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Abstract

A COMPARATIVE STUDY OF RISK MANAGEMENT IN AGRICULTURE UNDER CLIMATE CHANGE

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Climate change affects the mean and variability of weather conditions and the frequency of extreme events, which to a great extent determines the variability of production and yields. This paper reviews the scientific literature on the impacts of climate change on yield variance and investigates their implications for the demand of crop insurance and effectiveness of different farm strategies and policy measures using crop farm data in Australia, Canada and Spain. A microeconomic farm level model is calibrated to different types of farms and used to simulate the responses and impacts of four policy measures: *ex post* disaster payments and three types of crop insurance (individual yields, area-based yield and weather index). The strong uncertainties about climate change are captured in a set of seven scenarios covering different assumptions about the scope of climate change (no change, marginal change, and high occurrence of extreme events), and farmers' adaptation response (no adaptation, diversification, and structural adaptation). Policy decision making under these uncertainties is analysed using a standard Bayesian probabilistic approach, but also using other criteria that look for robust second best choices (MaxiMin and Satisficing criteria).

JEL Classification: Q54, Q18, H84, G22, D81

Keywords: Crop insurance, climate change, adaptation, uncertainty, second best policies.

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Executive Summary

This study examines agricultural risk management policies and how these respond under conditions of climate change. It investigates the demand and effectiveness of different risk management policy tools using a microeconomic simulation model that is calibrated on different types of individual crop farms in three samples from Australia, Canada and Spain, which are affected in different ways by climate change. Four types of policies are analysed: individual yield insurance triggered by observed yield shocks on the farm; area yield insurance triggered by a reduction in the average yield in a given location; weather index insurance triggered by a rainfall index built from the nearest meteorological station; and *ex post* payments triggered by a large systemic shock.

Few insights into the impact of climate change on the variability of crop yields are provided in the available literature, although there is relatively more empirical information of its impacts on the level of yields. The impact of climate change differs depending on the location. For example, the most reliable sources to date reveal that climate change will increase production risk as measured by yield variability of the main crops in continental Spain, but that yield variability on the Canadian Prairies will likely be reduced for crops such as wheat and barley. In Australia, the evidence varies with some commodities showing increased production risk and others showing reduced risk.

As with any modelling work this study has its limitations: the samples of farms are not representative of their respective country or province, the climate change and behavioural scenarios are subject to strong uncertainties, the model only measures welfare gains for individual farmers, the number and representation of farmers' strategies and policy instruments are not exhaustive, and the value of the parameters could always be improved. The objective of this study is not to deliver specific policy advice to the countries participating in the analysis. On the other hand, this research does provide valuable insights about how policies interact with risk management and adaptation strategies, and how to tackle policy-making under strong uncertainties.

There are strong links between adaptation and risk management policies, and government responses to protect farmers from climate change risks will affect their strategies. For example, public support for insurance schemes and for *ex post* payments may reduce the incentive to diversify farm production away from more climate sensitive crops and farm practises. In this sense these government supported instruments can potentially crowd out appropriate adaptation strategies by farmers.

Previous OECD work has shown that in general, insurance subsidies do not correct potential insurance market failures. This study confirms that the gain for the farmer from lower risk is generally smaller than the budgetary cost of the measure. In this sense, these risk management policies are a second best response to reduce farm risk. This study shows that, given an objective of reducing the variability of farm income, it is possible to investigate which is the most cost effective instrument under different scenarios, and then identify a policy that is robust across scenarios. In the absence of perfect and symmetric information, and thus the inability to implement first best policies, the analysis of these second best solutions can provide good guidance for policy making.

The most reliable scenario of climate impacts only marginally changes the risk environment and, therefore, only marginally increases the demand for insurance (except in Spain). Individual yield insurance tends to be very costly for governments, while weather index insurance and *ex post* payments are cheaper on average. *Ex post* payments are highly variable and can be extremely high in some years. On the whole, however, climate change is likely to only slightly modify the yield variability in some locations and new risks associated with climate change do not seem to be an appropriate justification or basis on which to develop new risk management policies.

The analysis in this study goes beyond a standard climate change scenario and investigates policy making under strong uncertainty. First, two different climate change scenarios are examined: standard climate change versus a situation with numerous extreme events. Second, three different behavioural responses by farmers are examined: no response due to ignoring climate change (misalignment); adaptation by diversification; and structural adaptation. The strong uncertainties about the climate change scenarios and behavioural responses (referred to as "ambiguities") are organised in seven scenarios. Additionally, two different policy objectives related to reducing farm income risk are investigated. Estimating the cost-effectiveness of each measure in each scenario is a complex quantitative exercise and the results are not always intuitive and differ across countries and farm types.

The possibility of extreme events and misalignment scenarios significantly changes the policy decision environment. The analysis of government's best response to this ambiguity is very challenging and requires a significant change in the approach. Rather than identifying optimal policies, the definition and understanding of the plausible scenarios is a core part of the analysis. Governments may seek the implementation of "robust" policies that are not optimal under any scenario but that may be able to respond well to different environments and avoid very bad outcomes, particularly under extreme events and misalignment. The misalignment scenarios are characterised by high budgetary expenditure and low adaptation practices. Other policy initiatives that focus on information and training can help prevent the misalignment of risk perceptions. This study shows that it is technically feasible to define plausible scenarios and implement robust criteria in response to strong climate change uncertainties.

The first policy objective considered in this study is the reduction of the overall risk of farm income. It is focused on normal, or marketable, risk and, therefore, there is not a strong case for public support unless it is temporary or oriented to developing insurance markets. It is known that reducing farmer's exposure to normal and marketable risks has crowding out effects on farmer's risk management and adaptation strategies. If a government retains the objective to reduce the overall risk, then area yield and weather index insurance are, in general, robust policy options: cheaper than individual yield insurance and covering a significant part of the farm specific risk.

The second possible objective considered in this study is to provide an indemnity only when the lowest farm income outcomes occur. This objective is related more to catastrophic risk and the case for market failure and government support is stronger. *Ex post* payments can be effective in dealing with extreme systemic risk situation and are robust across scenarios. Individual yield insurance with the appropriate deductibles can also be better targeted to individual low returns than to overall risk, but it is commodity specific and more costly than other types of insurance.

Ex post payments have disadvantages that are not fully reflected in this analysis. The costs of assessing systemic losses may be significant; many countries also experience governance difficulties (such as those derived from moral hazard) in disciplining these *ex post* payments. Other existing social safety nets need to be considered as alternatives.

Insurance schemes offer a continuum from programmes that are individually triggered to those that are triggered based on specific indices. Area-based insurance is similar to individual yield insurance when fewer farmers are included in the area, and similar to an index insurance the larger the size of the area. The associated costs also run along a continuum and this is why there is no obvious best choice among these different instruments. A good alternative is to develop a range of instruments with limited government financial support so that individual farmers can self-select their insurance. Providing free *ex post* assistance in addition to subsidized insurance can hinder the effectiveness of these programmes.

Introduction

The variability of weather conditions generates variability in production and yields. Some of these risks, such as catastrophic events that are systemic, rare and highly damaging, are likely to deserve some government action (OECD, 2011). Disaster assistance is sometimes provided through *ex post* payments to farmers. Other risks can be managed on the farm or through market instruments such as insurance. However, insurance programmes with subsidies are also used by some governments as disaster assistance devices. Decisions by farmers, policy makers and insurance companies will be affected by climate change and the expectations on future climatic conditions and the associated level of uncertainty of future weather patterns.

Climate change affects the mean and variability of weather conditions, and the variance and covariance of weather events, including an estimated increase in the frequency and scope of extreme events. These trends imply changes in yields, their average and the distribution of their more extreme values, and they affect the appropriateness of different risk management tools. The implications will differ by location and crop. Farms (e.g. crop farms) need to respond to these developments and to adapt their farming practices, changing crops and varieties planted, and adjusting their risk management strategies. One of the major policy issues is the extent to which the use of different policy instruments may hinder or enhance adaptation to climate change. On the one hand, it has been argued that the availability of insurance potentially enhances resilience and competitiveness. The use of insurance in this case can be seen as an adaptation response to climate change. On the other hand, if subsidised insurance or *ex post* payments protect from climate shocks, farmers could be less inclined to change their production techniques and portfolio of activities.

Most climate change projections are 30 to 50 years into the future, and even up to 2100. Although it may seem irrelevant to analyse the policy options that governments may have to implement so far into the future, such an exercise is useful for two reasons. First, the development of efficient insurance systems requires long-term learning and database building for periods of up to twenty years (OECD, 2011). Second, the marginal climate change scenario provides information on a long-term trend, the timeframe of which is very uncertain. If sophisticated insurance systems are to be developed, the need for long periods to mature these systems and the uncertainty about the time in which climate change impacts will occur should be taken into account.

This paper investigates the effectiveness of different types of insurance and ex post payments to achieve agricultural risk management objectives under climate change. The main tool is a stochastic farm level model. The model is calibrated with crop farm panel data from three small samples from Australia, the Canadian province of Saskatchewan, and Spain. While these samples are not designed to be representative of the whole country or province, they are used to analyze several policy issues: the increase in demand for insurance due to climate change, responses by farmers in terms of adaptation, and the implications in terms of the cost-effectiveness of policies. Livestock farms are not analyzed even if they are likely to be significantly affected by climate change.

Annex I describes the technicalities of the farm level stochastic model, the data and the main results for each of the country samples. Several aspects are analysed, such as the interaction between crop insurance and other risk management strategies (e.g. diversification by farmers), and the extent to which insurance can improve the outcome compared with *ex post* disaster assistance by governments. This framework does not determine if there is a market failure nor does it evaluate the total social welfare impact of policies. The purpose is to investigate government policy responses when there is asymmetric information and strong uncertainties and provide insights on the budgetary cost-effectiveness of different policy instruments to reduce farming risk under different scenarios, and identifying robust policies across them. Such policies are second best as compared to first best solutions that could only be taken under perfect and symmetric information.

The topic has at least five different dimensions that add complexity to the analysis (Table 1).

First, there are significant uncertainties about the impacts of climate change on yields and production risk. There is little information available and different studies often estimate quite different numbers. This uncertainty is reflected through three different climate scenarios. If production risk is not affected by climate change then current risk environment will prevail (*baseline scenario*). According to some empirical studies, however, changes in climate patterns could affect production risk and the most reliable numbers gathered by the Inter-Governmental Panel on Climate Change (IPCC) are used to define a *"marginal" scenario*. Finally, the climate change literature has identified a likely higher frequency of extreme events that is reflected in an *extreme events scenario*. The uncertainty on the exact nature and probability of these scenarios is likely to remain as a structural feature of the decision environment in the next years and decades.

Second, there are uncertainties about how farmers will change their behaviour as a consequence of climate change. It is possible that farmers remain unaware of the production implications of climate change and, therefore, will not adjust their perceptions of production risk nor their response. This means that a farmer's expectations are not aligned with scientific knowledge (misalignment behaviour in Table 1). It is also possible that farmers learn about the new risk environment and decide to make major changes that include investments in new varieties or production practices (structural adaptation). Alternatively, farmers may decide to take only marginal adaptation decisions such as minor changes in the timing of planting and cropping, or on the composition of their basket of productions (adaptation by diversification).

Third, production risk has a strong farm-specific or idiosyncratic component, implying that different types of farms have different risk profiles. Both the variability of yields and its correlation with other farms, commodities and indexes is specific to each location and farm. Farmers with similar risk characteristics can be grouped together to analyse a differentiated impact for different farms.

Fourth, the objectives of government policies can also be diverse. Some governments may focus mainly on providing relief after the occurrence of extreme low income circumstances affecting farms, while others may focus on the overall reduction of risk or variability of farm income. Two different indicators can be used for these different objectives.

Fifth, the range of different policy instruments can be very large. In this paper, we have reduced the set of instruments to four: three types of subsidised insurance policies (individual yield, area yield and weather index) and *ex post* payments that are triggered when a shock is widespread.

Table 1. Risk management under climate change: dimensions of the policy problem

Dimension	Stylised options	Coverage in this paper		
		Chapter 1	Chapter 2	Annex i
1. Climate scenarios	Baseline (B), Marginal (M), Extreme Events (E)	B, M	B, M, E	B, M, E
2. Farm behaviour	Misalignment (Ms), Structural Adaptation (S), Adaptation by Diversification (D)	D	Ms, S, D	Ms, S, D
3. Farm diversity	Low (L), Medium (Me) and High (H) Risk farms, and Average	L, Me, H	A	L, Me, H
4. Policy objective	Variability of Income (V) , Low Income (Li)	V, Li	V, Li	V, Li
5. Policy options	Individual yield (I), Area yield (A) and Weather index (W) insurance, and *Ex post* payments (Ex)	I,A,W,Ex	I,A,W,Ex	I,A,W,Ex

The multidimensional nature of the climate change problem makes it difficult to identify the right policy in a context of strong uncertainty. This problem is tackled by applying the concept of "robust" policies defined as those that perform "reasonably well" under a variety of different plausible scenarios even though they do not necessarily provide the most cost effective choice for each individual case. Robust policies are analysed under seven different scenarios covering the first two dimensions of structural uncertainties combining different climate and behavioural options. Using these scenarios, all five dimensions have been investigated for three case studies using a sample of crop farms from Australia, Saskatchewan (Canada) and Spain.

The study has several limitations: the samples of farms are not representative of the respective country or province, the model is calibrated with parameters such as risk aversion for which there is limited empirical evidence, the climate change and behavioural scenarios are subject to strong uncertainties, and the number and representation of policy instruments is not exhaustive. As with any modelling exercise, this is a stylized representation of real policy choice. Nonetheless it has several strengths: it recognizes that some of these uncertainties are structural and likely to remain at the core of the policy decision problem, it develops a consistent framework to tackle this uncertainty, and it allows farmers and policy makers to adjust their response to their limited information. The purpose of the study is not to provide prescriptive policy advice to specific countries, but to obtain insights about robust risk management policies under strong climate change uncertainties.

Chapter 1 discusses the empirical literature on the projected impacts of climate change on crop yields and briefly examines the adaptation options and their implications. The analysis in this chapter is limited to a single representation of climate change as a "marginal scenario" in the locations of the samples under study with no structural adaptation (only diversification). This is a standard comparison between a stylized climate change scenario and a baseline without climate change. The implications on the cost-effectiveness of different instruments are discussed, and a sensitivity analysis of the results for different types of farms in the sample is undertaken.

Chapter 2 focuses on the analysis of different uncertain scenarios with limited information. The sensitivity and robustness of the policy results across scenarios are investigated because they are likely to provide the best policy insights about the challenges of climate change. The objective of identifying robust policies is pursued using different decision criteria: Bayesian, satisficing and MaxMin. To reduce the scope of the discussion, farm diversity is not considered in Chapter 2.

Both Chapters 1 and 2 analyse the four policy options under the two policy objectives. Annex I describes the model, the calibration process and the detailed results for each country and farm type in all scenarios. Annex II discusses the evidence on regional climate change projections.

Chapter 1.

Effects of climate change and its impacts on risk management policy options

Several implications of climate change such as rainfall patterns and changes in CO_2 fertilisation have an influence on agricultural production and risk. Chapter 1 identifies these effects and, based on the available empirical literature, attempts to quantify them into a single "highly likely" climate change scenario labelled as "marginal". The interaction between risk management policies and adaptation strategies on farm are discussed and analysed. The microeconomic model described in Annex 1 with a representation of four risk management policy instruments (*ex post* payments and three types of supported insurance schemes based on individual yield, area yield and weather index) is used to compare between this "marginal" scenario and a baseline scenario without climate change. The model is applied to three samples of farms from Australia, Saskatchewan (Canada) and Spain, measuring the cost-effectiveness of policies under the two scenarios.

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

There are two main ways in which greenhouse gas emissions may be relevant for agriculture. First, increased atmospheric CO_2 concentrations can have a direct effect on the growth rate of crop plants and weeds. Secondly, CO_2-induced changes of climate may alter levels and variability of temperature, rainfall and sunlight that can influence plant productivity. There is extensive literature dating from the 1970s on the potential impacts of climate change on plant physiology, and this continues to be an active field for research today. The research highlights the complexity of the topic given the many uncertainties concerning how climate change will affect variables relevant for crop production. Most studies concentrate on the implications of climate change for the mean levels of climatic variables, and their impact on the mean levels of production and yields. It is hard to extrapolate these results to scenarios that focus on variability, which is the main interest for risk management.

Effects of CO_2 fertilisation

If increases in atmospheric CO_2 were occurring without the possibility of associated changes in climate then, overall, the consequences for agriculture would probably be beneficial. Evidence of this is that increases in CO_2 concentration would increase the rate of plant growth. A doubling of CO_2 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 CO_2 concentration causes about a 40% decrease in stomatal aperture in plants (Morison, 1987) which may reduce transpiration by 23 to 46% (Cure and Acock, 1986). There are, however, important differences between the photosynthetic mechanisms of different crop plants[1] and hence in their response to increasing levels of CO_2.

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 the development 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; the rate of development increases broadly linearly with temperature to an optimum, above which it decreases broadly linearly (Squire and Unsworth, 1988).[2] In addition to growing season length in days several formulas have been developed to provide more precise

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[1] The three types of photosynthesis are C3, C4, and CAM with different responses to CO2 concentrations. C3 photosynthesis is the typical photosynthesis that most plants use (95%) and C4 and CAM photosynthesis are both adaptations to arid conditions because they result in better water use efficiency. C3 crops are, for example, rice, soybean, wheat, rye, oats, millet, barley, potato while C4 crops are maize, sorghum, pearl millet and sugarcane. They are called C3 because the CO2 is first incorporated into a 3-carbon compound and C4 because the CO2 is first incorporated into a 4-carbon compound. C4 plants use CO2 efficiently and an increase in the concentration does not help them much while C3 plants benefit greatly from increases in CO2 because less of the inefficient O2 photosynthesis occurs. Plants in a high CO2 environment increase their plant mass by 20 to 25%. Yields of some crops can be increased by up to 33%. Some of the current major food staples, such as wheat, rice and soya beans tend to respond positively to increased CO2. In experiments, 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 levels of 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 physiologists recognise that experimental results and model simulations may overestimate actual field-level responses (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.

[2] 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 the 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 ten days per °C and in central Japan by about eight days per °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 CO_2 concentrations and rainfall changes can have a small beneficial effect on the main cereal crops, notwithstanding that such simulations are highly uncertain (IPCC, 2007, WGII, Ch.5, p. 285).

information to account for the effect of temperature in crop development, such as Growing Degree Day (GDD) and Crop Heat Units (CHU).[3] For example, Bryant *et al.* (2008) report the change of Corn Heat Units under climate change scenarios in their analysis on the economic impacts of climate change on cash crop farms in Québec.

Whether crops respond to higher temperatures with an increase or decrease in yield depends on whether their yield is strongly limited by insufficient warmth. In cold regions very near the present-day limit for arable agriculture, any temperature increase, even as much as the 7 to 9°C indicated for high latitudes under a doubling of CO_2, 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 by about 3%/°C, assuming there is no concurrent change in rainfall. In Finland, the marketable yield of barley increases by 3 to 5%°/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 North American corn belt, the European lowlands and Ukraine, increases in temperature would probably lead to decreased cereal yields due to a shortened period of crop development (Adams, R.M. *et al.*, 1990).

Effects of changes in rainfall

In most 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 the 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 world-wide have adopted some form of ratio of rainfall to potential evaporation to delimit moisture-availability zones, which are then overlaid on temperature and soil maps to indicate agro-ecological zones. A strong 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.

There are relatively few studies on the combined effects of possible changes in temperature and rainfall on crop yields, and those that exist are based on a variety of different methods. An earlier review of results from ten studies in North America and Europe (Warrick *et al*, 1986) 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 (+1°C) might reduce average yields by about $5\pm4\%$; and a 2°C warming might reduce average yields by about $10\pm7\%$. In addition, reduced precipitation could also decrease yields of wheat and maize in these breadbasket regions. A combination of increased temperatures (+2°C) and reduced precipitation could lower average yields by over a fifth.

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[3] Growing Degree Days (GDDs) are defined as the number of temperature degrees above a certain threshold base temperature, which varies among crop species. The base temperature is that temperature below which plant development is zero. GDDs are calculated each day as maximum temperature plus the minimum temperature divided by two minus the base temperature. GDDs are accumulated by adding each day’s contribution as the season progresses. Crop specific indices that employ separate equations for the influence of the daily minimum (night time) and the maximum (day time) temperatures on growth are called crop heat units (CHUs).

Effects on pest and diseases

Studies suggest that temperature increases may extend the geographic range of some insect pests currently limited by temperature. A major threat 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 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 become more severe in areas where precipitation increases (Beresford and Fullerton, 1989).

Effects from climatic extremes

Important effects stemming from climate changes include those in variability and in the frequency of extreme weather events. The balance between profit and loss in commercial farming often depends on the relative frequency 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). The information about the variability of temperature and rainfall under climate change scenarios is very scarce.

Much of the impact on agriculture from climatic change can be expected from the effects of extreme events. Consider the significantly increased costs resulting from the increased frequency of extremely hot days that cause heat stress in crops. In central United States, the number of days with temperatures above 35°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 the limit of their heat tolerance.[4]

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) decreased by 10% (an amount projected by some General Circulation Models under a 2 CO_2 climate), this would raise the probability of less than 25 mm being received by 46%. For cattle, crops and trees, a 1% reduction in rainfall could mean that drought-related yield losses increase by as much as a half (Waggoner, 1983). To our knowledge, there is no information about the quantitative impacts of the higher frequency of extreme events on the variability of production.

Projections for selected regions

The Fourth Assessment Report of the Intergovernmental Panel for Climate Change (IPCC, 2007a) is the basis for climate change projections. It provides 50-year projections based on a large body of empirical literature and scientific research synthesised through the IPCC. According to the brief review of the literature presented in the previous section,

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[4] 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 1°C warming could reduce effective winter chilling by between 10% and 30% (Salinger, 1989).

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. 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. But there are high levels of uncertainty for other regions. These trends in global warming and catastrophic events are likely to impact on agricultural and livestock production, or yields and their variability. Annex 1 reviews the empirical literature and discusses the methodological challenges to estimate quantitative impacts of climate change in different regions. The estimates in the following paragraphs have been identified for the purpose of the modelling analysis for Australia, Canada and Spain.

Regional variations in climatic changes means that the potential impact on crop yields vary by region in Australia. For example, areas in south-western Australia are likely to have significant yield reductions in wheat by 2070, whereas regions in north-eastern Australia are likely to have moderate increases in wheat yield (Howden and Jones, 2004). Based on Van Gool and Vernon (2006) and Luo *et al.* (2011), this would mean a change in the mean yield of -17.4% for wheat, -28.8% for barley and -28.7% for canola. This paper uses these estimates to build the basic marginal climate change scenario. The change in the standard deviation of yields is assumed to be +10% for wheat, 0% for Barley, and -6% for canola.

For the province of Saskatchewan, Canada, the annual mean temperature is expected to be 3.2°C to 3.6°C warmer, and rainfall ranges from unchanged to an increase of 14 mm, which masks considerable variation in changes in monthly precipitation. De Jong *et al.* (2001) report that these changes translate into reductions of 3% to 9% in the mean yield of barley, reductions of 12% to 17% for wheat, and of 14% for canola. A recent analysis, reported by Zhang *et al.* (2011), uses an updated version of the EPIC crop model that is better calibrated to Canadian conditions. In their scenarios, using the Canadian Global Model (CGM) with CO_2 fertilisation, they find that the changes in temperature and precipitation in the south west of Saskatchewan, where the farms in the Canadian sample are located, entail a change in the mean yield of -3% for wheat, -10% for barley, and -13% for canola. This paper uses these estimates to build the basic marginal climate change scenario. The change in the standard deviation of yields is assumed to be -2% for wheat, -17% for barley and +2% for canola. It should be noted that considerable uncertainty remains on the variability of yields as is demonstrated by the difference in results between De Jong *et al.* (2001) and Zhang *et al.* (2011).

In continental Spain, increases in temperature and reductions in average rainfall are expected to lead to increased water deficits (Ruiz-Ramos and Minguez, 2010). For the simulations presented in this paper, data were taken from Guereña *et al.* (2001) which provides information on changes in the mean and the variability of yields for both wheat and barley. The change in the mean yield in central Spain are expected to be -1.8% for wheat, and +7.3% for barley, with changes in the standard deviation of yield of 110.5% and 89.3%, respectively. This paper uses these estimates to build the basic marginal climate change scenario.

Table 2 summarises the quantitative changes due to climate change according to the empirical literature and are the basis for the simulations of all the scenarios in this paper. The numbers in this table assume there is structural adaptation of farming practices, but three different degrees of adaptation are explored and discussed in this paper.

Table 2. Impacts of climate change on the distribution of yields (% changes)

	Australia[1]		**Canada**[2]		**Spain**[3]	
	Mean	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**
Wheat	-7.2	10.3	-3.0	-2.0	-1.8	110.5
Barley	-20.0	0.0	-10.0	-17.0	7.3	89.3
Canola	-19.9	-6.1	-13.0	2.0		

Sources: 1. Luo *et al.* (2010), Van Gool and Vernon (2006), 2. Zhang *et al.* (2011), and 3. Guereña *et al.* (2001).

2. A farm level model with risk and risk management policies

OECD (2010) investigated the risk environment in which farmers make production decisions. Using a stochastic micro-simulation model, it examined the consequences when the environment in which such decisions were taken changed due to government policies. Although climate change was not the focus of that analysis, the model is used here as the starting point for the analysis of how climate change might affect the management of risk at 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 payments from government, and other risk management strategies. The simulation scenarios determine a set of optimal decisions on the farm, including the land allocation and the coverage level of risk market instruments.

The model defines a stochastic farm profit 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 costs per unit of land. The model assumes that total land input is fixed and allocated between n crops. The model is calibrated with individual farm level 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 based on the observed distributional information in the farm level data. Following this calibration, a set of risk management strategies is introduced in each country. Details of the model are found in Annex 1.

2.1. Modelling climate change impacts on production risk

Climate change will modify the distribution of risks. It is assumed here that it will affect the systemic component of the yield risk, while the basis risk[5] will remain the same. This will involve a change in the yield distribution for different crops in the following ways.

- The mean yield decreases with climate change. Under the model assumption of decreasing absolute risk aversion, this would imply greater absolute risk aversion.
- The variance could increase. This also depends, however, on correlations between yields of different crops, and price yield correlations. For instance, more correlated

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[5] "Basis" risk is a technical term to denote the risks that are specific for a concrete location or farm, and that typically occur at different times in different farms, or occur only in some farms but not in others. For instance hail tends to be very location specific and is typically a basis risk.

risks (systemic) and lower price/yield correlations (natural hedge) will imply even riskier scenarios.

- Increase in the probability of very extreme events. In statistical terms this could imply an increase in negative skewness (third central moment) or lower kurtosis (fourth central moment).
- The correlation of yields with the chosen weather index may change. This would affect the relative demand and performance of weather index insurance *vis-à-vis* other risk management tools.

Table 3 outlines the relevance for risk management of the different aspects of climate change relating to agriculture as outlined above. The hypotheses concerning the quantitative implications of climate change on the distribution (mean and standard deviations) is that only the systemic yield shocks are affected by the distribution changes defined in Section 1. It is also assumed that climate change does not modify the correlation between the weather index and the idiosyncratic yield risk; in the case of an increase in the variance of yields, this implies an increase in the relative importance of the systemic component of yield risk.

Table 3. Impact of different forms of climatic changes on the relevant parameters of the model

Climatic change indicator	Impact on yield distribution	Impact on link between weather index and yield (θ)
Increase in CO_2 concentration	Will increase the mean for some plants, covariance unaffected	Correlation should not change (since SD also not changing)
Number of days above or below 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	

2.2. Modelling risk management instruments under climate change

It is common in the literature to segment risk in a way that matches risky outcomes with different tools to transfer, pool or manage 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. The most efficient instruments to manage risk may differ across layers. Following OECD (2009), in the **Risk retention layer** of frequent events that cause relatively limited losses (normal risks), farmers are best placed to manage this risk efficiently and smooth their income; in the **Market Insurance layer,** risks more significant but less frequent and there is scope for farmers to use insurance or other market options (marketable risks); finally, in the **Market failure layer,** risks generate very large and systemic losses at low frequencies which makes them difficult to pool through insurance (catastrophic risks). Government may decide to intervene after these catastrophic events, typically with *ex post* payments.

Even though this three layers approach is conceptually straightforward, it can be challenging to implement in practice. The boundaries between layers are not well drawn and the definition of catastrophic risks is determined by how government responds to specific events and manages the demand for assistance. Subsidized insurance systems are sometimes used to assist farmers after disasters. They have the advantage of a formal contract with the financial participation of farmers, the expert evaluation damages and relatively quick payment of indemnities. But support to insurance has also its drawbacks; in particular it can prevent the development of other fully private solutions and it typically does not fully replace *ex post* assistance. When subsidised insurance becomes a tool to deliver disaster assistance the boundaries between catastrophic and marketable risk can become blurred. Unclear boundaries are not desirable but are common among OECD countries (OECD, 2011).

Three types of crop production insurance are investigated and compared with *ex post* assistance: – individual yield, area-yield and weather index insurance. They – have different characteristics in terms of data requirements, administrative costs, distribution of risk, and its impact on farmers' incentives to adapt to climate change. Traditional **individual-yield crop insurance** makes an indemnity payment when the farm incurs a yield loss. To pay indemnities, the insurance provider must estimate the value of yield loss for each farm and commodity that makes a claim. Hail insurance is the most common peril insurance and is offered in the majority of OECD countries. Multiple-peril crop insurance, which covers losses due to multiple risks, is more complex and rarely offered without government subsidies due to the high costs of loss assessment under asymmetric information (Miranda, 1991; Goodwin, 1993). To avoid moral hazard in loss assessment, multi-peril crop insurances usually have high deductibles[6] (typically 30%) such that a small yield loss is not covered. Climate change is likely to affect the distribution and cost of multiple-peril crop insurance. In addition, the complexity of delivering such insurance greatly increases administrative costs compared to single peril insurance.

An alternative crop insurance scheme is **area-yield crop insurance**, in which both indemnities and premiums are based on the aggregate yield of a geographical area. The indemnity equals the difference in value, if positive, between the area yield and some predetermined critical yield level. Participating producers in a given area would receive the same indemnity per insured unit of land, regardless of his own crop yield, and all would pay the same premium rate (Miranda, 1991; Barnett *et al.*, 2005). Area-yield crop insurance offers advantages over individual-yield crop insurance because it reduces information asymmetries. Administrative costs are reduced since information regarding the distribution of the area-yield is generally available and verification of individual production histories would no longer be required. Moreover, because the indemnities would be based on 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 programme, moral hazard is significantly reduced. For this reason, area-yield insurance usually does not apply a deductible, and hence covers even small systemic yield losses. However, area-yield insurance is less effective if the yield risk of an individual farmer has less correlation with systemic yield risk (basis risk). Under changing climate conditions, area-yield insurance would have the advantage of maintaining incentives to adapt since farmers with successful strategies will be more profitable than those who do not adapt to new climatic conditions.

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[6] The application of a 30% deductible is also a requisite for insurance subsidies to be eligible for the green box exemption in WTO agreement in Agriculture.

Weather index insurance is another option that attempts to overcome the moral hazard and adverse selection problems. It provides an indemnity based on values obtained from a weather index that serves as a proxy for losses rather than on the individual losses of policyholders. The underlying index is based on 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 to transfer 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 and, therefore, there is the basis risk retained by the farmer. Weather index insurance has some of the same advantages as area-yield insurance over standard individual yield crop insurance, such as the reduction of moral hazard and adverse selection, and not discouraging adaptation to climate change (Collier *et al*., 2009). Furthermore, it usually requires only that a weather station generates the necessary index. All these advantages translate into lower administrative costs. One of the disadvantages of index insurance is, however, the basis risk: the insured farmer could suffer a loss and not receive any or enough indemnity. The amount of basis risk will depend on how well the chosen index maps individuals' losses. If there is too much basis risk, this will diminish its interest because farmers will perceive index insurance as providing poor protection against risk.

Administrative costs play an important role in demand for insurance by farmers. Since different insurance instruments have different administrative costs, it is necessary to make assumptions about their relative costs in order to compare across instruments. These cost estimates need to be comprehensive and are calculated as the difference between total premiums (paid by farmers or by government subsidies) and total average indemnities across several years (sum of fair premiums). To this end, the administrative costs of insurance are expressed as a percentage on the top of the fair premium: 5% for weather (rainfall) index insurance, 10% for area-yield insurance, and 30% for individual yield.[7] This assumption is meant to quantify in an approximate way the impact of loss assessment and payments under different insurance instruments.

For different reasons, these three types of insurance instruments do not emerge easily in the market. Available insurance programmes for crop production have typically needed more than a decade to become financially viable and most are maintained only because of government subsidies. In fact, it is sometimes argued that these types of insurance not only cover insurable risks, but also catastrophic risks for which markets can fail, which provides a rational for government intervention.

By definition a “fair premium” is a level of premium at which a risk neutral farmer will be indifferent between buying or not buying the insurance. If subsidies are larger than administrative costs, the net premium for the farmers is below the fair premium, and any risk-averse farmer will fully ensure his production. There would be no decision in the margin between insuring and not insuring. In reality uncertainty makes farmers perceive that a “fair premium” is lower that what insurance companies think. These additional

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[7] This is in line with the empirical literature (OECD, 2011) and with the data provided by ENESA to the OECD for Spain. These latter imply loading factors of 31% for multi-peril insurance and 2% of weather index (satellite image) insurance. These numbers are used for the simulation on Spain in Section 7.

"uncertainty" costs beyond the administrative costs can be modelled by ensuring that net premiums for farmers are never below their perceived fair premium. That is, the subsidy does not cover beyond the administrative plus other (uncertain) costs. Under this assumption insurance demands respond to the level of subsidy. To obtain a meaningful uptake, all insurance policies are assumed to be subsidised at 95% of their respective administrative costs (90% in the case of Spain). Annex 1 provides technical details on the design and modelling of these insurance policies.

Assistance after a catastrophe is the typical response in OECD countries to risks under the last layer covering market failure for extreme events. A standard policy response consists of triggering ***ex post*** **catastrophic/disaster payments**. For instance, a flat payment per unit of land is paid for losses beyond the threshold. In the modelling exercise, it is assumed that *ex post* payments are triggered when all systemic yield variables fall below the 40 percentile (all crops are affected simultaneously) and a lump sum per unit of land, equal to the expected indemnity of area yield insurance, is paid. The administrative costs of these *ex post* payments are presumably low and assumed to be zero in the model.

The present analysis investigates how climate change affects the effectiveness of these insurance instruments to deliver disaster assistance as compared to the alternative of *ex post* assistance. However there are other risk management tools and policies in OECD countries that directly interact with insurance and disaster payments (Box 1).

Box 1. Risk management policies and tools

There is widespread consensus that risk management policies should focus on helping farmers manage catastrophic, rare, but highly damaging, and systemic events (OECD, 2011). However, there is no consensus on the boundary defining catastrophic risks nor on the most efficient policy arrangement to deliver disaster assistance. In addition, there is no single definition of what constitutes a risk management policy because most agricultural support policies reduce risk exposure. OECD (2009) also underlines the need to have a holistic approach to risk management.

There are agricultural policies that have a significant risk management dimension. For instance, price support measures have been extensively used in the past with market intervention systems that are triggered by threshold intervention prices. These policies have proved to be inefficient income support mechanisms and their capacity to reduce farming risk is also limited to very low intervention prices (OECD, 2011). Agricultural policies in some OECD countries have a very strong countercyclical design. This is the case for different types of payments in the United States triggered by administered prices (CCPs, and Marketing Loan programmes), and revenue stabilisation payments like ACRE. AgriStability in Canada is triggered by a reduction of the whole farm margins as compared with their recent individual farm history.

These programmes, have crowding out effects on farmers' strategies to manage risk, as it is also the case for subsidized insurance and *ex-post* payment. The scope of this crowding out is greater for the programmes that focus on normal risks and are triggered more frequently (OECD, 2011).

Non-sector specific policies are well equipped to enhance farmers' risk management strategies. Income tax and social security provisions are designed in OECD countries to provide help to those having low income. These instruments can be adjusted to the reality of the agricultural sector. For instance, the possibility of averaging taxable income across several years (Australia, Canada, the Netherlands), providing tax incentives to save through deposits (Australia, New Zealand, Canada), and adjusting the assets tests for farmers accessing social security programmes (Australia). These policy tools have advantages in terms of transparency and assessment because through them farmers are inserted in the general social protection system with comparable rules applying to all individuals.

Continued

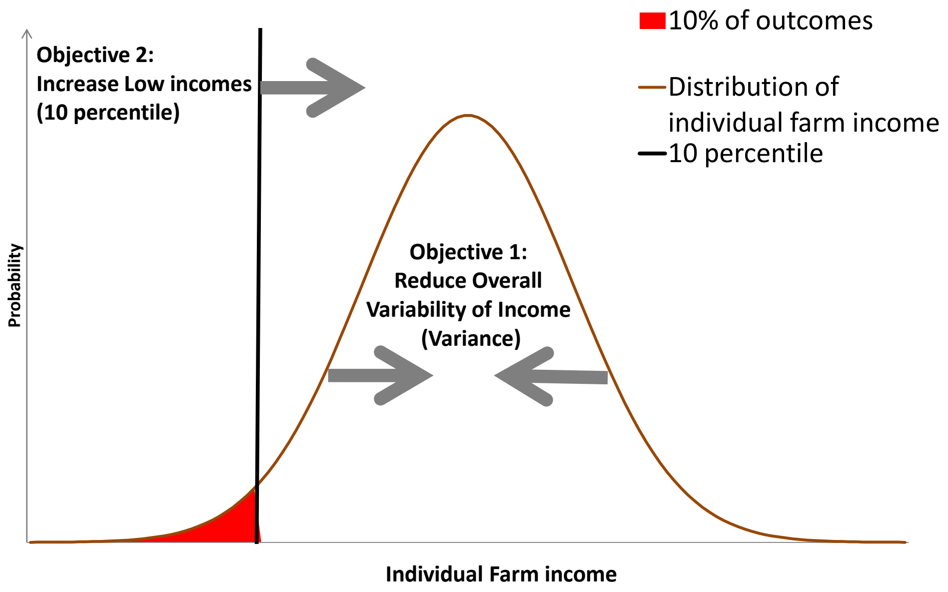
The risk management strategies of farmers go well beyond government policies. As part of their business management, farmers must manage associated risks and they are best placed to assess the nature and scope of their individual risks and the suitability of different strategies. Their decisions on the portfolio of activities of the farm and the techniques to be applied are part of their management of risks. Farmers can also use market instruments like insurance or futures when these are available, as well as marketing and production contracts and different ways of vertical or horizontal diversification. They can organise themselves into co-operatives that provide access to information and risk management services. In some countries, there are industry bodies (levy organisations in New Zealand and Australia, and commodity boards in the Netherlands) that implement useful collective risk management strategies.

2.3. Policy objective and indicators of cost effectiveness of policy

The objective of risks management policies in the context of climate change is assumed to be a reduction of risk at the farm level. Our modelling framework cannot measure if the policy intervention will be welfare improving because we are unable to value either the social value of reducing this risk or the capacity of governments to reduce information asymmetries. Instead of welfare criteria, cost-effectiveness criteria are used for the policy choice. That is, policies are evaluated according to their effectiveness in reducing the risk faced by the farmers.

Two possible indicators of policy effectiveness are considered: (i) the capacity of the policy measure to reduce income variability, and (ii) its budgetary costs. An indicator of budgetary cost-effectiveness is defined as the impact of each USD of public expenditure in reducing farmer income variability. There are two versions of this indicator derived from two different definitions of the policy objective: the reduction of overall income variability, versus the improvement of the low income outcomes (Figure 1).

Figure 1. A graphical representation of two different definitions of the policy objective of reducing farming risk



The first policy objective focuses on the overall distribution of income outcomes, envisaging the reduction of risks in the three layers: normal, marketable and catastrophic risks; it could be measured by the reduction in the variance or variability of farm income; alternatively it is proposed to measure it as the farmer's welfare gains from reduced income variability (or variance), not accounting for welfare gains due to higher mean income. The second policy objective focuses only on the lowest tail of the distribution of possible outcomes in each farm, envisaging providing an indemnity or a payment only when an event makes the income of that farm atypically low for its own history. It is measured as the increase in the lowest 10 percentile income of each individual farm (lowest tail or catastrophic risks).

The impacts of implementing the four different policy instruments defined (individual, area and weather insurance, and *ex post* payments) are presented in Annex 1. These numbers allow the ratios that constitute the cost effectiveness indicators to be calculated and are the main target for policy decisions in this study. These indicators must be interpreted in terms of the objective to reduce farming risk; they do not measure the overall economic efficiency of different policy measures. In the policy interventions in the model, government support increases the demand for insurance either through a subsidy premium or a free *ex post* payment; therefore, any measured welfare gains must be smaller than the budgetary costs of the policy measure. There can only be a net social welfare gain if society gives some value to this risk reduction (for instance, under extreme events) or if the government policies reduce information asymmetries or transaction costs (for instance, through public-private partnership arrangements to create and share databases, OECD, 2011). This study cannot measure the potential gains from government policies.

3. Adaptation to climate change

The probability distribution for farmer's expected income is altered by the climate change factors such as those listed in Table 3 by their impact on the distribution of yields. The difficulty of updating the probability distribution of yields in the presence of climate change may push actors to conjecture probability distributions based on historical experience that do not take into account climate change. This is referred to as a ***misalignment in expectations*** when farmers, 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. Misalignment is analysed in the scenarios of Chapter 2 and they imply no adaptation response. Other scenarios with different degrees of adaptation seem also plausible.

Farmer adaptation has the ability to affect both the distribution of yield for a given crop and how responsive yields are to weather patterns. Farmers can adopt several adaptation strategies, from switching crops to improving the resilience of specific crops by changing variety, adjusting planting dates, changing fertiliser applications, and irrigation. Some of these adaptation measures come at relatively low cost, such as adjusting the date of planting, while others like irrigation may require significant investment.

According to Mendelsohn (2010), efficient adaptation results in the actual net damages (damages minus the cost of adaptation) being less than the potential damages from climate change. Thus, if farmers adapt their behaviour to new climatic conditions, then the net impact to the farm and the sector can be lessened. Crop impact studies that incorporate adaptation predict a much lower impact of climate change both in developed and developing countries (Mendelsohn *et al*., 1994; Mendelsohn and Dinar, 1999; 2003; 2009). However, this may vary by country, as was reported in the IPCC Fourth Assessment Report (2007), which states that the adaptations assessed were most effective in mid-latitudes and least effective in low-latitude developing regions with poor resource endowments.

Smith (1997) distinguishes between *anticipatory* and *reactive* adaptation, in which anticipatory adaptation forecasts climate change and acts before it unfolds, while reactive adaptation changes behaviour only after climate change has taken place. The IPCC (2007) makes a similar distinction between *planned* and *autonomous* adaptation. Whether it is preferable to plan adaptation or to act in reaction to already existing climate impacts depends on the costs and benefits of the adaptation measures (Agrawala and Frankhauser, 2008). According to Mendelsohn (2010), most adaptation in the agricultural sector is likely to be reactive (autonomous), since there is much less uncertainty involved in reactive than in anticipatory adaptation.

Cross sectional studies have revealed that both crop and livestock choices are very important climate sensitive decisions by farmers. The probability of choosing each crop changes across climates and the distribution of crops by climate provides insight into how crop choice will be affected by further climate change (Mendelsohn, 2010). Moreover, the choice of farm type and the adoption of new technologies and seeds, such as drought or salinity resistant varieties, are also climate sensitive. For instance livestock farms can be more prominent in drier and hotter locations and crop farms in temperate and wet locations (Seo and Mendelsohn, 2008).

Adaptation through cropping pattern change can in some cases ease the exposure of plants to critical higher temperatures; for example by introducing winter types that may benefit from, or are less susceptible to higher temperatures (Peltonen-Sainio *et al*., 2011). Also, changing planting time may help avoid heat stress during the critical growth phases, although this adjustment may not alleviate yield losses sufficiently (Rötter *et al*., 2011). Another means is to introduce cultivars that mature later. As regards precipitation changes and water shortage, farmers can adjust by improving soil water-holding capacity by adding crop residues or manure, or by adopting conservation tillage such as reduced tillage or no-till (Smith and Olesen 2010; Känkänen *et al*., 2011). Altering fertiliser rates to maintain grain or fruit quality consistent with the climate is another option. All these types of adaptations are facilitated by seasonal climate forecasting, which reduces production risk by providing additional information on which types will most likely succeed.

Regarding pests, weeds and disease problems, farmers can implement adaptation measures, such as diversifying land allocation and increasing crop rotation, as well as using high quality certified seeds. Moreover, the adoption of modern alarm systems is a means to cope with crop protection risks (Peltonen-Sainio, 2012).

Diversification of the cropping system provides the means for resilience and adaptation at the farm level. According to Howden *et al*. (2007), there are basically two ways to diversify cropping systems: implement either more diverse crop rotations (that is, more crop species) or more diverse cultivars that differ genetically in their responsiveness to climate conditions. In the analysis, a distinction is made between a scenario characterised as *adaptation by diversification*, where farmers simply change the mix of crops in response to climate, and a *structural adaptation* scenario that incorporates both changes in crop mix and changes in crop yields stemming from the management practices mentioned above (changing planting times, fertiliser rates, conservation tillage, etc.).

Howden *et al.* (2007) estimates that, on average, under conditions of a rain decrease and 2-4 degrees of temperature increase, adaptation benefits will imply an increase of 11.1% in yields. The scenarios of adaptation by diversification are built on the basis of this figure that implies lower yields, rather than on the structural adaptation scenarios[8] in Table 1.

In a situation where farmers have no insurance, this should in principle be a strong incentive to adapt to climate change (Mendelsohn, 2010). Farmer reactions are more nuanced, however, and lack of insurance has shown that there is a lower likelihood of farmers adopting new technologies (Feder *et al.*, 1985; Antle and Crissman, 1990), of lower investments (Skees *et al.*, 1999), but also of greater diversification (Skees *et al.*, 1999). Under changing climate conditions, adaptation options will typically be risk-decreasing, so that increased weather variability should favour their adoption, although total output may still decline on average. Finally, even though certain practices may decrease risk once they are mastered by the farmer, the risk of crop-failure can increase initially because changing practices can be risky as farmers learn new technologies (e.g. split fertilisation) (Marra *et al.*, 2003).

Crop insurance, and especially how it is designed, will affect incentives to adapt (Collier *et al.*, 2009). For example, traditional agricultural insurance (which makes an indemnity payment when the farm incurs a production loss) is known to be expensive and will diminish incentives to adapt to climate change. Furthermore, climate change is likely to affect the demand and the cost of multiple peril crop insurance, with significant implications for its viability.

Weather index insurance or area yield insurance can help keep administrative costs down so that insurance becomes a viable option; however, index or area yield insurance by itself is not a means for structural adaptation. It simply maintains the link between the ability to adapt to climate change and farmers' returns. Therefore, if appropriately designed, weather index or area yield insurance may improve farmer welfare while not discouraging adaptation since indemnities are paid independently of loss. Despite this potential positive effect of index insurance in the context of climate change, policy makers will most likely have to weigh carefully whether to provide premium subsidies for this type of insurance. Farmers will incorporate insurance subsidies in their production decisions, which may favour insurance over crop diversification or other risk management and adaptation strategies.

It is difficult to disentangle the interactions between the impact of insurance on the incentive to adapt and the degree of adaptation adopted by farmers. In the modelling framework used for this analysis, insurance will have an effect on the crop mix chosen endogenously (adaptation by diversification); however, the yield effects associated with other forms of adaptation (structural adaptation) are assumed to be exogenous to the insurance demand decisions. In theory, one could adjust endogenously the yields according to different insurance designs and adaptation strategies; in practice, such data are not presently available. It is for this reason that the *diversification* and the *structural* adaptation scenarios are presented separately so as to bracket the possible outcomes under different risk management instruments for different forms of climate change. This chapter discusses only a marginal climate change scenario that captures diversification responses

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[8] Given the lack of information about the standard deviation, it is assumed that bot structural and non-structural adaptation scenarios imply the same shock in the standard deviation of yields.

but it does not include structural adaptation, which is modelled and discussed in Annex 1 and chapter 2.

In this context, it is important to develop an indicator to measure how pro-active risk management by diversification performs under climate change. What is important is the variability of farm returns under the different scenarios. To this end, a diversification index was developed to capture the change in variability of profits due to farmer choice in the composition of commodities in response to exogenous changes due to climate change (Box 2).

Box 2. The diversification index under climate change scenarios

Diversification is a key risk management business strategy. Most often, there is a need to tradeoff between the gains from reduced variability of profits and the losses from lower returns from scale economies. Under climate change, diversification becomes a possible adaptation strategy.

Kimura, Anton and LeThi (2010) and Kimura and LeThi (2011) have defined a diversification index that is useful in the context of modelling farmers' decisions on the portfolio of commodities to be produced. A classical concentration index like the Herfindahl index would not be able to capture the extent to which a given portfolio is able to diversify the risk of variability in returns. This is why a useful index is built on the coefficient of variation of market revenue when changing the portfolio of commodities produced, while keeping the variability of yields constant. A change in the diversification index I_{div} is calculated as the negative of the percentage change in this coefficient of variation. A change in the index has to be interpreted as a reduction in variability of profits due to the farmer's new choice in the composition of commodities in the farm production portfolio.

$$I_{div} = CV\left[\sum \tilde{p}_i^1 \tilde{y}_i^1 a_i^0\right] - CV\left[\sum \tilde{p}_i^1 \tilde{y}_i^1 a_i^1\right]$$

with $\tilde{p}_i^1, \tilde{y}_i^1$ price and yield random variables

and a_i^0, a_i^1 initial and final decisions on allocation of land to commodity "i"

Table 4 summarises the impacts of the marginal climate change scenarios of yield variability as defined in Table 2. In Canada, reduction of diversification is observed in two out of the three types of farms because climate change scenarios imply a reduction of risk and variability. In general, adaptation to climate change might not necessarily lead to more diversification but may create opportunities to pursue higher return by specialising in crops which profit from climate change. In Australia and, particularly, in Spain, climate change implies increases in variability and the farmers' logical response would be to adapt by increasing diversification on the farm.

Table 4. Change in diversification index in response to marginal climate change (percentage change)

	Australia	Canada	Spain
Low risk farm	17.6	-3.6	19.8
Medium risk farm	16.3	-2.7	n.a.
High risk farm	13.7	3.1	22.4

4. 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 Australian Drought Policy. It excludes interest rate subsidies and focuses on three potential types of insurance and an *ex post* disaster payment that is not fully comparable with the Exceptional Circumstances Relief Payments (ECRP).

4.1. Brief technical description of Australian model and data

The model is based on micro data from 78 broad-acre farms in Australia that produce wheat, barley, and canola and with revenues derived from other activities (livestock). The data covers the period 2003-08. To examine the impact of different risk management instruments, a typology of farms was developed according to their risk characteristics. Three clusters or farm types were identified in the sample using the cluster analysis method described in Kimura and LeThi (2011).

- **Low risk farms** have high level yield and low variation of yield and income. They also tend to have low correlation with systemic yield risk. They represent 14% of farms in the sample.
- **Medium risk farms** have average level of yield and variation of yield and income. They tend to have high correlation with systemic yield risk. This group represents 53% of farms in the sample.
- **High risk farms** have low level and high variation of yield and income. They tend to have medium correlation with systemic yield risk. They represent 32% of farms in the sample.

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 reviewed in section 1.2, are reported in Table 1 and corrected to exclude the effect of structural adaptation (Section 3 in this chapter). These changes in mean yield and variance are applied in the simulations presented in this section. Climate change is assumed to imply a 17% to 29% reduction in mean yields across all three commodities, which is likely to dominate impacts as compared to changes in the variability of yields. The marginal climate change scenario has different implications for the standard deviation of yields of different commodities: this indicator of variability will increase by 10% for wheat, remain constant for barley, and decrease by 6% for canola. This scenario would create a diverse set of relative incentives: wheat is the commodity that performs best in terms of average yield under climate change, but it has the highest increase in variability. Furthermore, broad-acre farms in Australia produce crops and livestock, but the simulations in this section do not model the impacts of climate change on livestock production, nor on livestock insurance.

4.2. Impacts and costs of insurance and ex-post payments under "marginal" climate change

This section compares the baseline without climate change to the scenario with marginal climate change with no structural adaptation (but with diversification between crops) as presented in Table 5. For each farm type, a set of indicators measures the impact of the introduction of four policy tools of the *status quo* baseline and marginal climate change scenarios. These indicators include the share of land that is insured, an index of diversification in production, the budgetary government cost per hectare, and the two indicators of cost effectiveness on risk welfare gains and low incomes.

In the baseline, there is a strong preference by farmers to buy individual yield insurance due to the high level of risk. Furthermore, since 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. The purchase of insurance is associated with less diversification, particularly as concerns medium and high risk farms. For the medium risk farm, the most numerous group in the sample, there is considerable demand for area yield insurance, likely due to the high positive correlation between the farm and area yield (systemic risk).

Insurance demand is hardly affected by climate change, which in some cases can decrease. An increase in demand could occur mainly for weather insurance and high risk farms (Table 5). This happens because climate change is expected to have a dual effect of reducing yields in Australia, but with variability expected to increase only for some commodities. In any case, a higher risk environment does not always imply a higher purchase of insurance because premiums also increase with the risk.

The negative risk related welfare gains for most policies and farm types (with the exception of individual and area yield insurance for high risk farms) indicate that the net effect of insurance is more specialisation and higher income variability. This is due to the cross effects with livestock production in Australian mixed farms, and the effect is stronger under climate change for low and high risk farms. This effect may be exaggerated in the model because livestock returns are assumed to have no possibility of insurance and a low correlation with systemic risk and with weather index. However, this type of response is likely in mixed farms: insurance reduces diversification and can imply a net increase in farm income variability. Policies tend to perform better in terms of their impact on low incomes (lowest 10 percentile) than in terms of welfare gains. Performance improves sometimes under the marginal climate change scenario as compared to the baseline, but these improvements tend to be marginal.

The biggest budgetary costs occur for individual yield insurance, but they do not particularly increase with climate change. This is why, despite its lower buy-up rates as compared to individual yield insurance, area yield insurance is the instrument that performs relatively better for both low and high risk farms. The reason being that individual yield insurance implies much higher budgetary cost per hectare than other options. *Ex post* payments can perform well for some types of farms, such as medium risk farms, but their budgetary costs increase too much so that it is not cost efficient under climate change.

Table 5. Impact of the introduction of insurance and *ex post* payments under climate change (marginal) in Australia

	Baseline					Marginal climate change				
				Cost effectiveness					Cost effectiveness	
	% of land insured	Diversification index (percentage change)	Budgetary cost (AUD/ha)	Welfare gain per AUD expenditure	Impact on low incomes per AUD expenditure	% of land insured	Diversi-fication index (percentage change)	Budgetary cost (AUD/ha)	Welfare gain per AUD expenditure	Impact on low incomes per AUD expenditure
Low risk farm										
Individual yield	100.0	-2.5	8.20	0.08	0.49	100.0	-3.77	8.07	-0.13	0.37
Area yield	19.7	0.1	1.10	2.58	6.82	18.5	0.65	1.00	2.70	6.03
Weather index	51.0	-1.4	2.40	-0.73	-2.56	70.3	-3.20	2.70	-0.83	-3.66
Ex post payment	0.0	-0.1	1.30	-0.06	-0.47	0.0	-0.16	1.53	-0.06	-0.42
Medium risk farm										
Individual yield	100.0	-11.4	8.30	-0.36	-0.25	98.1	-7.21	8.63	-0.06	0.33
Area yield	80.2	-8.7	4.90	-0.60	-2.97	79.1	-11.72	5.05	-0.52	-2.06
Weather index	54.8	-3.2	2.40	-0.60	-0.42	74.3	-6.48	2.85	-0.34	1.11
Ex post payment	0.0	-0.9	5.80	-0.06	-0.02	0.0	-1.77	7.71	-0.06	0.09
High risk farm										
Individual yield	77.1	-4.7	10.90	0.12	1.73	100.0	-18.22	14.47	-0.30	0.33
Area yield	19.0	4.5	1.10	2.00	15.03	31.3	-1.26	1.81	0.45	2.16
Weather index	48.7	-7.3	2.30	-0.57	-2.30	63.0	-11.59	2.42	-0.58	0.57
Ex post payment	0.0	-0.4	1.30	-0.05	0.99	0.0	-0.98	2.76	-0.05	-0.39

Note: The welfare gain reported is the only 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. Both impact numbers are divided by the budgetary costs to express them as cost effectiveness indicator per AUD of expenditure.

Area yield insurance performs best in both reducing overall risk and increasing low incomes. Weather index insurance has a low budgetary cost per hectare because administrative costs are low, but has low performance in reducing risk as highlighted by these instruments' impact on low incomes and farmer welfare. With marginal climate change, the budgetary cost per hectare is typically stable for insurance instruments, whereas it increases for *ex post* payments.

5. Impact of climate change on risk management instruments in the Canadian case study

This section focuses on the analysis of risk management decisions at farm level using farm level data from a sample from the south west the Canadian province of Saskatchewan. The data contains only sole proprietor farms and exclude partnership or corporation farms due to difficulty to separate revenue and expense data. Unfortunately, off-farm income data was not available in the sample to tell the significance of crop revenue in farm household income. 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 focuses on three hypothetical types of insurance and an *ex post* disaster payment. Analysis of the implications of such programmes for risk management and their crowding out effects for the demand for insurance were undertaken in Antón *et al.* (2011).

5.1. Brief technical description of the Canadian model and data

The model, based on micro data from a specific region in Saskatchewan, includes 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 their risk characteristics. Three clusters, or farm types, were identified in the sample using the cluster analysis method described in Kimura and LeThi (2011). The mean, standard deviation and correlations of prices yields and costs are calculated from the data in each sample cluster. They have the following characteristics.

- **Low risk farms** have a low level and variation of yield and income. They tend to be large and have a relatively low correlation with systemic yield risk. They represent 54% of farms.

- **Medium risk farms** have medium wheat yield variability and medium yield levels. They also have a relatively high correlation with systemic yield risk. They represent 30% of the farms in the sample.

- **High risk farms** have high variance and mean yields. They have medium correlation with systemic yield risk. They represent 16% of the farms in the sample.

It is assumed that crop yield distribution in the three farm types are affected in the same way by climate change. The perturbations introduced by climate change, gleaned from the literature reviewed in section 1.2, were reported in Table 1, and corrected to exclude the effect of structural adaptation as explained in section 3. These numbers show a 13% to 23% reduction in mean yields across all commodities while the change in the standard deviation is negative (a reduction in variability) for wheat and barley and positive for canola. In the case of barley the reduction of variability is 17%, much bigger than the 10% reduction in the mean yields. Under this marginal climate change scenario, variability does not increase.

5.2. Impacts and costs of insurance and ex post payments under "marginal" climate change

This section compares the baseline without climate change to the scenario with marginal climate change with no structural adaptation (but possible diversification or reallocation between crops) as presented in Table 6. These baseline results indicate there is a general preference by farmers to buy area yield insurance, due to a relatively high positive correlation between the farm and the area yield (the farms in the Canadian sample come from a very small location within Saskatchewan), and lower net administrative cost than individual yield insurance. If the net administrative cost was identical between individual yield and area yield insurances, farmers most likely would have preferred individual yield insurance which also covers basis risk for individual farmers. The demand for weather index is highest for the medium risk farm category.

Surprisingly, given that yield variability does not increase in the marginal climate change scenario in the Canadian case study, demand for insurance increases slightly for low and high risk farm types after climate change. Some farmers such as those in the low risk farm category particularly increase individual yield insurance demand. Other farmers, such as those in the high risk farm category, boost more the demand for area yield insurance. With climate change high risk farms experience a proportionately larger increase in the systemic part of their risk (since they start from a low correlation with systemic risk), which is more correlated with the area yield and benefits the demand for this type of insurance. It also increases the correlation between yields and the weather index.

The four instruments have a positive impact on risk-related welfare for both scenarios and the three farm types. The welfare gains reported in the table include only the change in welfare that is linked to the reduction in variability of income, and not the gains from changes in mean income associated with transfers. According to this indicator, both in the baseline and the marginal climate change scenarios, *ex post* payments are consistently the least effective instrument for 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 relative reduction in income. In practice *ex post* payments are rarely based on individual loss assessment and they are triggered by the existence of a systemic shock. 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 high demand by farmers for this type of insurance.

Table 6. Impact of the introduction of insurance and *ex post* payments under climate change (marginal) in Saskatchewan

	Baseline					**Marginal climate change**				
				Cost effectiveness					Cost effectiveness	
	% of land insured	Diversification index (percentage change)	Budgetary cost (CAD/ha)	Welfare gain per CAD expenditure	Impact on low incomes per CAD expenditure	% of land insured	Diversification index (percentage change)	Budgetary cost (CAD/ha)	Welfare gain per CAD expenditure	Impact on low incomes per CAD expenditure
Low risk farm										
Individual yield	21.5	-1.3	0.40	-0.01	-1.16	65.6	-7.2	1.66	0.02	-0.89
Area yield	58.3	5.5	0.59	0.12	-0.47	59.6	-0.5	0.57	0.08	-1.06
Weather index	23.8	1.5	0.19	0.04	0.86	28.9	1.2	0.22	0.05	5.66
Ex post payment	0.0	0.1	0.24	0.01	1.24	0.0	0.2	0.29	0.00	1.28
Medium risk farm										
Individual yield	58.7	-7.0	0.55	0.12	2.92	56.8	-2.2	0.53	0.06	0.48
Area yield	60.6	-1.6	0.62	0.18	4.84	60.1	-0.5	0.57	0.16	4.67
Weather index	46.5	3.3	0.37	0.25	2.01	33.3	2.6	0.25	0.12	6.12
Ex post payment	0.0	0.3	0.25	0.04	5.71	0.0	0.3	0.30	0.01	4.06
High risk farm										
Individual yield	31.6	-10.5	0.87	0.11	0.34	68.0	-5.4	1.65	0.11	-0.07
Area yield	47.4	-5.8	0.48	0.13	-4.85	63.0	-5.1	0.60	0.08	-2.35
Weather index	37.7	2.5	0.30	0.21	-7.30	31.6	0.7	0.24	0.05	0.35
Ex post payment	0.0	0.1	0.20	0.03	-0.29	0.0	0.0	0.31	0.00	-0.06

Note: The welfare gain reported is the only component linked to the reduction in variability of income, not from changes in mean income associated with transfers. The impact on low incomes instead refers to the income change for farms in the lowest 10th percentile of income per acre, and includes both components from changes in mean and variability. Both impact numbers are divided by the budgetary costs to express them as cost effectiveness indicator per CAD of expenditure.

Climate change does not systematically modify the impact of insurance on diversification strategies: sometimes this crowding out is increased, sometimes it is reduced. Crowding-out effects remain large for individual yield insurance and exist for area yield insurance. Weather index insurance, on the contrary, is found to enhance diversification strategies.

In the baseline, the lowest budgetary cost per hectare insured across all three farm types is for weather index insurance and the *ad hoc* payments. The budgetary cost per hectare of different policy instruments typically increases slightly with marginal climate change, mainly due to the increase in demand for insurance. Although there are differences between farm types, costs of individual yield insurance are impacted relatively more by climate change

Ex post payments perform well for low income objectives under the baseline, but are out-performed by cheaper weather index under marginal climate change. Area yield insurance performs best for welfare objectives, particularly under climate change, ahead of weather insurance that performs well in the baseline.

Agri-Stability is an additional government programme that is not included in the modelling presented in this paper. Producers are not charged an actuarially sound premium for AgriStability coverage, but pay and administrative participation fee which is scaled to the producers' margin level. The programme triggers a payment when the calculated margin is below a reference level based on recent record of that farm. The payments cover differently different "tiers" of income, but it includes all kind of risks, one of which is yield risk covered by the insurance programmes.[9] In this sense, it is an imperfect substitute for insurance and its presence would induce farmers to reduce their demand for insurance with and without climate change. AgriStability covers broad normal risks. Compared to AgriInsurance,[10] Antón *et al*. (2011) shows that it has stronger effects on reducing diversification, which is part of a farmer's strategy to adapt to production variability under climate change.

6. Impacts of climate change on risk management instruments in the Spanish case study

This section focuses on the analysis of risk management decisions at farm level using farm level data from Spain. A simplified version of the model developed in OECD (2011) is used. It focuses on three hypothetical types of insurance and an *ex post* disaster payment.

6.1. Brief technical description of Spanish model and data

The model is based on micro data from 12 crop farms located in the province of Valladolid, Spain, producing barley, wheat and other commodities such as sunflowers and olives. The data covers the period 2001-07. To examine the impact of different risk management instruments, a typology of farms was developed according to whether or not they were irrigated. Two clusters of farms have the following characteristics.

- **Irrigated farms** have high level yield and low variation of yield and income. Their yield risks also tend to have lower correlation with precipitation risk. Correlation with systemic yield risks tends to be high. They represent one-third of the sample farms.

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[9] AgriStability payments are corrected to avoid any double compensation from insurance or other disaster assistance.

[10] AgriInsurance is the Canadian public insurance programme. It offers mainly individual yield insurance for crops.

- **Non-irrigated farms** have average level of yield and variation of yield and income. They tend to have higher correlation with precipitation risk. Correlation with systemic yield risks tends to be high as well. This group represents two thirds of farms in the sample.

Similar to the other country case studies, it is assumed that crop yield distributions in the two farm types are affected in the same way by climate change. The perturbations introduced by climate change, gleaned from the literature reviewed in section 1.2 and reported in Table 2 and corrected to exclude the effect of structural adaptation as explained section 3. The numbers show reductions in the order of 8% to 17% in expected yield. Under the marginal climate change scenario in this section, the variability of barley and wheat yields increases by 89% and 110%. This climate change scenario for Spain implies a very significant increase in the variability of the yields of both commodities, well beyond the changes in the mean yields.

6.2. Impacts and cost of insurance and ex post payments under "marginal" climate change

The insurance policy most in demand in the baseline is area yield insurance for irrigated farms. These farms have a very strong systemic risk component and correlation with area yield. The small size of the sample of farms in Spain also contributes to exacerbate a high correlation with area yield.

Climate change significantly increases the demand for insurance by non-irrigated farms. However, it hardly impacts the demand for insurance by irrigated farms, and hardly changes the relative demand for different insurance. This increase in demand is particularly strong for area yield and individual yield insurance. This is consistent with a climate change scenario in Spain that implies very strong increases in the variability of yields.

Budgetary costs of *ex post* payments are always the highest across policy tools. All programmes experience a significant increase in the budgetary costs after climate change. Due to lower uptake, individual yield insurance does not become much more costly for the government budget than area yield insurance, despite its higher administration costs. *Ex post* payments exhibit exploding budgetary costs under climate change.

The best performance in reducing variability as measured by the welfare gain and the reduced low income cost effectiveness indicators corresponds to area yield insurance followed by individual yield insurance (the latter for non-irrigated farms welfare gains under climate change). The performance of weather index insurance is the worst choice across farm types and scenarios, indicating that the correlation between rainfall and yields, which is higher than in the other countries, is not high enough even among non-irrigated farms.

Table 7. Impact of the introduction of insurance and *ex post* payments under climate change (marginal) in Spain

	Baseline					Marginal climate change				
				Cost effectiveness					Cost effectiveness	
	% of land insured	Diversification index (percentage change)	Budgetary cost (EUR/ha)	Welfare gain per EUR expenditure	Impact on low incomes per EUR expenditure	% of land insured	Diversification index (percentage change)	Budgetary cost (EUR/ha)	Welfare gain per EUR expenditure	Impact on low incomes per EUR expenditure
Irrigated farm										
Individual yield	82.5	-1.4	4.60	0.03	2.96	77.8	-2.8	11.38	-0.02	3.28
Area yield	100.0	-0.5	6.25	0.19	8.63	100.0	-7.5	12.95	0.05	6.13
Weather index	59.3	-0.5	1.20	-0.29	-0.09	108.2	-4.7	2.09	-1.26	-27.19
Ex post payment	0.0	-0.4	13.38	0.02	1.85	0.0	-2.0	45.08	0.01	1.76
Non-irrigated farm										
Individual yield	17.7	-0.8	1.34	0.08	6.05	49.4	-7.8	12.22	0.02	4.63
Area yield	19.0	-2.3	1.35	0.26	13.58	100.0	-20.2	12.92	0.01	3.14
Weather index	55.1	-6.2	1.11	-0.23	-9.15	98.7	-11.5	1.91	-0.31	-22.72
Ex post payment	0.0	-0.3	2.88	0.02	2.92	0.0	-5.9	44.96	0.01	1.94

Note: The welfare gain reported is only the component linked to the reduction in variability of income, not from changes in mean income associated with transfers. The impact on low incomes instead refers to the income change for farms in the lowest 10th percentile of income per acre, and includes both components from changes in mean and variability. Both impact numbers are divided by the budgetary costs to express them as cost effectiveness indicator per EUR of expenditure.

Diversification is crowded out by all policy tools. This reduced adaptation of the production mix is largely accentuated by climate change. For weather index insurance this effect is enough to make a negative contribution to risk-related farm welfare. Area yield insurance for non-irrigated farms becomes much less cost effective after climate change because all land is already insured and subsidies become, in part, redundant; all land would continue to be insured even with less subsidisation.

7. Conclusions and policy implications

There is general agreement in the literature about the potential channels for the impact of GHG emissions and climate change in agriculture. But the evidence from the empirical literature on climate change is not conclusive in terms of the quantitative impacts in different regions, particularly when looking at variability of yields. The literature review concurs on reductions in average yields across crops in Australia and Canada, but concludes that there are more moderate decreases or even increases in the case of Spain. However, there is little information about the impact on the variability of yields, and the information available shows increases, decreases (in the case of all commodities in Canada) or no changes. The exception is Spain for which the variability is estimated to significantly increase across commodities.

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. In general, insurance uptake is only marginally increased under the marginal climate change scenario. In Spain, climate change is estimated to have a strong impact on increasing yield variability and, consequently, there is more insurance demand. The model is not able to tackle the crucial question of the overall efficiency of these programmes because the simulations assume that the government is not able to modify potential inefficiencies in the market due, for example, to information asymmetries.

Some policy measures have a negative risk reduction effect for some types of farms, particularly in Australia where the effect of discouraging diversification is strong. A policy choice of area yield insurance in Australia will have a negative risk reduction impact for medium risk farms in the baseline, even if its performance is best for low and high-risk farms. Governments will typically not know the best instrument for each type of farm, and a self-selection process would be preferred, even if this implies offering several types of insurance. This does not apply to *ex post* payments given for free and which, therefore, cannot be offered simultaneously with subsidised insurance because they would crowd out the demand for insurance (OECD, 2011)

Individual yield insurance usually has a positive impact on individual risk reductions, but is expensive when compared to other instruments. *Ex post* payments tend to be cheaper, but tend to be more effective for the low income objectives than for overall risk reductions. They are rarely the most cost effective policy choice. Climate change can boost the costs of some of the programmes, in particular in Spain where the climate change scenario includes a strong increase in variability.

In Australia, climate change is expected to have a strong impact in reducing avearage yields, which dominate the effects on variability. The highest demand corresponds to individual yield, but area yield and *ex post* payments perform well in terms of reducing variability and increasing the lowest income outcomes. But individual yield insurance also incur the highest costs. All these programmes have a strong impact on specialisation in the most profitable (and risky) activities in Australia to increase the net variability of income. Climate change does not alter this crowding out of diversification and often has negative risk-related welfare impacts on farmers. Area yield insurance seems to perform best for low and high risk farms, but can have negative effects on medium-risk farms in the baseline.

In Canada, climate change will not have systematic effects in the performance of different instruments because this marginal scenario implies a less risky environment. Area yield insurance performs well in the baseline and in the marginal climate change scenarios, both with respect to insurance demand and reduction in risk. *Ex post* payments perform well for increasing low incomes of low and medium risk farms, but climate change improves the correlation between yields and the weather index, and makes weather index insurance more cost effective.

Finally, climate change in Spain will cause very large increases in the variability of yields and this variance dominates the impact on expected yields. Insurance demand increases significantly for all instruments. Area yield insurance performs well in reducing farmers’ risk. Climate change has a strong effect on non-irrigated farms, with large increases in insurance demand, but this does not translate into improvement of the cost effectiveness of insurance. Climate change increases the budgetary costs of all programmes, in particular, of *ex post* payments.

All these results are subject to significant uncertainties under the most likely climate change climate change scenario. A strong incidence of extreme events could increase the variability of production in a way that is not captured by the standard estimations in the literature. Farmers may significantly adapt farming practices, or, on the contrary, they could just remain unaware of the implications of climate change due to a misalignment in their expectations. Different degrees of adaptation to climate change could be observed. The complexity of policy making in this context of uncertainty is analysed in Chapter 2.

Chapter 2.

Robust policies under strong uncertainties

1. Introduction

Chapter 1analysed several risk management tools and policies by comparing their impact under two stylised scenarios: a baseline with no change in the climate and a marginal climate change scenario. Unfortunately the reality is more complex and the risk environment of crop production in the long term is subject to very strong uncertainties about the exact impact of climate change in each location and farmers' behaviour in this context of uncertainty. The willingness of insurers to supply agricultural insurance will also be affected by uncertainty and expectations.

Agricultural risk management decisions by farmers, policy makers, and insurance companies will be affected by their expectations on future climatic conditions and the associated level of uncertainty in weather patterns. Current estimates of climate change impacts are generally characterised by large uncertainty that depends on the 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, but it is unlikely that such uncertainties will be resolved. It is therefore important to incorporate the uncertainties on the impact of climate change on production variability and farmers' responses when analysing agricultural risk management and risk-related policies.

How can policy makers decide on policies related to risk management in agriculture given these uncertainties? Different stylised scenarios are considered in this chapter: marginal climate change versus climate change with increased extreme events; and adaptation by diversification of the portfolio of crops using existing varieties versus structural adaptation that may imply the use of new varieties and other investments. It is also possible that farmers, governments and insurers are not aware enough of the changes in the distribution of yields due to climate change, holding expectations that are not aligned with the scientific knowledge about climate change and avoiding adaptation.

Different approaches to uncertainty and ambiguity are explored in a comparative analysis for Canada, Australia and Spain. First, characterizing the uncertainty through a set of "plausible" scenarios; second testing the sensitivity of the results by running model exercise and analysis for each scenario; third attempting to solve the decision problem when contradictory results may occur in different plausible scenarios. Different decision criteria are considered for governments to manage the strong uncertainty or structural lack of knowledge about which scenario will emerge. The simplest one consists on assigning probabilities to the scenarios; the most sophisticated attempt to find robust solutions that have a satisficing behaviour across scenarios.

Based on the empirical literature reviewed in Chapter 1, six stylised scenarios have been developed as probability distributions for the yield shocks in each country. Estimates are provided for the risk outcomes, budgetary implications and cost effectiveness associated with the policy options in each scenario. Implications are drawn concerning the robustness of different policy mixes in the face of uncertainty about the perturbation caused by climate change.

2. Stylized climate change scenarios

The literature provides consistent information on whether climate change will increase or decrease average yields for a crop in a given region; however, little information is available concerning how variability will be affected. There is a general consensus that in many regions variability of weather conditions will increase, but there is a lack of information as to how this would affect the probability distribution of crop yields. It is particularly relevant to risk management in agriculture whether the change in variability is distributed evenly around the mean or whether the probability of extreme events increases in the form of stronger and more frequent drops in yields.

Table 8. Typology of climate change scenarios

Description			Climate scenarios		
			Baseline (No climate change)	**Marginal climate change**	**Extreme events**
Behavioural Response	Business-as-usual	Expresses how policy instruments would function without climate change	Baseline		
	Adaptation by Diversification	Based on expected impact on yields assuming farmers can only adapt by diversifying among existing varieties		Marginal	Extreme
	Structural adaptation	Expected impact on yields based on the literature, assuming farmers can switch to crop varieties that reduce impact of climate change		Marginal with adaptation	Extreme with adaptation
	Misalignment (no adaptation)	Farmers make production decisions based on their historical experience and therefore do not take into account the increase in systemic risk (no adaptation)		Marginal with misalignment	Extreme with misalignment

Table 8 above outlines a typology of plausible climate scenarios. Three scenarios on climate conditions are considered. The baseline scenario implies business as usual with no climate change, assuming that current distribution of yields will remain valid in the future. The marginal climate change scenario assumes that the distribution of yields will be modified by climate change according to the most reliable numbers in the empirical literature. Finally, a more radical climate change scenario assumes that the potential impacts of more frequent extreme climate events affects agriculture. These two latter climate change scenarios are combined with three different sub-scenarios that reflect the behavioural conditions of farmers. First, adaptation by diversification assumes that farmers will adjust the combination of crops they produce, but will not get involved in further responses such as those included in the second structural adaptation sub-scenario. The third "misalignment" sub-scenario foresees the possibility of farmers and other agents ignoring the reality of climate change.

Marginal climate change

The starting point is the marginal climate change scenario with adaptation by diversification, with the same quantitative assumptions made as in Chapter 1. This scenario assumes endogenous adaptation through the diversification of the portfolio of commodities. The other two sub-scenarios are combined with marginal climate change: structural adaptation and misalignment.

Extreme events

Assessments of climate change tend to state that the frequency and extent of extreme weather events are likely to increase. An extreme events scenario is developed 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. This proves the structural uncertainty behind any quantitative estimation of the implications of climate change on the variability of agricultural production. The extreme events[11] scenarios in this paper add an additional stochastic extreme systemic shock based on the lowest 25 percentile of the yield distributions. It is assumed that yields in the lowest tail of the distribution are (randomly) halved on average.[12] The other two sub-scenarios are also combined with extreme events: structural adaptation and misalignment.

Structural adaptation

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 fertiliser applications, and irrigation. Some of these adaptation measures come at no cost, such as adjusting the date of planting, while others like irrigation may require investments. The model in this paper captures adaptation changes in the composition of the portfolio of commodities on the farm. This adaptation by diversification scenario is compared with a stronger adaptation scenario that has more structural adaptation strategies represented as exogenous shocks in the mean distribution of yields. The literature review in Chapter 1 defines the quantitative assumptions under the structural adaptation scenario (Howden *et al.*, 2007) implying a stylised increase of 11.1% in the mean yield. These assumptions together with the assumptions on extreme events are used to define the simulated climate change scenarios in each country (Tables 9, 14 and 19).

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[11] The extreme value theory provides statistical tools to estimate the numbers associated with these extreme values from a reduced sample of observations. We cannot directly apply this theory because there is no observation of these events under climate change. However, this literature could be a reference for any further work on distributions and simulations of extreme values.

[12] The following procedure has been applied. The realised Monte-Carlo values of the 25 lowest percentile of the original distribution of systemic yields under climate change (based on section 2.2) are multiplied by a random number extracted from a uniform [0,1] distribution. This implies, on average, dividing by two the lowest values of the yield distribution. An empirical distribution is then calibrated and used with the same original correlation values- for the Monte-Carlo extreme events scenario.

Misalignment

Finally, we consider a scenario in which the agents (farmers, government and insurers) are not informed about the climate change that is taking place. They take their decision as if distribution of production had not changed with the climate.

3. Methods for policy decision making under severe uncertainty and ambiguity

The marginal climate change scenario with adaptation by diversification that was analysed in Chapter 1 is only one possibility among several scenarios. The seven combinations of scenarios discussed in the previous section are all plausible outcomes according to current empirical evidence. However, the available knowledge is not sufficient to match each scenario with a scientifically estimated probability. That is, there are uncertainties about climate change that cannot be “probabilised”. These severe uncertainties are often called “ambiguity”, which is represented in this paper by the lack of information about the likelihood of the different scenarios occurring (baseline, marginal climate change and extreme events), and how farmers will behave (whether they will undertake structural adaptation and whether their expectations will be misaligned).

Policy makers must take their decisions taking account this ambiguity. Early work by Keynes (1921) and Knight (1921) brought this kind of management uncertainty to the core of economic thinking. Bringing it to the core of policy making has proved more difficult and it is only recently that there have been attempts to seriously tackle this problem (Gollier, 2011). Ben-Haim (2006) provides a very technical response to cover information gaps in these types of problems. Etner *et al*. (2010) propose two theoretical alternatives to manage decision making under ambiguity: 1) A standard Bayesian treatment consists of assigning objective or subjective probabilities to events and then applying preferences using expected values or an expected utility approach; and 2) a non-Bayesian approach with a formal definition of ambiguity and different degrees of ambiguity aversion. This latter approach may take several forms depending on the structure of beliefs and priorities about probabilities and the confidence that the decision maker has in these beliefs.

The purpose of this chapter is to analyse agricultural risk management policy decisions under severe uncertainties about the climate change scenarios. A standard Bayesian approach will be used building *a priori* probabilities for the different scenarios. Two alternative simple non-Bayesian approaches will be considered: satisficing and MaxiMin criteria. Both represent different degrees of ambiguity aversion by the decision maker and they respond to the idea of providing robust choices. A robust choice is defined as one that performs “reasonably well” under a variety of different plausible scenarios even though it does not necessarily provide the most cost effective policy. These three approaches are defined in Box 3 and will be applied to the results in the Australian, Canadian and Spanish case studies. Other criteria are also available in the literature (Etner *et al*. 2010), but all involve some *a priori* beliefs about probabilities, confidence on these probabilities, and/or ambiguity aversion of the government.

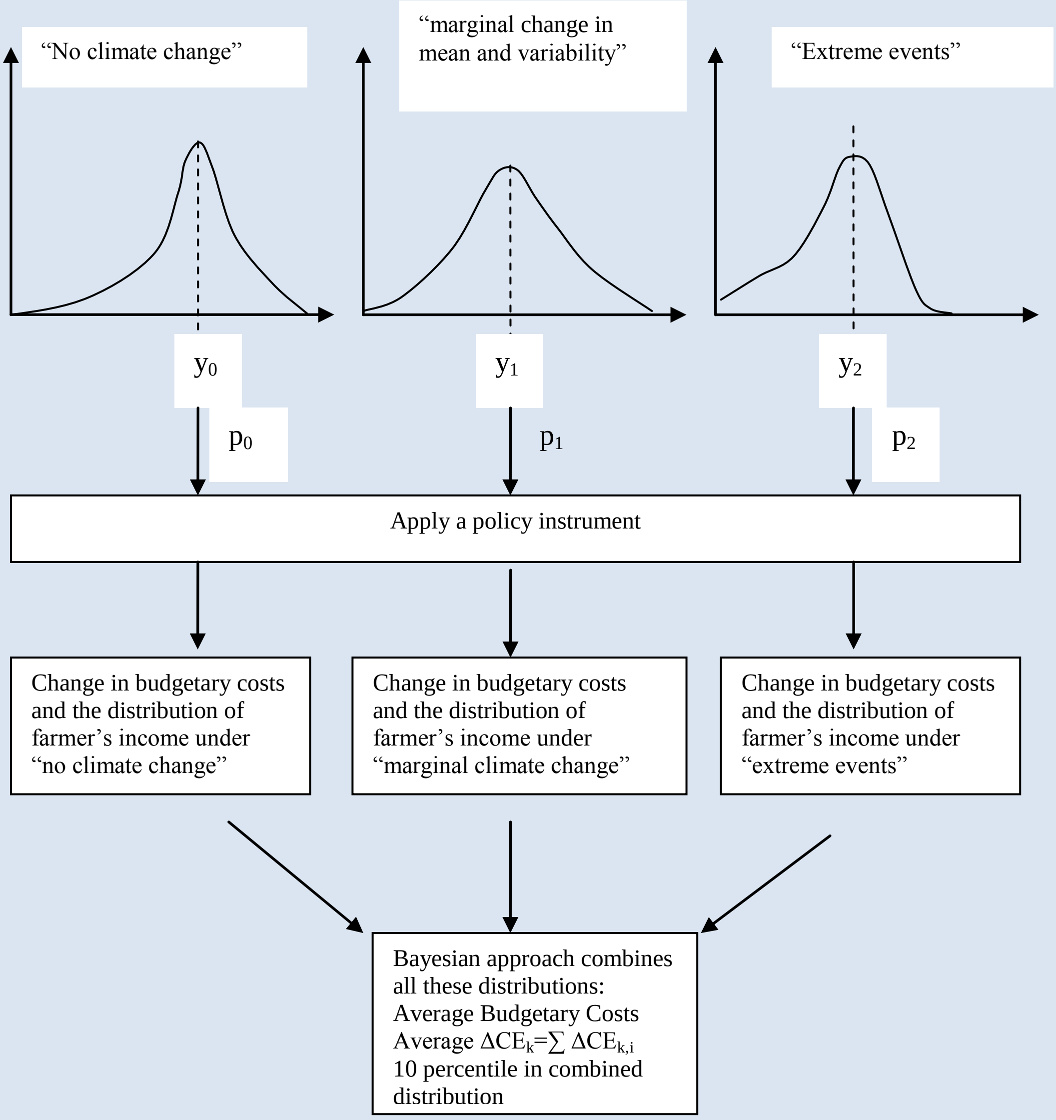
For all these decision making rules, two indicators of policy cost effectiveness will be used. The first is defined as the welfare gains (measured by the certainty equivalent income) of reduced income variability and measures the overall increase in the variability; the second is defined as the increase in the lowest 10 percentile income and measures the impact in the lower tail of the distribution (Chapter 1).

Box 3. Three approaches to decision making under strong uncertainty

Bayesian "probabilistic" approach

The uncertainty across scenarios can be handled through a standard Bayesian probabilistic approach. The standard Bayesian approach to manage this ambiguity consists in assigning probabilities to each scenario and obtaining a combined distribution of outcomes that accounts for different scenarios to occur. Decision making can be based on standard expected utility theory with or without government risk aversion. We assume no government risk aversion, but a preference to reduce farmers' income risk as defined by risk reduction and cost effectiveness indicators.

Figure 2. The Bayesian approach to ambiguity: Combining probability distributions from different scenarios



continued

"Satisficing" criterion

The “satisficing” principle is based on the idea of ensuring a reasonably good outcome. Since it will be difficult for a single policy instrument to be optimal across all possible states of the world (climate change and behaviour scenarios) for all farm types, an analysis can be carried out to see if there is an instrument that performs “well enough” in all situations under consideration. 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 the policy maker which scenarios are most disregarded under each choice. For the purpose of applying this criterion, a policy choice is defined as “satisficing” if the value of the cost effectiveness indicator is within 35% of the best performing policy in all the scenarios.

MaxiMin criterion

Another possibility is to focus on avoiding worst-case outcomes in an adverse state of the world, i.e. maximising the minimum outcome or MaxiMin (von Neumann, 1928). The principle is to take the worst-case scenario for any given instrument and choose the instrument that has the highest value for cost-effectiveness indicator in its worst-case scenario. This criterion is very conservative, representing high ambiguity aversion, and has the advantage of always choosing a single instrument across all scenarios.

4. Conclusions and policy implications

The two budgetary cost-effectiveness indicators are employed to assess robustness of instruments across different climate change scenarios. This ambiguity in the policy choice is represented in Table 9, showing the optimal policy choice for the two policy objectives across a set of seven climate change and behavioural scenarios. We assume there is no scientific information about the likelihood of these scenarios and we call this “ambiguity.” We use the available information discussed in this paper to build scenario results that allow making an optimal decision in each scenario. This optimal decision for the weighted average or pool of all farms[13] is represented in each cell of Table 9. These results are obtained from the modelling analyses detailed in Annex 1. These results aim at investigating whether it is possible to identify policies that perform reasonably well across highly varied climate change scenarios.

Starting with Australia, the results in Table 9 show that for farmer welfare gain area yield insurance performs best in all scenarios except under extreme events with misalignment in which weather index performs best. This is explained by the fact that the demand for weather index insurance is large despite the misalignment when its budgetary costs are kept under control. Area yield still performs best to increase incomes under marginal climate change while *ex post* payments perform best under extreme events cases. This is because there is a high level of risk in Australia that is systemic and because *ex post* payments are always better suited to low income objectives that typically occur under very systemic shocks.

With regard to the Canadian study the results show that with respect to farmer welfare gains, area yield performs best under marginal climate change scenarios, while weather index performs best with marginal climate change with misalignment and in all cases related to extreme events. This is explained by the fact that extreme events increase the correlation between yields and the weather index, while it can boost the budgetary costs of area yield insurance. As to budgetary cost-effectiveness of increasing low incomes, none of the instruments perform best across scenarios. In fact, all types of policies perform are best in at least one of the scenarios.

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[13] Details about different results across farm types can be found in the country studies in Part III.

Table 9. Optimal policy choice under different scenarios

		Marginal climate change			Extreme events		
Country case	**Baseline**	**Adaptation by diversification**	**Adaptation**	**Misalign-ment**	**Adaptation by diversification**	**Adaptation**	**Misalign-ment**
Australia							
CE* gain	Area yield	Area yield	Area yield	Area yield	Area yield	Area yield	Weather index
Low incomes gain	Area yield	*Ex post* payment	Area yield	Area yield	*Ex post* payment	*Ex post* payment	*Ex post* payment
Canada							
CE* gain	Area yield	Area yield	Area yield	Weather index	Weather index	Weather index	Weather index
Low incomes gain	Weather index	*Ex post* payment	Weather index	Individual yield	Area yield	Area yield	Weather index
Spain							
CE* gain	Area yield	Area yield	Area yield	Area yield	Area yield	Area yield	Area yield
Low incomes gain	Weather index	Weather index	Weather index	Weather index	Weather index	Weather index	Weather index

*CE: Certainty Equivalent of income.

The Spanish case study results show the two best performing instruments across all scenarios to be area yield for farmer welfare gain and weather index for low incomes. Weather index is assumed to have smaller transaction costs and higher correlations than in other countries, which is the most likely driver of the good performance of weather index insurance for low income objectives. In this case, there is no need to apply a specific criterion for robust policies since a single instrument out-performs all the others in all the scenarios.

In most of the cases and scenarios, area yield and weather index seem to perform well for farmer welfare gain while results are more diverse for low income gains. In particular, *ex post* and individual yield insurance that do not appear as optimal policies for overall risk welfare gains are preferred choices in some specific scenarios. In general, *ex post* payments are better equipped for low income objectives because they are triggered only for very systemic events. For different reasons, individual yield insurance can also be relatively efficient for low income objectives: indemnities are triggered with 30% deductible and are targeted to individual (even if commodity specific) yields.

Area yield insurance seems to out-perform most other instruments. The reality may be more nuanced because the difference between area yield and individual yield insurance is continuous. Area yield insurance converges to individual yield when the number of farms included in the area yield calculations is small enough so that the individual yields are highly correlated with those of the rest in the same area. In the case of Australia and, in particular, Spain, the number of farms in the sample is small. In the case of Canada, all the farms come from a concentrated part of Saskatchewan and therefore must be highly correlated. These correlations are above 90% for Spain, and around 70% or 80% for Australia and Canada (Annex 1). Our assumption about the administrative costs of this type of insurance (10% compared to 30% for individual yield) seems to make it particularly attractive. This identifies the main technical challenge for the insurance instruments: creating efficiency gains by maximising correlations while keeping administrative costs low. For this task, the development of different indexes can help for the welfare gains objective. Index insurance, on the contrary, is more likely to fail to respond to the objective of low income outcomes.

In general, optimal policies under one scenario are not optimal under a different scenario. There is a need to bring together policy impacts across different scenarios. The simplest way is to average weights defined as probabilities and following a probabilistic or Bayesian approach. Other decision rules are possible, particularly when the policy objective is to improve low income outcomes. Table 10 identifies best Bayesian choices and robust policy choices across all climate and behavioural scenarios using two different policy choice criteria, that is Satisficing and MaxiMin.

For Spain, there is not an issue because the same policy is best across all scenarios. These results are confirmed by the robust criteria results and for farmer welfare gains area yield is the best choice under Bayesian and Satisficing criteria while weather index becomes first choice under MaxiMin. Weather index is the best choice under Bayesian and Satisficing criteria for increasing low incomes, while area yield is preferred under MaxiMin. *Ex post* payments are not a good option in Spain because they are triggered too often (every 4-5 years) and become expensive, while weather index is much cheaper and has a higher correlation with yields than in other countries.

As regards Australia and farmer welfare gains, area yield is the best performing instrument according to all decision criteria, while for increasing low incomes *ex post* payments are the best option in Bayesian optimum and MaxiMin. In the case of Satisficing criterion, none of the instruments performed well enough across all climate and behavioural scenarios. Therefore, area yield emerges as a robust policy choice to reduce the overall risk of the average farmer in Australia: it is correlated enough with individual risk and, in general, cheaper than individual yield insurance and has less crowding out of diversification. If, however, the objective is to tackle low income outcomes, *ex post* payments exhibit the most robust performance because they are triggered only when very systemic event occur and expected budgetary costs do not overshoot as much as insurance under the misalignment scenario. However, *ex post* payments are triggered relatively often (once every seven years) and the expenditure becomes large in those years.

In the case of Canada and farmer welfare gain, weather index performs best with all decision criteria, while for increasing low incomes weather index is the best option in Bayesian optimum and *ex post* payments in MaxiMin. In the case of Satisficing criterion, none of the instruments performed well enough across all scenarios. Weather index is not the best policy in most of the scenarios for Canada, but performs well enough because it avoids the risk of heavy budgetary costs in the case of misalignment of other kinds of insurance. An alternative policy approach would be to ensure information and training for farmers to avoid the misalignment scenario from occurring, although the result is more uncertain. For low income objectives, *ex post* payments are more robust while weather index is better in a Bayesian average. This is because the former avoids the possibility of index insurance being ineffective under misalignment.

Table 10. Robust policy choice across climate change scenarios

Country case	Bayesian optimum	Satisficing	MaxiMin
Australia			
CE gain	Area yield	Area yield	Area yield
Low incomes gain	Ex-post payment	-	*Ex post* payment
Canada			
CE gain	Weather index	Weather index	Weather index
Low incomes gain	Weather index	-	*Ex post* payment
Spain			
CE gain	Area yield	Area yield	Area yield
Low incomes gain	Weather index	Weather index	Weather index

Results across all countries, objectives and choice rules should be interpreted with caution given the limitations of this study. They seem to find that for a farmer welfare gain area yield or weather index are robust while for low incomes gain it is either *ex post* payments or weather index. However, the discussion here shows that results are specific to the risk profile of each country and even each farm (Annex 1) and depends on the availability of good indexes or highly correlated area yields, while keeping administrative costs low. Results also show that robust criteria can provide different answers than Bayesian traditional probabilistic criteria. This is particularly important for the low income objectives.

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Annex 1.

The model, data and country studies

1. The model

The stochastic simulation model used in Chapters 1 and 2 introduces a set of risk management strategies that are relevant in Australia, Canada and Spain; 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 triggered by a systemic yield loss. The model also analyses empirically the producer's participation in the risk market and its impacts on farm welfare and low income risk. Interactions between a diversification strategy 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 is tailored to the risk exposure and strategic environment revealed by the micro data.

The model analyses a representative farm producing major crops under price, yield uncertainty in addition to the uncertainty in other agricultural revenue (other crop revenue in Canada and Spain, and livestock revenue in Australia) and cost. Income depends on agricultural revenue, insurance indemnity and payments from the government. The simulation scenarios determine a set of optimal decisions at the farm; the land allocation and the insurance coverage. Since the first order conditions to maximise the expected utility lead to analytical expressions that are difficult to quantify, the analysis depends on Monte-Carlo simulations 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) present the technical background of stochastic model in greater detail and further sensitivity analysis of the model with respect to some key parameters such as risk aversion.

1.1. Stochastic simulation model

The representative farms in Australia, Canada and Spain are assumed to allocate land among major crops (wheat, barley, oilseed in Australia and Canada, and wheat and barley in Spain) and other residual crops or livestock. The initial wealth necessary to compute the farm welfare is computed as the average net worth of grain and oilseed farms in Saskatchewan in 2008 for all types of farms, CAD 1467 per acre. In Australia, average wealth position of AUD 1551 per hectare in the dataset is assumed to all the representative farms. In Spain, initial wealth of EUR 9731 per hectare is assumed the average net worth of crop farm in 2007 based on FADN database.[1] The representative

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[1] The average net worth of crop farm in 2007 based on FADN database.

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 this model is that it treats risk management strategies as endogenous, allowing the interaction between policies and farmer's decision to be analysed.

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

$\pi=\tilde{p}_i*\tilde{q}_i*f_i(L_i,A_i,I_i)-r*L-w*A-n*I+g(\tilde{p},\tilde{q},\gamma\ldots)$ 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 ($\tilde{\pi}$) is defined as the crop revenue less the variable cost for crop production plus the net transfer or benefit from a given risk management strategy. Since the crop specific cost is not available in the data, the uncertain variable cost ($\tilde{c}$) is not crop specific. However, the crop specific production cost adjustment factor (c_i) is calibrated for each crop so that the initial land allocation becomes the optimum. The model assumes that total land input is fixed and is allocated between *n* crops, other crop or livestock production. Given the Monte-Carlo draw of 1 000 price, yield, revenue and variable cost combinations, the model maximises the expected utility with respect to area of land allocated to each commodity and the level of insurance coverage.

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

where:

$\tilde{p}_i$ $\tilde{p}_i$	uncertain output price of crop *i*
$\tilde{q}_i$	uncertain yield of crop *i*
$\tilde{c}$	uncertain variable cost
c_i	cost adjustment factor of crop *i*
L_i	area of land allocated to crop *i* and
OR	revenue from other crops in Canada, livestock in Australia
g	transfer from government or insurance indemnity
λ	level of insurance coverage decided by farmer

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

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

ω	initial wealth of the farmer

1.2. 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 a fixed area of farmland and allocate land between available crops and livestock in each country. Although farmer tends to rotate crops due for biological reasons, the model assumes no limit on the scope of crop diversification. The degree of crop diversification is represented by the coefficient of variation of market revenue per unit of land. A higher coefficient of variation of crop revenue is used as an indicator of less use of crop diversification strategies and built on a lower diversification index. If the farmer uses less diversification strategy and specialises 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 at 100 and the change of the diversification index is expressed as *-1* times the percentage change in the coefficient of variation of market return.

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 the yield risk of individual farms. The indemnity is paid in the case where the individual crop yield turns out to be below the insured level of yield (30% of deductible), which means that the farmer needs to plant these crops to insure yield risk. 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) with no administrative cost or 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, and wheat and barley in Spain.

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

p_{fi}	forward price of commodity *i*
L_{Ii}	area of land for commodity *i* which farmer insures its yield
q_{hi}	historical average yield of commodity *i*
β_{qi}	proportion of yield insured for commodity *i*
γ	net of administration cost of insurance and subsidy to insurance premium

Area-yield insurance

Area yield insurance is based on systemic yield risk. Insurance premium is calculated by crop from the systemic yield risk parameter so that all farmers pay the same insurance premium. The model assumes no deductible so that the insured farmer receives an indemnity when the systemic yield falls below the expected level. Unlike individual yield insurance, farmers do not need to actually plant the insured crops, but the model assumes the insured area cannot exceed total area of land. 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, and wheat and barley in Spain.

Weather index insurance

Weather index insurance is calibrated based on regional precipitation risk in Canada and Spain, but based on the amount of water inflow into the major river system in Australia. The design follows a standard weather index contract. In Canada, weather index insurance is triggered if the cumulative rainfall index between 1 April and 31 October falls below 250 mm in the region. If the cumulative precipitation index falls below 150 mm, insurance compensates the 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 the 1 000 gigalitres level of Murray inflow. The weather index insurance in Spain is triggered when the cumulative rainfall index between 1 April and 31 October falls below 200 mm in the region and assumes complete yield loss below 150 mm of cumulative rain fall. Since the insurance premium is calculated based on systemic precipitation risk, all farmers pay the same insurance premium and there is no upward limit for insurance subscription. The yield loss is evaluated based on the expected price level of wheat in Australia and Canada, and barley in Spain.

Insurance premium subsidy

In the absence of a government premium subsidy, the insurance premium is assumed to be different between insurance products. Since individual yield insurance usually has high administrative costs (e.g. loss assessment of individual farmers), the market insurance premium is assumed to be 30% additional to the fair insurance premium in Australia and Canada, and 31% in Spain.[2] On the other hand, area yield insurance and weather index insurance do not require individual premium setting or loss assessment. Therefore, the percentage of additional administrative costs is set at 10% for area yield and 5% for weather index insurance (2% in Spain). The government programme to subsidise insurance premiums is modelled as subsidising a fixed percentage of administrative costs (95% in Australia and Canada, and 85% in Spain). By definition under risk aversion, if insurance is priced with a fair premium and no administrative costs, all land would be insured. This is not observed in reality because farmers face other types of costs associated uncertainty and asymmetric information, and they do not fully insure crop yields even though the administrative costs are fully covered by the government. The model assumes that farmers perceive that subsidies do not cover any

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[2] The administrative cost of individual yield insurance and weather index in Spain is calculated from the average loading factor (total premium divided by total claim) of the Multi-risk damage insurance and weather index insurance between 2006 and 2010, respectively.

part of the fair premium. This is a reduced form for modelling the additional non observable costs of insurance. The modelling of insurance instruments is generic and does not necessarily reflect the specific policy parameters of the actual programme.

The extent to which area-yield insurance or weather index insurance is attractive to individual farmers depends largely on the correlation between their yield risk and indices (regional average yield and weather index). These correlations are presented in the section on data.

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 crops fell below 40 percentile thresholds simultaneously. The level of the payment is set individually, which is equivalent to the expected indemnity from area-yield insurance.

2. The data

The modelling work in this study is data intensive and based on different sources. Two types of data were collected and used for the calibration and simulation exercises. First, six to ten years of production data were collected from a panel of individual farms. Second, meteorological data, most commonly on rainfall, was used to design location specific weather index insurance. Different sources were used in different countries with the active collaboration of experts in the respective Ministries of Agriculture and other agencies.[3]

The model in the previous section is calibrated with data from three samples: 402 non-corporate crop farms in South West Saskatchewan, 78 broadacre farms in Australia and 12 crop farms in the province of Valladolid, Spain. Table 11 summarises the data sources.

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[3] In Australia, the farm survey data used is taken from the broadacre farm survey by the Australian Bureau of Agriculture and Resource Economics (ABARES), and the annual inflow in the Murray River is from the Productivity Commission. In Canada, the Saskatchewan crop farm survey data, historical regional yields and the baseline climate change impacts on crop yields are contributed by Agriculture and Agri-Food Canada (AAFC). The farm survey data is taken from the SasCAS/AgriStability data for “Where Canada Delivers” and rainfall information is from the National Climate Data and Information Archive (Environment Canada). In Spain, farm data information was extracted from the FADN database collected by the statistical unit of the Spanish Ministry of Agriculture, Food and Environment, area yield time series were provided by ENESA (the Insurance State entity), and the meteorological data is from the National Meteorological Agency (AEMET). The authors would like to thank the OECD delegations of these countries and the different government units and agencies for their work and collaboration.

Table 11. Source of farm-level data

	Australia	Canada	Spain
Data source	Broadacre farm survey	CAS/AgriStability data for "Where Canada Delivers"	National FADN database
Sample size	78	402	12
Year	2001-07	2003-08	2001-07
Type farms	Mixed farm of crop and livestock	Crop farm	Crop farm
Major crops	Wheat, barley and oilseeds	Wheat, barley and canola	Barley and wheat
Location	Not specified	Census regions of 3AN, 3BN, 3BS, 3ASW, 3ASE in the province of Saskatchewan	Province of Valladolid

2.1. Calibration of representative farms

A hierarchical analysis is applied to groups of farmers according to the similarity of risk in Australia and Canada. The groupings begin with many clusters of sample farms, but merge these 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 minimised while maximising the distance 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. In the case of Spain, the sample farms are divided into low and high risk farm groups based on the availability of irrigation on their farm.

Table 12. Characteristics of each cluster of farms

	Australia			Canada			Spain	
Risk cluster	Low	Medium	High	Low	Medium	High	Low	High
Number of farms in cluster	11	42	25	220	144	38	4	8
Area of operation	936	2 262	483	380	319	257	87	91
Wheat yield								
Mean (tonnes per ha)	3.8	2.0	1.6	1.4	1.9	2.3	3.6	2.6
Coefficient of variation	33.8	36.9	61.8	26.9	31.7	45.3	31.0	31.5
Gross agricultural output								
Mean (AUD, CAD thousand)	524.7	565.2	508.9	98.8	100.1	107.7	31.6	25.0
Coefficient of variation	35.5	30.6	38.4	29.4	29.6	36.9	40.0	44.5

2.2. Calibration of systemic risk and idiosyncratic risks of the representative farms

Agricultural risk of individual farm can be decomposed into 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 face the same price risk, but have unique yield risk). Production risk is represented by stochastic yields in the model. It is assumed that the yield risk of a given set of commodities in farm “i” can be expressed by a random vector with two additive components:

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

The first component $\tilde{s}$ denotes the systemic part of yield risk, affecting all farms in the same area. This variable is built as the average production shock for a given farm type. The second component $\tilde{b}_i$ denotes basis risk for that particular farm and is the residual non-systemic or idiosyncratic component of risk.

A weather index “w” based on rainfall or temperature is used to model index insurance. The main characteristic of this index is the parameter θ_i expressing the correlation between the weather index and the systemic component of yields $\tilde{s}$. Climate change will affect $\tilde{s}$ and may also affect θ_i depending on whether or not the weather variables capture the limiting factors affecting yields.

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. The calibrated systemic risk also includes weather indices. Table 13 describes the sources of weather indices in three countries.[4]

Table 13. Sources of weather indices

	Australia	**Canada**	**Spain**
Definition	Annual inflow to the Murray River system, including Darling	Cumulative rain fall between 1 April to 31 October	Cumulative rain fall between 1 April to 31 October
Year	1978-2008	1977-2007	1981-2011
Location of observed index	n.a.	The weather station located at “Val Marie” in the province of Saskatchewan	The weather station located at “Campasperi” in the province of Valladolid
Coefficient of correlation with systemic wheat yield	61%	61%	74%

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[4] The coefficients of correlation with systemic yield risks are derived from its correlation with county level yield data during the same period in Canada and Spain. The coefficient of correlation between precipitation risk and systemic yield risk in Australia are assumed to be the same as in Canada.

Because the number of observations in available farm level data is too small, the joint distribution of prices, yields and other risks was based on the observed characteristics of systemic risk in Canada and Australia. This distribution is used for the Monte Carlo analysis. The simulation assumed a truncated normal distribution except for the extreme event scenario. The distributions are truncated so that it does not generate values that are higher or lower than the value observed at the sample data. The truncated points are selected as maximum and minimum values of the sample data. Tables 14, 15 and 16 present the characteristics of systemic risks in Canada, Australia and Spain, respectively. In Australia and Spain, the correlation of yields across crops is much higher than in Canada, implying less scope for crop diversification as a risk management strategy. In Australia the correlation between crop yield and livestock revenue is very small, indicating that diversification between these two operations is a potentially important risk management strategy.

Table 14. Characteristics of systemic risk, Australia

Maximum, Minimum, Mean and Standard deviation

	Price (AUD/tonne)			Yield (tonne/ha)			Livestock revenue (AUD/ha)	Cash cost (AUD/ha)	Murray system inflow (thousand gigalitres)
	Wheat	Barley	Oilseed	Wheat	Barley	Oilseed			
Minimum	135.4	103.5	168.4	0.71	0.93	0.38	0.0	28.9	1.0
Maximum	365.2	308.1	433.0	4.63	3.95	2.13	5927.7	1561.0	20.0
Mean	227.2	189.8	344.0	2.14	2.09	1.31	141.3	258.0	9.2
Standard deviation	46.1	38.3	63.7	0.86	0.65	0.46	72.1	211.5	5.7

Coefficient of correlation

		Price			Yield			Livestock revenue	Cash cost	Murray system inflow
		Wheat	Barley	Oilseed	Wheat	Barley	Oilseed			
Price	Wheat	1	0.28	0.44	-0.22	-0.20	-0.06	0.02	0.00	0
	Barley		1	0.25	-0.11	-0.21	-0.01	-0.02	-0.01	0
	Oilseed			1	0.04	0.17	-0.02	-0.01	0.12	0
Yield	Wheat				1	0.69	0.65	0.08	0.30	0.61
	Barley					1	0.55	0.05	0.21	0.67
	Oilseed						1	0.07	0.20	0.63
Other crop revenue								1	0.24	0
Cash cost									1	0
Cumulative precipitation										1

Table 15. Characteristics of systemic risk, Canada

Maximum, minimum, mean and standard deviation

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

Coefficient of correlation

		Price (CAD/tonne)			Yield (tonne/ac)			Other crop revenue	Cash cost	Cumulative precipitation
		Wheat	Barley	Canola	Wheat	Barley	Canola			
Price	Wheat	1	0.59	0.66	-0.06	0.10	-0.05	0.24	0.33	0
	Barley		1	0.34	-0.07	-0.16	-0.08	0.15	0.39	0
	Canola			1	0.01	-0.10	0.03	0.24	0.08	0
Yield	Wheat				1	0.42	0.11	-0.08	-0.04	0.61
	Barley					1	0.13	0.09	0.05	0.67
	Canola						1	-0.07	0.03	0.63
Other crop revenue								1	0.33	0
Cash cost									1	0
Cumulative precipitation										1

Table 16. Characteristics of systemic risk, Spain

Maximum, minimum, mean and standard deviation

	Price (EUR/tonne)		Yield (tonne/ha)		Other crop revenue (EUR/ha)	Cash cost (EUR/ha)	Cumulative precipitation (mm)
	Barley	Wheat	Barley	Wheat			
Minimum	96.1	111.5	0.79	0.29	0.0	13.0	94.0
Maximum	321.2	469.9	10.38	6.05	3403.0	1004.0	444.0
Mean	150.9	165.8	3.36	2.84	281.0	102.0	217.4
Standard deviation	31.7	35.3	1.53	0.84	214.4	24.1	56.1

Coefficient of correlation

		Price		Yield		Other crop revenue	Cash cost	Cumulative precipitation
		Barley	Wheat	Barley	Wheat			
Price	Barley	1	0.73	0.22	0.12	0.37	0.06	0
	Wheat		1	0.01	0.15	0.29	0.40	0
Yield	Barley			1	0.75	0.29	0.19	0.74
	Wheat				1	0.28	0.45	0.74
Other crop revenue						1	0.13	0
Cash cost							1	0
Cumulative precipitation								1

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

2.3. Calibration of climate change risk

The model assumes that climate change affects systemic risk. The different climate change scenarios are described in Table 8 in Chapter 2. The model assumes that structural adaptation to climate change affects only the level of yield. Under the extreme event scenario more frequent extreme weather events are modelled assuming that the farmer suffers from correlated uniform shock to the lowest 25 percentile yields.

2.4. Correlation between yields and area and weather indexes

Table 17 summarises the correlation of individual wheat yield and insurance indices by climate change scenario.

Table 17. Correlation of wheat yield risk and insurance indices

Coefficient of correlation

		Baseline	Marginal climate change		Extreme events	
			Diversification	Structural adaptation	Diversification	Structural adaptation
Systemic yield risk						
Australia	Low	0.58	0.69	0.65	0.73	0.68
	Medium	0.72	0.81	0.78	0.84	0.80
	High	0.65	0.74	0.70	0.78	0.74
Canada	Low	0.08	0.50	0.46	0.65	0.61
	Medium	0.62	0.66	0.62	0.79	0.77
	High	0.52	0.57	0.53	0.69	0.66
Spain	Low	0.98	0.99	0.99	0.99	0.99
	High	0.85	0.95	0.94	0.95	0.94
Precipitation risk						
Australia	Low	0.37	0.44	0.41	0.46	0.43
	Medium	0.45	0.51	0.49	0.53	0.49
	High	0.40	0.46	0.44	0.49	0.46
Canada	Low	-0.41	0.28	0.26	0.36	0.33
	Medium	0.38	0.40	0.37	0.47	0.45
	High	0.30	0.31	0.29	0.39	0.37
Spain	Low	0.64	0.68	0.68	0.67	0.67
	High	0.62	0.68	0.68	0.67	0.68

3. The case study on Australia

3.1. Climate change scenarios

Perturbations introduced by climate change in Australia are gleaned from the literature reviewed in Chapter 1. Table 18 reports the results of the random draws obtained from these distributions. Two climate change scenarios (marginal and extreme events) are combined with two behavioural scenarios (diversification and structural adaptation). These changes in mean yield and variance are applied in the simulations in this section. The numbers show a reduction in mean yields across all commodities and scenarios while, under marginal climate change, the change in the standard deviation is negative or positive for each of the three commodities. Only under the extreme events scenario does the standard deviation of yields increase for all commodities. It is assumed that crop yield distributions in the three farm types are affected in the same direction and magnitude by climate change. In this section, we present more detailed information on how the policy instruments would perform under alternative scenarios.

Table 18. Simulated climate change scenario in Australia

	% change in mean yield				% change in standard deviation			
	Without adaptation		With adaptation		Without adaptation		With adaptation	
	Marginal	Extreme events	Marginal	Extreme events	Marginal	Extreme events	Marginal	Extreme events
Wheat	-14.0	-16.8	-7.4	-16.5	8.4	22.5	9.0	18.3
Barley	-27.1	-29.3	-20.1	-27.1	-0.7	20.2	-0.5	15.1
Oilseeds	-29.3	-29.7	-20.0	-27.1	-7.9	17.9	-7.8	14.4

Note: Based on Luo *et al.* (2010), Van Gool and Vernon (2006) and Howden *et.al*. (2007).

3.2. Demand for insurance

Table 19 presents the results on the share of land insured under each scenario. In the first two columns of Table 19 the share of land insured under the baseline and the marginal climate change without adaptation are reported. Similar 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. Under the misalignment scenario farmers make decisions based on past information and therefore buy the same insurance as in the baseline. The extreme events climate change scenario tends to increase further demand for area-yield and weather index insurance in particular. This is partly because the proportion of systemic risk in individual yield risk increases, making correlation between individual yield, and yield and weather indices higher than baseline and marginal climate change scenarios.

Table 19. Percentage of land insured under different insurance and climate change scenarios in Australia

	Baseline	Marginal climate change		Extreme events	
		Diversification	Structural adaptation	Diversification	Structural adaptation
Low risk farm					
Individual yield	100	100.0	91.2	100.0	89.4
Area yield	19.7	18.5	14.8	22.5	16.4
Weather index	51	70.3	53.9	77.4	66.1
Medium risk farm					
Individual yield	100	98.1	93.8	88.4	100.0
Area yield	80.2	79.1	29.9	75.6	79.9
Weather index	54.8	74.3	64.1	86.7	75.9
High risk farm					
Individual yield	77.1	100.0	100.0	100.0	100.0
Area yield	19	31.3	26.6	40.3	34.3
Weather index	48.7	63.0	54.4	69.2	62.1

3.3. The risk reducing impacts

In this section we present how the policy instruments would impact the risk reduction objective under alternative scenarios. The results on welfare impacts due to reduced variability are negative for most policies, scenarios and farm types in Table 20. This means that none of these programmes achieve the objective of reducing farm income risk. The impacts of individual yield insurance and weather index insurance on welfare gain from reduced income risk is negative for all climate change scenarios except for the misalignment scenario which means farmers use these insurance products to specialise more in crops that generates relatively higher returns. Under climate change, diversification of livestock production become more important due both to low correlation with crop yield risk and to higher returns relative to crop production compared to the baseline scenario. These insurance instruments crowd out the diversification strategy. This is very different from the impact of area yield insurance, which in many cases have a positive impact on welfare gain from lower income risk. *Ex post* payment has a relatively small impact on reducing the variability of income in Australia.

Table 20. Impact of different policy programmes on welfare gain from reduced income variability under different climate change scenarios in Australia (AUD/ha)

	Baseline	Marginal climate change			Extreme events		
		Diversification	Structural adaptation	Misalignment	Diversification	Structural adaptation	Misalignment
Low risk farm							
Individual yield	0.69	-1.05	-0.44	5.97	-1.91	-0.52	7.24
Area yield	2.84	2.71	2.03	3.86	2.00	2.14	4.72
Weather index	-1.75	-2.23	-1.58	-0.16	-2.48	-1.90	0.59
Ex post payment	-0.08	-0.09	-0.06	0.41	-0.14	-0.14	0.42
Medium risk farm							
Individual yield	-2.98	-0.53	-0.56	-0.06	-0.26	-2.82	0.82
Area yield	-2.93	-2.63	1.22	0.25	-1.30	-1.47	1.83
Weather index	-1.43	-0.96	-1.44	-0.12	-1.06	-0.49	0.30
Ex post payment	-0.32	-0.43	-0.08	0.91	-0.47	-0.74	1.00
High risk farm							
Individual yield	1.36	-4.30	-5.91	2.39	-5.39	-6.16	2.73
Area yield	2.20	0.82	0.99	2.61	0.27	0.41	3.10
Weather index	-1.32	-1.41	-1.40	-0.21	-1.53	-1.34	0.17
Ex post payment	-0.06	-0.14	-0.10	0.39	-0.23	-0.27	0.38

If one views subsidised 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 directed towards helping farmers under exceptional circumstances which are beyond their capacity to manage. In this respect, the results show differences. For many scenarios under baseline and climate change, the "lowest 10th percentile" indicator shows positive outcomes for some policy instruments. The effectiveness of individual yield insurance is relatively high in covering large yield shocks and avoiding large income losses. This is because the individual yield insurance is triggered only if the yield loss exceeds more than 30% of the individual expected yield, while other insurance products have no deductibles. Moreover, risk reductions from *ex post* payments are positive for almost all the scenarios. In Australia, yield risk is systemic so that *ex post* payment triggers more often when farmers experience a large income shock. They have also the lowest crowding out effect on diversification because they are not commodity specific. They nevertheless retain some crowding-out effects because they are not triggered after livestock shocks. Area yield insurance performs better than other instruments, but it may not necessarily cover low income risk in some scenarios if the individual incidence of low income is not correlated with systemic yield shock.

Table 21. Impacts of different policy programmes on transfer to farms with the lowest 10th percentile income under different climate change scenarios in Australia (AUD/ha)

	Baseline	Marginal climate change			Extreme events		
		Diversification	Structural adaptation	Misalignment	Diversification	Structural adaptation	Misalignment
Low risk farm							
Individual yield	4.05	2.95	10.90	46.33	4.18	9.58	60.89
Area yield	7.50	6.06	15.76	17.40	8.05	10.47	34.58
Weather index	-6.14	-9.86	3.75	-11.67	-0.31	3.62	-4.73
Ex post payment	-0.61	-0.65	0.98	6.36	3.28	6.57	3.23
Medium risk farm							
Individual yield	-2.11	2.82	13.32	22.12	6.98	-3.84	35.38
Area yield	-14.54	-10.42	6.46	36.01	-6.32	-3.69	50.06
Weather index	-1.01	3.17	3.70	-16.71	11.85	-4.43	-9.87
Ex post payment	-0.10	0.70	3.10	34.96	9.15	9.00	32.23
High risk farm							
Individual yield	18.82	4.77	-1.95	19.16	-6.88	-2.60	17.27
Area yield	16.53	3.89	1.84	28.08	0.78	-0.77	22.64
Weather index	-5.30	1.37	-4.24	-7.06	-3.67	-9.56	-14.18
Ex post payment	1.29	-1.08	-0.22	6.78	2.70	-1.39	8.11
All farm							
Individual yield	8.44	-4.61	-1.65	25.26	-2.17	-3.66	29.59
Area yield	3.20	-6.49	2.64	27.61	-3.18	-0.83	32.89
Weather index	-0.09	-6.15	-5.43	-11.07	0.96	-4.98	-6.95
Ex post payment	1.83	2.15	1.91	16.08	7.23	3.39	19.95

3.4. Budgetary costs of different policies

From the previous section it appears 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, it can provide important insights (Table 22). Between individual yield insurance and other instruments we observe that individual yield insurance would be very expensive in both the baseline and climate change scenarios. The budgetary cost of area yield insurance tends to be lower than both individual yield insurance and *ex post* payment but costs more than other instruments in the misalignment scenario. 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 misalignment. An important distinction in budgetary cost between insurance products and *ex post* payments is that the cost of *ex post* payment could be extremely high when triggered, whereas the cost of subsidising insurance premium is stable across time. 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.

Table 22. Budgetary costs of different policy programmes under different climate change scenarios in Australia (AUD 1 000 for the whole sample of farms)

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Structural adaptation	Misalignment	No struct. adapt.	Structural adaptation	Misalignment	
No policy	0	0	0	0	0	0	0	0
Individual yield	2193	2652	2694	6712	2974	3256	7202	3955
Area yield	604	708	354	7530	878	893	7872	2691
Weather index	526	591	568	485	668	596	493	561
***Ex post* payment**	712	1081	461	4584	1461	1655	4567	2074
Percentage of triggering	11.2	14.5	12.4	36.2	15.8	18.5	33.7	
Budgetary cost when triggered	6358	7456	3721	12664	9246	9401	13829	

3.5. Policy cost effectiveness indicators

Table 23 converts the impact on welfare gain from lower variability of income to per dollar spending to estimate the relative cost efficiency across different policy instruments. For both low and high risk farms, area yield insurance has the highest cost effectiveness for all scenarios. This result comes from generating higher welfare gain from lower income risk and its lower cost as compared to individual yield insurance. The area yield insurance is the best option with the weighted average across farms, with the exception of misalignment under extreme events when this results in large government insurance deficits.

In terms of cost effectiveness in reducing low income risk, area yield insurance outperforms other instruments in all scenarios for low risk farm and majority of scenario for medium and high risk farms. Individual yield insurance has larger gross impacts in some scenarios, but its high cost reduces the cost effectiveness relative to area yield insurance. *Ex post* payments have a higher cost effectiveness in extreme events and become the best policy option when pooling all farms. This is because the payment is more targeted to extreme events in which farmers tend to suffer from more correlated yield loss.

Table 23. Increase in Certainty Equivalent of Income per AUD in the Australian study

Low risk farm - certainty quivalent gain from lower variability

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	0.08	-0.13	-0.06	0.13	-0.19	-0.06	0.14	-0.037
Area yield	2.66	2.70	2.60	0.24	1.37	1.83	0.28	1.931
Weather index	-0.74	-0.83	-0.68	-0.07	-0.84	-0.74	0.27	-0.658
***Ex post* payment**	-0.07	-0.06	-0.06	0.04	-0.06	-0.06	0.05	-0.043

Medium risk farm- certainty quivalent gain from lower variability

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	-0.36	-0.06	-0.07	0.00	-0.03	-0.23	0.02	-0.12
Area yield	-0.60	-0.52	0.73	0.00	-0.24	-0.24	0.03	-0.17
Weather index	-0.59	-0.34	-0.52	-0.06	-0.32	-0.17	0.12	-0.38
***Ex post* payment**	-0.06	-0.06	-0.04	0.03	-0.05	-0.07	0.03	-0.04

High risk farm- certainty quivalent gain from lower variability

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	0.12	-0.30	-0.39	0.10	-0.34	-0.37	0.11	-0.151
Area yield	2.05	0.45	0.64	0.17	0.10	0.16	0.20	0.748
Weather index	-0.59	-0.58	-0.60	-0.10	-0.58	-0.55	0.08	-0.504
***Ex post* payment**	-0.047	-0.052	-0.051	0.042	-0.049	-0.05	0.04	-0.034

Weighted average across clusters - certainty quivalent gain from lower variability

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	-0.141	-0.146	-0.169	0.050	-0.150	-0.253	0.064	-0.117
Area yield	0.709	0.246	0.963	0.092	0.097	0.178	0.119	0.418
Weather index	-0.612	-0.484	-0.571	-0.072	-0.474	-0.371	0.129	-0.459
***Ex post* payment**	-0.055	-0.055	-0.044	0.034	-0.052	-0.063	0.035	-0.038

Table 24. Transfers to farms with the lowest 10th percentile income per AUD in Australia

Low risk farm- change in 10 percentile income per dollar spending

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	0.49	0.37	1.43	1.00	0.42	1.08	1.16	0.89
Area yield	7.02	6.03	20.16	1.09	5.51	8.94	2.08	9.28
Weather index	-2.60	-3.66	1.62	-5.21	-0.10	1.41	-2.11	-1.31
***Ex post* payment**	-0.48	-0.42	0.96	0.67	1.35	2.88	0.36	0.62

Medium risk farm - change in 10 percentile income per dollar spending

	Baseline	Marginal Climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	-0.25	0.33	1.65	0.62	0.68	-0.32	0.82	0.52
Area yield	-2.98	-2.06	3.86	0.62	-1.14	-0.61	0.80	-0.06
Weather index	-0.42	1.11	1.34	-7.80	3.56	-1.51	-4.01	-0.82
***Ex post* payment**	-0.02	0.09	1.42	0.98	1.00	0.83	0.87	0.71

High risk farm- change in 10 percentile income per dollar spending

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	1.72	0.33	-0.13	0.81	-0.44	-0.16	0.67	0.54
Area yield	15.41	2.16	1.19	1.88	0.28	-0.30	1.44	4.72
Weather index	-2.35	0.57	-1.82	-3.30	-1.38	-3.98	-6.62	-2.38
***Ex post* payment**	1.02	-0.39	-0.11	0.74	0.58	-0.28	0.93	0.33

All farms - change in 10 percentile income per dollar spending

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	0.308	-0.148	-0.053	0.239	-0.060	-0.097	0.244	0.07
Area yield	0.456	-0.825	0.661	0.309	-0.325	-0.086	0.345	0.21
Weather index	-0.013	-0.772	-0.732	-1.696	0.107	-0.631	-1.015	-0.63
***Ex post* payment**	0.222	0.179	0.366	0.297	0.444	0.187	0.364	0.28

3.6. The policy choice

Policy choices consist in comparing each farm type and scenario, and the value of the indicator for the four policy instruments. The instruments with the best performance in terms of change in the 10 percentile income are listed in Table 25. The second and third best performances are shown only if within 35% of the best. The most frequent best performing instrument is area yield insurance (particularly for low risk farms). For middle and high risk farm types there is no single instrument that outperforms the rest in the seven scenarios. Individual yield insurance, weather index insurance or *ex post* payment are cost effective in one of the scenarios. This justifies the need to apply a decision rule to identify a preferred policy.

The “**probabilistic**” standard Bayesian approach to this ambiguity is to assign probabilities to each scenario and thus obtain a combined outcome that accounts for different scenarios to occur. Decision making can be based on maximising the expected budgetary cost-effectiveness. It is assumed in the three country studies that the following subjective probabilities are assigned: 25% probability to the baseline (no climate change);

50% to the marginal climate change; and 25% to climate change with extreme events disrupting yields. In climate change scenarios, each behavioural sub-scenario (adaptation, without adaptation and misalignment) is assigned a third of the probability. The last columns of Tables 25 and 26 report the results of applying the Bayesian decision rule by assuming these probabilities.

Table 25. Best performing policy instruments according to budgetary cost-effectiveness in Australia for different farm types under each scenario

(second-best only recorded if its cost effectiveness is within 35% of the optimal instrument for a farm type and scenario)

		Marginal climate change			Extreme events		
	Baseline	**Adaptation by diversification**	**Structural adaptation**	**Misalignment**	**Adaptation by diversification**	**Structural adaptation**	**Misalignment**
Low risk farm	Area**	Area**	Area**	Area** Individual*	Area**	Area**	Area**
Medium risk farm	*Ex post* **	Weather **	Area**	*Ex post* **	Weather**	*Ex post* **	*Ex post* ** Individual* Area*
High risk farm	Area**	Area**	Area**	Area**	*Ex post***	Individual**	Area**
Pool of all farms	Area** Individual*	*Ex post* **	Area**	Area** *Ex post* * Individual*	*Ex post* **	*Ex post* **	*Ex post* ** Area* Individual*

Note: For each climate scenario: ** best, * within 35% of best. Cost effectiveness indicator is increase in the lowest percentile income.

Under the Bayesian criterion, two instruments (area yield insurance and *ex post* payments) perform well and area yields over-performed for low and high risk farms both in terms of welfare gain from lower income risk and reducing low income risk. *Ex post* payment is the optimal policy choice for the largest number of medium risk farm based on the Bayesian rule. Across all farms the best instruments according to the Bayesian rule is area yield insurance if the policy objective is to reduce the variability of income. However, *ex post* payments are selected as the best choice if the policy objective is to deliver relief to farms with low returns. This is due to a great extent to the good performance of *ex post* payments under extreme events: the systemic triggering mechanism is efficient under extreme climate change.

Table 26. Using the MaxiMin criterion to guide instrument choice: worst-case outcome scenario for budgetary cost-effectiveness for different instruments in Australia (by farm type)

	Low risk farm	Medium risk farm	High risk farm	Pool of all farms
Individual yield	Marginal without structural adaptation (0.37)	Extreme with adapt. (-0.32)	Extreme without structural adaptation (-0.44)	Marginal without structural adaptation (-0.15)
Area yield	Marginal with misalignment (1.09)	Baseline (-2.98)	Extreme with adaptation (-0.3)	Marginal without structural adaptation (-0.82)
Weather index	Marginal with misalignment (-5.21)	Marginal with misalign. (-7.8)	Extreme with misalignme,nt (-6.62)	Marginal with misalignment (-1.70)
***Ex post* payment**	Baseline (-0.48)	Baseline (-0.02)	Marginal without structural adaptation (-0.39)	Marginal without structural adaptation(0.18)
MaxiMin across instruments	Area yield	*Ex post*	Area yield	*Ex post*

The **Satisficing** criteria provide a suitable solution only for low risk farms (area yield insurance). For other farms it does not pick up a single policy.

MaxiMin criterion: Table 26 shows the worst-case scenarios in the case of avoiding low income risk. The last row in the table indicates, for each farm type, the instrument that performs the best in the worst scenario (MaxiMin). Under a MaxiMin decision rule, *ex post* payments are the most robust choice for the largest group of medium-risk farms and consequently for the pool of all farms. It avoids the potential for ineffective outcomes that would occur with insurance products. Area yield insurance is the most robust choice for low and high risk farms by limiting the crowding out effects of diversification strategy. However, in aggregate terms, *ex post* payments are preferred.

3.7. Policy discussion

Table 27 summarises the robust policies in Australia according to different decision-making criteria both in terms of welfare gain from low income variability and avoiding low income risk. It is clear that area yield insurance is the best policy option for low- and high-risk farms based on any criteria irrespective of policy objective, whereas *ex post* payment outperforms for medium risk farm in all cases. However, the best policy option becomes less obvious once the simulated policy impacts are averaged or pooled across all the farms. If the policy focus is to reduce the variability of income, area yield insurance is the best policy option. On the other hand, *ex post* payment is overall the best policy choice if the government aims to reduce the incidence of low income. This difference is results predominantly from the different design of two policies. *Ex post* payment is more targeted to low income risk, while insurance triggers under relatively small yield loss contributes more to income stabilisation.

Table 27. Robust policies in Australia

	Low-risk farm	Medium-risk farm	High-risk farm	Average / pool
Risk welfare				
Bayesian	Area	*Ex post*	Area	Area
Satisficing	Area	-	Area	Area
MaxiMin	Area	*Ex post*	Area	Area
Low incomes				
Bayesian	Area	*Ex post*	Area	*Ex post*
Satisficing	Area	-	-	-
MaxiMin	Area	*Ex post*	Area	*Ex post*

The main policy challenge in Australia is to focus from mitigating financial impacts of short-term adverse climatic events to facilitating farmer adaptation to climate change. Australia currently relies on *ex post* payment such as EC relief payments as a tool to provide support to farmers suffering from low income due to exceptional circumstance such as drought. The policy simulation shows some rationale in this policy framework because low income risk is correlated with systemic yield loss in Australia and payment is triggered in such circumstance. The analysis shows that implementing individual yield insurance costs more than *ex post* payment not only because it requires a large amount of subsidy, but it crowds out farmer adaptation behaviour.

This does not necessarily mean that the *ex post* payment is the best policy option for all types of farms. The simulation results show that area yield insurance could be the more cost effective option both in terms of income stabilisation and low income relief. Area yield insurance usually requires much less subsidy to implement than individual multi-peril insurance and has the advantage of crowding out less farmer adaptation strategies. In Australia, the systemic characteristics of yield risk makes individual yield risk highly correlated with systemic yield. Diversification of policy instruments to index-based insurance could provide a cost effective risk management tool and enhance farmer adaptation under climate change.

4. The Canadian case study

4.1. Climate change scenarios

The perturbations in the distribution of yields induced by marginal climate change are gleaned from the literature in Chapter 1. The results of the random draws are reported in Table 28 for all the relevant scenarios and are applied in the simulations presented in this section. These numbers show a reduction in mean yields across all commodities and scenarios, while the change in the standard deviation is zero or negative for marginal climate change scenarios and only positive for the extreme events scenario. Only under the extreme events scenario does the variability of yields increase for all commodities. It is assumed that the two parameters of the crop yield distributions (mean and standard deviation) in the three farm types defined in Chapter 1 are affected in the same direction and magnitude by climate change.

Table 28. Simulated climate change scenario in the Canadian case study

	% change in mean yield				% change in standard deviation			
Scenarios	Marginal		Extreme events		Marginal		Extreme events	
Adaptation	No	Yes	No	Yes	No	Yes	No	Yes
Spring wheat	-13.3	-2.9	-19.5	-10.5	-5.3	0.0	30.4	35.0
Barley	-18.0	-8.8	-25.2	-16.7	-11.4	-9.4	27.6	35.7
Canola	-18.5	-10.6	-28.4	-20.7	-4.4	-1.5	29.2	37.9

Note: Based on Zhang *et al.* (2011).

4.2. Demand for insurance

Demand for insurance is not expected to significantly increase under climate change given that the simulated scenarios imply reductions of variability rather than increases. In fact climate change hardly modifies the level of insurance demand. However, it increases insurance demand in some cases (high risk farms) and, in particular, in the extreme events scenarios that imply significant increases in the standard deviation of yields.

Table 29. Percentage of land insured under different insurance programmes and climate change scenarios in the Canadian case study (Saskatchewan)

	Baseline	Marginal climate change		Extreme events	
		Diversification	Structural adaptation	Diversification	Structural adaptation
Low risk farm					
Individual yield	21.5	65.6	70.6	46.9	71.5
Area yield	58.3	59.6	65.3	45.7	74.0
Weather index	23.8	28.9	26.1	36.9	42.6
Medium risk farm					
Individual yield	58.7	56.8	58.9	67.5	60.7
Area yield	60.6	60.1	61.7	49.3	70.2
Weather index	46.5	33.3	28.4	51.2	47.7
High risk farm					
Individual yield	31.6	68.0	39.4	66.6	56.6
Area yield	47.4	63.0	68.5	68.2	74.0
Weather index	37.7	31.6	20.7	42.3	53.3

4.3. Risk reducing impacts

Tables 30 and 31 and display the impacts on risk reduction of the different policy instruments under different climate change scenarios. Almost all the numbers are positive indicating a positive effect in reducing risk.

In terms of absolute welfare gains due to reduced variability (Table 30), simulation results can be very different across scenarios, but in all cases welfare gains are very low, with a maximum of 18 cents for each CAD spent. Even in relative terms the risk reduction ranking of different risk management instruments changes when climate change is accompanied by adaptation and extreme events. Most often risk is reduced the most by area yield insurance. For high risk farms, individual yield insurance performs better.

Extreme events and misalignment do not dramatically change this result. *Ex post* payments exhibit the lowest values for this risk impact indicator.

Table 30. Impact of different policy programmes on welfare gain from reduced income variability under different climate change scenarios in the Canadian case study (Saskatchewan) (CAD/ac)

	Baseline	Marginal climate change			Extreme events		
		Diversification	Structural adaptation	Misalignment	Diversification	Structural adaptation	Misalignment
Low risk farm							
Individual yield	0.00	0.03	0.07	0.06	0.05	0.13	0.09
Area yield	0.07	0.05	0.05	0.05	0.06	0.01	0.13
Weather index	0.01	0.01	0.01	0.09	0.03	0.02	0.12
Ex post payment	0.00	0.00	0.00	0.02	0.01	0.00	0.04
Medium risk farm							
Individual yield	0.07	0.03	0.04	0.08	0.09	0.05	0.21
Area yield	0.11	0.09	0.08	0.13	0.13	0.09	0.26
Weather index	0.10	0.03	0.03	0.02	0.06	0.06	0.08
Ex post payment	0.01	0.00	0.00	0.02	0.01	0.01	0.05
High risk farm							
Individual yield	0.10	0.18	0.11	0.07	0.09	0.06	0.09
Area yield	0.06	0.05	-0.01	0.06	-0.01	0.12	0.12
Weather index	0.06	0.01	0.02	0.02	0.04	0.06	0.05
Ex post payment	0.00	0.00	0.00	0.01	0.00	0.01	0.03

In terms of transfers to the farms under the lowest 10th percentile of income, simulation results are also very different across scenarios (Table 31). Area yield insurance performs well in terms of transfer to lowest income events as it does in terms of welfare gains across all outcomes, but individual and area yields do not perform well for low and high risk farms and, in some scenarios, they decrease the value of the 10 percentile income. *Ex post* payments are, in general, relatively more effective in achieving this low income objective than in reducing the overall income risk. However, they rarely show as having the highest impact.

Table 31. Impacts of different policy programmes on transfer to farms with the lowest 10th percentile income under different climate change scenarios in the Canadian case study (Saskatchewan) (CAD/ac)

	Baseline	Marginal climate change			Extreme events		
		Diversification	Structural adaptation	Misalignment	Diversification	Structural adaptation	Misalignment
Low risk farm							
Individual yield	-0.47	-1.48	-2.00	2.29	1.15	1.74	2.06
Area yield	-0.28	-0.60	-2.44	1.63	1.11	-0.36	5.99
Weather index	0.16	1.23	-1.49	3.27	2.49	1.21	3.03
Ex post payment	0.30	0.38	0.08	1.44	-0.10	0.12	3.40
Medium risk farm							
Individual yield	1.60	0.26	0.15	3.82	1.86	0.53	10.94
Area yield	2.98	2.68	3.62	8.06	4.76	3.33	14.89
Weather index	0.75	1.53	-1.58	1.05	1.48	1.11	1.16
Ex post payment	1.44	1.20	2.01	3.43	0.13	0.89	4.28
High risk farm							
Individual yield	0.30	-0.11	4.32	3.76	2.90	0.08	7.00
Area yield	-2.35	-1.41	2.31	5.40	0.00	4.68	11.42
Weather index	-2.21	0.08	3.49	0.98	3.08	0.45	2.48
Ex post payment	-0.06	-0.02	1.42	1.85	0.58	0.60	2.86
All farm							
Individual yield	1.49	2.33	0.61	3.99	3.11	0.88	7.54
Area yield	1.29	1.47	0.13	5.46	2.75	2.17	11.87
Weather index	0.78	-0.06	2.39	-0.18	0.40	0.27	2.20
Ex post payment	0.42	0.86	1.68	1.66	0.22	0.23	2.53

4.4. Budgetary costs of different policies

Having examined the demand for different types of insurance, and the reduction in risk that these instruments entail for farmers, we now examine the budgetary implications of the different instruments (Table 32). Weather index insurance is the cheapest instrument for the government and its budgetary costs remain reasonable even under the scenarios of extreme event and misalignment. *Ex post* payments are second lowest in budgetary terms and their triggering frequency remains below a reasonable 5%, or once every twenty years. The budgetary outlay when they are triggered is very large, however, and the frequency and total amount of expenditure explode under misalignment.

Individual yield insurance becomes the most expensive under the climate change scenarios, while budgetary outlays for area yield insurance are maintained at lower levels. The exception is the misalignment scenarios for which individual yield insurance is more attractive than area yield because of lower budgetary costs. 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 extremely high budgetary costs under misalignment, especially in the case of area-yield insurance.

Table 32. Budgetary costs of different policy programmes under different climate change scenarios in the Canadian case study (1 000 CAD for the whole sample of farms)

		Marginal climate change			Extreme events			
	Baseline	No Struct. Adapt.	Structural adaptation	Misalignment	No Struct. Adapt.	Structural adaptation	Misalignment	Bayesian decision
No policy	0	0	0	0	0	0	0	0
Individual yield	68	179	198	227	185	236	399	213
Area yield	82	80	90	630	87	134	1070	310
Weather index	36	32	31	95	41	49	88	53
***Ex post* payment**	56	41	42	199	35	48	308	104
Percentage of triggering	3.9	4.9	4.0	14.0	3.8	3.4	17.0	
Budgetary cost when triggered	867	840	945	1419	917	1374	1925	

4.5. Policy costs effectiveness indicators

Tables 33 and 34 combine risk reducing impacts and budgetary costs into single cost effectiveness indicators on risk reducing welfare and low incomes, respectively. The highlighted cells indicate the best policy for each scenario represented in a column.

For the certainty equivalent indicator (Table 33), area yield insurance is one of the best performing instruments across farms for the marginal climate change scenarios. Individual yield insurance shows also good performance for high risk farms. However, extreme events tend to explode budgetary costs and make the weather insurance more attractive across all types of farms.

The costs effectiveness indicators built on the impacts on the lowest ten percentile are displayed in Table 34. Weather index shows the best performance for several farm types and scenarios, particularly those with extreme events. *Ex post* payments become the best performing policy in some marginal climate change scenarios, particularly for low and medium risk farms. All four policy instruments, however, display at least one best performance in the table.

Table 33. Increase in certainty equivalent of income per CAD in the Canadian case study (Saskatchewan)

Low risk farm - certainty quivalent gain from lower variability

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	-0.01	0.02	0.04	0.04	0.04	0.06	0.05	0.03
Area yield	0.12	0.08	0.08	0.01	0.10	0.02	0.02	0.07
Weather index	0.04	0.05	0.04	0.17	0.12	0.06	0.23	0.08
Ex post payment	0.01	0.00	0.00	0.02	0.02	0.01	0.02	0.01

Medium risk farm - certainty quivalent gain from lower variability

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	0.12	0.06	0.07	0.04	0.07	0.05	0.04	0.07
Area yield	0.18	0.16	0.14	0.03	0.20	0.10	0.03	0.13
Weather index	0.25	0.12	0.13	0.02	0.16	0.17	0.08	0.15
Ex post payment	0.036	0.007	0.008	0.013	0.024	0.02	0.02	0.02

High risk farm- certainty quivalent gain from lower variability

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	0.11	0.11	0.10	0.07	0.05	0.48	0.05	0.14
Area yield	0.13	0.08	-0.01	0.02	-0.01	0.12	0.02	0.06
Weather index	0.21	0.05	0.10	0.02	0.13	0.14	0.07	0.12
Ex post payment	0.03	0.00	0.00	0.01	0.01	0.03	0.02	0.01

Weighted average across clusters - certainty quivalent gain from lower variability

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	0.049	0.041	0.056	0.044	0.052	0.094	0.044	0.055
Area yield	0.142	0.111	0.095	0.017	0.126	0.055	0.022	0.091
Weather index	0.131	0.073	0.080	0.103	0.137	0.106	0.162	0.107
Ex post payment	0.020	0.002	0.005	0.014	0.021	0.018	0.018	0.013

Table 34. Transfers to farms with the lowest 10th percentile income per CAD in Canada

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	-1.16	-0.89	-1.03	1.67	0.84	0.78	1.07	-0.12
Area yield	-0.47	-1.06	-3.88	0.36	1.88	-0.37	0.74	-0.41
Weather index	0.86	5.66	-6.80	6.47	9.66	3.65	6.00	3.52
Ex post payment	1.24	1.28	0.29	1.01	-0.40	0.35	1.45	0.64

Medium risk farm- change in 10 percentile income per dollar spending

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	2.92	0.48	0.26	1.73	1.63	0.50	2.11	1.551
Area yield	4.84	4.67	6.09	1.71	7.47	3.63	1.75	5.155
Weather index	2.01	6.12	-6.61	1.06	4.14	3.00	1.17	1.633
Ex post payment	5.71	4.06	8.05	2.31	0.50	2.70	1.75	3.953

High risk farm - change in 10 percentile income per dollar spending

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	0.34	-0.07	3.754	3.31	1.60	0.68	4.14	1.651
Area yield	-4.85	-2.35	2.275	1.45	0.00	4.81	1.70	-0.984
Weather index	-7.30	0.35	19.984	1.23	10.40	1.09	3.10	4.366
Ex post payment	-0.29	-0.06	1.615	1.58	1.69	1.72	1.48	0.875

All farms - change in 10 percentile income per dollar spending

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	0.818	0.608	0.168	0.846	0.720	0.258	0.857	0.655
Area yield	0.766	0.842	0.057	0.422	1.315	0.754	0.508	0.740
Weather index	0.904	-0.089	3.768	-0.079	0.444	0.241	0.958	0.937
Ex post payment	0.603	0.958	1.203	0.407	0.267	0.228	0.376	0.645

4.6. The policy choice

The table below summarises the best performing policies for different farms and different scenarios. Second and third best options are also displayed if within 35% of the optimal performance. The objective is to identify policies that have a robust performance across scenarios with three possible policy rules. One of the policies focuses on the average best results (the Bayesian or probabilistic approach), and the other two are based on some robustness criteria: satisficing a minimum indicator level of 35% of the optimal, and maximising the worst outcome (MaxiMin). The exercise on robust policies is limited to one indicator of cost-effectiveness performance: the welfare gains from risk reductions.

The **"probabilistic"** standard Bayesian approach to this ambiguity is assigning probabilities to each scenario and obtaining a combined outcome that accounts for different scenarios to occur. The same set of assigned probabilities is used in three countries.[5] Decision-making can be based on maximising the expected budgetary cost-effectiveness. In the last columns of Tables 33 and 34, we observe that the Bayesian decision by assuming those probabilities favours weather index insurance, except for high risk farms. This occurs despite the good performance of area and individual yield insurance under marginal climate change. The reason is that weather index largely over performs under the extreme events and misalignment scenarios. For high risk farms, however, individual yield insurance is more cost effective in reducing income variability. When averaged over all farms, the Bayesian approach indicates that weather index insurance is slightly more cost-effective than other instruments from a budgetary perspective.

Table 35. Best performing policy instruments according to budgetary welfare cost-effectiveness in the Canadian case study for different farm types under each scenario

(second-best only recorded if its cost effectiveness is within 35% of the optimal instrument for a farm type and scenario)

		Marginal climate change			**Extreme events**		
	Baseline	**Adaptation by diversification**	**Structural adaptation**	**Misalignment**	**Adaptation by diversification**	**Structural adaptation**	**Misalignment**
Low-risk farm	Area**	Area**	Area**	Weather**	Weather** Area*	Weather** Individual*	Weather**
Medium-risk farm	Weather** Area*	Area** Weather*	Area** Weather*	Individual** Area*	Area** Weather*	Weather**	Weather**
High-risk farm	Weather**	Individual** Area*	Weather** Individual*	Individual**	Weather**	Individual**	Weather** Individual*
Weighted average	Area** Weather*	Area** Weather*	Area** Weather*	Weather**	Weather** Area*	Weather** Individual*	Weather**

Note: For each climate scenario: ** best, * within 35% of best. Cost effectiveness indicator is welfare gain from reduced income variability.

The **"Satisficing"** is the simplest approach to robust policies. This rule unfortunately does not provide a robust result for none of the three farm types because there is not a single policy that performs well enough (within a 35% from optimal) in all scenarios. However, if we weigh the farms by their area, we obtain that weather index performs well enough in all the scenarios, and therefore, qualifies for the satificing criterion. If the government decides to implement weather index insurance, it will be giving more weight to the outcomes for higher risk farms and extreme scenarios. This criterion helps to define the nature of the tradeoffs that the government needs to manage, but, in general, it may not necessarily identify a single choice for the decision maker.

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[5] It is assumed in the three country studies that the following subjective probabilities are assigned: 25% probability to the baseline (no climate change), 50% to the marginal climate change and 25% to climate change with extreme events disrupting yields. Each behavioural sub-scenario (diversification, structural adaptation and misalignment) is assigned a third of the probability.

The **MaxiMin criterion** is the most conservative and consists in ensuring that policy does not lead to serious mistakes that result in significant expenditures. 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. Table 36 displays the worst-case scenarios for insurance instruments. Surprisingly, the worst cases occur for marginal scenarios rather than the extreme events. The last row indicates the instrument that performs the best for each farm type in a worst-case situation (MaxiMin).

Table 36. Using the MaxiMin criterion to guide instrument choice: Worst-case outcome for budgetary cost-effectiveness for different instruments in the Canadian case study (by farm type

	Low risk farm	**Medium risk farm**	**High risk farm**	**Weighted average**
Individual yield	Baseline (-0.01)	Marginal with misalignment (0.04)	Extreme (0.05)	Marginal (0.04)
Area yield	Marginal with misalignment (0.01)	Marginal with misalignment (0.03)	Marginal with adaptation (-0.011)	Marginal with misalignment (-0.01)
Weather index	Baseline. (0.037)	Marginal with misalignment (0.02)	Marginal with misalignment (0.02)	Marginal (0.07)
***Ex post* payment**	Marginal (0.00)	Marginal (0.01)	Marginal (0.00)	Marginal (0.00)
MaxiMin across instruments	Weather index	Individual yield	Individual yield	Weather index

Under a MaxiMin decision rule across scenarios, weather index insurance is the most robust choice for the low risk farms. Individual yield insurance is the most robust choice for medium and high risk farms by limiting the negative impacts of misalignment on budgetary cost- effectiveness. In both cases MaxiMin decisions avoids the potential for ineffective outcomes that would occur with area-yield insurance under misalignment. When weighting the best options across farm types, weather index insurance becomes the most cost effective.

Area yield insurance, which performs very well under marginal climate change, is not attractive under a MaxiMin criterion. Area-yield shows very bad performance under misalignment scenarios which is the main driver of worst-case scenarios. Therefore area yield would not be chosen using this criterion. This is indeed the case for medium and low risk farms. This is due to the large budgetary expenditure that it triggers, thereby reducing the budgetary cost-effectiveness.

4.7. Policy discussion

Table 37 displays the policy choice under different decisions rules. The satisficing criterion is not very useful and does not provide a better choice for any of the farm types. For overall risk welfare objectives, low risk farms would be better served with weather index insurance according to both the Bayesian and MaxiMin criteria, while individual yield insurance would be the best option for high risk farms. For medium-risk farms Bayesian rule picks up weather index insurance while MaxiMin prefers individual yield.

For low income objectives different rules pick up different policies for different farms: weather, *ex post* area and individual.

Table 37. Robust policies in Canada

	Low-risk farm	Medium-risk farm	High-risk farm	Average / pool
Risk welfare				
Bayesian	Weather	Weather	Individual	Weather
Satisficing	-	-	-	Weather
MaxiMin	Weather	Individual	Individual	Weather
Low incomes				
Bayesian	Weather	Area	Weather	Weather
Satisficing	-	-	-	-
MaxiMin	*Ex post*	Area	Individual	*Ex post*

In Canada, no single policy option dominates others across decision criteria for each farm type. Compared to other countries, farmers suffer more from idiosyncratic risk specific to each farm. In this case, the performance of index based insurances may vary across different farm types. For instance, individual yield insurance outperforms in most cases for high-risk farms because it is more tailored to the individual yield risk. The diverse results in Canada imply the potential benefit of diversifying policy instruments. The best policy instrument for certain types of farm may change under different climate change scenarios but not necessarily be the best choice for other types of farm.

5. The Spanish case study

5.1. Climate change scenarios

The following shocks were implemented for the climate change scenarios in Spain. They are based on Guereña *et al.* (2001). Structural adaptation scenarios differ from marginal climate change because of the lower reduction in the expected yield due to adaptation responses by farmers. This is based on Howden *et al*. (2007) as explained in Chapter 2. Extreme event scenarios assume an additional extreme event shock on yields as defined also in Chapter 2. The latter increases the change in the standard deviations, which is already very large in the case of Spain (around 90%).

Table 38. Simulated climate change scenario in the Spanish case study

	% change in mean yield				**% change in standard deviation**			
Scenarios	Marginal		Extreme events		Marginal		Extreme events	
Structural adaptation	No	Yes	No	Yes	No	Yes	No	Yes
Barley	-4.3	7.3	-6.4	1.2	85.1	83.6	86.3	86.3
Wheat	-11.5	-1.8	-13.4	-7.7	90.5	83.2	99.5	95.4

Note: Own calculation from Monte-Carlo simulations, based on Guereña *et al.* (2001).

5.2. Demand for insurance

Climate change implies significant increases in production risk in Spain, which explains an increase in the demand for insurance across all climate change scenarios. Insurance (particularly area yield) is demanded for all the land in several scenarios for the two types of farms. Individual yield insurance demand was weak for non-irrigated land in the baseline and more than doubles in all climate change scenarios. Area yield insurance shows the strongest demand because of the high systemic component of production risk in Spain and the relatively good price of premiums (lower transaction costs).

Table 39. Percentage of land insured under different insurance programmes and climate change scenarios in Spain

	Baseline	Marginal climate change		Extreme events	
		Diversification	Structural adaptation	Diversification	Structural adaptation
Irrigated farm					
Individual yield	82.5	77.8	100.0	100.0	92.8
Area yield	100.0	100.0	100.0	100.0	100.0
Weather index	59.3	108.2	99.9	110.4	102.8
Non-irrigated farm					
Individual yield	17.7	49.4	54.3	52.0	71.0
Area yield	19.0	100.0	100.0	100.0	100.0
Weather index	55.1	98.7	91.6	100.3	95.6

5.3. Risk reducing impacts

The following tables display the impact of the implementation of the four policy programmes on two possible policy objective indicators. First, the overall variability of farmer’s income measured by the welfare gain for the farmer associated with lower variability (Table 40). Second, the impact on low income occurrences measured as the increase in the lowest ten percentile income (Table 41). Both are measured in Euros per hectare. The impacts are positive across the board, although some negatives, in particular for weather index insurance, which is indicative of its inability to reduce risk at farm level.

Table 40. Impacts of different policy programmes on welfare gain from reduced income variability under different climate change scenarios in Spain (EUR/ha)

	Baseline	Marginal climate change			Extreme events		
		Diversification	Structural adaptation	Misalignment	Diversification	Structural adaptation	Misalignment
Irrigated farm							
Individual yield	0.13	-0.23	0.56	2.61	0.38	-0.27	2.74
Area yield	1.19	0.59	3.07	4.87	2.79	1.46	5.11
Weather index	-0.34	-2.64	-0.76	0.76	-0.87	-2.20	0.75
Ex post payment	0.22	0.31	0.21	1.17	0.25	0.24	1.20
Non-irrigated farm							
Individual yield	0.11	0.30	0.29	0.42	0.34	0.28	0.45
Area yield	0.35	0.18	-0.16	1.30	1.25	1.40	1.34
Weather index	-0.25	-0.59	-0.83	0.56	-0.02	0.35	0.52
Ex post payment	0.07	0.49	0.45	0.32	0.46	0.45	0.32

Table 41. Impacts of different policy programmes on transfer to farms with the lowest 10th percentile income under different climate change scenarios in the Spanish case study (EUR/ha)

	Baseline	Marginal climate change			Extreme events		
		Diversification	Structural adaptation	Misalignment	Diversification	Structural adaptation	Misalignment
Irrigated farm							
Individual yield	13.6	37.3	63.6	128.5	64.0	41.3	137.7
Area yield	53.9	79.3	128.7	225.9	125.0	104.3	245.6
Weather index	-0.1	-56.8	-5.9	69.0	-12.6	-38.0	78.8
Ex post payment	24.8	79.3	77.0	100.8	84.9	73.0	109.2
Non-irrigated farm							
Individual yield	8.1	56.5	66.5	28.3	58.2	83.1	29.1
Area yield	18.3	40.6	37.1	69.1	57.9	68.8	68.6
Weather index	-10.2	-43.4	-39.3	78.2	-23.6	-9.9	75.7
Ex post payment	8.4	87.4	81.2	25.3	87.4	85.4	21.6
All farm							
Individual yield	0.5	37.9	39.5	20.5	36.4	41.5	23.2
Area yield	7.0	59.6	55.2	59.8	80.1	83.6	60.1
Weather index	2.3	20.3	21.2	90.8	18.0	30.1	85.4
Ex post payment	5.9	74.7	66.4	21.9	67.3	53.0	18.6

In terms of the overall risk welfare gain indicator, the area yield insurance is the most effective instrument across most scenarios and farms, followed by individual yield insurance. The reduced number of farms in the Spanish sample (twelve) has an impact in a very high correlation between individual yield and area yield (across all farms). The correlation with the weather index is much smaller as is the demand for this type of insurance. This makes area yield insurance as modelled in Spain more similar to an individual yield insurance than to an index insurance.

Ex post payments perform much better in terms of improving low income outcomes and are often the best performing instrument in terms of impact. This is a general result because *ex post* payments are triggered on occasions of systemic shocks that affect all products and farms at the same time. Area and individual yield insurance follow in terms of their impacts on low incomes.

5.4. Budgetary costs of different policies

The highest budgetary costs in Spain are associated with *ex post* payments which are triggered very often (every four years or even more often). They also imply very high costs when the payment is triggered. Climate change implies that the costs of such a policy could be multiplied by up to seven. Area yield does not differ so much from individual yield in terms of budgetary costs, and both are multiplied as a consequence of climate change, in particular when there is misalignment. Weather index remains the cheapest option in all scenarios expect for misalignment, under which the costs overshoot.

Table 42. Budgetary costs of different policy programmes under different climate change scenarios in the Spanish case study (EUR for the whole sample of farms)

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No Struct. Adapt.	Structural adaptation	Misalign-ment	No Struct. Adapt.	Structural adaptation	Misalign-ment	
No policy	0	0	0	0	0	0	0	0
Individual yield	2 577	12 845	15 157	24 270	14 868	17 701	25 718	16 162
Area yield	3 150	13 896	13 598	44 748	13 460	13 684	47 800	21 477
Weather index	1 227	2 118	2 132	54 776	2 106	2 156	54 776	17 042
Ex post payment	6 739	48 377	43 963	26 261	44 967	42 494	27 641	34 349
Percentage of triggering	18	30	28	33	28	26	34	
Budgetary cost when triggered	37 028	163 436	159 865	78 862	158 336	160 963	82 022	

5.5. The policy cost effectiveness indicators

The impacts on reducing risk described in section 5.3 need to be compared with the budgetary costs of the different measures through the cost effectiveness indicators, one for the certainty equivalent or risk welfare gain of income, and the other for the lowest 10 percentile income in the corresponding tables below. The highlighted cells in Tables 43 and 44 indicate the highest value of that indicator for the scenario and identifies the corresponding preferred policy.

Table 43. Increase in certainty equivalent of income per EUR in Spain

Irrigated farm - certainty quivalent gain from lower variability

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	0.03	-0.02	0.04	0.05	0.02	-0.02	0.05	0.02
Area yield	0.19	0.05	0.25	0.05	0.22	0.11	0.05	0.15
Weather index	-0.29	-1.26	-0.36	0.01	-0.42	-1.04	0.01	-0.47
Ex post payment	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.01

Non-irrigated farm - certainty quivalent gain from lower variability

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	0.08	0.02	0.02	0.04	0.03	0.02	0.04	0.04
Area yield	0.26	0.01	-0.01	0.07	0.10	0.11	0.07	0.10
Weather index	-0.23	-0.31	-0.43	0.01	-0.01	0.18	0.01	-0.18
Ex post payment	0.023	0.011	0.011	0.030	0.011	0.01	0.03	0.02

Weighted average across clusters - certainty quivalent gain from lower variability

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adapt.	Adaptation	Misalignment	No struct. adapt.	Adaptation	Misalignment	
Individual yield	0.066	0.010	0.026	0.046	0.025	0.005	0.045	0.035
Area yield	0.238	0.024	0.074	0.067	0.141	0.112	0.065	0.116
Weather index	-0.247	-0.626	-0.406	0.012	-0.145	-0.229	0.012	-0.277
Ex post payment	0.021	0.010	0.009	0.027	0.009	0.010	0.026	0.016

The increased certainty equivalent of income due to the risk reductions associated to EUR 1 spent on risk management programmes are relatively small, both in the baseline and under climate change. This means that EUR 1 spent results only in a few cents of farmer's welfare gains due to lower risk. Area yield insurance is the best performing instruments across the two types of farms and scenarios, but individual yield insurance is also a preferred option in some scenarios. The same results are found for the weighted average farm with best performance of area yield insurance.

Table 44. Transfers to farms with the lowest 10th percentile income per EUR in Spain

Irrigated farm- change in 10 percentile income per dollar spending

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adaptation	Adaptation	Misalignment	No struct. adaptation	Adaptation	Misalignment	
Individual yield	2.96	3.28	4.04	2.65	3.81	2.79	2.72	3.35
Area yield	8.63	6.13	10.35	2.46	10.01	8.18	2.49	7.81
Weather index	-0.09	-27.14	-2.80	1.29	-6.03	-18.03	1.47	-6.31
Ex post payment	1.85	1.76	1.92	1.89	2.04	1.84	1.94	1.90

Non-irrigated farm- change in 10 percentile income per dollar spending

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adaptation	Adaptation	Misalignment	No struct. adaptation	Adaptation	Misalignment	
Individual yield	6.05	4.63	4.99	2.77	4.69	4.81	2.60	4.749
Area yield	13.58	3.14	2.91	3.92	4.62	5.41	3.69	6.210
Weather index	-9.15	-22.71	-20.41	1.57	-12.46	-5.03	1.52	-12.326
Ex post payment	2.92	1.94	1.97	2.37	2.09	2.16	1.95	2.300

All farms - change in 10 percentile income per dollar spending

	Baseline	Marginal climate change			Extreme events			Bayesian decision
		No struct. adaptation	Adaptation	Misalignment	No struct. adaptation	Adaptation	Misalignment	
Individual yield	0.087	1.607	1.360	0.349	1.245	1.294	0.376	0.886
Area yield	0.920	2.303	2.191	0.546	3.200	3.282	0.512	1.870
Weather index	1.008	5.074	5.264	0.879	4.503	7.406	0.827	3.247
Ex post payment	0.362	0.830	0.816	0.342	0.805	0.670	0.276	0.623

The impacts on lowest percentile income per Euro spent are higher, and often larger, than one. Area and individual yield insurance are also the preferred options across most scenarios and farm types (including a weighted average farm) according to this criterion. However, when analysing the impacts across the pool of farms, weather index surprisingly becomes the best performing instrument. The technical reason is the impact of weather index insurance on the 20 percentile of the non-irrigated farms that have significantly lower income than irrigated farms. Nevertheless, area yield insurance still performs very well.

5.6. The policy choice

The table below summarises the best performing policies for different farms and different scenarios. Best performing options are displayed if within 35% of the optimal performance. The objective is to identify policies that have a robust performance across scenarios with three possible policy rules. The first would focus on the average best results (the Bayesian or probabilistic approach), and the other two based on some robustness criteria: satisficing a minimum indicator level of 35% of the optimal, and maximising the worst outcome (MaxiMin). The exercise on robust policies in this section is limited to one indicator of cost-effectiveness performance: the welfare gains from risk reductions.

Table 45. Best performing policy instruments according to budgetary cost-effectiveness in Spain for different farm types under each scenario

Second-best only recorded if its cost effectiveness is within 35% of the optimal instrument for a farm type and scenario

		Marginal climate change			Extreme events		
	Baseline	**Adaptation by diversification**	**Structural adaptation**	**Misalignment**	**Adaptation by diversification**	**Structural adaptation**	**Misalignment**
Irrigated farm	Area**	Area**	Area**	Individual** Area*	Area**	Area**	Individual** Area*
Non-irrigated farm	Area**	Individual**	Individual**	Area**	Area**	Weather**	Area**
Pool of all farms	Area**	Area**	Area**	Area** Individual*	Area**	Area**	Area**

Note: For each climate scenario: ** best, * within 35% of best. Cost effectiveness indicator is welfare gain from reduced income variability.

The results of the “Probabilistic” standard Bayesian approach are in the last column of Tables 43 and 44. This criterion assigns given probabilities to each scenario in order to make an optimal probability weighted decisions.[6] The highlighted cell identifies the optimal policy for this farm type. As expected for an averaging criterion, Area yield insurance is picked up as the preferred option because it is the best across most of the cases. This happens for all farm types and for the two policy criteria defined, which means some robustness of the result. As explained above, this is not the case for the 10 lowest percentile of the pool of farms.

The “Satisficing” criterion would require that a single policy option appear in all the cells in the entire same row in Table 45. For irrigated farms, area yield insurance satisfied the satisficing criterion. For non-irrigated farms no single policy satisfies this criteria, so that if area yield insurance is implemented, it risk-reducing outcome will be more than 35% below the optimal in the marginal and structural adaptation (marginal and extreme events) scenarios. For the pool of farms, area yield insurance also satisfied the criterion.

The MaxiMin criterion is a more conservative decision rule that tries to maximise the worst foreseeable outcome. Table 45 identifies for each farm the scenario under which each policy instrument has the worst performance. Then the MaxiMin criterion chooses within this column the policy that shows the highest value of the cost effectiveness

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[6] It is assumed in the three country studies that the following subjective probabilities are assigned: 25% probability to the baseline (no climate change), 50% to the marginal climate change and 25% to climate change with extreme events disrupting yields. Each behavioural sub-scenario (diversification, structural adaptation and misalignment) is assigned a third of the probability.

indicator in its worst scenario. These lead to select area yield both for the irrigated farm and the weighted average farm. For the non-irrigated farm, however, individual yield insurance is chosen to avoid the potential bad performance of area yield under marginal climate change with structural adaptation scenario. In this scenario, area yield provides a negative impact on reducing risk.

Table 46. Using the MaxiMin criterion to guide instrument choice: worst-case outcome for budgetary cost-effectiveness for different instruments in Spain (by farm type)

	Irrigated farm	Non-irrigated farm	Weighted average
Individual yield	Marginal (-0.018)	Extreme with adaptation (0.016)	Extreme with adaptation (0.005)
Area yield	Marginal (0.045)	Marginal with adapt. (-0.01)	Marginal without structural adaptation (0.024)
Weather index	Marginal without structural adaptation (-1.26)	Marginal with adaptation (-0.43)	Marginal without structural adaptation (-0.63)
***Ex post* payment**	Extreme (0.01)	Marginal. (0.01)	Marginal with adaptation (0.01)
MaxiMin across instruments	Area yield	Individual yield	Area yield

5.7. Policy discussion

Table 47 summarises the robust policy choices for the two policy criteria and the different farm types. Bayesian solutions point towards area yield insurance under both policy objectives. The satisficing criterion also chooses the area yield insurance, but is unable to choose a good enough policy for non-irrigated farms under the welfare gains policy objective. MaxiMin criterion gives different choices for the two types of farms and the two policy objectives, alternating area and individual yield insurance.

Table 47. Robust policies in Spain

	Irrigated farm	Non-irrigated farms	Average/pool
Risk welfare			
Bayesian	Area	Area	Area
Satisficing	Area	-	Area
MaxiMin	Area	Individual	Area
Low incomes			
Bayesian	Area	Area	Weather
Satisficing	Area	Area	Weather
MaxiMin	Individual	Area	Weather

The policy simulation results indicate that the cost effectiveness of a single policy option tends to outperform across different farms. This is due to the systemic nature of yield risk in Spain across different types of farms. The current risk management policy framework largely depends on subsidised insurance system. The simulation result shows that implementing *ex post* payment is not cost effective as it requires large budgetary outlays, which indicates some rationale in the current policy choice. However, high yield risk under climate change may increase the cost of subsidising individual yield insurance enormously. Diversification of insurance instruments to index type insurance (area yield and weather index insurance) would most likely improve the cost effectiveness of the policy set under climate change.

Annex 2.

Regional climate change projections and impact on crop production and yields

The main base for climate change projections is the Fourth Assessment Report (IPCC, 2007a) of the Intergovernmental Panel for Climate Change (IPCC). It provides projections 50 years into the future and is based on a large body of empirical literature and scientific research synthesised through the IPCC. Global warming and catastrophic event trends are likely to impact agricultural and livestock production or yields and their variability. The analysis of the impact of climate change on farming risks poses strong methodological challenges (Box A.1). This annex discusses the available empirical literature that estimates the impacts on the distribution of yields on three continents of interest via cases studies on Australia, Canada and Spain.

Box A.1. Incorporating the effect of climate change on agricultural risk

Different approaches exist to incorporate the impact of climate change on agriculture, and these tend to focus on different aspects of this impact, from analysing 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 to investigate the impact of climate change on agriculture. These tend to rely on simulation models incorporating an understanding of plant physiology to simulate yields given daily and sub-daily inputs. An early example is Black and Thompson (1978). More recent examples are provided in Torriani *et al.* (2007) who 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). To date, few models have 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 yields 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 United States, and 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 direct applicability in production 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 is provided by John, Pannell, and Kingwell (2005) who investigate 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 in response to lower yields. 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.

Europe

Greater warming in winter and autumn is projected for northern Europe and greater warming in summer for southern Europe (IPCC, 2007). 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 historical variability only by the 2060s in spring and summer, and beyond 2100 for winter and spring. In northern Europe, precipitation signals are projected to emerge by the 2050s-2060s for winter and spring, and by 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 and 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.

In continental Spain, increases in temperature are expected and reductions in average rainfall, leading to increased water deficits (Ruiz-Ramos and Minguez, 2010). An overview of predictions of different global climate models for Spain is presented in Garrido *et al*. (2011). The impact of climate change varies considerably across regions and crops. It is projected that precipitation in Spain will decrease by 30% in the south and by 5% in the north (Rodriguez-Puebla and Nieto, 2009). Typically spring wheat will be positively affected, whereas winter wheat yields will decrease (Olesen *et al*., 2007; Minguez *et al*., 2007). The decrease in winter wheat yields is due to the need for low temperatures for flower induction, which will be harder to obtain in some regions. Spring wheat, sown just after winter, is favoured by milder winters which promote greater crop growth

However, considerable uncertainties concerning the magnitude of the impact of climate change on yields in Spain have been reported in comparisons across simulation models (Olesen *et al*., 2007; Iglesias *et al*., 2010). Based on Rey *et al.* (2011), changes in mean maize yield in the period 2071-2100 will vary depending on the region, ranging from an 8% reduction on the south-eastern coast to a 20-25% reduction in most regions, due to sensitivity to higher temperatures. For dryland wheat, there is also considerable regional variation: in projections up to 2050, the mean yields can increase by up to 35% (mostly in the north) or decrease by 35%, with different models providing different predictions within this range (Iglesias *et al*., 2000). The impact is due to a combination of water availability and temperature, with irrigated areas showing a lesser response to climate change.

Data for the simulations presented in this paper were taken from Guereña *et al* (2001), which provides information on changes in the mean and the variability of yields for both wheat and barley analysed for the case of Spain. The change in the mean yield in the central part of the country is expected to be of -1.8% for wheat and +7.3% for barley, with changes in the standard deviation of yield of 110.5% and 89.3%, respectively. This paper uses these estimates to build the basic marginal climate change scenario.

North America

Model results synthesised in the IPCC’s Fourth Assessment Report, 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 historical variability for the northern United States 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.

For Canada, the increase in average annual mean temperature for a doubling of CO_2 relative to pre-industrial times ranges from 1.9°C to 3.6°C, depending on the region. The increase in the monthly mean is projected instead to range from 0.5°C to 6.5°C depending on the region and month of the year (De Jong *et al*., 2001). As mentioned in the previous paragraph, precipitation mostly increases with changes in annual mean precipitation ranging from -11 mm to +140 mm (with considerable variations in monthly averages, see De Jong *et al*., 2001). For Atlantic Canada Bootsma *et al*. (2006) report an expected decrease in mean barley yields between 8% and 12%; however, Pearson *et al*. (2008) conclude that in eastern Canada productivity for corn and soybeans will increase.

For the province of Saskatchewan, the annual mean temperature is expected to be 3.2°C to 3.6°C warmer, and rainfall ranges from unchanged to an increase of 14 mm, although this masks considerable variation in changes in monthly precipitation. De Jong *et al*. (2001) report that these changes translate into reductions of 3% to 9% in the mean yield of barley, reductions of 12% to 17% for wheat, and of 14% for canola. A more recent analysis, reported by Zhang *et al*. (2011), uses an updated version of the EPIC crop model that is better calibrated to Canadian conditions. In their scenarios using the Canadian Global Model (CGM) with CO_2 fertilisation, they find that the changes in temperature and precipitation entail a change in the mean yield of main commodities of -3% for wheat, -10% for barley, and -13% for canola. This paper uses these estimates to build the basic marginal climate change scenario. The change in the standard deviation of yields is assumed to be -2% for wheat, -17% for barley and +2% for canola. It should be noted that considerable uncertainty remains on the variability of yields as is demonstrated by the difference in results between De Jong *et al*. (2001) and Zhang *et al*. (2011).

Australia and New Zealand

The Fourth Assessment Report from the IPCC predicts seasonal warming to be slightly greater during winter and autumn. A wide range of seasonal precipitation changes is projected covering both increases and decreases in most seasons, but with a tendency towards decreases in winter. For northern Australia, there is no overall consensus between the IPCC models on precipitation changes, nor 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 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.

The regional variation in climatic changes means that the potential impacts on crop yields vary regionally. For example, areas in south-western Australia are likely to have significant yield reductions in wheat by 2070, whereas regions in north-eastern Australia are likely to have moderate increases in wheat yield (Howden and Jones, 2004). Based on

Van Gool and Vernon (2006) and on Luo *et al.* (2011), this would mean a change in the mean yield of main commodities of -17.4% for wheat, -28.8% for barley and -28.7% for canola. This paper uses these estimates to build the basic marginal climate change scenario. The change in the standard deviation of yields is assumed to be +10% for wheat, zero for Barley, and -6% for canola.