Comparative Study of Risk management in Agriculture Under Climate Change

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# Comparative Study of Risk management in AgricultureUnder Climate Change

## Executive summary

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. At the same time it is recognized that there is large uncertainty about the quantitative impacts of climate change in agriculture. Policy decisions need to be informed by scientific knowledge, but they also need to recognize the lack of knowledge that is inherent to the quantification of impacts of climate change. This paper attempts to explore some avenues to tackle the problem of policy decision making under these constrains. The method proposed has three components: a revision of the empirical literature, the use of microeconomic simulation model, and the analysis of different decision making rules by the government.

The revision of the empirical literature on climate change is needed to ensure that the best available scientific knowledge on the impact of climate change on farming risk is used. In particular the focus is on crop yield risk in two specific locations: Australia and the Canadian province of Saskatchewan. There is general agreement that GHG emissions and climate change will affect agriculture through their effects on CO2 fertilization, increased temperatures, changes in rainfall, effects on extreme events and on pest and diseases. 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 believes, and an extreme events scenario.

The micro simulation model is calibrated using micro farm level data from the Canadian province of Saskatchewan and from Australia. 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 in each country. The model is unable to measure the overall efficiency of these policy measures because there is no information about the potential ability of governments to reduce the efficiency costs of potential market failure due to asymmetric information or limits for systemic risk reinsurance. Cost-effectiveness of different policies under different climate change scenarios are calculated in terms of welfare gains of reductions in farm income risk, and in terms of increases in the lowest 10 percentile income.

The analysis is completed by applying different policy decision making rules. First governments could just assume that one scenario will prevail and then take the optimal policy under this scenario. Second, governments could assign a priori probabilities to each scenario and then chose policy that better performs under this compound distribution of yields (“probabilistic” approach). Third, governments could select the policy that performs well enough across all scenarios (“satisficing” approach). Fourth, governments could be very conservative and try to avoid the biggest mistake (“Max Min” approach). Looking to this set of criteria allows governments to think about what is a robust policy measure in the context of strong uncertainty.

Results from the empirical literature show that the mean yields in these two locations are reported to fall under climate change, but the variability of this yields may increase or decrease for different commodities. Climate change introduces significant uncertainty about the distribution of yields, but evidence shows that this does not mean that it increases the variability of these yields. More climate change uncertainty may not imply more risk.

The marginal climate change scenario shows little and sometime non-intuitive impacts on insurance uptake and farm risk exposure. Insurance uptake is hardly increased and in the case of Australia, most of the programs tend to increase the final farm income variability across farm types due to an increased specialization in insured crops that have high but very variable returns. However, diversification to livestock production becomes more important risk management strategies under climate change. In Saskatchewan area yield insurance performs relatively well in terms of insurance uptake and reduced variability in both baseline and marginal climate change scenarios, while ex post payments is not to be effective. However, under the misalignment scenario, area yield insurance risks to incur in very large budgetary costs. This underlines the need of good information and extension policies to avoid to the extent possible farmers’ misperception of risks under climate change. The effectiveness of index insurance critically depends on the correlation between individual and systemic risk, on which the indices are based. In Australia ex post payments seem to perform better than other policies to increase the levels of income in the extreme tail of the distribution, but it does so by providing very high total budgetary payments after a systemic event.

The optimal government decision is not straight forward in either case. Different scenarios and different farm types lead to different best options and taking a decision based on a single scenario is too naïf and most likely inefficient. The probabilistic approach provides single policy responses across scenarios but on the basis of *a prioris* that are based on scarce scientific knowledge, which still has large margins of uncertainty. The analysis of robust policies with criteria such as “satisficing’ or “maxmin” are helpful instruments for policy making under strong uncertainty. This methodological approach deserves further analysis and consideration.

## 1. Effects of climate change on agricultural risk and yield distributions

### 1.1 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.

 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 modeling, several aspects are analyzed such as the interaction between crop insurance and other risk management strategies (e.g., diversification by farmers), and the extent to which they could improve the outcome of of government’s *ex post* disaster assistance. The framework does not allow determining if there is a market failure nor evaluating the total social welfare impact of policies. The purpose is to gives insights about the most efficient instruments to reduce farming risk if the government decides this is its policy objective.

 Estimates are provided for the budgetary and welfare implications associated with a potential misalignment of the farmers’ expectations relative to the actual probability distribution of weather events. Case studies are presented for Canadian farms in Saskatchewan and for farms in Australia. Implications are drawn concerning the robustness of different policy mixes in the face of uncertainty about the perturbation that will be brought about by climate change.

 The paper begins by introducing the relevant variables for analyzing the impacts of climate change on agricultural production, and then continues by examining the projected impacts at the regional level and the impact on mean yields and variability. The paper then continues by rapidly examining adaptation options and their implication for mean yields and correlations. Once the introductory aspects are covered, the central elements of risk management and their relation to climate change are presented, highlighting different policy instruments available to address yield risk. The results of model simulations for Australian farms and Canadian farms in Saskatchewan are then presented, and conclusions are drawn on how climate change affects the optimal policies related to risk management, and the robustness of policy options is discussed. The paper then closes with insights on how policymakers can come to a decision on policies related to risk management in agriculture given the uncertainties introduced by potential climate change. The comparative analysis for Canada and Australia highlights how the two countries, with agricultural risk taking very different forms, may require different responses to agricultural risk and to climate change risk in particular.

### 1.2 Potential impacts of greenhouse gas emissions and climate change on agriculture

 There are two main ways in which the emissions of greenhouse gases may be relevant for agriculture. First, increased atmospheric CO2 concentrations can have a direct effect on the growth rate of crop plants and weeds. Secondly, CO2-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.

#### Effects of CO2 fertilization

 If increases in atmospheric CO2 were occurring without the possibility of associated changes in climate then, overall, the consequences for agriculture would probably be beneficial. The evidence in this respect is that increases in CO2 concentration would increase the rate of plant growth. A doubling of CO2 may increase the photosynthetic rate by 30 to 100%, depending on other environmental conditions such as temperature and available moisture (Pearch and Bjorkman, 1983). A doubling of ambient CO2 concentration causes about a 40 per cent decrease in stomatal aperture in plant (Morison, 1987) which may reduce transpiration by 23-46 per cent (Cure and Acock, 1986).

 There are, however, important differences between the photosynthetic mechanisms of different crop plants and hence in their response to increasing CO2. Some of the current major food staples, such as wheat, rice and soya beans tend to respond positively to increased CO2.[[1]](#footnote-1) At 550 ppm CO2, spring wheat increased grain yields by 8–10% under well-watered conditions (Pinter *et al.*, 1996). More recent studies with optimal nitrogen and irrigation increased final grain yield by 15 and 16% for two growing seasons at elevated CO2 concentration (550 ppm), compared with control treatments (Pinter *et al.*, 1996). Other major staples, such as maize, sorghum, sugarcane and millet are less responsive to increased CO2 concentrations. On average across several species and under unstressed conditions, recent data analyses find that, compared to current atmospheric CO2 concentrations, crop yields increase at 550 ppm CO2 in the range of 10-20% for C3 crops and 0-10% for C4 crops (Ainsworth et al., 2004; Gifford, 2004; Long et al., 2004). Simulation results of unstressed plant growth and yield response to elevated CO2 in the main crop- simulation models have been shown to be in line with recent experimental data, projecting crop yield increases of about 5-20% at 550 ppm CO2 (Tubiello et al., 2007b).However, plant physyiologists recognise that experimental results and model simulations may overestimate actual field-level response (IPCC 2007). Much will depend on the effects of climatic changes on temperatures, water availability, and pests and weeds, all of which can be limiting factors on the yield potential of different crops.

#### Effects of increased temperatures

 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.One of the most important effects of an increase in temperature, particularly in regions where agricultural production is currently limited by temperature, would be to extend the growing season available for plants (e.g. between last frost in spring and first frost in autumn) and reduce the growing period required by crops for maturation. The effects of warming on length of growing season and growing period will vary from region to region and from crop to crop. For wheat in Europe, for example, the growing season is estimated to lengthen by about 10 days per deg.C and in central Japan by about 8 days per deg.C. (Brouwer, 1988; Yoshino et al., 1988). In general the conclusion is that increased mean annual temperatures in mid- to high-latitude regions, if limited to one to three degrees, across a range of CO2 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).

 Whether crops respond to higher temperatures with an increase or decrease in yield depends on whether they are determinate or indeterminate, and whether their yield is currently strongly limited by insufficient warmth. In cold regions very near the present-day limit to arable agriculture any temperature increase, even as much as the 7-9deg.C indicated for high latitudes under a doubling of CO2, can be expected to enhance yields of cereal crops. For example, near the current northern limit of spring-wheat production in the European region of Russia yields increase about 3 per cent per deg.C, assuming no concurrent change in rainfall. In Finland, the marketable yield of barley increases 3-5 per cent per deg.C (Kettunen et al, 1988).

 Away from current temperature-constrained regions of farming and in the core areas of present-day cereal production such as in the Corn Belt of North America, the European lowlands and Ukraine, increases in temperature would probably lead to decreased cereal yield due to a shortened period of crop development (Adams, R.M. *et al*. , 1990).

#### Effects of changes in rainfall

 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. Thus, many schemes used to map zones of agricultural potential around the world have adopted some form of ratio of rainfall to potential evaporation to delimit moisture-availability zones, which are then overlaid on temperature and soils maps to indicate agro-ecological zones. A strongly positive relationship between rainfall and crop yield is generally found in the major mid-latitude cereal-exporting regions of the world, such as the US Great Plains and Ukraine.

 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.

#### Effects from climatic extremes

 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).

 Much of the impact on agriculture from climatic change can be expected to stem from the effects of extreme events. Consider, first, the significantly increased costs resulting from increased frequency of extremely hot days causing heat stress in crops. In the central USA the number of days with temperatures above 35deg.C, particularly at the time of grain filling, has a significant negative effect on maize and wheat yields (Thompson, 1975; McQuigg, 1981; Ramirez and Bauer, 1973). The incidence of these very hot days is likely to increase substantially with a quite small increase in mean temperature. The increase in risk of heat stress on crops and livestock due to global warming could be especially important in tropical and subtropical regions where temperate cereals are currently grown near their limit of heat tolerance.

 An important additional effect of warming, especially in temperate regions, is likely to be the reduction of winter chilling (vernalization). Many temperate crops require a period of low temperatures in winter either to initiate or to accelerate the flowering process. Low vernalization results in low flower-bud initiation and, ultimately, reduced yields. A 1deg.C warming could reduce effective winter chilling by between 10 and 30 per cent (Salinger, 1989).

 Changes in rainfall could have a similarly magnified impact. For example, if mean rainfall in the Corn Belt in March (which is about 100 mm [4 inches]) decreased by 10 per cent (an amount projected by some GCMs under a 2 x CO2 climate) this would raise the probability of less than 25 mm [1 inch] being received by 46 per cent. For cattle, crops and trees a 1 per cent reduction in rainfall could mean that drought-related yield losses increase by as much as a half (Waggoner, 1983).

#### Effects on pest and diseases

 Studies suggest that temperature increases may extend the geographic range of some insect pests currently limited by temperature. One of the major threats of climatic change is the establishment of "new" or migrant pests as climatic conditions become more favourable to them. In cool temperate regions, where insect pests and diseases are not generally serious at present, damage is likely to increase under warmer conditions. Most agricultural diseases have greater potential to reach severe levels under warmer conditions. Fungal and bacterial pathogens are also likely to increase in severity in areas where precipitation increases (Beresford and Fullerton, 1989).

### 1.3 Regional projections of relevance for the three cases studies

#### Europe

 According to the IPCC’s 4th Assessment Report (2007), compared to the other seasons, greater warming in winter and autumn in is projected Northern Europe, and greater warming in summer for Southern Europe. For Northern Europe, increases in winter precipitation and potential decreases in summer precipitation are projected, while year-round decreases are projected for Southern Europe, particularly in summer. In Southern Europe, precipitation signals are assessed to emerge above natural variability only by the 2060s in spring and summer, and beyond 2100 for winter and spring. In Northern Europe, precipitation signals emerge by the 2050s-2060s for winter and spring, and the 2080s for autumn, while the majority of models do not agree on the sign of precipitation changes in summer. Increases in the frequency of extremely wet seasons are projected, especially in winter in spring in northern Europe. Small decreases in dry season frequency for winter, spring and autumn are indicated for Northern Europe. In Southern Europe, the projections suggest decreases in wet season frequency and increases in dry season frequency, especially during spring and summer.

#### North America

 Based on the IPCC’s 4th Assessment Report, models indicate greater seasonal warming over winter and autumn in northern North America, and greater warming in summer over Central and Western North America. Year-round increases in precipitation are projected for Northern North America, particularly over winter and autumn. Precipitation signals are clearly discernible over natural variability for the Northern USA and Canada in all seasons by the 2040s. Decreases in the frequency of extremely dry seasons are indicated over Northern North America and Canada, and little change or small decreases in dry season frequency elsewhere, except an increase for Central North America in summer. The projections suggest increases in the frequency of extremely wet seasons in Northern North America and Canada, especially for winter and autumn for the latter. Increases in the occurrence of very wet seasons are projected for Central, East and Northern North America in winter, spring and autumn.

#### Australia and New Zealand

 The Fourth Assessment Report from the IPCC predicts seasonal warming to be slightly greater during winter and autumn. A very wide range of seasonal precipitation changes is projected covering both increases and decreases in most seasons, but with a tendency towards winter-time decreases. For Northern Australia, there is no overall consensus between the IPCC models on the sign of precipitation changes, or for Southern Australia during winter and spring. Precipitation signals are not clearly discernible over Southern Australia in summer and autumn until at least 2100. The only notable change in the frequency of wet seasons indicated is a slight reduction for Northern regions in summer. The frequency of extremely dry seasons is projected to decrease slightly for Northern regions in spring, and increase in Southern regions for spring, summer and autumn.

### 1.4 Incorporating the effect of climate change on agricultural risk and the associated policy response

 Based on the brief review of the literature presented in the previous section climate change is likely to increase mean temperatures, affect rainfall patterns, increase extreme events in some areas, and may increase the geographic range of some pests. However considerable uncertainty remains on the extent and the spatial distribution of these events (IPCC, 2007a). There is an expectation that in the future, the risk of drought in middle and high latitudes will increase, as will the risk of extreme rainfall events. These global warming and catastrophic events trends are likely to impact on agricultural and livestock production or yields and their variability. Their impact on farming will derive both from increasing uncertainty and increasing risk, which poses strong methodological challenges. 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 modelling 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. An early example can is Black and Thompson (1978). More recent examples are provided in Fuhrer *et al.* (2006) and Torriani *et al.* (2007) examine climate risk impacts on agriculture in Switzerland. Xiong *et al.* (2007) assessed potential maize production in China given alternative climate change scenarios. Although these analyses are informative in expressing the challenges posed by climate change, they do not incorporate farmer adaptation strategies or allow for risk management.

 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, Ramanathan, 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. For example, Schlenker and Roberts (2009) use a panel data set incorporating the whole distribution of weather data and linking it to yields for corn and soybeans in the U.S., and they find non-linear temperature effects across time, location, crops and the sources of variation in temperature and precipitation. This approach is valuable in providing insights on the role of variability of weather patterns, but of limited applicability in risk management.

 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 by 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 indicate 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 while its variability was reduced.

 Continuing in the line of the stochastic approach, OECD (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. Climate change was not the focus of that analysis; however, that model is used here as the starting point for the analysis of the role how climate change might affect the management of risk at the farm level, and the ability of different policy instruments to reduce farming risk and increase farmers’ wellbeing.

 The model analyses representative farms producing several crops under price and yield uncertainty whose income depends both on the crop revenue, and the payments from the government and other risk management strategies. The basic framework of the model is adapted from OECD (2005) developed to analyze the impact on production incentive of different risk reducing policies. The simulation scenarios determine a set of optimal decisions on the farm: the land allocation and the coverage level of risk market instruments.

 In the model a stochastic farm profit is defined as the crop revenue less variable production costs plus net transfer or benefit from a given risk management strategy. The revenue from each crop is expressed as the multiplication of uncertain output price and uncertain yield, less average production cost per hectare. The model assumes that total land input is fixed and is allocated between *n* crops. The model has been calibrated with farm data. More specifically, in order to model a farm producing multiple crops under price and yield uncertainty, the joint distribution of prices and yields of crops is constructed based on the observed distributional information in the farm level data. Following this calibration a set of risk management strategies that are relevant in each country are introduced.

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



Where  denotes the systemic part of yield risk, affecting all farms in the same area, and  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.

 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, which can have an impact on:

1. The mean yield, where if yields are decreasing under the assumptions of the model (decreasing absolute risk aversion) it would imply greater absolute risk aversion.
2. Increase in the variance. However this depends also on correlations between yields of different crops, and price yield correlations. For instance more correlated risks (systemic) and lower price/yield correlations (natural hedge) will imply even riskier scenarios.
3. Increase in the probability of very extreme events. In statistical terms this could imply increase in negative skewness (third central moment) or lower kurtosis (fourth central moment).
4. The correlation of yields with the chosen weather index, affecting the relative demand and performance of weather index insurance vis-à-vis other risk management tools.

 Table 1 outlines the relevance for risk management of the different aspects of climate change relating to agriculture as outlined in the previous section. Hypotheses are made concerning the link with yields and the qualitative role of a variable on the mean, variability, and skewness of yields.

 Table 1. Impact of different forms of climatic changes on the relevant parameters of the model

|  |  |  |
| --- | --- | --- |
| **Type of climatic change** | **Impact on yield distribution** | **Impact on link between weather index and yield (***θ***)** |
| Increase in CO2 concentration | Will increase the mean for some plants, covariance unaffected | Correlation should not change (since SD also not changing) |
| Number of days above a minimum or maximum temperature | Will generally affect mean yield | May decrease correlation |
| Cumulative rainfall  | Can affect both mean and variance | None (because weather index expressed as cumulative rainfall) |
| Increase in variability of rainfall | Can affect both mean and variance | May decrease correlation |
| Extreme events | Will affect skewness of yield distribution, since extreme events tend to lower yields |  |

### 1.5 Policy Design: Risk management instruments under the threat of climate change

 It is common in the literature on risk to segment risk in a way that matches risky outcomes with different “buyers” of risk or mechanisms to transfer or pool risk. These layers are typically defined in terms of the probability of occurrence and the magnitude of the losses, and therefore, the extent to which risk is catastrophic. In Figure 1(a) we present a representation of this layering subdividing it between: (i) **risk retention layer** where events are frequentbut cause relatively limited losses. Farmers should manage this risk so as to smooth income; (ii) **Market Insurance layer** withrisks that are more significant but less frequent where there is scope for farmers to use insurance or options; (iii) **Market failure layer** with risks that generate very large losses at low frequencies making them difficult to pool through insurance and where government may decide to intervene, typically with ex-post payments.

 Figure 1. Probability density function of discrepancy relative to expected income and risk layering: baseline *vs*. with climate change

 The layering approach is intuitively appealing to the extent that once the layers are defined in terms of where the insurance is viable, or is desired to be viable, it also helps define in what region other mechanisms should apply and how to integrate them in a risk management strategy. However, even though this approach is conceptually straightforward, it can be challenging to implement in practice. OECD (2009) highlights three difficulties: (i) defining the underlying variable in the distribution of risk, such as choosing between the distribution of production / yields, or that of income; (ii) estimating an up-to-date probability distribution; and (iii) defining the boundaries between the layers in terms of probability or in terms of losses.

 In figure 1(b) a qualitative representation is provided of how the probability distribution for the discrepancy relative to expected income is altered by the climate change factors listed in Table 1 through their impact on the distribution of yields. The figure highlights the difficulty of estimating an up-to-date probability distribution in the presence of climate change and how actors may be making decisions on probability distributions based on historical experience that do not account for climate change. We refer to a **misalignment in expectations** when farmers or government or insurance companies are not aware of the change in systemic risk brought about by climate change and behave as if this distribution had not changed.

 For the market insurance layer several options are available in terms of how insurance contracts are designed. Three types of insurance can be envisaged for addressing agricultural risk: individual yield, area-yield and weather index insurance, each having different characteristics in terms of data requirements, administrative costs, distribution of risk, and impact on farmers incentives to adapt to climate change. Traditional **individual-yield crop insurance** makes an indemnity payment when the farm household incurs a yield loss. To pay indemnities, the insurance provider must estimate the value of yield loss for each farm household that makes a claim. There are two main types of crop insurance: named peril, and multiple perils. The former involves assessing yield losses based upon a specific risk or peril, with the damage being identifiable with that risk. Hail insurance is the most common named peril insurance, and is offered in the majority of OECD member states. Multiple perils crop insurance, which covers losses due to multiple risks, is more complex, and it has rarely been offered without government subsidies due to high costs of performing a loss assessment that attempts to separate the actual loss by event (Miranda, 1991; Goodwin, 1993). To avoid moral hazard in loss assessment, multiple crop yield insurances usually have high deductible so that small yield loss is not covered in insurance. Climate change is likely to affect the cost of multiple perils crop insurance, further impacting its viability as an affordable option. The complexity of delivering multiple perils crop insurance greatly increases the administrative costs relative to single peril insurance. In the modelling exercise we assume that administrative cost is 30% additional to the fair insurance premium and insurance payments are not triggered if yield loss is less than 30% of the expected level.

 An alternative crop insurance scheme is **area-yield crop insurance**, in which both indemnities and premiums would be based not on a producer's individual yield but rather on the aggregate yield of a surrounding geographical area. Under a so-called area-yield plan, a participating producer would receive, in any given year, an indemnity equal to the difference, if positive, between the area yield and some predetermined critical yield level. Every participating producer in a given area would receive the same indemnity per insured hectare, regardless of his own crop yield, and therefore would pay the same premium rate (Miranda, 1991; Barnett *et al*., 2005). Area-yield crop insurance offers numerous advantages over individual-yield crop insurance. Since information regarding the distribution of the area-yield is generally available also administrative costs would be substantially reduced because claims would not have to be adjusted individually and verification of individual production histories would no longer be required. Moreover, because the indemnities would be based on the area yield rather than the producer's yield, a producer could not significantly increase his indemnity by changing production practices. Thus, under an area-yield insurance program, moral hazard essentially would be eliminated.For this reason area-yield insurance usually does not apply a deductible, and hence it covers even small systemic yield loss. However, area-yield insurance is less effective if yield risk of an individual farmer has less correlation with systemic yield risk. Under a changing climate area-yield insurance would have the advantage of maintaining farmers’ incentives to adapt since farmers with successful adaptation strategies will be more profitable than those who do not adapt to new climatic conditions. In the modelling exercise we assume that administrative cost is 10% additional to the fair insurance premium and insurance payment triggers whenever systemic area yield falls below expected level.

 **Weather index insurance** is another option that attempts to overcome the complexity of individual-yield crop insurance by providing indemnity payments that are based on values obtained from a weather indexthat serves as a proxyfor losses rather than upon the individual losses of each policyholder. The underlying index is based upon an objective measure, such as rainfall or temperature that exhibits a strong correlation with the variable of interest, usually crop yields. A threshold in the proxy variable marks the point at which payments begin. Once the threshold is reached, the payment increases incrementally as the value of the index worsens. For example, an index insurance contract for transferring drought risk would begin making indemnity payments if rainfall levels, as measured at an agreed weather station, fall below the threshold over a defined time period, such as a month or a season, up to a maximum indemnity payment. The payment rate is independent of the actual loss incurred by a policyholder, but depends instead on the value of the index relative to the threshold and the amount of the liability purchased.

 Since indemnities are not tied to actual losses incurred, weather index insurance has some of the same advantages as area-yield insurance over standard individual yield crop insurance, such as requiring a lot less information gathering on risk exposure of individual farms, no need for farm-level individual loss adjustment, the reduction of moral hazard and adverse selection, and not discouraging adaptation to climate change (Collier et al., 2009). Furthermore, it usually requires only weather station to generate the necessary index. All these advantages translate into lower administrative costs, making the insurance more affordable to farmers. Nonetheless, index insurance also has disadvantages, the main one being that the insured could suffer a loss and not receive any or enough indemnity to compensate for the loss (basis risk). The amount of basis risk will depend on how well the chosen index maps into individuals’ losses. If there is too much basis risk, this will diminish interest because farmers will perceive index insurance provides poor protection against risk. In the modelling exercise we assume that administrative cost is 5% additional to the fair insurance premium.

 Finally, the other layer presented in Figure 1 covering market failure for extreme events typically represents the trigger level for **ex-post catastrophic payments** bythe government, whereby a flat payment per hectare is paid for losses beyond the threshold. In the modelling exercise we assume that ex-post payments are triggered when all systemic yield variables fall below the 40 percentile (all crops are being affected at the same time) and a lump sum per hectare is paid when triggered, equal to the expected indemnity of area yield insurance.

### 1.6 Stylized climate change scenarios and adaptation strategies

 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 2.

 Table 2. 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 absed 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 and they  |
| 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 OECD (2008).

 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.

## 2. Impacts of climate change on risk management instruments in Saskatchewan

 This section focuses on the analysis of risk management decisions at farm level in the Canadian province of Saskatchewan. A simplified version of the model developed in OECD (2011) is used. It does not include a representation of all Business Risk Management policies in Canada, such as Agristability. It just focuses on three hypothetical types of insurance and ex post disaster payments.

### 2.1. Brief technical description of Sasketchewan model and data

 The model is based on micro data from Saskatchewan for 457 crop farms producing wheat, barley, and canola. The data covers the period 2003-2008. To examine the impact of different risk management instruments a typology of farms was developed according to the risk characteristics of farms. Three farm types were identified using cluster analysis:

* **Median farms** – These are farms of medium land size with an average level and variation of yield and income. These farms have a medium correlation with systemic yield risk, and they represent 54% of farms (Cluster 1).
* **Small farms** with low variance, high yield. These farms have a high correlation with systemic yield risk, and they represent 30% of the farms in the sample (Cluster 2).
* **Big farms** with high variance, low yields. These farms have low correlation with systemic yield risk and they represent 16% of the farms in the sample (Cluster 3).

 It is assumed that crop yield distributions in the three farm types are affected in the same way by climate change. The perturbations introduced by climate change, gleaned from the literature, are reported in Table 3. These changes in mean yield and variance are applied in the simulations presented here. 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 3. 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).

### 2.2. Impacts and costs of insurance and ex post payments under “Marginal” Climate Change

 As was shown in the previous section 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. To this end, administration costs of insurance are expressed here as a percentage of the fair premium: 5% for weather index insurance, 10% for area-yield insurance and 30% for individual yield. The assumption on administrative costs is meant to quantify in an approximate way the impact of loss assessment and payments under the different insurance instruments. To obtain a meaningful uptake, all insurance policies are assumed to be subsidized at 95% of their respective administration costs.

 Considerable uncertainty exists about possible climate change scenarios. To introduce some of the issues results are first presented comparing the baseline without climate change to the scenario with marginal climate change with no structural adaptation (but with reallocation between crops), presented in Table 4, and in the next section the performance of different instruments under alternative climate scenarios and farmers’ behaviour is presented.

 Impacts of the introduction on insurance and ex post payments under Climate Change (marginal) in Saskatchewan

|  |  |  |
| --- | --- | --- |
|  | **Baseline** | **Marginal Climate Change** |
|  | % of land insured | Welfare gain ($/ha) | Impact on low incomes($/ha) | Diversif. index (% change) | Gov. cost ($/ ha) | % of land insured | Welfare gain ($/ha) | Impact on low incomes($/ha) | Diversif. index (% change) | Gov. cost ($/ ha) |
| **Median 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 |
| **Small 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 |
| **Large 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 hectare, and includes both components from changes in mean and variability.

 The results for the baseline presented in Table 4 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 small 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 (see Annex 2). Some farmers such as those in the median farm category particularly increase individual yield insurance demand. Other farmers such as those in the large farm category boost the demand for index insurance. With climate change large 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 income distribution (see annex for more details). 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.

 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 hectare 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 hectare 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 hectare budgetary cost without climate change, are more heavily impacted by climate change for one of the farm types (e.g. individual yield insurance for median farms, or weather index insurance in the case of large farms). Despite the impact of climate change on the budgetary cost of weather index insurance for large 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.

### 2.3. Insurance demand and impact on risk exposure under alternative Climate Change scenarios.

 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 increae in extreme events were simulated. In this section we present 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 set of scenarios are then those defined in section 1.6: baseline, marginal climate change, adaptation, extreme events and misalignment. The rationale is to analyze policy instruments in the face of uncertainty and attempt to provide inisght on instrument sensitivity to different factors exogenous to policy design. We present in Annex 3 three sets of results under each scenario and for each farm type: the share of land insured the welfare impact and the impact on the lowest 10percentile income.

 When compared to results presented in the previous section, 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 marginal climate change scenario without adaptation. There is a reduction in demand for insurance relative to the marginal climate change case without adaptation, which 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. In the case of extreme events there is a tendency to increase further the demand for insurance across different instruments. Simulations indicate that weather index insurance is sensitive to how the extreme events disrupt the correlation between yields and the weather index.

 In terms of absolute welfare gains due to reduced variability, simulation results can be very different across scenarios (see Annex 3). Even in relative terms the risk reduction ranking of different risk management instruments changes when climate change is accompanied by adaptation and extreme events. 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.

### 2.4. Budgetary costs of different policies: Saskatchewan

 Having examined the demand for different types of instruments for managing risk, and the reduction in risk that these instruments entail for farmers, we now examine the budgetary implications of the different instruments. From analyzing ex-post payments and demand for insurance instruments and their risk reduction properties, we concluded that area yield insurance would likely be preferred by farmers facing uncertain outcomes associated with climate change, followed by individual yield insurance. However, one must take into consideration that these different instruments do not come at the same budgetary cost for the government. From Table 5 we observe that weather insurance and ex-post payments tend to be cheaper for the government, however, ex-post payments are cheap because of the low triggering level imposed. An important distinction in budgetary cost between insurance products and ex-post payments is that cost of ex-post payment could be extremely high when it triggers, whereas cost for subsidizing insurance premium is stable across time.

 Table 8. Budgetary costs of different policy programs under different climate change scenarios in Saskatchewan

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Baseline** | **Marginal Climate Change** | **Extreme events** |
|  |  | No adaptation | Adaptation | Misalignment | (no adaptation) |
| **Individual yield**  | 210 | 411 | 224 | 641 | 599 |
| **Area yield**  | 197 | 214 | 103 | 2436 | 262 |
| **Weather index**  | 80 | 109 | 74 | 211 | 101 |
| **Ex-post payment** | 82 | 151 | 52 | 311 | 75 |
| Percentage of triggering | 3.8 | 5.6 | 4.6 | 14.4 | 2.6 |
| Budgetary cost whentriggered | 2051 | 2565 | 1083 | 4303 | 2756 |

 Individual yield insurance tends to be the most expensive, as one would expect. Furthermore, without adaptation climate change risks increase significantly the budgetary cost of individual yield insurance, particularly in the misalignment and the extreme events scenarios.

 Area yield insurance performs quite well under climate change relative to the baseline in terms of budgetary expenditure as long as farmers’ expectations are not misaligned. Misalignment can create very large budgetary outlays in general, but it results particularly large in the area yield insurance simulations. This can be explained because area yield insurance is based on the systemic component of risk that is most likely to increase under climate change. This is in theory also true for weather index insurance; however, under misalignment the uptake of weather index insurance is lower than for area yield insurance and hence the budgetary costs do not rise as dramatically. As long as there is no misalignment in expectations about climate outcomes, the cost of instruments does not increase radically with climate change; however, governments need to be aware of the possibility of these extremely high budgetary costs under misalignment, especially in the case of area-yield insurance.

## 3. Impacts of climate change on risk management instruments in Australia

 This section focuses on the analysis of risk management decisions at farm level in Australia. A simplified version of the model developed in OECD (2011) is used. It does not include a full representation of the Drought Policy. It excludes the interest rate subsidies and it just focuses on three potential types of insurance and an ex post disaster payment that is not fully comparable with the ECRP payments.

### 3.1. Brief technical description of Australian model and data

 The model is based on micro data from 78 broadacre farms in Australia producing wheat, barley, and canola and with revenue from other activities (livestock). The data covers the period 2003-2008. As for the Canadian case, to examine the impact of different risk management instruments a typology of farms was developed according to the risk characteristics of farms. Three farm types were identified:

* **Median farms**– This group represents 53% of farms in the sample, and farms are of medium size with an average level yield and average variation of yield and income, but high correlation with systemic yield risk
* **Small farms**– These farms have high level yield and low variation of yield and income with, and a low correlation with systemic yield risk. They represent 14% of farms in the sample
* **Large farms**– These farms have low level and high variation of yield and income with medium correlation with systemic yield risk, and the group represents 32% of farms in the sample

 Similarly to the Canadian case, it is assumed that crop yield distributions in the three farm types are affected in the same way by climate change. The perturbations introduced by climate change, gleaned from the literature, are reported in Table 6. These changes in mean yield and variance are applied in the simulations presented here. 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. As in the case of Australia, only under the extreme events scenario the standard deviation of yields increases for all commodities.

 Simulated Climate Change Scenario in Australia

|  |  |  |
| --- | --- | --- |
|   | % Change in mean yield | % Change in standard deviation |
|  | No adaptation | Adaptation | Extreme events | Marginal change | Extreme events |
| Wheat  | -17.4 | -7.2 | -13.7 | 10.3 | 10.5 |
| Barley  | -28.8 | -20.0 | -27.4 | 0.0 | 9.4 |
| Canola  | -28.7 | -19.9 | -29.1 | -6.1 | 1.7 |

### 3.2. Impacts and costs of insurance and ex post payments under “Marginal” Climate Change

 In the baseline there is a strong preference by farmers to buy individual yield insurance, due to the high level of risk, which is systemic and strongly correlated across crops (Table7). Furthermore, insurance is offered only for crops, and since individual yield insurance covers both systemic and basis risk, it is profitable for farmers to reduce livestock production (for which no insurance is provided) and increase production of crops that are more risky but have higher returns. For the median farm there is considerable demand also for area yield insurance, which is likely due to the high positive correlation between the farm and the area yield by construction since this is the median farm. The demand for weather index is highest for the large farms category, indicating that the demand for weather index insurance critically depends on the correlation between farm yield and weather index.

 Surprisingly, insurance demand is hardly affected by climate change and can decrease substantially in some cases. This is the case for individual yield insurance for both the median farm and the large farm typologies. The change occurs because there is not higher variability for all commodities and higher yield risk increases the insurance premium, making it more expensive to insure.

 The negative welfare gains for most policies and farm types indicate that the net effect of insurance is more specialization and higher income variability. This is due to the cross effects with livestock production in Australian mixed farms. This effect may be exaggerated in the model because livestock returns are assumed to have no possibility of insurance and low correlation with systemic risk and with weather index. But it is a likely effect in mixed farms: insurance reduces diversification and can increase farm income variability. Of the two instruments that do perform relatively less badly – individual yield insurance and ex-post payments – neither dominates across allfarm types. Individual yield insurance is better for large and small farms both for welfare associated with reducing variability and for the impact on the lowest 10th percentile of income; however, this instrument comes consistently at a much higher cost per hectare than ex-post payments.

 Impacts of the introduction on insurance and ex post payments under Climate Change (marginal) in Australia

|  |  |  |
| --- | --- | --- |
|  | **Baseline** | **Marginal Climate Change** |
|  | % of land insured | Welfare gain ($/ha) | Impact on low incomes($/ha) | Diversif. index (% change) | Gov. cost ($/ ha) | % of land insured | Welfare gain ($/ha) | Impact on low incomes($/ha) | Diversif. index (% change) | Gov. cost ($/ ha) |
| **Median Farm** |  |  |  |  |  |  |  |  |  |  |
| Individual  | 100.0 | -4.41 | -1.69 | -12.4 | 9.4 | 58.4 | 0.30 | 7.38 | -3.09 | 5.27 |
| Area yield  | 72.4 | -2.55 | -6.60 | -4.9 | 4.3 | 58.1 | -1.05 | -4.63 | -4.63 | 3.08 |
| Weather index  | 44.4 | -1.15 | -2.09 | -1.8 | 2.1 | 43.9 | -0.62 | 2.22 | -4.12 | 1.81 |
| Ex-post  | 0.0 | -0.21 | 2.34 | -0.5 | 4.9 | 0.0 | -0.14 | 6.18 | -1.11 | 5.30 |
| **Large Farm** |  |  |  |  |  |  |  |  |  |  |
| Individual  | 80.7 | 3.06 | 11.60 | -23.7 | 68.7 | 64.8 | 0.23 | 2.63 | -5.33 | 7.71 |
| Area yield  | 24.2 | 0.33 | -6.31 | 1.7 | 1.1 | 38.0 | -1.20 | -6.56 | -4.40 | 2.23 |
| Weather index  | 56.4 | -0.80 | -6.15 | -4.1 | 1.5 | 36.7 | -0.56 | 0.30 | -6.10 | 1.52 |
| Ex-post  | 0.0 | -0.05 | 2.38 | -0.3 | 1.4 | 0.0 | -0.14 | 3.32 | -1.18 | 3.84 |
| **Small Farms** |  |  |  |  |  |  |  |  |  |  |
| Individual  | 94.2 | -0.14 | 20.53 | -2.8 | 8.2 | 87.7 | 0.03 | 10.45 | -2.95 | 6.32 |
| Area yield  | 33.8 | -1.41 | -6.26 | -0.4 | 2.2 | 37.7 | -1.12 | -7.87 | -1.37 | 2.14 |
| Weather index  | 38.8 | -1.40 | 2.14 | -0.8 | 1.8 | 40.2 | -1.01 | -4.02 | -1.79 | 1.66 |
| Ex-post  | 0.0 | -0.18 | 0.00 | -0.1 | 2.8 | 0.0 | -0.18 | 3.42 | -0.29 | 3.67 |

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 hectare, and includes both components from changes in mean and variability.

 In the baseline, the lowest budgetary cost per hectare is for either weather index insurance (median and small farms) or area yield insurance (large farms). However, to these low budgetary costs correspond low benefits as highlighted by these instruments’ impact on low incomes and on farmer welfare. With marginal climate change the budgetary cost per hectare typically decreases for insurance instruments, whereas it increases for ex-post payments (Table 7).

### 3.3. Insurance demand and impact on risk exposure under alternative Climate Change scenarios: Australia.

 In this section we present how the policy instruments would perform under alternative scenarios. Detailed results are presented in Annex 4. Unlike in the Canadian case, the demand for insurance in Australia with adaptation tends to be greater than both the baseline and the scenario without adaptation, or in the higher range of that interval. This is due to the relative attractiveness of livestock *vis-à-vis* crops: with adaptation crops become more attractive relative to livestock (as in the baseline), but with greater systemic risk associated with climate change there is a comparable demand, or greater, than in the baseline.

 The extreme events climate change scenario tends to increase further the demand for insurance across different instruments. Given how extreme events affect both livestock and crops, the availability of crop insurance under such a scenario, and the correlation across all activities of these impacts, then farmers specialize even more than the baseline case, as opposed to diversify with livestock as in the marginal climate change without adaptation. All forms of insurance would be in high demand in the case of extreme events, and particularly individual yield insurance which covers both the systemic and basis risk elements.

 If one views subsidized insurance or ex-post payments as a way to safeguard the incomes of the most vulnerable farmers in years of adverse conditions, then a more appropriate measure may be the transfers that policy instruments provide to the farmers in the lowest 10th percentile of income (per hectare). In fact, the drought policy framework in Australia is more directed toward helping farmers under exceptional circumstance, which is beyond their capacity to manage. In this respect the relative performance ranking of different risk management instruments changes when climate change is accompanied by adaptation and extreme events; however, depending on the scenario and the cluster, either individual yield or ex-post payments typically remain to be preferred.

 As in Canada, the performance of individual yield insurance is relatively higher in covering large yield shocks and avoiding large income losses. Moreover, ex-post payment performs much better than in the case of Canada. This is because it is, by design, triggered by systemic yield shocks. In Australia, yield risk is very systemic so that ex-post payment triggers more often when farmers experience large income shock. In any case, it is less straightforward to find a single instrument that will perform well across farm types and in the range of uncertainty identified for the impacts of climate change. According to the results in Annex 4, one could exclude area yield and weather index insurance as policy instruments of choice in Australia.

### 3.4. Budgetary costs of different policies: Australia

 From the previous section it appears that there is no single instrument that emerges as a best option in terms of welfare gain or safeguarding more vulnerable farmers, across all farm types and possible climate change scenarios. However, taking into consideration the different budgetary costs of instruments can provide some insight. Despite area yield and weather index insurance being attractive from a budgetary perspective they are already excluded on the limited contribution from a welfare perspective. Between Individual yield insurance and ex-post payments we first of all observe that individual yield insurance would be very expensive in the baseline scenario without climate change, especially when compared to the ex-post payment that is lower than the budgetary cost of individual yield insurance even if the ex-post payments are triggered (Table 8). Compared to the Canadian case one can observe that ex-post payments are triggered more often in the Australian case, as one would expect given the higher level of systemic risk present even in the baseline.

 Marginal climate change, unless there is misalignment in expectations, makes individual yield insurance become budgetary less onerous because of the lower rate of uptake by farmers. As one would expect, with misalignment the budgetary outlay increases because the uptake of insurance is identical to the baseline (by construction) and there are additional costs associated with climate change because the government is assumed to cover part of the additional insurance indemnities associated with the misalignment case. Across all scenarios individual yield insurance is confirmed to be the most expensive, as one would expect. Furthermore, if there is misalignment this increases significantly the budgetary cost of individual yield insurance. However, an important distinction in budgetary cost between insurance products and ex-post payments is that cost of ex-post payment could be extremely high when triggered, whereas the cost of subsidizing insurance premium is stable across time.

 Budgetary costs of different policy programs under different climate change scenarios in Australia

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Baseline** | **Marginal Climate Change** | **Extreme events** |
|  |  | No adaptation | Adaptation | Misalignment | (no adaptation) |
| **Individual yield**  | 9 279 | 1 498 | 2 152 | 10 389 | 3 092 |
| **Area yield**  | 569 | 585 | 650 | 5 518 | 1 222 |
| **Weather index**  | 398 | 372 | 416 | 363 | 559 |
| **Ex-post payment** | 658 | 1 004 | 1 030 | 3 330 | 1 503 |
| Percentage of triggering | 10.8 | 15.5 | 14.3 | 29.8 | 11.1 |
| Budgetary cost when triggered | 6 148 | 6 156 | 6 841 | 1 0841 | 12 860 |

 Ex-post payments perform quite well under climate change relative to the baseline in terms of budgetary expenditure as long as farmers’ expectations are not misaligned (Table 8). Misalignment can create very large budgetary outlays in general across instruments, but it results particularly large in the two options that are attractive from a welfare gain perspective: individual yield insurance and ex-post payments. This can be explained because in the misalignment case farmers are assumed to be planning their production decisions without taking into account the increased variability due to climate change, which has implications for individual yield indemnities and for the triggering more often the ex-post payments. As long as there is no misalignment in expectations about climate outcomes, the cost of instruments does not increase radically with climate change; however, governments need to be aware of the possibility of these extremely high budgetary costs if misalignment occurs.

 The main message from this section is that given the similar risk reduction outcomes of adopting individual yield insurance and ex-post payments, and given the much lower budgetary cost of ex-post payments, then ex-post payments are likely to be the preferred 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 needed for managing climate risk through any of these instruments could increase beyond control.

## 4. Robust Policies under ambiguity: the government perspective

### 4.1 Possible approaches for choosing a risk management policy under uncertainty

 In the previous sectionswe analyzed welfare changes expressed as the changes in certainty equivalent associated with a reduction in the variability of income, and we also analyzed the impact of policy instruments on the income for famers in the lowest 10th percentile 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 (presented in Annex 3 Tables 21-22 for Canada, and Annex 4 Tables 24-25 for Australia). 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 3. The Bayesian approach to ambiguity: Combining probability distributions from different scenarios

y0

“No climate change”

y1

“marginal change in mean and variability”

y2

“Extreme events”

p0

p1

p2

ΔCE1: Change in certainty equivalent for an instrument under “no climate change”

ΔCE1 : Change in certainty equivalent for an instrument under “marginal climate change”

ΔCE2 : Change in certainty equivalent for an instrument under “extreme events”

Apply a policy instrument

Bayesian approach combines ΔCEi based on probability of different states of the world

ΔCEk=∑ ΔCEk,i

 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 on Canada and Australia. 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.

### 4.2 What policies for Saskatchewan?

 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 9 we observe that the Bayesian decision by assuming those probabilities favours area-yield insurance and weather index insurance depending on thefarm type. In the case of farmers that had relatively higher variation of yield in the baseline (median and large farms) area yield insurance is the most cost-effective, whereas for farms with lower variability of yields weather index insurance appears to be more effective. However, the two instruments perform in a quite similar manner. When averaged over all farms based on the number of hectares 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.

 Increase in certainty equivalent of income per $ spent in one hectare in Saskatchewan

|  |  |  |
| --- | --- | --- |
| **Median 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 |
|  |  |  |  |  |  |  |
| **Small 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 |
|   |  |  |  |  |  |  |
| **Large 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 10 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).[[2]](#footnote-2) However, this does not hold for farms that have high correlation with systemic yield risk (small 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 small 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.

 First- and second-best policy instruments according to budgetary cost-effectiveness in Saskatchewan

(second-best only recorded if within 35% of optimal instrument for a given farm type and scenario)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Baseline** | **Climate Change (CC)** | **CC with adaptation** | **CC with misalignment** | **CC with extreme events** |
|  |
| **Median farm** | Weather\*\*\* | Area\*\*\* | Area\*\*\* | Weather\*\*\* | Weather\*\*\* |
| **Small Farm** | Weather\*\*\*Area\*\* | Weather\*\*\* | Weather\*\*\* | Weather\*\*\* Area\*\*\* | Weather\*\*\*Area\*\*\* |
| **Large 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 10 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 11 is derived from Table 9 by indicating for each farm type (columns) the scenario resulting in the worst-case outcome a given instrument (rows). The last row in Table 11 indicates the instrument that performs the best for each farm type in a worst-case situation (MaxMin).

 Using the Max-min criterion to guide instrument choice: worst-case outcome for budgetary cost-effectiveness for different instruments in Saskatchewan

(by farm type)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Median farm** | **Small farm** | **Large 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) |
| **Max-min 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 median and large farms (Table 11). 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 small 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 Max-Min 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 median and small farms. This is due to the large budgetary expenditure that it triggers, thereby reducing the budgetary cost-effectiveness.

### 4.3 What Policies for Australia?

 Transfers to farms with the lowest 10th percentile income per $ spent in one hectare in Australia

|  |  |  |
| --- | --- | --- |
| **Median Farm– transfer to lowest income farms per AUD spent**  |  |  |
|  | **Baseline** | **Marginal Climate change**  | **Extreme events** | **Bayesian decision** |
|  | **No adapt.** | **Adaptation** | **Misalignment** |  |   |
| **Individual yield** | -0.18 | 1.40 | 1.44 | 0.16 | 0.06 | 0.47 |
| **Area yield**  | -1.53 | -1.50 | -1.42 | 0.46 | -0.34 | -0.88 |
| **Weather index** | -1.02 | 1.22 | -3.03 | -7.32 | -3.62 | -2.68 |
| **Ex-post payment** | 0.48 | 1.17 | 0.18 | 0.63 | 1.95 | 0.94 |
|  |  |  |  |  |  |  |
| **Small Farm- transfer to lowest income farms per AUD spent** |  |  |
|  | **Baseline** | **Marginal Climate change**  | **Extreme events** | **Bayesian decision** |
|  | **No adapt.** | **Adaptation** | **Misalignment** | **No adapt.** |   |
| **Individual yield** | 2.50 | 1.65 | 1.69 | 0.87 | 0.51 | 1.454 |
| **Area yield**  | -2.87 | -3.69 | -1.99 | 0.64 | -2.95 | -2.294 |
| **Weather index** | 1.19 | -2.42 | -1.49 | -14.69 | -4.32 | -3.883 |
| **Ex-post payment** | 0.00 | 0.93 | 0.34 | 1.06 | -0.51 | 0.261 |
|  |  |  |  |  |  |  |
| **Large Farm- transfer to lowest income farms per AUD spent** |  |  |
|  | **Baseline** | **Marginal Climate change**  | **Extreme events** | **Bayesian decision** |
|  | **No adapt.** | **Adaptation** | **Misalignment** |  |   |
| **Individual yield** | 0.17 | 0.34 | -0.87 | 0.44 | 0.53 | 0.159 |
| **Area yield**  | -5.54 | -2.94 | -3.32 | 0.59 | -1.67 | -2.749 |
| **Weather index** | -4.03 | 0.20 | -5.10 | -5.33 | 6.12 | -1.183 |
| **Ex-post payment** | 1.75 | 0.87 | 0.26 | 0.49 | 1.44 | 1.065 |
|   |   |   |   |   |   |  |
| **Pool of all farms- transfer to lowest income farms per AUD spent** |
|  | **Baseline** | **Marginal Climate change**  | **Extreme events** | **Bayesian decision** |
|  | **No adapt.** | **Adaptation** | **Misalignment** |  |   |
| **Individual yield** | 0.205 | 0.134 | 0.356 | 0.170 | 0.109 | 0.189 |
| **Area yield**  | -0.386 | -0.468 | 0.138 | 0.156 | -0.340 | -0.210 |
| **Weather index** | -0.458 | -0.475 | 0.008 | 1.023 | -0.369 | -0.114 |
| **Ex-post payment** | 0.505 | 0.148 | 0.368 | 0.166 | 0.497 | 0.364 |

 Unlike Table 9 for Saskatchewan, Table 12 for Australia present the cost-effectivenes indicators in terms of the increase in the lowest 10% income of each farm type and for the pool of all farms. The definition of the indicator that will be targeted is also an important decision for policy makers.

 **“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 12 we observe that the Bayesian decision by assuming those probabilities favours ex-post payments for median and large farms and individual yield for small farms. However, the two instruments perform in a quite similar manner. When averaged over all farms based on the number of hectares in each farm category, the Bayesian approach indicates that ex-post payments are more cost-effective than individual yield insurance in delivering relief to farms with low returns.

 **“Satisficing”** - In Table 13 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 individual yield insurance or ex-post payments depending on the farm type and scenario, and (ii) area yield and weather index insurance are not budgetarily cost-effective since for most of the scenarios or farm types these instruments have an outcome in terms of impact on low income farms per dollar spent that is not within 35% of the preferred option. At the aggregate level the preferred instrument to reduce the impact on the lower income farms are ex-post payments as long as misalignment is avoided. In relatively moderate outcomes, where the state of the world is the baseline or where marginal climate change occurs and farmers realize the change it appears that for small farms it is cost-effective to have individual yield insurance, whereas for large farms it is more cost-effective to have ex-post payments. With misalignment or with extreme events it is less evident what policy instrument is budgetarily more cost-effective in terms of these more disruptive scenarios since there is variation across farm types: although ex-post payments remain a viable option, in these more disruptive scenarios also insurance instruments can become cost-effective.

 First and second-best policy instruments according to budgetary cost-effectiveness in Australia

(second-best only recorded if within 35% of optimal instrument for a given farm type and scenario)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Baseline** | **Climate Change (CC)** | **CC with adaptation** | **CC with misalignment** | **CC with extreme events** |
|  |
| **Median farm** | Ex-post\*\*\* | Individual\*\*\*Ex-post\*\*Weather \*\* | Individual\*\*\* | Ex-post\*\*\*Area yield\*\* | Ex-post\*\*\* |
| **Small farm** | Individual\*\*\* | Individual\*\*\* | Individual\*\*\* | Ex-post\*\*\*Individual\*\* | Individual\*\*\* |
| **Large farm** | Ex-post\*\*\* | Ex-post\*\*\* | Ex-post\*\*\* | Area yield\*\*\*Individual\*\*Ex-post\*\* | Weather \*\*\* |
| **Pool of all farms** |  Ex-post\*\*\* | Ex-post\*\*\*Individual\*\* | Ex-post\*\*\* Individual\*\* | Weather\*\*\* | Ex-post\*\*\* |

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

 **MaxMin criterion** - As one would expect, Table 12 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 14 is derived from Table 12 by indicating for each farm type (columns) the scenario resulting in the worst-case outcome a given instrument (rows). The last row in Table 14 indicates the instrument that performs the best for each farm type in a worst-case situation (MaxMin).

 Using the Max-min criterion to guide instrument choice: worst-case outcome for budgetary cost-effectiveness for different instruments (by farm type) in Australia

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Median farm** | **Small farm** | **Large farm** | **Weighted average** |
| **Individual yield** | Baseline (-0.18) | Extreme (0.51) | Adaptation (-0.87) | Extreme (0.11) |
| **Area yield**  | Baseline (-1.53) | No Adapt. (-3.69) | Baseline (-5.54) | No Adapt. (-0.47) |
| **Weather index** | Misalignment (-7.32) | Misalignment (-14.69) | Misalignment (-5.33) | No Adapt. (-0.48) |
| **Ex-post payment** | Adaptation (0.18) | Extreme (-0.51) | Adaptation (0.26) | No Adapt. (0.15) |
| **Max-min across instruments** | Ex-post | Individual | Ex-post | Ex-post |

 Under a MaxMin decision rule, ex-post payments are the most robust choice for median and large farms. It avoids the potential for ineffective outcomes that would occur with area-yield or weather index insurance under the baseline or misalignment scenarios. Individual yield insurance is the most robust choice for small farms by limiting the negative impacts of misalignment on budgetary cost- effectiveness. It should be noted that in terms of worst-case outcomes individual yield insurance performs quite well also for median and large farms. However, in aggregate terms ex-post payments are preferred.

## 5. Concluding remarks

 The analyses presented in this paper using stochastic modelling focuses on the impact of climate change, and the uncertainty surrounding it, on farmers’ risk management decisions and the outcome of risk management policies. The first part of the paper reviews the available information on the impacts of climate change and, more specifically, its impacts on the variability of yields. The second part of the paper presents results of micro simulations using the information on climate change in the first part. They include results on three types of farms in Saskatchewan and Australia show that different farmers face different type of risks and effectiveness of each policy instrument largely depends on the characteristics of risk that they face. The third part of the paper focuses on different criteria for policy decision making.

 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 the variability of yields. The literature states reductions in average yields across crops in both locations under study in this paper (Australia and 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 very difficult to define appropriate scenarios and take 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. Even under climate change, most of the programs increase the variability of farm income in the simulations on Australia. This is due to an increase in farm specialization once they are covered for the risks of the most profitable activities. The framework is not able to tackle the crutial question of the overall efficiency of these programmes because the simulations assume that the government is not able to modify the potential inefficiencies in the market due to information asymmetries or other reasons.

 In **Saskatchewan**, 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 needed for an area-yield insurance program could increase beyond control.

 In **Australia**, which has a higher level of risk and this risk is more systemic, results are very different from Saskatchewan. Whereas ex-post payments would perform poorly in Canada, they perform well in Australia as does individual yield insurance. Farmers react to the introduction of insurance by reducing livestock and specializing in crops, which can lead to very high costs for indivdual yield insurance. Under marginal climate change livestock is an attractive diversification risk management option even with subsidized crop insurance, and ex-post payments appear to be providing the most benefits per dollar spent. The Australian example underlines the importance of risk management instruments that are not commodity specific in order to avoid the specialization on the most risky activities.

 In both the Saskatchewan and the Australian case studies 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.

 The first step in the policy process is to define the policy objective and target indicator to measure the performance of different instruments. Two objectives have been considered in this paper: reducing the income variability faced by farmers (as measured by its welfare impact) or increasing the lowest 10 percentile income of farmers. The first is used to analyze policy decision making in Canada and the second in Australia. Given the opportunity costs of using public funds, government’s target indicator is built to represent budgetary cost-effectiveness. The results are shown to be sensitive to the choice of a different objective or target indicator.

 It may not always be straightforward to find a single instrument that will perform well across farm types and in 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 scenario. The standard probabilistic approach would just provide 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 enoughacross scenarios and farm types, or maximising the outcome under the worse possible situation. The first one does not guarantee to pick up 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.

 For Saskatchewan farmers, the avoiding bad outcomes maxmin criterion favours weather index insurance instead of area yield. 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 small farmers for which max min criterion leads to individual yield insurance as the preferred option..

 For Australia, for which the objective of improving the lowest 10 percentile is used, different decision rules provide different answers, so that there is no straightforward answer to what policy would be the best. However, it does emerge from these preliminary results that for all three decision rules area yield and weather index insurance are not budgetarily cost-effective. Based on these preliminary results the tentative conclusion is that, at the aggregate level in Australia, ex-post payments could be a more cost-effective option for Australia to reduce the impact of climate variability on the lower income farms compared to insurance instruments.

Questions for delegates

 The document is a preliminary draft for a three-country study. Spain will be added in the coming months following the same structure of the current document. The Secretariat requests that delegates provide guidance on how to improve this work, in particular its policy relevance:

* How could we improve the representation of the uncertainty associated with climate change?
* How could we improve the representation of potential policy choices?
* How could we improve the the method to define robust policy responses?
* Are the policy results on the Canadian province of Saskatchewan and on Australia meaningful?

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# Annex 1- Technical background on the policy simulation

 The stochastic simulation model in Chapter XX introduces a set of risk management strategies that are relevant in Canada and Australia; namely production diversification and three types of insurance: individual crop yield insurance, area yield insurance and weather index insurance. In addition, the model introduces an ex-post payment that is triggered by a systemic yield loss. The model also analyzes empirically the producer’s participation in the risk market and its impacts on farm welfare. Interactions between diversification and the use of insurance products and ex-post payments are also investigated. The basis of the model is Expected Utility Theory, but the model are tailored to the risk exposure and strategic environment revealed by the micro data of 402 crop farm in the State of Saskatchewan in Canada an 78 broadacre farms in Australia.

 The model analyses a representative farm producing three major crops (wheat, barley and oilseed) under price, yield uncertainty in addition to the uncertainty in other agricultural revenue (other crop revenue in Canada and livestock revenue in Australia) and cost. The income depends both on agricultural revenue, insurance indemnity and payments from the government. The simulation scenarios determine a set of optimal decisions in the farm; the land allocation and the insurance coverage. Since the first order conditions to maximize the expected utility lead to analytical expressions that are difficult to quantify, the analysis depends on Monte-Carlo simulation with an empirically calibrated model. The first step of calibration generates the multivariate empirical distribution of uncertain prices, yields and cost for crop production as well as the revenue from other production for each representative farm. The second step introduces a set of insurance products and ex-post payment. Kimura and LeThi (2011) presents technical back ground of stochastic model more in detail.

### Calibration of 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 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. Observed characteristics of three clusters of farms

 Characteristics of each cluster of farms



### Calibration of systemic risk and idiosyncratic risks of representative farms

 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. Table 16 presents the characteristics of systemic risks in Canada and Australia.[[3]](#footnote-3)

 Characteristics of systemic risk, Canada

Maximum, Minimum, Mean and Standard deviation



Coefficient of correlation



 Characteristics of systemic risk, Australia

Maximum, Minimum, Mean and Standard deviation



Coefficient of correlation



 Because the number of observations in available farm level data is too small, the joint distribution of prices, yields and other risks was constructed based on the observed characteristics of systemic risk in Canada and Australia. This distribution is used for Monte Carlo analysis. The simulation in Canada assumed a truncated normal distribution. The distributions are truncated so that it does not 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.

 On the other hand, idiosyncratic risk calibrated as the difference between the average yields and the yields of a representative single farm chosen in each group. The choice of farm is made based on its approximations to the characteristics of each cluster of farm. Monte-Carlo simulation assumed normal distribution assuming that idiosyncratic yield risk are correlated across crops.

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### Calibration of climate change risk

 The model assumes that climate change mainly affects systemic risk. There climate change scenarios were developed: marginal climate change with and without adaptation, and extreme events scenario. 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).[[4]](#footnote-4) 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. Table 18 presents the yield risk calibrated under different climate change risk scenarios.

 Yield risk under climate change scenario

Canada



Australia



### Stochastic simulation model

 The representative farm in Canada and Australia is assumed to allocate land among three crops and other residual crops or livestock. The initial wealth that is necessary to compute the farm welfare is computed as the average net worth of grain and oilseed farms in Saskatchewan in 2008 for all farms, CAD 1467 per ha. In Australia, average wealth position of AUD 1551 per ha in the dataset is assumed to all the representative farms. The representative farms are assumed to be risk averse and the coefficient of constant relative risk aversion of 2 is applied to all of our simulations.

 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) $U\left(\tilde{π}+ω\right)=\frac{(\tilde{π}+ω)^{(1-ρ)}}{(1-ρ)}$

$π=\tilde{p}\_{i}\*\tilde{q}\_{i}\*f\_{i}\left(L\_{i}, A\_{i}, I\_{i}\right)-r\*L-w\*A-n\*I+g(\tilde{p},\tilde{q},γ…)$where the utility (U) depends on the uncertain farm profit and initial wealth; $ρ$ stands for the degree of constant relative risk aversion (CRRA).

 The uncertain margin ($\tilde{π})$ 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 () is not crop specific. However, the crop specific production cost adjustment factor () is calibrated for each crop so that the initial land allocation becomes the optimum. The model assumes that total land input is fixed and is allocated between wheat, barley, oilseed and other crop or livestock 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)****

where:

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

 $\tilde{q}\_{i}$ uncertain yield of crop *i*

  uncertain variable cost

  cost adjustment factor of crop *i*

  area of land allocated to crop *i* and

 *OR* revenue from other crops in Canada, livestock in Australia

  transfer from government or insurance indemnity

  level of insurance coverage decided by farmer

 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) $ CE=[\left(1-ρ\right)EU(\tilde{π}+ω)]^{^{1}/\_{(1-ρ)}}-ω$

 initial wealth of the farmer

### Calibration of risk management strategies

#### Crop diversification

 Since the specification of crop production is neutral to the farm size in this model, the representative farm is assumed to cultivate fixed area of farmland and allocate land between available crop and livestock in each country. Although farmer tends to rotate crop due to the biological reason, the model assumes no limit on the scope of the crop diversification. The degree of crop diversification is represented by the coefficient of variation of market revenue per hectare. A higher coefficient of variation of crop revenue is used as indicator of less use of crop diversification strategies and built on a lower diversification index. If the farmer uses less diversification strategy and specializes in a specific crop, the diversification index declines because the farmer allocates more land to crops that generate a higher return with higher variability. The initial value of diversification index is set as 100 and the change of the diversification index is expressed as *-1* times the percentage change in the coefficient of variation of market return.

### Calibration of insurance products and ex-post payment

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.

#### 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 in Canada and Australia.

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 Indemnity receipt Insurance premium payment

 forward price of commodity *i*

 area of land for commodity *i* which farmer insures its yield

  historical average yield of commodity *i*

 proportion of yield insured for commodity *i*

 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 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 in Canada and Australia.

#### Weather index insurance

 Weather index insurance is calibrated based on precipitation risk in Canada and Australia. The design follows a standard weather index contract. In Canada, 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. In Australia, the triggering point is set at annual inflow to Murray system of 9 000 gigalitres. Complete yield loss is assumed below 1 000 gigalitres level of Murray inflow. 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 for wheat in Canada and Australia.

 *Insurance premium subsidy*

 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 the paper). The model does not allow positive transfer of income through subsidy to insurance premium. However, farmer faces other types of costs associated with the use of crop yield insurance and may not insure crop yield risk fully even though the administrative costs are fully covered by the government. The modelling of insurance instruments in Canada and Australia is rather generic and does not necessarily reflect the policy parameters of the actual program.

 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). Table 19 summarizes the correlation of individual wheat yield and insurance indices by climate change scenario.

 Correlation of wheat yield risk and insurance indices

Coefficient of correlation



 *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.

# Annex 2 – Insurance demand For Saskatchewan

 An element of crucial importance when assessing a risk management portfolio is the extent of demand for instruments where participation is voluntary. For example, when it comes to insurance a higher proportion of land insured reduces income variability, which leads potentially to a welfare gain in the form of an increase in certainty equivalent income. Figure 2.1 plots the relationship between the cost (above the fair premium) for two types of insurance, individual yield and weather index, and the demand for these insurance instruments by median farms (cluster 1). The cost of insurance and demand for insurance are expressed as the percentage additional cost to the fair insurance premium and the proportion of planted area insured, respectively.[[5]](#footnote-5) The simulation result shows that farmers do not purchase individual yield insurance unless the percentage of the additional cost is below 2%, whereas this threshold increases to 3% in the “marginal climate change” scenario. This result illustrates both the difficulty to allow farmers to participate in the individual yield insurance market, and the potential impact that climate change may have in demand for insurance. This is highlighted by the more than 50% of land in the median farm category (cluster 1) being insured if administration costs are kept below 2%. This is due to the farmers experiencing more systemic risk after climate change and, therefore, their demand for insurance can expand significantly. This result notwithstanding, demand for any kind of insurance continues to be zero for administrative costs beyond 5 to 8%.

 (a). Individual Yield Insurance Demand: Cluster 1; (b) Weather Insurance Demand: Median farm type

 

 Figure 2(a) Figure 2(b)

 The results for weather index insurance also show that farmers do not demand it if the administrative cost is more than 2% additional to the fair insurance premium both in the baseline and marginal climate change scenarios. Given the lower administrative costs of this type of insurance relative to individual yield, weather index insurance may be more viable. Nonetheless, the simulation results suggest that even taking into account climate change, crop insurance markets, in particular individual yield insurance, are most likely not viable without government subsidyto cover administrative costs.

# annex 3- saskatchewan: impact on risk exposure under alternative Climate Change scenarios.

 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 increae in extreme events were simulated. In this section we present 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 inisght on instrument sensitivity to different factors exogenous to policy design. We present results on the share of land insured under each option presented in section 1.6 (baseline, marginal climate change, adaptation, extreme events and misalignment), the welfare impact on, and the budgetary expenditures for the farms in the overall sample.

 Percentage of land insured under different insurance programs and climate change scenarios in Saskatchewan

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Baseline** | **Marginal Climate Change** | **Extreme events** |
|  |  | No adaptation | Adaptation | Misalignment | (no adaptation) |
| **Median 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 |
| **Small 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 |
| **Large 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 20 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 CC case 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: small 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 small farms demand for weather index insurance increases substantially relative to marginal climate change. However, for large 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 (Table 20). In terms of reduction in variability both area and individual yield insurance become more effective in reducing risk,

 Impacts of different policy programs on welfare gain from reduced income variability under different climate change scenarios in Saskatchewan ($/ha)

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Baseline** | **Marginal Climate Change** | **Extreme events** |
|  |  | No adaptation | Adaptation | Misalignment | (no adaptation) |
| **Median 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 |
| **Small 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 |
| **Large 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-postpayment | 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 21). 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 small 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.

 Impacts of different policy programs on transfer to farms with the lowest 10th percentile income under different climate change scenarios in Saskatchewan ($/ha)

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Baseline** | **Marginal Climate Change** | **Extreme events** |
|  |  | No adaptation | Adaptation | Misalignment | (no adaptation) |
| **Median Farm** |  |  |  |  |  |
| Individual yield  | 0.51 | -0.21 | 3.86 | 0.80 | 0.97 |
| Area yield  | 2.69 | -0.84 | 1.54 | 8.66 | -0.12 |
| Weather index  | 3.80 | -1.02 | 3.00 | 1.26 | 0.84 |
| Ex-post payment | 1.38 | -0.01 | 0.75 | 1.50 | -0.03 |
| **Small Farm** |   |   |  |   |   |
| Individual yield  | -0.08 | 2.18 | 1.36 | 7.19 | 3.36 |
| Area yield  | 2.15 | 3.09 | 0.41 | 8.64 | 2.12 |
| Weather index  | 4.31 | 0.02 | 1.71 | 0.39 | 1.65 |
| Ex-post payment | 0.60 | 0.44 | 0.10 | 2.00 | 0.28 |
| **Large Farm** |   |   |   |  |   |
| Individual yield  | 2.35 | 1.42 | 2.69 | 4.40 | 2.01 |
| Area yield  | 0.75 | 2.44 | 1.46 | 6.21 | 0.62 |
| Weather index  | -0.06 | 3.14 | 1.95 | 0.65 | 1.03 |
| Ex-post payment | 0.10 | 0.02 | 0.04 | 0.33 | 0.20 |

 In terms of transfers to the farms with the lowest 10th percentile of income per hectare, simulation results can be very different across scenarios (Table 22). Similarly to welfare gains, transfers compensating for welfare losses associated with yield variability tend to be greater under individual yield insurance for both the scenario with adaptation and the one with extreme climate-related events. Area yield insurance does not perform as well in terms of transfer to lower income farms as it does in terms of welfare gains across all farms. As for the welfare gain, individual yield insurance being tailored to individual yield risk, which always covers low yield risk beyond insured level (70% of expected yield). This is not the case for area-yield insurance or weather index insurance do not necessarily provide an indemnity for a specific farmer suffering large yield losses. Ex post payments remain ineffective in buffering low income farms from catastrophic events as they were in reducing income variability under the different scenarios because of the difficulty of targeting to low income risk.

# Annex 4- australia:Insurance demand and impact on risk exposure under alternative Climate Change scenarios.

 As for the Canadian analysis, 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 increae in extreme events were simulated. In this section we present how the policy instruments would perform under alternative scenarios. 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. We present results on the share of land insured under each option presented in section 1.4 (baseline, marginal climate change, adaptation, extreme events and misalignment), the welfare impact on, and the budgetary expenditures for the farms in the overall sample.

 Percentage of land insured under different insurance programs and climate change scenarios in Australia

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Baseline** | **Marginal Climate Change** | **Extreme events** |
|  |  | No adaptation | Adaptation | Misalignment | (no adaptation) |
| **Median Farm** |  |  |  |  |  |
| Individual yield  | 100.0 | 58.4 | 72.4 | 100.0 | 100.0 |
| Area yield  | 72.4 | 58.1 | 81.1 | 72.4 | 93.4 |
| Weather index  | 44.4 | 43.9 | 49.1 | 44.4 | 74.6 |
| **Large Farm** |  |  |  |  |  |
| Individual yield  | 80.7 | 64.8 | 93.4 | 80.7 | 100.0 |
| Area yield  | 24.2 | 38.0 | 25.6 | 24.2 | 59.0 |
| Weather index  | 56.4 | 36.7 | 35.2 | 56.4 | 56.4 |
| **Small Farm** |  |  |  |  |  |
| Individual yield  | 94.2 | 87.7 | 93.7 | 94.2 | 92.2 |
| Area yield  | 33.8 | 37.7 | 43.3 | 33.8 | 69.4 |
| Weather index  | 38.8 | 40.2 | 42.3 | 38.8 | 63.8 |

 In the first two columns of Table 23 are reported the share of land insured under the baseline and the marginal climate change without adaptation discusses in the previous subsection. Similarly to the Canadian case, one would expect the adaptation scenario to be in the middle between the baseline and the climate change scenario without adaptation. However, this appears to be more the exception than the rule in the case of Australia.

 As in the Canadian case, under the misalignment scenario farmers make decisions based on past information thereby they buy the same insurance than in the baseline (Table 23). For Australia, as for Canada, the extreme events climate change scenario tends to increase further the demand for insurance across different instruments. Given how extreme events affect both livestock and crops, the availability of crop insurance under such a scenario, and the correlation across all activities of these impacts, then farmers specialize even more than the baseline case, as opposed to diversify with livestock as in the marginal climate change without adaptation. All forms of insurance would be in high demand in the case of extreme events, and particularly individual yield insurance which covers both the systemic and basis risk elements.

 . Impacts of different policy programs on welfare gain from reduced income variability under different climate change scenarios in Australia ($/ha)

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Baseline** | **Marginal Climate Change** | **Extreme events** |
|  |  | No adaptation | Adaptation | Misalignment | (no adaptation) |
| **Median Farm** |  |  |  |  |  |
| Individual yield  | -4.41 | 0.30 | 0.74 | -2.20 | -3.60 |
| Area yield  | -2.55 | -1.05 | -2.98 | -1.20 | -3.65 |
| Weather index  | -1.15 | -0.62 | -1.16 | -0.62 | -1.20 |
| Ex-post payment | -0.21 | -0.14 | -0.32 | 0.15 | -0.30 |
| **Large Farm** |  |  |  |  |  |
| Individual yield  | 3.06 | 0.23 | -2.55 | 0.44 | -2.39 |
| Area yield  | 0.33 | -1.20 | 0.26 | 0.84 | -3.17 |
| Weather index  | -0.80 | -0.56 | -0.68 | -0.26 | -1.25 |
| Ex-post payment | -0.05 | -0.14 | -0.07 | 0.09 | -0.20 |
| **Small Farm** |  |  |  |  |  |
| Individual yield  | -0.14 | 0.03 | 0.26 | 3.30 | -0.89 |
| Area yield  | -1.41 | -1.12 | -1.76 | -0.61 | -3.85 |
| Weather index  | -1.40 | -1.01 | -1.40 | -0.67 | -2.07 |
| Ex-post payment | -0.18 | -0.18 | -0.26 | 0.00 | -0.34 |

 The results on welfare impacts due to reduced variability are negative for most policies, scenarios and farm types in Table 24. This means that none of these programs achieve the objective of reducing farm income risk. However, if one views subsidized insurance or ex-post payments as a way to safeguard the incomes of the most vulnerable farmers in years of adverse conditions, then a more appropriate indicator may be the transfers that policy instruments provide to the farmers in the lowest 10th percentile of income (per hectare). In fact, the EC relief payments in Australia are more directed toward helping farmers under exceptional circumstance, which is beyond their capacity to manage. In this respect the results are qualitatively similar to the welfare gains discussed above, but with some differences (Table 24). For several scenarios under marginal climate change the “lowest 10th percentile” indicator shows positive outcomes for some policy instruments. The results for this indicator favours in particular ex-post payments. By design these payments’ trigger is better targeted to low farm income due to a very systemic event. They have also the lowest crowding out effect on diversification because they are not commodity specific. However they retain some crowding out effects because they are not triggered after livestock shocks.

 Impacts of different policy programs on transfer to farms with the lowest 10th percentile income under different climate change scenarios in Australia ($/ha)

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Baseline** | **Marginal Climate Change** | **Extreme events** |
|  |  | No adaptation | Adaptation | Misalignment | (no adaptation) |
| **Median Farm** |  |  |  |  |  |
| Individual yield  | -1.69 | 7.38 | 10.07 | 0.16 | 0.77 |
| Area yield  | -6.60 | -4.63 | -7.05 | 0.46 | -2.37 |
| Weather index  | -2.09 | 2.22 | -6.61 | -7.32 | -10.38 |
| Ex-post payment | 2.34 | 6.18 | 1.45 | 0.63 | 16.65 |
| **Large Farm** |  |  |  |  |  |
| Individual yield  | 11.60 | 2.63 | -10.17 | 0.44 | 7.39 |
| Area yield  | -6.31 | -6.56 | -4.11 | 0.59 | -7.09 |
| Weather index  | -6.15 | 0.30 | -7.97 | -5.33 | 13.25 |
| Ex-post payment | 2.38 | 3.32 | 0.51 | 0.49 | 7.48 |
| **Small Farm** |  |  |  |  |  |
| Individual yield  | 20.53 | 10.45 | 12.47 | 0.87 | 4.82 |
| Area yield  | -6.26 | -7.87 | -5.52 | 0.64 | -14.52 |
| Weather index  | 2.14 | -4.02 | -2.80 | -14.69 | -10.57 |
| Ex-post payment | 0.00 | 3.42 | 1.48 | 1.06 | -3.10 |

 The results for Australia highlight the importance of livestock in the risk management mix available to farmers. An unexpected impact of diversification through livestock is that insurance demand can decrease substantially under the marginal climate change without any adaptation, and then increase if there is adaptation that improves the crop response. In terms of instruments performance there appears to be a dichotomy between individual yield insurance and ex-post payments, where each appears to perform well under some scenarios but not others. As in Canada, the performance of individual yield insurance is relatively higher in covering large yield shocks and avoiding large income losses. Moreover, ex-post payment performs much better than the case in Canada. This is because it is, by design, triggered by systemic yield shocks. In Australia, yield risk is very systemic so that ex-post payment triggers more often when farmers experience large income shock. In any case, it is less straightforward to find a single instrument that will perform well across farm types and in the range of uncertainty identified for the impacts of climate change. Nonetheless, one can already exclude area yield and weather index insurance as policy instruments of choice in Australia.

1. These major staples belong to a category with the C3 photosynthetic pathway (the first product in their biochemical sequence of reactions has three carbon atoms) tend to respond positively to increased CO2 because it tends to suppress rates of photorespiration responsible for a lower efficiency of the photosynthetic process. [↑](#footnote-ref-1)
2. [↑](#footnote-ref-2)
3. . Precipitation risk in Canada 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). On the other hand, precipitation is in Australia is defined an annual inflow to Murray system (including Darling) between 1978 and 2008. The coefficient of correlation between precipitation risk and systemic yield risk are assumed to be same as those in Canada. [↑](#footnote-ref-3)
4. . 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. [↑](#footnote-ref-4)
5. . Fair insurance premium is calculated at the level where the expected indemnity payment equals to the premium payment. This is the case when there is no administration cost in the insurance market. The simulation changes the cost of insurance for all crops at the same rate. [↑](#footnote-ref-5)