	193.5	219.3	210.7	207.9	205.5	187.5	180.2	177.7	174.3	213.1	204.7	201.8	200.1
		CO2 & Water Limit	39.5	37.4	29.2	19.0	98.4	94.6	84.7	70.4	104.6	100.6	89.5	76.9	84.3	81.0	73.6	58.7	103.7	99.9	86.9	75.3
		No CO2 & No Water Limit	159.3	153.0	150.0	145.4	143.3	137.6	134.6	130.9	154.6	148.5	144.9	139.6	130.1	125.0	119.8	116.4	150.2	144.4	140.1	137.3
		No CO2 & Water Limit	47.0	45.2	38.5	27.2	56.0	54.0	45.5	31.3	54.0	52.1	42.3	30.1	36.7	35.3	30.9	19.1	50.2	48.3	39.5	24.3
	SSB	CO2 & No Water Limit	223.1	214.5	212.9	199.9	210.3	202.2	199.8	186.9	223.5	214.9	212.4	200.0	188.4	180.9	179.5	167.4	214.4	206.1	203.2	192.3
		CO2 & Water Limit	210.8	202.6	202.2	181.1	218.1	209.5	209.1	187.8	209.7	201.5	201.0	179.1	191.6	184.3	183.9	161.5	202.0	194.2	193.1	171.7
		No CO2 & No Water Limit	148.8	143.1	141.4	126.2	137.8	132.5	130.7	115.5	149.1	143.3	140.9	125.7	120.8	116.0	113.6	98.5	141.5	136.1	133.2	119.5
		No CO2 & Water Limit	134.3	129.0	128.7	102.7	140.3	134.8	133.8	107.1	133.8	128.5	128.5	101.6	119.3	114.8	113.2	86.0	126.1	121.2	120.5	93.7
	D_N	CO2 & No Water Limit	332.8	319.5	314.7	315.4	299.2	287.4	279.2	279.9	350.0	336.0	330.4	331.1	319.5	306.8	302.8	303.6	340.4	327.0	321.0	321.7
		CO2 & Water Limit	293.7	282.0	275.9	276.6	309.5	297.3	288.5	289.2	314.6	302.0	296.0	296.7	322.7	309.9	304.2	304.9	359.0	345.0	338.8	339.5
		No CO2 & No Water Limit	249.5	239.6	232.7	233.5	234.6	225.4	216.9	217.8	269.0	258.3	250.9	251.7	254.8	244.7	239.6	240.5	271.3	260.8	252.7	253.6
		No CO2 & Water Limit	239.4	229.9	221.6	222.4	251.2	241.4	231.4	232.2	253.7	243.6	236.4	237.2	259.2	249.0	241.4	242.2	296.9	285.3	277.8	278.6
Imp	SMT	CO2 & No Water Limit	452.6	434.6	432.2	434.8	411.0	394.7	392.5	395.9	461.8	443.4	440.3	443.7	416.2	399.7	396.6	394.6	448.4	430.6	428.5	432.0
		CO2 & Water Limit	162.3	155.7	147.8	124.4	147.0	141.0	136.9	116.1	171.2	164.4	156.0	142.1	134.4	129.0	122.7	105.0	152.5	146.5	138.2	120.7
		No CO2 & No Water Limit	390.7	375.1	372.1	374.2	344.2	330.4	328.6	331.1	401.1	385.1	381.4	384.8	361.4	347.1	342.0	340.1	390.5	374.9	371.5	375.1
		No CO2 & Water Limit	92.4	89.0	77.5	64.5	86.9	83.7	73.5	61.7	97.0	93.2	80.6	67.4	76.9	74.0	61.2	55.2	92.1	88.7	74.1	64.6
	SSB	CO2 & No Water Limit	411.5	395.6	393.0	395.2	386.5	371.6	369.1	370.6	411.6	395.5	393.7	395.7	383.1	367.9	365.6	366.0	403.2	387.5	386.2	388.4
		CO2 & Water Limit	298.0	286.6	284.5	280.8	298.6	287.1	285.5	281.0	293.2	281.9	279.8	272.9	269.7	259.3	257.5	256.0	281.6	270.8	268.5	266.3
		No CO2 & No Water Limit	337.3	324.2	321.4	323.8	312.9	300.8	297.8	298.8	339.4	326.1	323.9	323.9	312.6	300.2	298.1	298.4	333.6	320.6	318.5	320.9
		No CO2 & Water Limit	207.9	199.9	197.1	190.2	205.3	197.4	195.9	189.3	205.1	197.2	195.5	185.3	190.9	183.6	179.7	176.0	194.7	187.2	184.6	179.4
	D_N	CO2 & No Water Limit	451.2	433.2	431.0	426.9	407.5	391.3	387.3	381.7	471.5	452.7	450.1	445.2	433.6	416.5	413.0	408.2	457.2	439.2	436.0	432.3
		CO2 & Water Limit	280.9	269.6	243.5	237.2	338.1	324.7	320.1	311.6	393.8	378.0	375.0	367.7	359.6	345.3	341.4	334.1	386.6	371.4	366.6	361.4
		No CO2 & No Water Limit	346.1	332.2	329.6	318.7	327.2	314.2	310.3	297.1	369.6	354.8	351.7	339.7	351.0	337.1	334.3	324.7	369.1	354.6	350.7	342.7
		No CO2 & Water Limit	282.9	271.6	267.9	251.8	268.6	257.9	253.0	236.0	301.8	289.6	286.1	269.8	284.9	273.5	270.2	256.7	302.5	290.6	286.4	274.3

Potential Income Improvement

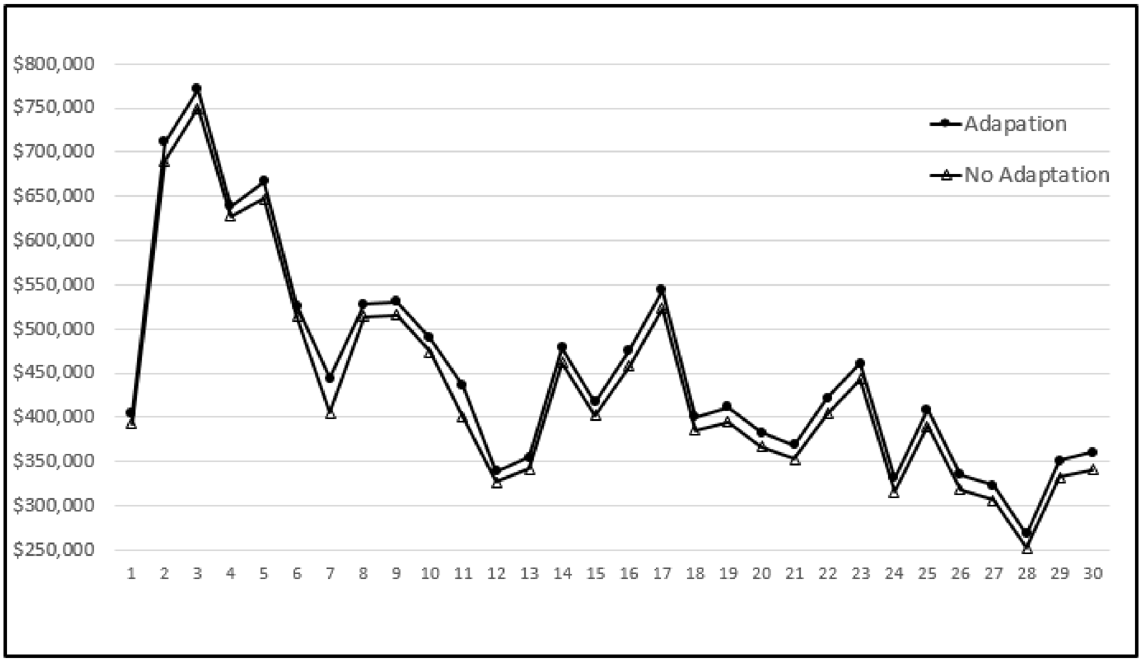
Adaptation to climate change is important not only to maintain and stabilize net farm returns, but provides an opportunity to increase producers' returns. Table 6 presents both the largest and least potential income improvement that could take place when adaptation strategies were applied under each condition. According to the results, all farm operations can benefit from financial risk management tools such as insurance programs, but to a different extent. Higher benefits from risk management tools can be observed when water limitations apply, and a lack of CO_2 enhancement would exacerbate this situation. Differences in the average annual potential income improvement was quite small across scenarios, except for Ste-Martine, which can possibly benefit by 106.3% under unfavorable conditions in the Cold & Humid scenario and 73.1% in the Hot & Dry scenario (using the reference cultivar model). Some general observations can be made about the climate scenario, even though it was water availability that was critical in determining a producers' potential benefit from the insurance programs. For instance, sites in the Montérégie could benefit more from the insurance programs with the Cold & Dry or Median scenarios prevail, while producers in North Dundas can take advantage from these strategies in the Hot & Humid scenario.

Table 6: Average Annual Potential Income Improvement, 2010-2039

	CO2 & No Water Limit	CO2 & Water Limit	No CO2 & No Water Limit	No CO2 & Water Limit
Reference Cultivar				
SMT	6.5%(C&H)-7.6%(C&D)	36.0%&(M)-108.1%(H&D)	9.4%(H&H)-11.7%(C&D)	73.1%(H&D)-106.3%(C&H)
SSB	11.5%(C&H)-12.5%(H&H)	16.1%(H&H)-18.6%(C&D)	17.9%(H&D)-22.6%(C&D)	30.8%(H&D)-38.8%(C&D)
D_N	5.2%(C&D)-6.9%(H&H)	5.8%(C&H)-7.0%(H&H)	6.0%(C&D)-7.7%(H&H)	6.6%(C&H)-8.2%(H&H)
Improved Cultivar				
SMT	3.8%(C&H)-5.8%(C&D)	20.5%(M)-30.4%(H&D)	3.9%(H&H)-6.3%(C&D)	39.3%(C&D)-43.9%(M)
SSB	3.8%(C&H)-4.7%(C&D)	5.3%(C&D)-7.5%(M)	4.0%(C&H)-4.8%(M)	8.5%(H&H)-10.7%(M)
D_N	5.7%(H&D)-6.8%(H&H)	7.0%(C&H)-18.5%(H&D)	7.7%(C&H)-10.1%(H&H)	10.3%(C&H)-13.8%(H&H)

On the other hand, since the planning horizon was 30 years, this study can be broken down into three periods (2010-2019, 2020-2029 and 2030-2039) in terms of producers' periodical net returns with and without adaptation. It is indicated that whether adaptation strategies were adopted or not, the net farm return under most cases tends to decline in the median-term. Exceptions exists, for example, the net return might decline in the short term and then rebound to the initial level, or vice versa, in the Cold scenarios in North Dundas. If using the reference cultivar model, producers in Ste-Martine would be very sensitive to climate change under water limitation, even with financial adaptation. They were likely to suffer consecutive years with negative margins in the Hot & Dry scenario at the end of the planning horizon. However, if water availability was guaranteed, the Hot & Dry scenario would be the most favorable climate scenario for producers at this site. The Median scenario was more desirable in St-Sébastien and North Dundas when there was no water limitation. If water is limited, producers in the Montérégie would be better off under Hot & Humid scenario while those in North Dundas would benefit more from the Cold & Humid scenario, whether or not CO_2 enhancement applies. Using the improved cultivar model can increase producers' net return substantially for all scenarios and decrease the potential losses in income, especially for those producers in the Montérégie. Figure 3 takes Ste-Martine as an example of the periodical trend on farm net returns over the modeling horizon under Hot and Dry climate scenario, in combination of CO_2 enhancement and no water limitation.

Figure 3: Ste-Martine: Periodical Trend of Farm's Net Return: Hot and Dry_ CO2 Enhancement_ No Water Limitation_ Improved Cultivar, 2010-2039



Even though the difference was very small, producers generally benefit more from adaptation strategies in the first period and less in the final period. This makes sense since insurance institutions will adjust the premium rate every year according to the producer's previous performance, so as to be actually sound in the long run. Farms with consecutive bad performances may be either no longer qualified for the insurance program or suffering very high premium rates. But these financial risk management tools are still necessary to cushion large margin reductions. On the other hand, technological development, which was reflected in the improved cultivar model in this study, can be very effective in benefiting producers in the short or medium term under all scenarios and conditions.

CONCLUSIONS AND RECOMMENDATIONS

This study assessed the potential economic impact of climate change on farm businesses in Montérégie west and eastern Ontario by integrating output from a climate modelling process and crop biophysical performance model with an economic model at a modeling horizon of 30 years. Five climate scenarios (Hot & Dry, Hot & Humid, Median, Cold & Dry, Cold & Humid), four weather conditions (with or without CO2 enhancement and water limitation), as well as four major field crops (corn, wheat, barley and soybean) were selected to address how the various climate scenario and weather conditions would influence producers' resource allocation decisions, economic vulnerability and financial risk management strategies.

The results from this study indicate that farm resource allocation, sales and storage, and net returns were dependent on the various climate scenarios and weather conditions. Water availability plays an essential role in farm production and water limitation tend to result in producers suffering severe financial losses, particularly when coupled with no CO_2 enhancement. Climate change, which was predicted to have a warming tendency, will favor producers in Ste-Martine more than those from other sites if adequate water was available. But with water limitation, Ste-Martine will be extremely vulnerable and may suffer negative margins if financial risk management tools are not available.

Technological development, as reflected in improved cultivars in this study, was expected to increase crop yields under most situations, especially in the Montérégie region. Technological development contributes to more flexibility and resilience when producers make farm management decisions. This can lead to effective strategies in improving farm operation performance for all sites and scenarios in the short and medium run. Higher land cultivation proportions and labour employment, a reduction in the frequency and magnitude of margin reduction, less participation in crop production safety insurance programs, as well as higher annual net returns either with or without institutional adaptations, were all observed in the analysis with improved cultivars. In general, it can effectively help producers to reduce production losses and economic vulnerability, and make agricultural production more profitable. However, financial risk management tools are still necessary when facing large margin reduction or when consecutive large losses prevail.

With the subsidy from both federal and provincial governments, producers can benefit from the insurance programs at all sites, conditions and crop varieties. But government payments take place only when real losses occur, especially for AgriStability and ASRA (or RMP). The more these insurance programs payout to producers, the larger the losses producers have suffered. According to the potential income improvement analysis, the net benefit from these insurance programs was subject to decrease in the long run, especially in scenarios and conditions where producers were suffering bad years successively. An exception exists with the AgriInvest program. Producers in all scenarios can benefit from this risk-free program by making a deposit every year of up to 1.0% of their operation's adjusted net sales (Parry et al.). But there exists a dilemma regarding this program. As institutional insurance is a risk management tool targeting at protecting and benefiting vulnerable producers, it is the producer who has already made substantial net returns, that gains the greatest benefits from this program rather than the vulnerable ones whose adjusted net sales are lower. Thus, it has the potentiality to exacerbate economic inequality in the long run.

For policies at the institutional level, the main target of adaptation strategies should be to provide a proactive, systematic and integrated way of promoting a stable and resilient framework to protect the vulnerable. Right incentives should be provided at this level rather than increasing the level of uncertainty or unnecessary risks. Public infrastructures, such as transportation and communication network, must first be constructed to mitigate the magnitude of potential losses. Government could run in partnership with the private sector to provide vulnerable producers with new crop insurance, with emphasis on preventive strategies and regional disasters. In this way, the right incentives should be provided to encourage producers to be self-resilient and preserving financial sustainability. This can work efficiently in helping absorb large production and economic shocks caused by climate change. Institutional strategies have to evolve; however, it also needs to take security of expectations into consideration. Institutional change that is too rapid creates uncertainty and decreases the security of expectations of the producers. Government also needs to partner with scientists in promoting technological development of crop varieties. This study suggests that this is an effective strategy to reduce producers' production and economic vulnerability. Government policies that promote trade or eliminate trade barriers can play a role of securing commodity markets and decrease market risk.

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