Effective Risk Management Policy choices under Climate Change:

An Application to Saskatchewan Crop Sector

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Abstract

There is growing concern about the impact of climate change on agriculture and the potential need for better risk management instruments that respond to a more risky environment. This is based on the widespread assumption that climate change will increase weather and yield variability and will expose farmers to higher levels of risk. But it is not obvious what will be the net impact of those on the distribution of yields and its correlation with weather indexes. Five stylized scenarios for crop yields are built on the basis of the available empirical information: baseline, marginal climate change without adaptation, with adaptation and with misalignment of expectations, and an extreme events scenario. A micro simulation model is calibrated using micro farm level data from the Canadian province of Saskatchewan. Four alternative policy measures are analyzed: three types of subsidized insurance (individual yield, area-yield and weather index) and an *ex post* disaster payment. Results on insurance uptake, budgetary costs and impacts on diversification, farmers' welfare and farm income variability, are presented for three different types of farms. The paper goes beyond indentifying the effectiveness of risk management instruments under stylized climate change scenario and analyze the policy decision criteria when policy makers face ambiguous climate change contingencies.

1. Introduction

In the agricultural domain, decisions of farmers, policymakers, and insurance companies will be affected by their expectations about future climatic conditions and the associated level of uncertainty in weather patterns. Current estimates of climate change impacts are generally characterized by large uncertainties that depend on limited knowledge we have of many physical, biological, and socio-economic processes. These limitations hinder efforts to anticipate and adapt to climate change. Reducing these uncertainties through an improved understanding of the relative contributions of individual factors will be important in the future; however, it is unlikely that such uncertainty will be resolved in the short-term. It is therefore important to incorporate the uncertainties introduced by climate change into agricultural risk management and risk-related policies.

Different approaches exist to incorporate the impact of climate change on agriculture, and these tend to focus on different aspects of this impact, from analyzing how plant physiology reacts to changes in environmental variables, to modeling how farmers react to changes in the variability of weather events. The different approaches can schematically be grouped as agronomic, econometric, and stochastic simulation. Agronomic studies have historically been the predominant approach for investigating the impact of climate change on agriculture. These have tended to rely on simulation models incorporating an understanding of plant physiology to simulate yields given daily and sub-daily inputs (e.g., Black and Thompson (1978), Fuhrer *et al.* (2006), Torriani *et al.* (2007), Xiong *et al.* (2007)). Econometric studies exist that use panel data linking climate to changes in yields but these typically model the impact of changes in mean values of weather variables (see Auffhammer, Rmanathan, and Vincent (2006), and Deschênes and Greenstone (2007)). Few models have so far incorporated the impact of increased frequency of extreme events and weather variability on production and the implications for risk management. However, studies do exist indicating that increased frequency of extreme events, such as heat stress and flooding, reduce crop yield and livestock productivity beyond the impacts estimated based on changes in the average value of the variables (e.g., Schlenker and Roberts 2009).

An alternative approach is to model farmer decision-making in a stochastic environment that incorporates the variability introduced by climate change. An example of this approach is provided John, Pannell, and Kingwell (2005) investigating how changes in climate would affect agricultural profitability and management systems in Australia by using a farm-level linear programming model, with stochastic programming to represent climate risk. Their results inidcate that climate change may reduce farm profitability in the study region by 50% or more compared to historical climate conditions, leading to a decline in crop acreage. Van Asseledonk and Langeveld (2007) examined the potential impact of climate change on crop production in the Netherlands using a similar whole farm portfolio analysis approach with projected joint crop yield distributions derived from crop growth models. The results for a representative

Dutch farm with potatoes, sugar beets and winter wheat show projected crop yields and ultimately farm income increased.

This paper examines how climate change, by affecting the mean, variability, and covariance of weather events, affects the appropriateness of different risk management portfolios, using farm-level stochastic simulation model. The usefulness of micro-based stochastic modelling is that it can address the extent to which variability can have an impact on outcomes, which is what is of interest from the point of view of risk management (e.g., Kimura et.al 2010). In particular, several aspects are analyzed such as the interaction between crop insurance and other risk management strategies (e.g., production diversification by farmers), and the extent to which they could improve the outcome of government's ex post disaster assistance (see OECD 2009; 2011). Section two reviews the literature on the impact of climate change on agricultural risk and yield distribution and draw stylized climate change scenarios. Section three describes the data source and stochastic simulation framework. Section four then presents the simulation result on the effectiveness of risk management instruments under stylized climate change scenarios. Section five discusses policy choice of different risk management instruments under ambiguous climate change scenario, followed by the conclusion in the last section.

2. Effects of climate change on agricultural risk and yield distributions

There are two main ways in which the emissions of greenhouse gases may be relevant for agriculture. First, increased atmospheric CO_2 concentrations can have a direct effect on the growth rate of crop plants and weeds. Secondly, CO_2-induced changes of climate may alter levels and variability of temperature, rainfall and sunshine that can influence plant productivity. An extensive literature exists going back to the 1970s on the potential impacts of climate change on plant physiology, and it continues to be an active field. Existing research highlights the complexity of the topic given the many uncertainties concerning how climate change will affect variables relevant for crop production.

Temperature often determines the potential length of the growing seasons for different crops, and generally has a strong effect on the timing of developmental processes and on the efficiency with which solar radiation is used to make plant biomass (Monteith, 1981). Development does not begin until temperature exceeds a threshold; then the rate of development increases broadly linearly with temperature to an optimum, above which it decreases broadly linearly (Squire and Unsworth, 1988). An increase in temperature above the base but not exceeding optimum temperatures is thought to generally lead to lower yields in cereals and higher yields of root crops and grassland. In general increased mean annual temperatures in mid- to high-latitude regions, if limited to one to three degrees, across a range of CO_2 concentrations and rainfall changes can have a small beneficial effecton the main cereal crops, notwithstanding that such simulations are highy uncertain (IPCC, 2007, WGII, Ch.5, pg285).

In most of the tropical and equatorial regions of the world, and even in the high mid-latitudes, the yield of agricultural crops is often limited more by the amount of water availability than by air temperature. Reliability of rainfall, particularly at critical phases of crop development, can explain much of the variation in agricultural potential in tropical regions. However, relatively few studies have been made of the combined effects of possible changes in temperature and rainfall on crop yields, and those that have are based on a variety of different methods. An earlier review of results from about ten studies in North America and Europe noted that warming is generally detrimental to yields of wheat and maize in these mid-latitude core cropping regions. With no change in precipitation (or radiation) slight warming (+ 1deg.C) might decrease average yields by about 5 ± 4 per cent; and a 2deg.C warming might reduce average yields by about 10 ± 7 per cent (Warrick et al., 1986). In addition, reduced precipitation might also decrease yields of wheat and maize in these breadbasket regions. A combination of increased temperatures (+2deg.C) and reduced precipitation could lower average yields by over a fifth.

Important effects from changes of climate need not only stem from changes in average temperature and rainfall, but also from changes in the frequency of extreme climatic events that can be damaging and costly for agriculture. The balance between profit and loss in commercial farming often depends on the relative frequencies of favourable and adverse weather; for example, on the Canadian prairies a major constraint on profitable wheat production is related to the probability of the first autumn frost occurring before the crop matures (Robertson, 1973).

Stylized climate change scenarios and adaptation strategies in Saskatchewan

In the literature there appears to be information on whether average yields for a crop will increase or decrease in a given region; however, little information is available beyond anecdotal evidence concerning how variability will be affected. There is a general consensus that in many regions variability will increase, but a lack of information to characterize how this would affect the probability distribution of crop yields. Of relevance to risk management is whether the change in variability is distributed evenly around the mean or whether the probability of extreme events increases in the form of yield reductions.

To characterize the possible climate scenarios to be simulated we break down into the following typology presented in Table 1.

Table 1. Typology of climate change scenarios

Climate Change scenarios	Sub-scenarios based on farmers' response	Description
Baseline (No climate change)	Business-as-usual (no adaptation)	Expresses how policy instruments would function without climate change
Marginal climate change	Adaptation	Expected impact on yields based on the literature, assuming farmers can switch to crop varietals that reduce impact of climate change
	No adaptation	Based on expected impact on yields assuming farmers can only diversify among existing varietals
	Misalignment & No adaptation	Farmers make production decisions based on their historical experience and therefore do not take into account the increase in systemic risk
Extreme events	No adaptation	

Understanding how farmers adapt to climate change will involve in the first instance to understand, or hypothesize, how changing temperature and rainfall patterns will affect yield and price risks farmers are facing. In particular, the intention of the proposed work is to improve our understanding of how policies may affect incentives to adapt to evolving environmental conditions. To carry out an analysis on how farmers may react to climate change will require taking into account historical correlations among risks, and also how these may change over time. A useful starting point in this respect is the in-depth review of the literature on the sources of risk in agriculture, correlations among them and their relative importance presented by Kimura et.al (2010).

Farmer adaptation has the ability to affect both the distribution of yield for a given crop and how responsive yields are to weather patterns. There are several adaptation strategies a farmer can adopt, from switching crops to improving the resilience of specific crops by changing variety, adjusting planting dates, changing fertilizer applications, and irrigating. Some of these adaptation measures come at no-cost, such as adjusting the date of planting, while others like irrigation may require investments.

An extreme events scenario is built based on the general result that "extreme events will be more likely to occur under climate change". However there is no quantitative information about the scope of these extreme events under climate change. The scenarios in this paper add an additional stochastic extreme systemic shock based on the lowest 25 percentile of the yield distributions. Climate change will modify the distribution of risks and since it is a systemic process, it is assumed here that it will affect the systemic component of this yield risk, while the basis risk will remain the same. The systemic risk will involve a change in the yield distribution for different crops. The climate change impacts on the level and

variability of systemic yield risks are chosen based on Howden et al (2007) and De Jong et al (2001).[1] There climate change scenarios were developed: marginal climate change with and without adaptation, and extreme events scenario. The model assumes that an adaptation to climate change affects only the level of yield. Under the extreme event scenario assuming more frequent extreme weather events, the model calibrates that a farmer suffer from correlated uniform shock to the lowest 25 percentile yields. The perturbations introduced by climate change, gleaned from the literature, are reported in Table 2. These changes in mean yield and variance are applied in the simulations of climate change impact. These numbers show a reduction in mean yields across all scenarios and commodities while, under marginal climate change, the change in the standard deviation is negative, positive or zero for each of the three commodities. Only under the extreme events scenario the standard deviation of yields increases for all commodities.

Table 2. Simulated Climate Change Scenario in Saskatchewan

	% Change in mean yield			% Change in standard deviation	
	No adaptation	Adaptation	Extreme events	Marginal change	Extreme events
Spring Wheat	-21.5	-11.8	-26.0	0.0	22.2
Barley	-13.2	-2.5	-17.0	12.8	25.9
Canola	-23.7	-14.2	-23.6	-8.5	6.0

Sources: Howden et al. (2007) and De Jong et al. (2001).

3. Data and Analytical framework

Calibration of systemic risk and idiosyncratic risks

Kimura et.al (2010) investigated the risk environment in which farmers make production decisions and, using a stochastic micro-simulation model, examined the consequences when the environment in which such decisions are taken changes due to government policies. The model is tailored to the risk exposure and strategic environment revealed by the panel data of 402 crop farm in the State of Saskatchewan in Canada between 2003 and 2008. The model analyses a three representative farms producing under price, yield uncertainty in addition to the uncertainty in residual crop revenue. In order to define three representative farms, the hierarchical analysis is applied to group farmer according to the similarity of risk. The grouping begins with as many clusters as sample farms, but it merges clusters until only one cluster remains by applying the Ward's minimum variance criterion. This method forms the cluster by minimising the variances within clusters, meaning that the sum of squared distance from the

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1 .   One of the climate change scenario location in De Jong et.al. (2001) "Aneroid" is located in census region 3BS, one of the census regions that sample farms in Canada are located (census regions of 3AN, 3BN, 3BS, 3ASW, 3ASE in Saskatchewan). Since "Aneroid" does not include canola yield projection, "Yellow stone" is selected.

centre gravity of the cluster is minimized while maximizing the distances between clusters. The variables to characterise the cluster are selected according to the risk profile of wheat production: the level and variability of wheat yield. Table 3 describes the characteristics of three clusters of farms (low, medium and high risk farm).

Table 3. Characteristics of three representative farms

Risk Cluster	Low	Medium	High
Number of farms in cluster	220	144	38
Area of operation (ha)	380	319	257
Wheat yield			
Mean (tonnes per ha)	1.43	1.93	2.27
Coefficient of variation (%)	26.9	31.7	45.3
Gross agricultural output			
Mean (CAD)	98813	100132	107701
Coefficient of variation (%)	29.4	29.6	36.9

Calibration of systemic risk and idiosyncratic risks

In the model we assume that yield risk at farm "i" level can be expressed by the random vector

$$\tilde{y}_i = \tilde{s} + \tilde{b}_i$$

Where $\tilde{s}$ denotes the systemic part of yield risk, affecting all farms in the same area, and $\tilde{b}_i$ denotes basis risk for that farm. In the policy toolbox we also have weather index insurance with a parameter θ expressing the correlation between the weather index and the yields obtained. Climate change will affect $\tilde{Y}$ and may affect θ depending on whether or not the weather variables capture the limiting factors affecting yields.

Agricultural risk of individual farm can be decomposed to systemic risk, which is common to all farms, and idiosyncratic risk, which is unique to an individual farm. The model assumes that only yield risk has both systemic and idiosyncratic components (i.e., representative farms faces same price risk, but unique yield risk). Systemic risk is calibrated as an average mean and average standard deviation of risk variables across all farms. Matrix of correlations of systemic risk is also constructed as an average of correlation across risks. Annex table presents the characteristics of systemic risks in the dataset.[2] Based on the characteristics of systemic risk, we generated the joint distribution of prices, yields and other risks, which is used for Monte Carlo analysis. The simulation assumes a truncated normal distribution except for extreme event scenario where lower tail is skewed. The distributions are truncated so that it does not

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2 .   Precipitation risk in Saskatchewan is defined as a cumulative precipitation between April 1 and October 31. Calibration is made based on the monthly rainfall data from the weather station located at "Val Marie" in the state of Saskatchewan between 1977 and 2007. The coefficients of correlation with systemic yield risks are derived from its correlation with county level yield data during the same period (61% for wheat, 67% for barley and 63% for canola).

generate the values that are higher or lower than the value observed at the sample data. The truncated points are selected as maximum and minimum value of the sample data.

Stochastic simulation model

The model assumes that representative farms allocate land among three crops (wheat, barley and canola) and other residual crops. The model adopts the power utility function which assumes constant relative risk aversion (CRRA). The advantage of the model is that it treats farmers' risk management strategies as endogenous, allowing the interaction between policies and farmer's decision to be analysed.

(1) $\quad U(\tilde{\pi} + \omega) = \frac{(\tilde{\pi}+\omega)^{(1-\rho)}}{(1-\rho)}$

where the utility (U) depends on the uncertain margin ($\tilde{\pi}$) and initial wealth (ω); ρ stands for the degree of CRRA. [3]

The margin is defined as the crop revenue less variable cost for crop production plus net transfer or benefit from a given risk management strategy. Since the crop specific cost data is not available in the data, the uncertain variable cost ($\tilde{c}$) is not crop specific. However, the crop specific production cost adjustment factor (c_i) is calibrated for each crop so that the initial land allocation matches the observation in the dataset. The model assumes that total land input is fixed and is allocated between wheat, barley, canola and residual crop production. Given the Monte-Carlo draw of 1,000 price, yield, revenue and variable cost combinations, the model maximizes the expected utility with respect to area of land allocated to each commodity and the level of insurance coverage.

(2) $\quad \tilde{\pi} = \sum_{i=1}^{3}[(\tilde{p}_i * \tilde{q}_i - c_i) * L_i] + OR * (\overline{L} - \sum L_i) - \tilde{c} + g(\tilde{p}_i, \tilde{q}_i, \lambda)$

where:

$\tilde{p}_i$ uncertain output price of crop i

$\tilde{q}_i$ uncertain yield of crop i

$\tilde{c}$ uncertain variable cost

c_i cost adjustment factor of crop i

L_i area of land allocated to crop i and

OR revenue from other crops

g transfer from government or insurance indemnity

λ level of insurance coverage decided by farmer

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[3]   The initial wealth is computed as the average net worth of grain and oilseed farms in Saskatchewan in 2008 for all farms, CAD 1467 per acre. The coefficient of constant relative risk aversion of 2 is applied to all of our simulations.

Given the expected utility calculated in the optimization model, certainty equivalent farm income is used to compute the farmer's welfare for a given level of risk aversion.

(3) $\quad CE = [(1-\rho)EU(\tilde{\pi} + \omega)]^{1/(1-\rho)} - \omega$

Risk management instruments under consideration

The model introduces four government policy strategies: individual yield insurance, area-yield insurance, weather index insurance and ex-post payment. Only one insurance instrument or ex-post payment is available for each policy scenario.[4]

Individual yield insurance

Individual yield insurance is tailored to yield risk of individual farm. The indemnity is paid in case the crop yield turns out to be below the insured level of yield (30% of deductible). To avoid moral hazard and adverse selection effects, the model assumes the perfect insurance market so that risk neutral insurance companies offer crop insurance contact at the price equal to the expected value (fair insurance premium) without administrative cost and government subsidy. Fair insurance premium is calculated by each representative farm. The payment is determined by the area of land that the farmer insures and producers cannot insure more area than the one they plant. The forward price applied to calculate the insurance premium and indemnity is set at the expected price level. Individual yield insurance is available for wheat, barley and oilseeds.

$$g_1 = \underbrace{\sum p_{fi} * q_{h1} * L_i * Max(0, \beta_{qi} - \frac{\tilde{q}_i}{q_{hi}})}_{\text{Indemnity receipt}} - \underbrace{(1+\gamma) * p_{f1} * q_{hi} * L_i * E[Max(0, \beta_{qi} - \frac{\tilde{q}_i}{q_{hi}})}_{\text{Insurance premium payment}}$$

p_{fi} forward price of commodity i

L_{Ii} area of land for commodity i which farmer insures its yield

q_{hi} historical average yield of commodity i

β_{qi} proportion of yield insured for commodity i

γ net of administration cost of insurance and subsidy to insurance premium

Area-yield insurance

Area-yield insurance is designed based on systemic yield risk. Insurance premium is calculated by crop from the systemic yield risk parameter so all farmers face same insurance premium. The model assumes no deductible so that insured farmer receives indemnity when the systemic yield fell below the

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[4] Anton et.al (2011) reviews whole risk management strategies and policies in Canada

expected level. Unlike individual yield insurance, producers can insure more area than the one they plant. The forward price applied to calculate the insurance premium and indemnity is set at the expected price level. Area-yield insurance is available for wheat, barley and oilseeds.

Weather index insurance

Weather index insurance is calibrated based on precipitation risk in Saskatchewan. The design follows a standard weather index contract. The weather index insurance triggers if cumulative rainfall index between April 1 and October 31fell below 250 mm. If the cumulative precipitation index fell below 150 mm, the insurance compensates for full value of yield loss. The indemnity is linearly reduced between the precipitation index between 150 and 250 mm. Since the insurance premium is calculated based on systemic precipitation risk, all the farmers face same insurance premium and there is no upward limit for insurance subscription. The yield loss is valued based on the expected price level. Area-yield insurance is available only for wheat.

Insurance premium subsidy

The administration costs play an important role in farmers' demand for insurance. Since different insurance instruments carry different administration costs, to compare across instruments it is necessary to make assumptions about their relative costs. The insurance premium in the absence of government premium subsidy is assumed to be different between insurance products. Since individual yield insurance usually costs high administrative cost (e.g., loss assessment of individual farmer), the market insurance premium is assumed to be 30% additional to the fair insurance premium. On the other hand, area-yield insurance and weather index insurance does not require individual premium setting or loss assessment. Therefore, the percentage additional administration costs are set at 10% and 5% for area-yield and weather index insurance, respectively. The government program to subsidise insurance premium is modelled as subsidising a fixed percentage of administrative cost (95% in all scenario unless specified). The model does not allow positive transfer of income through subsidy to insurance premium. To which extent area-yield insurance or weather index insurance is attractive to individual farmer largely depends on the correlation between their yield risk and indices (regional average yield and precipitation recorded in the weather station).

Ex-post payments

Ex-post payment is designed as a fixed payment triggered by a systemic yield shock. The model assumes that the farmer receives ex-post payment if yields of all three crops fell below 40 percentile thresholds. The level of the payment is set individually, which is equivalent to the expected indemnity from area-yield insurance.

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4. Simulation results on the performance of insurance and ex-post payment under climate change

Performance of insurance and ex post payments under marginal climate change scenario

Considerable uncertainty exists about possible climate change scenarios. Table 4 compares the baseline without climate change to the scenario with marginal climate change. The results for the baseline indicate there is a general preference by farmers to buy area yield insurance, which may be due to a relatively high positive correlation between the farm and the area yield, and lower net administrative cost than individual yield insurance. If the net administrative cost is identical between individual yield and area yield insurances, farmers most likely would have preferred individual yield insurance which also covers basis risk for individual farmers. The demand for weather index is highest for the medium risk farms category, indicating that the demand for weather index insurance critically depends on the correlation between farm yield and weather index. Demand for insurance increases only slightly across the board after climate change. Some farmers such as those in the low risk farm category particularly increase individual yield insurance demand. Other farmers such as those in the high risk farm category boost the demand for index insurance. With climate change high risk farms experience a proportionately larger increase in the systemic part of their risk (since they start from a low correlation with systemic risk), which is more correlated with the index. In general, a more risky environment, as under climate change, reduces farmers' welfare. But higher demand for insurance may result in higher welfare for farmers, cancelling out part of the negative impact of climate change.

Farmers' welfare gain due to reduced variability is measured through the certainty equivalent of the margin distribution. The total welfare impact of policies is not calculated. In this respect, both in the baseline and the scenario with climate change, ex-post payments are consistently the least effective instrument across all three farm types. This limited effectiveness in reducing income risk is due to the difficulty of targeting ex-post payments to farms experiencing the greatest variability in income. It is administratively challenging to adjust ex-post payment based on individual loss assessment. Among the insurance instruments, area yield insurance appears to perform well in improving risk-related welfare both in the baseline and under climate change, which is consistent with farmers' high demand for this type of insurance. Individual yield insurance performs quite well too in terms of reducing the variability of income, whereas weather index insurance is more uneven, depending on the scenario and the farm type.

Table 4. Impacts of the introduction of insurance and ex post payments under baseline and marginal climate change scenarios

	Baseline					Marginal Climate Change (No adaptation)				
	% of land insured	Welfare gain (cad/ac)	Impact on low incomes (cad/ac)	Diversif. index (% change)	Gov. cost (cad/ac)	% of land insured	Welfare gain (cad/ac)	Impact on low incomes (cad/ac)	Diversif. index (% change)	Gov. cost (cad/ac)
Low risk Farm										
Individual	19.9	0.028	0.51	-1.20	0.59	64.4	0.101	-0.21	-6.26	1.53
Area yield	60.9	0.062	2.69	1.21	0.65	70.8	0.156	-0.84	0.72	0.67
Weather index	27.5	0.037	3.80	1.04	0.22	36.4	0.018	-1.02	-2.57	0.25
Ex-post	0.0	0.006	1.38	0.10	0.27	0.0	0.000	-0.01	-0.42	0.42
Medium risk Farm										
Individual	58.2	0.066	-0.08	-3.56	0.57	56.9	0.030	2.18	-2.54	0.55
Area yield	59.7	0.101	2.15	-0.45	0.60	65.6	0.068	3.09	2.64	0.63
Weather index	40.6	0.056	4.31	2.10	0.33	25.1	0.030	0.02	2.28	0.17
Ex-post	0.0	0.006	0.60	0.14	0.25	0.0	0.002	0.44	0.46	0.37
High risk Farm										
Individual	27.7	0.219	2.35	-2.51	0.73	38.3	0.086	1.42	-2.95	1.09
Area yield	30.2	0.143	0.75	-0.66	0.32	48.9	0.093	2.44	12.51	0.47
Weather index	16.7	0.024	-0.06	0.67	0.13	100.1	0.140	3.14	-4.98	0.69
Ex-post	0.0	0.001	0.10	0.04	0.12	0.0	0.004	0.02	-0.27	0.59

Note: The welfare gain reported is only the component linked to the reduction in variability of income, not from changes in mean income associated with transfers. The impact on low incomes instead refers to the income change for farms in the lowest 10th percentile of income per acre, and includes both components from changes in mean and variability. Diversification index is the inverse of percentage change in coefficient of variation of market return per unit of land. Lower diversification index indicates farmer specialized more to specific crop, leading to higher coefficient of variation of market return.

Climate change does not significantly modify the impact of insurance on diversification strategies. Crowding-out effects remain for individual yield insurance and they also exist for weather index insurance. On the contrary under climate change area yield insurance enhances diversification strategies, which explains the generally better results of this type of insurance.

In the baseline, the lowest budgetary cost per acre insured across all three farm types is for weather index insurance. This is in part by construction because of the lower administrative costs and because the uptake rate is lower for individual yield insurance than for other insurance instruments. The budgetary cost per acre of different policy instruments typically increases with marginal climate change. Although there are differences between farm types, area-yield insurance is impacted relatively modestly by climate change across farm types. Other instruments, which may come at a lower per acre budgetary cost without climate change, are more heavily impacted by climate change for one of the farm types (e.g. individual yield insurance for low risk farms, or weather index insurance in the case of high risk farms).

Despite the impact of climate change on the budgetary cost of weather index insurance for high risk farms, it still appears to be the least onerous from an overall budgetary perspective per unit area insured.

To summarize these initial results, it appears that area yield insurance performs well in the baseline and in the marginal climate change scenario, both with respect to insurance demand and reduction in risk. On the contrary, ex-post payments are not effective for any farm type for either of the two scenarios.

Performance of insurance and ex post payments under alternative climate change scenario

The marginal climate change scenario presented above is one of several possible scenarios, the main assumptions being that farmers correctly anticipated climate change, did not adapt beyond changing the mix of crops, and that the changes were marginal affecting the mean and variability but no increase in extreme events were simulated. This section presents how the policy instruments would perform under alternative scenarios. These alternative scenarios are meant to represent the spectrum of possible outcomes beyond the current baseline and marginal climate change. These range from farmers not expecting climate change to occur (misalignment of expectations), the possibility of extreme events, and a scenario where farmers counteract in part the impact of climate change through adaptation. The rationale is to analyze policy instruments in the face of uncertainty and attempt to provide insight on instrument sensitivity to different factors exogenous to policy design. We present results on the share of land insured under each option presented in Table 1 in Section 1 (baseline, marginal climate change, adaptation, extreme events and misalignment), the welfare impact on, and the budgetary expenditures for the farms in the overall sample.

Table 5. Percentage of land insured under different insurance programs under alternative climate change scenarios

	Baseline	Marginal Climate Change			Extreme events
		No adaptation	Adaptation	Misalignment	(no adaptation)
Low Risk Farm					
Individual yield	19.9	64.4	31.2	19.9	67.6
Area yield	60.9	70.8	23.1	60.9	56.1
Weather index	27.5	36.4	34.5	27.5	39.1
Med. Risk Farm					
Individual yield	58.2	56.9	56.5	58.2	66.4
Area yield	59.7	65.6	58.8	59.7	74.7
Weather index	40.6	25.1	29.6	40.6	60.9
High Risk Farm					
Individual yield	27.7	38.3	55.9	27.7	67.5
Area yield	30.2	48.9	46.9	30.2	51.0
Weather index	16.7	100.1	19.9	16.7	43.3

In the first two columns of Table 5 are reported the share of land insured under the baseline and the marginal climate change without adaptation discusses in the previous subsection. When compared to

these, the adaptation scenario, given it counteracts in part the impact of climate change on yields, tends to be in the middle between the baseline and the climate change scenario without adaptation. The reduction in demand for insurance relative to the climate change without adaptation is an expression of the role adaptation can play. It highlights that adaptation can meet, at least in part, the need to reduce risk associated with climate change that would otherwise require additional insurance (and hence additional subsidies for administrative costs). However the simulations show that the reduction in demand for insurance is uneven across farm types: medium risk farms are barely affected in their demand, whereas demand in the other farm types is substantially reduced with adaptation.

The extreme events climate change scenario tends to increase further the demand for insurance across different instruments. Weather index insurance is sensitive to how the extreme events disrupt the correlation between yields and the weather index. In the case of medium risk farms demand for weather index insurance increases substantially relative to marginal climate change. However, for high risk farms it appears that the correlation between yield and cumulative rainfall is weakened by occurrence of extreme events, hence lowering the demand for weather index insurance.

Under the misalignment scenario farmers make decisions based on past information thereby not adjusting their expectations to a changing climate and, therefore, they buy the same insurance as in the baseline. In terms of reduction in variability both area and individual yield insurance become more effective in reducing risk,

Table 6. Impacts of different policy programs on welfare gain from reduced income variability under alternative climate change scenarios ($/acre)

	Baseline	**Marginal Climate Change**			**Extreme events**
		No adaptation	Adaptation	Misalignment	(no adaptation)
Low Risk Farm					
Individual yield	0.028	0.101	0.120	0.041	0.049
Area yield	0.062	0.156	0.092	0.101	0.045
Weather index	0.037	0.018	0.040	0.023	0.037
Ex-post payment	0.006	0.000	0.002	-0.005	0.003
Medium Risk Farm					
Individual yield	0.066	0.030	0.015	0.114	0.171
Area yield	0.101	0.068	0.067	0.159	0.134
Weather index	0.056	0.030	0.051	0.018	0.053
Ex-post payment	0.006	0.002	0.004	0.01	0.005
High Risk Farm					
Individual yield	0.219	0.086	0.086	0.1312	0.148
Area yield	0.143	0.093	0.052	0.1382	0.001
Weather index	0.024	0.140	0.019	0.0917	0.037
Ex-post payment	0.001	0.004	0.002	0.0238	0.002

In terms of absolute welfare gains due to reduced variability, simulation results can be very different across scenarios (Table 6). Even in relative terms the risk reduction ranking of different risk management instruments changes when climate change is accompanied by adaptation and extreme events. Risk is reduced the most by individual yield insurance (except for medium risk farms in the adaptation scenario) for both the scenario with adaptation and the one with extreme climate-related events. In the case of extreme events this is likely because, although individual yield insurance is designed to have 30% deductible, it can generate more welfare gain once this threshold is exceeded (more likely with extreme events) because it is more targeted to risk of low yield on each farm than other insurance products. This is different from what emerged in Table 4 where for both the baseline and marginal climate change scenarios the area yield provided the most risk reduction across farm types. However, area yield insurance still performs reasonably well (second-best), both under climate change with adaptation and under extreme climate-related events. In the misalignment case the relative ranking from Table 4 is confirmed, with area yield insurance reducing risk the most, followed by individual yield insurance. Ex-post payments remain ineffective in reducing income variability under the different scenarios because of the difficulty in targeting.

5. Policy decision criteria under ambiguity of climate change scenario

In the previous sections we analyzed welfare changes expressed as the changes in certainty equivalent associated with a reduction in the variability of income. These are good overall indicators to express how farmers are affected by risk reduction policies; however, the policy instruments presented will come at a very different budgetary cost to the government. From a government perspective it would be useful to come up with guidance on which policy should be preferred. Such guidance should take into consideration **(i)** the welfare gains of reducing income variability, **(ii)** the budgetary cost to accomplish the welfare gain, **(iii)** the uncertainty both in climate outcomes and in how farmers will adapt, and **(iv)** that government will most likely introduce a single risk reduction policy despite heterogeneous impacts of policy instruments on different farm types. To address the first two points we introduce a measure of budgetary cost-effectiveness defined as the impact of each $ of public expenditure in increasing farmers' welfare or for protecting vulnerable farmers. This cost effectiveness have to be interpreted in terms of the objective of reducing farming risk and it does not measure overall economic efficiency of the different measures.

Concerning the uncertainty and the heterogeneity of impacts on farmers decision rules are proposed based on values of budgetary cost-effectiveness across scenarios and farm types. The uncertainty across scenarios can be handled through a Bayesian probabilistic approach or through other "robust"

decision making rules. The heterogeneity of results across farms requires a more "political" choice that the methods described in this section cannot solve, but they can help to understand the political trade-offs.

Knowledge about climate change and its impact on agriculture is subjected to uncertainty or ambiguity (Etner et al., 2010). That is, there are uncertainities about climate change that cannot be "probabilized". We represent this ambiguity by the lack of information about the likelihood of the different scenarios occurring: baseline, marginal climate change, or extreme events, and how farmers will behave ie whether there will adaptation and whether farmers' expectations are misaligned or not.

The standard Bayesian approach to this ambiguity is assigning probabilities to each scenario and obtaining a combined distribution of outcomes that accounts for different scenarios to occur. Then decision making can be based on standard expected utility theory with or without government's risk aversion.

Figure 1 The Bayesian approach to ambiguity: Combining probability distributions from different scenarios
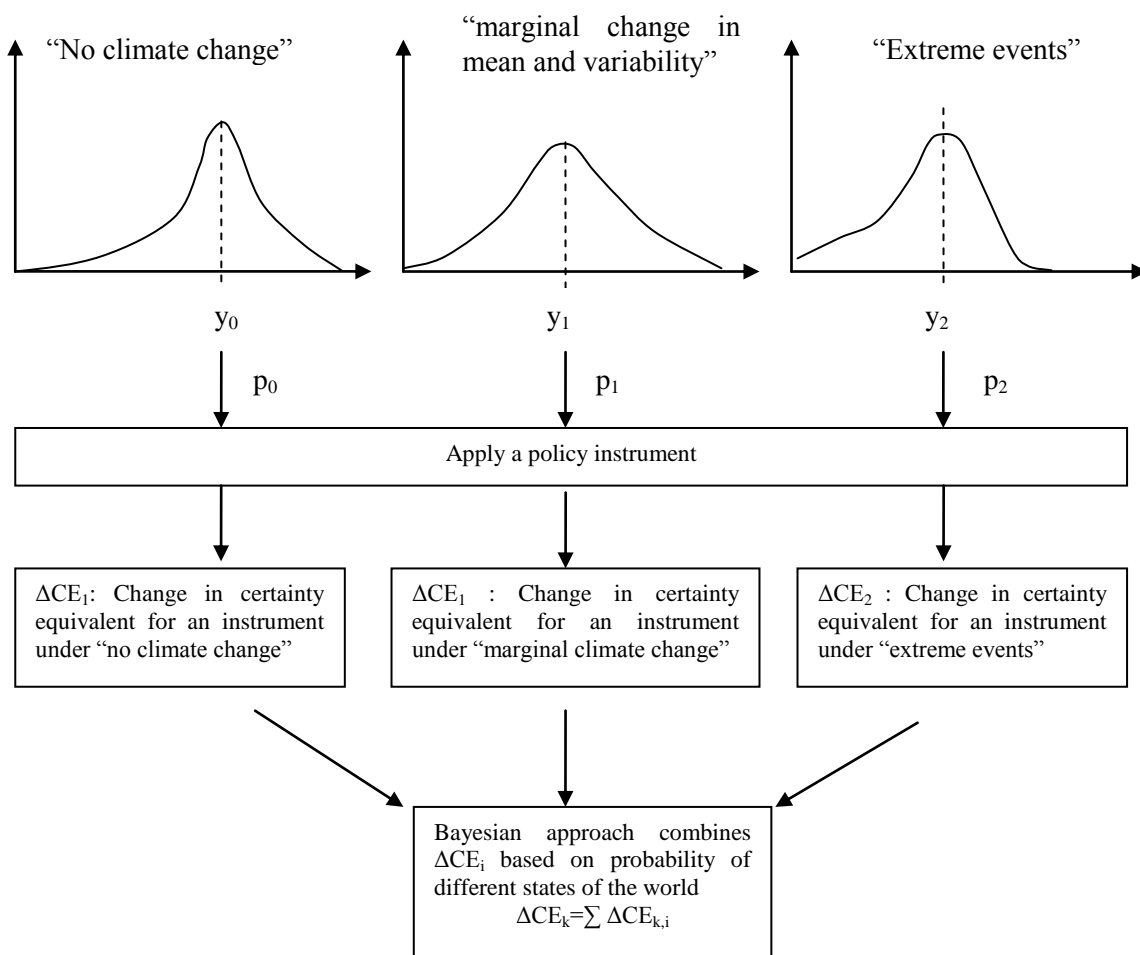
An alternative approach is acknowledging this ambiguity or lack of knowledge about the probabilities of different scenarios occurring and trying to define robust choices that are able to respond

correctly, even if not optimally, to a variety of different plausible scenarios. Several possible decision rules can be proposed to choose among the different policy instruments. One possibility would be using the "satisficing" principle: since it will be difficult for a single policy instrument to be optimal across all possible states of the world (climate change & expectations) for all farm types then a qualitative analysis can be carried out to see if there is an instrument that performs "well enough" in all situations under consideration. In the context of this analysis it would mean finding policy instruments that perform well under a range of uncertain climate scenarios This principle was introduced by Simon (1956) to describe behaviour in situations of bounded rationality and incomplete information. It is plausible that there is no instrument that performs "well enough' across all scenarios. In this case this criterion helps to show policy maker what scenarios are most disregarded under each choice.

Yet another possibility is to focus on avoiding worst-case outcomes in an adverse state of the world, ie. maximizing the minimum outcome (MaxMin). This criterion is very conservative and has the advantage of always picking up a single instrument across all scenarios. In the next section we just apply these three approaches to provide insight for choosing a risk management policy instrument based on the results from the previous sections. Other criteria are also available in the literature (Etner et Al. 2010). They all involve some a priori beliefs about probabilities, confidence on these probabilities, and/or ambiguity aversion of the government.

The different decision rules presented in the previous section may lead to the same conclusions or not depending on how the different instruments perform in the different scenarios and whether their outcome is very sensitive to the different scenarios or not. First we start with the probabilistic, or Bayesian approach to maximize the expected outcome.

"Probabilistic" - the standard Bayesian approach to this ambiguity is assigning probabilities to each scenario and obtaining a combined outcome that accounts for different scenarios to occur. Then decision making can be based on maximizing the expected budgetary cost-effectiveness. For illustration purposes we have assumed that there is a 25% probability that the baseline continues (no climate change), 50% that there is marginal climate change, and 25% that there climate change occurs with extreme events disrupting yields. In the marginal climate change scenario we further disaggregate into three further possible outcomes with equal probability: farmers adapt only through cropping decisions, they adapt affecting yields of different crops, or they do not adapt at all because their expectations do not account for climate change. In Table 7 we observe that the Bayesian decision by assuming those probabilities favours area-yield insurance and weather index insurance depending on the farm type. In the case of farmers that had relatively higher correlation with systemic yield risk in the baseline (low and high risk farms) area yield insurance is the most cost-effective, whereas for farms with relatively higher correlation of yields with precipitation index weather index insurance appears to be more effective. However, the two

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instruments perform in a quite similar manner. When averaged over all farms based on the number of acres in each farm type, the Bayesian approach indicates that area yield insurance is slightly more cost-effective than weather index insurance from a budgetary perspective.

Table 7. Increase in certainty equivalent of income per $ spent in one acre

Low Risk Farm- certainty equivalent gain from lower variability

	Baseline	Marginal Climate change			Extreme events	Bayesian decision
		No adapt.	Adaptation	Misalignment		
Individual yield	0.05	0.07	0.15	0.04	0.02	0.06
Area yield	0.10	0.23	0.40	0.01	0.06	0.15
Weather index	0.17	0.07	0.15	0.04	0.15	0.12
Ex-post payment	0.02	0.00	0.02	0.00	0.01	0.01

Medium Risk Farm- certainty equivalent gain from lower variability

	Baseline	Marginal Climate change			Extreme events	Bayesian decision
		No adapt.	Adaptation	Misalignment		
Individual yield	0.116	0.05	0.030	0.029	0.162	0.089
Area yield	0.168	0.11	0.115	0.021	0.142	0.118
Weather index	0.172	0.17	0.224	0.021	0.136	0.147
Ex-post payment	0.024	0.01	0.013	0.005	0.018	0.014

High Risk Farm- certainty equivalent gain from lower variability

	Baseline	Marginal Climate change			Extreme events	Bayesian decision
		No adapt.	Adaptation	Misalignment	No adapt.	
Individual yield	0.302	0.08	0.225	0.079	0.080	0.159
Area yield	0.445	0.20	0.501	0.039	0.001	0.235
Weather index	0.179	0.20	0.334	0.259	0.133	0.211
Ex-post payment	0.008	0.01	0.038	0.025	0.011	0.016

Weighted average across farm types- certainty quivalent gain from lower variability

	Baseline	Marginal Climate change			Extreme events	Bayesian decision
		No adapt.	Adaptation	Misalignment		
Individual yield	0.112	0.065	0.126	0.045	0.074	0.086
Area yield	0.178	0.190	0.335	0.020	0.075	0.154
Weather index	0.171	0.124	0.204	0.072	0.142	0.145
Ex-post payment	0.020	0.003	0.020	0.005	0.015	0.013

"Satisficing" - We propose a simple approach to robust policies using the satisficing principle. Since it will be difficult for a single policy instrument to be optimal across all possible states of the world (climate change & expectations) for all farm types then a qualitative analysis can be carried out to see if

there is an instrument that performs "well enough" in each situation under consideration (scenarios and farm types). In Table 8 we report the best and, if within 35% of the best then also the second-best option is presented. One observes that there are several scenarios where there is only one entry for a given farm type and climate scenario, indicating that the second-best option is not within 35% of the best. From a satisficing approach it appears that i) the preferred option is either area yield or weather index insurance depending on the farm type and scenario, and ii) individual yield insurance and ex-post payments as modelled are not budgetarily cost-effective since for most of the scenarios or farm types these instruments do not have an outcome in terms of welfare per dollar spent that is within 35% of the preferred option. In relatively moderate outcomes, where the state of the world is the baseline or where marginal climate change occurs and farmers realize the change, area-yield insurance appears to be more cost-effective in reducing variability of income (as is expressed also by averaging over all farms – last row). However, this does not hold for farms that have high correlation with systemic yield risk (medium risk farms). With misalignment or with extreme events weather index insurance is budgetarily more cost-effective in terms of these more disruptive scenarios. If the government decides to implement weather index insurance, it will be giving more weight to the outcomes for medium risk farms and extreme scenarios. This criterion helps to define the nature of the tradeoffs that the government needs to manage, but, in general, it may not necessarily identify a single choice for the decision maker.

Table 8. First- and second-best policy instruments according to budgetary cost-effectiveness

	Baseline	Climate Change (CC)	CC with adaptation	CC with misalignment	CC with extreme events
Low Risk Farm	Weather***	Area***	Area***	Weather***	Weather***
Medium Risk Farm	Weather*** Area**	Weather***	Weather***	Weather*** Area***	Weather*** Area***
High Risk Farm	Area***	Area*** Weather***	Area***	Weather***	Weather***
Weighted average across farm types	Area*** Weather**	Area***	Area***	Weather***	Weather***

Note. For each climate scenario: *** best, ** within 25% of best, * within 35% of best

MaxMin criterion - This is a very conservative criterion to ensure that policy does not lead to very big mistakes in terms of too much ineffective expenditure. The principle is to take the worst-case scenario for any given instrument and choose the instrument that maximizes the budgetary cost-effectiveness in such a worst-case situation. This is an approach that one would take if there are considerable differences in cost-effectiveness in the worst-case outcome combined with no prior

knowledge of the probability of the different scenarios. As one would expect, Table 9 indicates that the worst-case scenarios for insurance instruments tend to be either when expectations are misaligned or when climate change entails extreme events. Table 9 is derived from Table 7 by indicating for each farm type (columns) the scenario resulting in the worst-case outcome a given instrument (rows). The last row in Table 9 indicates the instrument that performs the best for each farm type in a worst-case situation (MaxMin).

Table 9. Using the MaxMin criterion: worst-case outcome for budgetary cost-effectiveness for different instruments

	Low risk farm	Medium risk farm	High risk farm	Weighted average
Individual yield	Extreme (0.02)	Misalignment (0.03)	Misalignment (0.03)	Misalignment (0.05)
Area yield	Misalignment 0.01)	Misalignment (0.02)	Extreme (0.00)	Misalignment (0.02)
Weather index	Misalignment (0.04)	Misalignment (0.02)	Extreme (0.13)	Misalignment (0.07)
Ex-post payment	Misalignment (0.00)	Misalignment (0.01)	Baseline (0.01)	No adapt. (0.00)
MaxMin across instruments	Weather index	Individual yield	Weather index	Weather index

Under a MaxMin decision rule across scenarios, weather index insurance is the most robust choice for the low and high risk farms (Table 9). It avoids the potential for ineffective outcomes that would occur with area-yield insurance under misalignment or extreme events. Individual yield insurance is the most robust choice for medium risk farms by limiting the negative impacts of misalignment on budgetary cost- effectiveness. Area yield insurance, which emerges as a possible option according to other decision rules, is not attractive under a MaxMin criterion. Area-yield appears to be the worst choice (across instruments) under misalignment therefore if misalignment is driving the worst-case scenario, area yield would not be chosen using this criterion. This is indeed the case for medium and low risk farms. This is due to the large budgetary expenditure that it triggers, thereby reducing the budgetary cost-effectiveness.

6. Conclusions

There is general agreement in the literature about the potential channels for the impacts of GHG emissions and climate change in agriculture. But the evidence from the empirical literature on climate change is not conclusive in terms of the quantitative impacts in different regions, particularly when looking at variability of yields. The literature concurs on reductions in average yields across crops in Saskatchewan. However, there is little information about the impact on the variability of yields, and the information available shows increases, decreases or no changes for different commodities. This makes it very difficult to define appropriate scenarios and optimal policy decisions. In this context it is not surprising that the results of the micro modelling under the marginal climate change scenario show little and sometimes non-

intuitive impacts on insurance uptake and farm risk exposure. Insurance uptake is hardly increased under climate change except under the "extreme events" scenario.

Among the different risk management policy instruments, area yield insurance performs well in the baseline and under a range of climate change scenarios, reducing variability of income, and therefore increasing farmer welfare. Ex-post payments are not effective for any farm type. We find that if adaptation occurs, under a scenario of marginal climate change the welfare effects of policies are typically in between the baseline scenario and that with climate change without adaptation. The bottom line is that the demand and risk reduction outcomes of adopting individual yield insurance as opposed to area yield insurance are comparable, but area yield insurance has much lower budgetary cost so that it may be an attractive option to reduce farming risk when facing uncertain climate change. However, it is imperative that farmers' expectations about climate be correctly aligned, otherwise the budget for an area-yield insurance program could increase beyond control. The potential misalignment of farmers' expectations about climate can dramatically increase the cost of those policy instruments that could be effective in controlling climate change risks. This highlights the importance of extension services and the provision of information that farmers find reliable.

This paper goes beyond indentifying the effectiveness of risk management instruments under stylized climate change scenario and analyze the policy decision criteria when policy makers face ambiguous climate change contingencies. The first step in the policy process is to define the policy objective and target indicator to measure the performance of different instruments. The policy objective in the case of Saskatchewan crop farm is chosen as reducing the income variability faced by farmers (as measured by its welfare impact). Given the opportunity costs of using public funds, government's target indicator is built to represent budgetary cost-effectiveness. It may not always be straightforward to find a single instrument that will perform well across farm types and the range of uncertainty identified for the impacts of different climate scenarios. If the government needs to take a decision to develop a single program for all farm types and potential scenarios, some decision criteria are needed. The decision needs to be made accounting for differences across all farm types and climate scenarios. The standard probabilistic approach only provides a priori probabilities to the different scenarios to obtain an optimal solution. However most often there is ambiguity or intrinsic lack of information about these probabilities.

It is therefore useful to know if an instrument's performance is robust across a set of scenarios and attempt to use this concept of robustness as a decision criterion. Two different approaches towards robust policy decisions have been explored: "satisficing" based on a policy performing well enough across scenarios and farm types, or maximising the outcome under the worse possible situation. The first one does not guarantee providing guidance for a single policy choice, while the second is, by nature, very conservative. The analysis in this paper shows the potential of this methodology to improve policy decision

making under severe uncertainty. The use of the MaxMin criterion for avoiding bad outcomes favours weather index insurance instead of area yield insurance. This is to avoid potential big outlays for area yield insurance under misalignment and extreme event scenarios. However this is done at the expense of medium risk farmers for which the MaxMin criterion leads to individual yield insurance as the preferred option.

Annex

Characteristics of systemic risk in sample farms

Maximum, Minimum, Mean and Standard deviation

	Price (CAD/tonne)			Yield (tonne/ac)			Other crop revenue (CAD/ac)	Cash cost (CAD/ac)	Precipitation (mm)
	Wheat	Barley	Canola	Wheat	Barley	Canola			
Minimum	72.1	59.6	261.5	0.13	0.38	0.23	6.3	16.1	122.8
Maximim	186.9	131.8	344.8	1.31	1.36	1.04	834.5	693.8	435.6
Mean	135.7	103.9	299.6	0.68	0.88	0.51	110.7	111.3	272.9
Standard deviation	14.6	18.9	16.4	0.20	0.26	0.17	79.6	63.1	85.0

Coefficient of correlation

		Price			Yield			Other crop revenue (CAD/ac)	Cash cost (CAD/ac)	Precipitation (mm)
		Wheat	Barley	Canola	Wheat	Barley	Canola			
Price	Wheat	1.00	0.59	0.66	-0.06	0.10	-0.05	0.24	0.33	0.00
	Barley		1.00	0.34	-0.07	-0.16	-0.08	0.15	0.39	0.00
	Canola			1.00	0.01	-0.10	0.03	0.24	0.08	0.00
Yield	Wheat				1.00	0.42	0.11	-0.08	-0.04	0.61
	Barley					1.00	0.13	0.09	0.05	0.67
	Canola						1.00	-0.07	0.03	0.63
Other crop revenue (CAD/ac)								1.00	0.33	0.00
Cash cost (CAD/ac)									1.00	0.00
Precipitation (mm)										1.00

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