Managing and Sharing the Risks of Drought in Australia

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Introduction

Australia is a large, dry and often hot continent. Australian farmers and agribusiness managers must be very adaptable to survive. Climate researchers are steadily improving the skill of their forecasts. Agricultural researchers are improving our knowledge of how systems respond to climate change and drought. Economists continue to improve our understanding of decisions under risk, including weather and climate risks.

In this paper we review the nature and extent of climate change and risks for Australia. Then we review the research and practice in adapting farm businesses. Sharing of financial risks is fairly easy, but sharing of climate risks is very difficult. We review the lessons of the past and the possibilities for the future. We believe that researchers, farmers and agribusiness must all work together to manage climate change and risks in the future. Communicating about such complex issues among diverse groups of people is not easy. Finally we propose a framework, based upon real options, for thinking about an d solving problems in adapting to climate change and sharing of climate risks.

Climate Change and Variability in Australia

The Bureau of Meteorology (BOM) identifies a number of major rainfall zones of Australia based on seasonality, as in Figure 1.

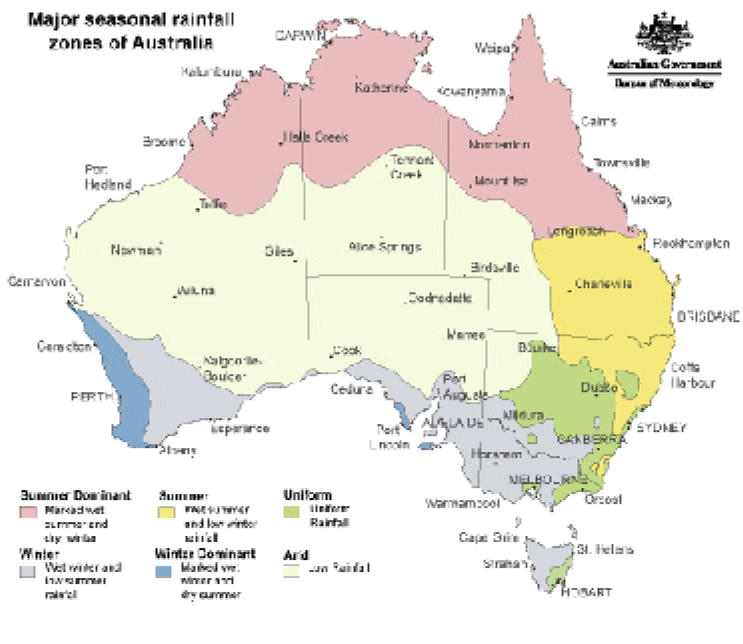

Figure 1: Major seasonal rainfall zones of Australia.
(Source: BOM, 2006a)

As a result of the influence of a high pressure belt, much of Australian rainfall is low and variable. Approximately 80 per cent of the continent has an average annual rainfall less than 600 mm. The vegetation of the arid interior adapts to dry conditions and responds quickly when rainfall is received. D ryland agriculture and pastoralism have adapted to the harsh climate of the vast inland tropical area (BOM 2006a).

Queensland in the Northeast has a rising and highly variable mean annual temperature, as shown in Figure 2.

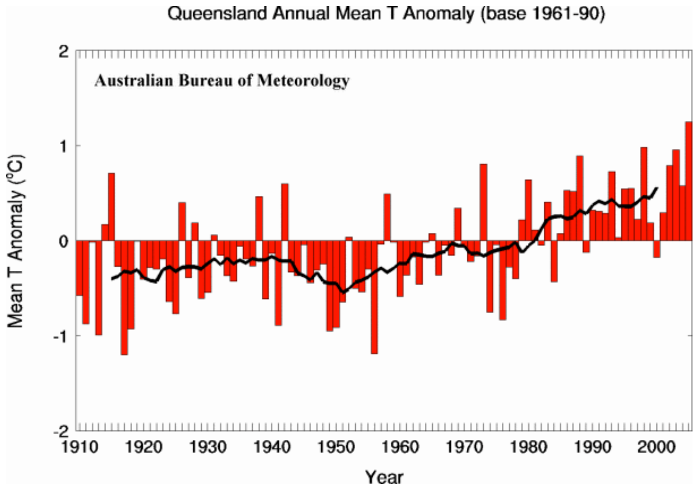

Figure 2: Mean annual temperature anomalies in Queensland, Australia.
(Source: BOM, 2006b)

The bars are temperatures reported as anomalies from the 1961-1990 average. By converting raw temperatures to anomalies, averages can be calculated over diverse localities. The line is the 11 year moving average to show decadal variation.

In some parts of Australia, rainfall has been declining, as in Southwestern Australia, as shown in Figure 3.

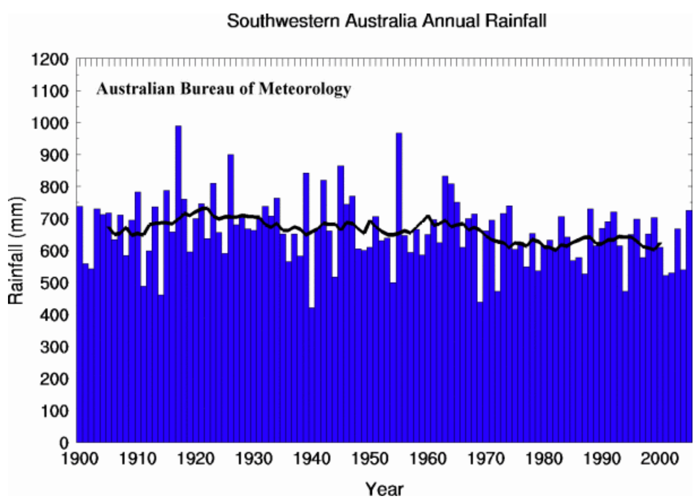

Figure 3: Average rainfall in Southwestern Australia.
(Source: BOM, 2006b)

More generally, the consensus of climate projections for Australia, based on Pittock (2003a,b) is:

(i) annual average temperatures are projected to increase by 0.4 to 2.0 °C by 2030, and 1.0 to 6.0 °C by 2070, relative to 1990. Associated changes are increases in potential evaporation and heatwaves, and fewer frosts. Warming is expected to be greater inland than near the coast.

(ii) Annual rainfall is projected to decline in the Southwestern Australia in the range of –20 to +5 per cent by 2030, and –60 to +10 per cent by 2070, while in the south-east changes of –10 to +5 per cent by 2030 and –35 to +10 per cent by 2070 are projected. In other parts of Northern and Eastern Australia, increases or decreases in rainfall are possible, depending on locality. However, when rainfall changes are combined with increases in potential evaporation, a general decrease in available soil moisture is projected across Australia, with droughts likely to become more severe. Downside risk in agricultural production is projected to increase.

(iii) Most regions are projected to experience an increase in the intensity of heavy rain events and the frequency of other extreme events such as floods, fires, droughts and high winds will increase.

Simulation and projection studies paint a complex spatial story for Australia (Howden and Jones 2001, 2004; Howden and Meinke 2003, Harrison 2001, Pittock 2003a, White *et al.* 2003, Kokic *et al.* 2005; Van Gool and Vernon 2005) regarding the nature and impacts of climate change and climate variability. For example, Howden and Jones (2004) report how the value of Australia's wheat production could be affected by a projected climate regime towards 2070. Response surfaces of mean wheat yields to CO_2, rainfall and temperature were developed for 10 sites representative of the wheat growing regions of Australia. The wheat simulation model I_Wheat (Meinke *et al*. 1998, Asseng *et al*. 2004) was run for a factorial combination of CO_2 increase, rainfall and temperature change using modified 100-year climate records (Reyenga *et al*. 1999) to generate response surfaces at each site. Their results suggest that the projected climate regime towards 2070 poses a significant risk for the Australian wheat industry, although adaptation strategies could substantially reduce this risk.

Howden and Jones project a skewed distribution of national impacts but also a marked spatial variation in possible impacts with wheat production in south-western Australia being deleteriously affected while southern Queensland and higher rainfall regions of New South Wales benefit. Their 2070 projection is for a 5 per cent increase in the median value of the nation's wheat crop. However, due to the projected rise in Australia's population and increased use of feed grains in feed-lot and intensive agriculture, Howden and Jones forecast the value of Australia's wheat exports to decline substantially, even assuming farmers react through adaptation.

The impact of climate change on cropping area was also investigated in an earlier study by Reyenga *et al.* (2001). They noted that climate change would likely alter the spatial distribution of cropping in Australia, given the importance of climate and soil characteristics in determining average yields and the frequency of failed sowings. They suggested that the viability of some cropping regions across Australia would decrease if the number or sequence of poor seasons increased.

ACG (2005) in a study commissioned by the Australian Greenhouse Office considered the impacts of climate change in seven regions of Australia, selected due to their potentially large adverse impacts of climate change. The agricultural regions they included were the Murray-Darling Basin, South western Australia and the rangelands of Australia. In developing their findings they drew on previous analyses relevant to those regions (CSIRO 2001, Jones 2001, IOCI 2002, AGO 2002, Pittock 2003a).

The ACG reported CSIRO modeling for the Murray-Darling basin that projected stream flows to decline by up to 20 per cent by 2030 and up to 45 per cent by 2070, although much variation surrounded these projections. ACG forecast problems of water shortages and increased competition for water. Drought frequency and its severity within the basin are also projected to increase with adverse impacts on rural businesses, infrastructure and greater loss of soil and biodiversity is expected. Accelerated woody weed invasions were one likely impact of drought.

In the rangelands of Australia, ACG reported that changes in flood and drought patterns would generate a range of spatial impacts. In southern rangeland regions where rainfall is anticipated to decline, animal production would commensurately decline through reductions in carrying capacity. The converse was likely to apply in northern rangelands.

Most climate models forecast warmer conditions across Australia with the implication that dairy and beef cattle will experience even greater heat stress, causing greater mortality and limitations on productivity. Howden and Turnpenny (1997) advocate further selection of cattle lines with greater thermoregulatory control, but they point out that this could be difficult because it may not be consistent with high production potential (Finch *et al.* 1982, 1984).

Beer and Williams (1995), Williams *et al.* (2001), and Cary (2002) report the potential impact of climate change on bushfire danger in Australia. These studies each found a general increase in fire danger, as measured by the McArthur forest fire danger index, with the enhanced greenhouse effect. Extreme fire danger is highly correlated with periodic drought conditions, leading to drying of fuel, and extremely hot summer and autumn days are conducive to fire spread. Both these conditions are expected to increase with global warming under all plausible scenarios, at least in southern Australia (Pittock 2003a).

Climate science endeavour in Australia has concentrated on improving our understanding of global climatology and ensuring that climate projections are underpinned by increasingly sophisticated process models. However, it needs to be emphasized that the eventual impacts of climate change and climate variability will not simply result from physical or environmental changes, no matter how accurately they may be forecast. Rather it is the direct and indirect impact of climate change and climate variability on the demand and supply of agricultural inputs and outputs (Kingwell 2006) that will generate economic impacts. Market signals linked to altered production possibilities will underpin the generation of sectoral, spatial and temporal impacts. Even if an agricultural region is not subject to much climate change nonetheless the prices it receives for its traded goods will be affected by the impacts of climate change on agricultural production in other regions or countries.

Adapting to Drought

Agricultural decision making in Australia has always been undertaken in an environment of considerable uncertainty. Because most farm inputs are allocated well before yields and product prices are known, farmers must allocate resources each season on the basis of their expectations about yields and prices (Anderson 2003). The accuracy of expectations affects resource use efficiency with associated effects on farm income.

While agricultural producers face many sources of uncertainty, climate variability has been highlighted as one of the most important. Anderson (1987) estimated that climate variability is responsible for just under 40 per cent of the variation in Australia's gross value of agricultural production and farm income. The value of agricultural production in the drought affected year of 2002-03 was just one quarter of that received in 2001-02. The drought was estimated to cost the economy $6.6 billion, or about one percent of GDP. Federal and state assistance to farmers during the drought and recovery period is estimated to be $1.2 billion (Drought Review Panel 2004).

Climate variability erodes the accuracy of expectations held by producers about future yields and reduces productivity and resource use efficiency. Producer responses to climatic variability are also thought to have adverse productivity and resource degradation consequences. The former occurs because producers choose strategies (e.g. crop or livestock activities which perform well under poor climatic conditions) which reduce the level of risk but that are less productive on average than other strategies. Resource degradation can result from the adoption of practices such as fixed long fallows that were introduced to buffer crop production against the variable climate, but are now suspected of contributing to deep drainage and erosion (Gilfedder *et al*. 1999). Finding better ways of managing climate variability is likely to be of ongoing interest with climate change research predicting increases in aridity and drought frequency for major areas of agricultural production in Australia (Pittock 2003).

Climate forecasting technologies

Seasonal climate forecasting is one of a number of technologies available to agricultural producers to reduce production risk. Most significant progress in forecasting technologies has been made in inter-annual or seasonal climate predictions. The best-defined pattern of inter-annual rainfall variability is the climatic anomalies referred to as the El Nino-Southern Oscillation (ENSO) (Hammer et al. 2001). ENSO involves sustained shifts in Sea Surface Temperatures (SST) in the eastern equatorial Pacific. A sustained warming of this area is accompanied by negative values of the Southern Oscillation Index (SOI), which is the standardised difference in atmospheric pressure between Tahiti and Darwin, and often a reduction in average rainfall over eastern Australia (El Nino). Conversely, a cooling of the area is associated with positive values of the SOI and often higher than average rainfall over eastern Australia (La Nina).

Research and experience over the last few decades has shown that ENSO plays an important role in explaining rainfall patterns in many parts of the world including Australia (Meinke and Stone 2004). Advances in our understanding of climatic interactions, combined with improvements in monitoring and computing power, now provide a degree of predictability about climate fluctuations (Hansen 2002a).

Climate forecasts offer information on climatic conditions in the coming season and are usually presented in the form of a probability of receiving a certain amount of rainfall, commonly described as discrete intervals like 'above or below median' or 'poor, average and good'. They offer skilful but uncertain information about climatic conditions in periods of 3 to 12 months ahead. Because climate will always contain uncertainty due to the chaotic behaviour of the atmosphere, climate forecasts are best interpreted as shifts of the climatological probability distribution (Hansen 2002). The value of these new probability distributions lies in the fact that they enable the decision-maker to better allocate resources between poor years and good years (Hayman *et al*. 2005).

The significance of the Southern Oscillation for Australian rainfall has only been recognised since the 1970's (Sturman and Tapper 2006). Annual rainfall in eastern Australia correlates in a general sense with the SOI and major droughts are frequently associated with large ENSO events, as shown in Figure 5.

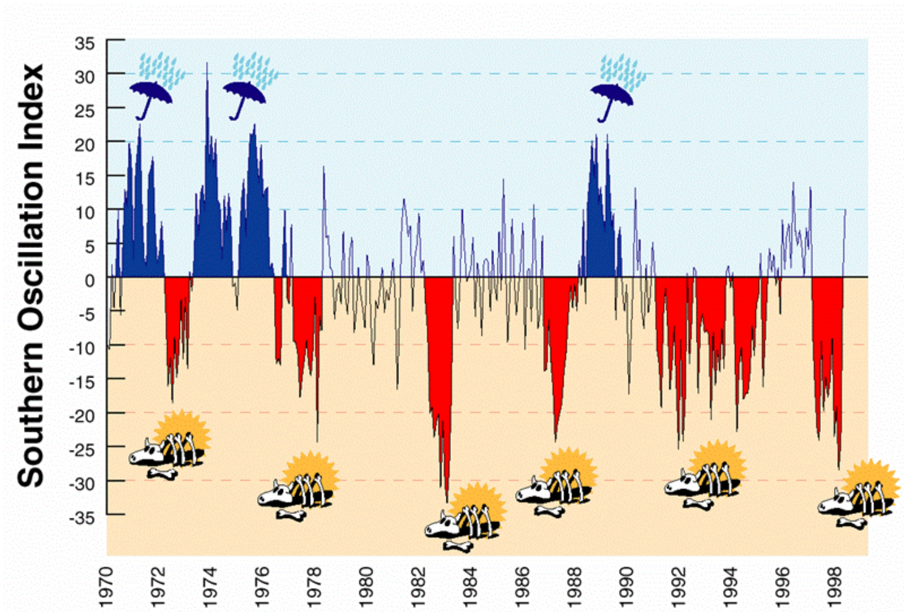

Figure 5: Southern Oscillation Index and the Occurrence of Drought in Australia. (Source: Clewett *et al.* 2003)

Seasonal climate forecasts have been issued in Australia since 1989. The current seasonal outlooks issued by the Bureau of Meteorology (BOM) are based on Australian rainfall/temperatures and SST records for the tropical Pacific and Indian Oceans (BOM 2006). Forecasts are also issued by the Queensland Department of Primary Industries and are based on phases (incorporating both the value of the SOI and its rate of change) in the SOI. The identification of 'phases' (Stone and Auliciems 1992; Stone *et al*. 1996) was an important advance in climate forecasting and led to improvements in forecast quality in a number of regions affected by ENSO. Statistical based forecasting systems, using either the SOI or SST have been the major source of seasonal forecasts used in agricultural practice (Hammer et al. 2001). Further progress in the development of seasonal climate forecasting systems is likely to rely more on dynamic climate models which are expected to provide improved forecast skill in the near future (Meinke and Stone 2005).

Use and value of seasonal climate forecasts

Recent advances in the accuracy of climate forecasts have led to some optimism about their potential economic value. Improved understanding of atmosphere and oceans through ENSO has been described by Glantz (1996) as 'Science's gift to the 20th century.' In a report to the US Academies of Science, Easterling (2000) claimed that seasonal climate forecasts based on the understanding of atmosphere and oceans was the premier advance of the atmospheric sciences in the 20th century (Hayman et al. 2005).

Improved climate forecasts provide opportunities for producers to better match decisions to pending climatic conditions. Value arises from decisions which either reduce losses associated with expected adverse climatic conditions or take advantage of expected good climatic conditions. Crop producers potentially benefit from climate forecasts through the selection of crop types, varieties and input levels better suited to impending climatic conditions. Similarly, graziers potentially benefit by tactically adjusting stocking rates to better match livestock demand to future pasture conditions. Both types of producers can use climate forecasts to make better decisions about the use of off-farm financial instruments to manage risk. There is also potential for environmental value arising from the use of climate forecasts in the form of reduce d land degradation, although there is little current evidence of this.

Despite various sources of potential value, to realise the benefits from climate forecasting a number of conditions must simultaneously be met. First, the decision maker must be facing a choice, the outcomes of which are sensitive to future climatic conditions, and hence potentially sensitive to incremental information provided by a climate forecast. Second, a climate forecast must give a prediction of relevant components of climate variability at an appropriate scale with sufficient accuracy and lead time for decisions (Hansen 2002b); and third, the forecast must be effectively communicated so that decision makers can apply it to their decision context.

Surveys of climate forecast use in Australia suggest that between 30 and 50% of farmers take seasonal climate forecasts into account when making farm management decisions (White 2001). This is relatively high compared with farmers in other countries, although the term 'use' is open to interpretation. Despite purported use, agricultural producers frequently raise concerns about the accuracy and timeliness of climate forecasts, experience difficulties in applying forecasts to farm management decisions and seek evidence of the economic val ue of climate forecasts to reduce risks associated with their adoption.

There has been renewed interest in the economic value of seasonal climate forecasts. Reviews of relevant studies can be found in Hill and Mjelde (2002), Mjelde et al (1998), Katz and Murphy (1997), Paull (2002) and Stern and Easterling (1999). Most field and farm based studies have concluded that seasonal climate forecasts can be valuable in some decision environments. The significance of results depends on attributes of the climate forecasting system and attributes of the decision making environment.

A common focus of studies has been on the value of seasonal climate forecasts in the management of a single enterprise. Hammer et al (1996) and Marshall et al (1996) assessed the value of climate forecasts for wheat management in Queensland. Lythgoe et al (2004) undertook an analysis for wheat production in south eastern Australia. Bowman et al (1995) assessed the value of climate forecasting to wool producing enterprises in Victoria. Mjelde and Dixon (1993) and Mjelde et al (1993) looked at attributes of forecast quality in corn production in Illinois. There have been relatively few whole-farm studies of the value of climate forecasts in mixed cropping environments (Mjelde et al. 1997; Mjelde and Hill 1999; Petersen and Fraser 2001; Podesta et al. 2002). This is unusual in an Australian context given that mixed cropping and livestock operations characterise a large proportion of broadacre agriculture in Australia.

The literature highlights a long list of impediments to the adoption of climate forecasts which can be broadly categorised as either to do with features of the decision making environment which make forecast use difficult (various restrictions in producer flexibility, government policies that dissuade use and difficulties that decision makers have in dealing with probabilities and uncertainties) or problems with the forecast themselves (e.g. accuracy, timeliness, relevance, communication). Hayman et al (2005) compare seasonal climate forecasts with other agricultural innovations that farmers are encouraged to adopt. They noted a number of key adoption challenges for seasonal climate forecasts including their level of complexity, inability to trial and general incompatibilities with how agricultural producers generally make decisions. On the positive side, they also suggested that the cognitive effort required in understanding and using climate forecast can be applied across the whole farm (economies of scale) and across a range of decisions and enterprises (economies of scope). Seasonal climate forecast are probably best interpreted as a technology to enhance rather than replace risk management strategies. They are probabilistic in nature and since they are largely based on ENSO phenomenon (3-7 year cycle), there will be periods of both low and high confidence in projections. Recognising when and when not to adapt management to the current forecast presents a challenge to both farmers and then advisers.

Farm characteristics and seasonal climate forecasts

The nature of farm businesses in Australia affects both their exposure to the risk of climate change and climate variability and their ability to respond to both. Currently, many farm businesses in Australia have high equity, both in aggregate and percentage terms. Farms are often diversified with portfolios of on-farm enterprises and off-farm investments (Martin *et al*. 2005). Larger businesses often are additionally spatially diversified (MacKay 2005). Kingwell and Pannell (2005) point out that this diversity has enabled businesses to cope with variation in climate and to capitalise on changes in the relative prices of agricultural commodities. It has enabled generations of farmers to be equipped with a range of management skills, created flexibility, and supported entrepreneurial action.

In spite of the potentially large long run impacts of climate change for Australian agriculture, nonetheless, for most farm businesses, even large businesses, climate change is unlikely to be a first-order issue. The commercial longevity of most farm businesses depends on their financial performance in the next few years rather than the more distant impacts of climate change, so it is rational for farmers to devote their energies toward the more pressing commercial issue of appropriately responding to climate variability and market opportunities over the next handful of seasons. Only when dealing with issues of farm succession or farm expansion may climate change impacts surface, and even then, perhaps only in passing.

Howden *et al.* (2003) reviewed the adaptive capacity of the Australian agricultural sector to climate change. They found that most potential adaptation options for Australian agriculture were extensions or enhancements of existing activities for managing current climate variability. In broadacre farming a range of coping and adaptation options are either available or are being developed.

John *et al.* (2005) examined the impact of climate change in a low rainfall broadacre farming region of Australia and found that the projected adverse climate change, that included an increased incidence of drought, reduced farm profit significantly. An implication was that a farmer's financial capacity for adoption of some innovations would be impaired due to reductions in financial liquidity. Expensive, lumpy capital investments (e.g. cropping gear, additional farmland) would be difficult to undertake, especially as these investments are often conditional on periods of favourable seasons. The reduced frequency of favourable seasons and the increased incidence of drought are likely to inhibit some capital replacement and expansion decisions of farmers.

Sharing the Risks of Drought

Current drought policy in Australia relies on the Exceptional Circumstances program, which aids farmers after extreme consecutive seasons, and Farm Business Deposits which allow smoothing of income by deferring income from good to poor seasons, effectively reducing the level of income tax. These programs do not directly cover farmers' exposure to weather and climate risk and because they are *ex post*, there are no efficiency gains in farm production. Consequently, researchers are investigating other instruments such as multi peril crop insurance, weather derivatives and yield index insurance.

Multi peril crop insurance

Traditional multi peril crop insurance schemes have failed wherever they have been implemented (Goodwin and Smith 1995). The U.S. and Canadian schemes have not been commercially viable with loss ratios approaching 3 (Gardner 1994, Sigurdson and Sin 1994). In other words, the costs of the scheme have been three times greater than the premiums paid by farmers. Nor has the situation improved recently (Skees *et al.* undated). Multi peril crop insurance schemes are complicated policies for subsidising farmers.

The final report compiled by the Multi Peril Crop Insurance Taskforce (2003) put to rest the concept of multi peril crop insurance in Western Australia. The premiums that farmers would have to pay are reasonable, as shown in Figure 5.

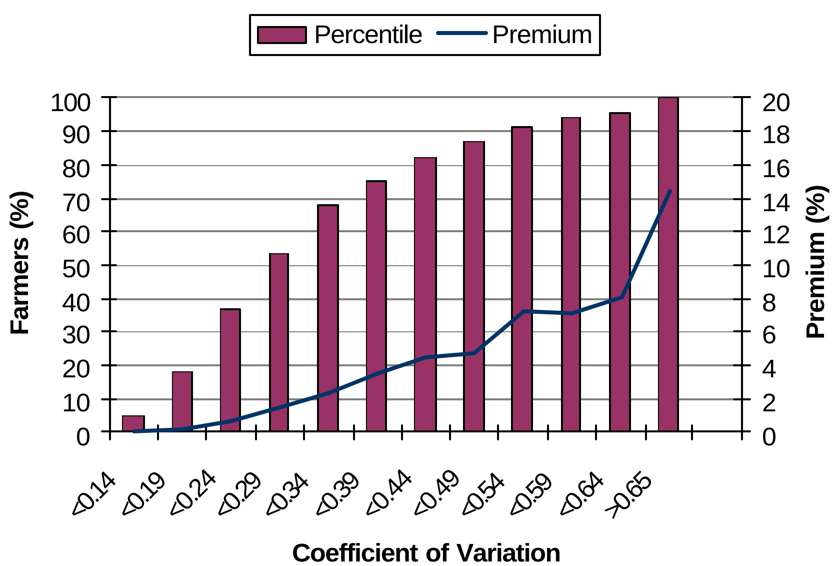

Figure 5: Percentile of farms and insurance premiums classified by the coefficient of variation. (Adapted from Multi Peril Crop Insurance Task Force 2003)

On the horizontal axis are risk categories measured by the coefficient of variation, which equals the standard deviation of yields on a farm divided by its average yield. For example, a coefficient of variation of 0.24 says that the standard deviation of yields is 24% of average yields. On the left-hand vertical axis is the cumulative percentage of farmers with yield risks less than the coefficient of variation. On the right-hand vertical axis is the premium for multi peril crop insurance as a percentage of the value of the crop. Most farmers would pay fairly low premiums. About 37% of farmers have a coefficient of variation less than 0.24 and would pay less than 0.6% of the value of their crop for insurance. Over 50% of farmers would pay less than 1.5% and 75% of farmers would pay less than 3.5%. These are relatively low premiums, reflecting the reliable wheat production in the state and suggest that crop insurance would be affordable in Western Australia.

Unfortunately there are many problems with multi peril crop insurance: moral hazard, adverse selection, high transaction costs and systemic risk. The most serious of these is adverse selection. The premiums that should be paid by the riskiest 10%, 20%, 30% and 40% of farms in 8 shires of Western Australia are shown in Table 1 below.

Table 1: Premiums for the Riskiest Farms in Each Shire.

		Riskiest Farms			
Shire	Average (%)	10%	20%	30%	40%
Dalwallinu	1.2	5.1	3.8	3.1	2.7
Wongan-Ballidu	1.3	7.6	5.6	4.1	3.1
Dandaragin	1.9	9.2	6.0	4.8	4.1
Katanning	2.2	7.1	5.4	4.0	3.4
Merredin	2.3	7.3	5.1	4.3	4.3
Kulin	2.5	7.9	5.8	5.5	4.9
Esperance	2.6	9.4	7.1	5.8	4.9
Jerramungup	4.1	10.9	9.8	8.3	7.3
Average	2.1	7.7	5.9	4.8	4.2

(Source Multi Peril Crop Insurance Task Force 2003)

There is some variation in premiums among shires. However there are risky farms in every shire and most of the variation is among farms within shires. An area yield insurance program might set premiums at the average for each shire. The riskiest farmers would consider insurance a bargain, the least risky farmers would consider insurance too expensive and adverse selection would destroy the program.

To sustain a multi peril crop insurance program, government could pay all or part of the premiums or underwrite the risks. Alternatively, insurance could be made compulsory for all farmers. Instead of government subsidies, some farmers could subsidise others. The Multi Peril Crop Insurance Task Force (2003) calculated a maximum transfer from less to more risky farmers of $14 per hectare per year. In Australia, neither of these alternatives is politically possible.

Weather derivatives and yield index insurance

A weather derivative is a contract based on the events of a weather variable measured at a given location (Dischell and Barrieu 2002, Stoppa and Hess 2003). Because weather variables are collected by a disinterested third party, such as the Bureau of Meteorology, the buy and seller of the contract have the same information and there is no adverse selection. Farmers cannot affect the weather and there is no moral hazard, unless the seller of the contract reneges or goes bankrupt. However, this is quite possible because drought in Australia can be wide-spread affecting the entire agriculture production and marketing system. Sellers of weather derivatives face systemic risk (Goodwin 2001, Hertzler 2005, Miranda and Glauber 2001, Stoppa and Hess 2003). An effective antidote for systemic risk is a market exchange (Collinson 2001) similar to a stock market or a futures market.

In the U.S. energy market, trade in weather derivatives began in 1996 through over the counter contracts and soon expanded to the Chicago Mercantile Exchange (2006). Financial operations in the energy industry are large and sophisticated. In contrast, financial operations in agriculture are often done at night around the kitchen table. Even so, with the total value of the agricultural industry, at 3% of the Australian GDP and secondary support industries much larger, the widespread adoption of weather derivatives might provide enough liquidity for exchange traded contracts or enough scale for over the counter contracts or for both.

The main advantage to agriculture, support industries and government is in sharing weather risks with institutional investors. There are advantages to the investors as well. The change in the value of weather derivatives will have very little correlation with their other investments. By selling weather derivatives, investors can add uncorrelated securities to their portfolios. They will also receive a premium from farmers in return for sharing the risks. The main disadvantage to agriculture and support industries is paying the premium. On average, they may make less profit; however, they will not face the potentially crippling consequences of an extreme adverse season. The government will also benefit from reduced assistance to agriculture.

Interestingly, profit may not be reduced. Weather derivatives will encourage the efficient allocation of capital. Currently, without direct cover for seasonal risk, farms diversify their production, usually at the expense of efficiency. Kingwell (1993) used an optimising farm model to determine the influence of risk aversion on profit. The optimal farm plans for the more risk averse farmers showed a reduction in profit of 2-6% and 10% fewer cropping hectares. By using weather derivatives to reduce the production risk, these farmers could increase their returns to offset the cost of the premium to purchase the weather derivative.

There are still some major issues to solve, however, before the agricultural and support industries can effectively use weather derivatives. The primary problem is basis risk. Basis risk occurs because weather is imperfectly correlated with yields on a farm and weather derivatives imperfectly hedge against yield risks. Basis risk can be reduced by using yield indexes, which are essentially stochastic production functions of weather. Then contracts can be written on the yield index instead of weather variables. Unfortunately, it is difficult to find simple yet highly correlated yield indexes, and economists do not yet agree on how to price them (Jewson and Brix 2005, Hertzler 2004, Musshoff, *et al.* 2006). For these reasons, it will be difficult to trade yield indexes on an exchange, which will increase transaction costs. Instead, a broker will sell yield index contracts over the counter. Figure 6 diagrams how it might work.

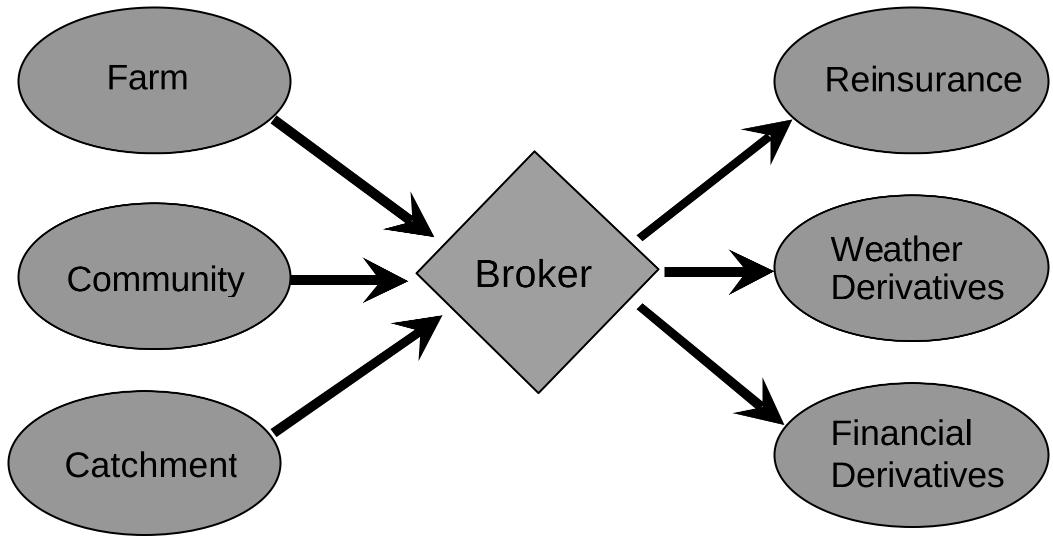

Figure 6: Risk sharing through a broker who diversifies and spread risks through out the world.

On the left are systems subject to climate risk. On the right are other systems subject to other risks. Two of these other systems are markets for weather and financial derivatives. In the middle of the figure is a broker who makes risk sharing possible. Farmers, communities and catchment authorities might buy contracts from the broker. As with traditional insurance, the broker must design contracts for each client and individually assess the insurance premiums. As in finance, the risks are assessed using publicly available data, in this case, weather data. An index is estimated from the data to correlate as closely as possible with outcomes for each client. By pooling the risks of several clients, the broker's portfolio becomes less risky. The broker will, in turn, share some risks. The broker may buy reinsurance from large companies who are exposed to weather in the Northern Hemisphere and want to diversify their portfolios to include weather in the Southern Hemisphere. In addition, the broker may buy weather derivatives and financial derivatives on market exchanges.

Real Options: The Future of Climate Risk Management?

While climate scientists are improving their forecasts, economists are helping farmers and natural resource managers to make better decisions. In economics, there have been two major streams of thought about optimal decisions under risk. The first stream began with von Neumann and Morgenstern and led to expected utility theory (Anderson *et al.* 1977, Hardaker *et al.* 1997). A recent generalisation is the state-contingent approach to decisions under uncertainty (Quiggin and Chambers 2004 and Quiggin and Chambers 2006). The second stream began with Einstein and led to stochastic dynamic programming (Kennedy, 1986). Recently, stochastic dynamic programming has evolved into an approach called real options (Dixit and Pindyck 1994, Copeland and Antikarov 2001).

Suppose we are gambling. We place our bets and roll the dice. Then we watch and wait until the dice stop tumbling to learn the outcome and calculate our gains and losses. This is the conception of probability and risk underlying expected utility theory and the state-contingent approach. But suppose, in this electronic age, we could react quickly and modify our bets while the dice are still tumbling. This is the conception of probability and risk underlying stochastic dynamic programming. It is the conception that is most useful for adapting to climate change and sharing climate risks because the climate dice are always tumbling. Adding asymmetric outcomes, in which losses are risky and gains are good luck, extends stochastic dynamic programming to become real options.

Real options can be highly mathematical (Duffie 1996, Dixit and Pindyck 1994) or a simple framework for organising our thoughts (Copeland and Antikarov 2001) or both. A simple framework for real options uses decision diagrams. These are an adaptation of decision trees to include all possible states of nature as well as decisions which depend upon the current state and probabilities of future states. As two examples, grazing decisions must adapt to climate change and yield index insurance could help farmers avoid the downside risks of drought.

Grazing Decisions

A grazier may adapt to climate change by conserving fodder and altering stocking rates. A simple decision diagram is shown in Figure 7.

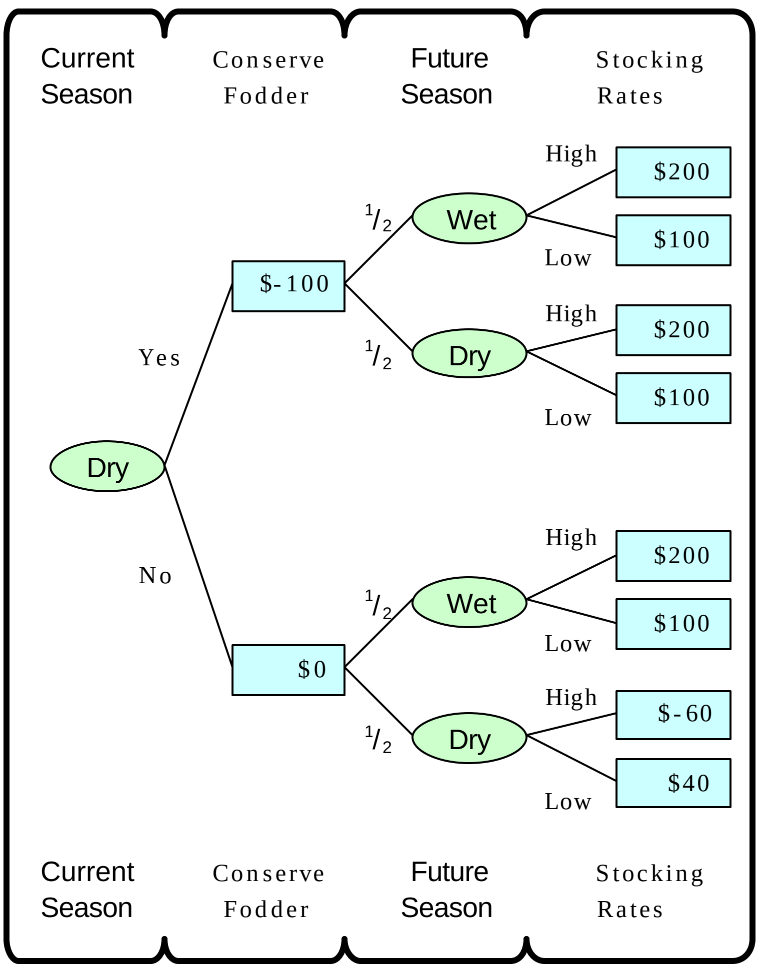

Figure 7: Grazing decisions with climate change.

Along the top and bottom of the figure, current and future seasons are the states of nature. Decisions are fodder conservation and stocking rates. In the interior of the figure, states of nature are represented by ovals. The dollar outcomes of decisions are contained in the rectangles. States of nature are linked to dollar outcomes by decisions and, in turn, dollar outcomes are linked to future states of nature by probabilities. In this simple example, the only states of nature are wet or dry seasons. On the left, the current season has been revealed as a dry season. The grazier can decide yes, conserve fodder, or no, do not conserve fodder. Each of these has a cost. Future wet and dry seasons are equally probable. Once the future season is revealed, the grazier will choose a high or low stocking rate. On the right, the outcomes of the stocking rate decision will depend upon whether or not fodder was conserved.

Should fodder be conserved? Before climate change, the forecast for dry seasons is 1 out of every 2 seasons and the real option value (ROV) of fodder conservation is:

$$ROV = -100 + ½\ 200 + ½\ 200 = \$100$$

Conserving fodder cost $100. Once fodder is conserved, high stocking rates are optimal, even in dry seasons. The returns from stocking rates are multiplied by probabilities to get the expected returns. Subtracting the costs from the expected returns gives a real option value of $100. Similarly, the real option value without fodder conservation is:

$$ROV = 0 + ½\ 200 + ½\ 40 = \$120$$

The grazier can expect to be $20 better off without fodder conservation. Therefore, the real option value, in the current season, is $120.

After climate change, suppose dry seasons are forecast for 3 out of 4 seasons and the real option value of fodder conservation is:

$$ROV = -100 + ¼ \cdot 200 + ¾\ 200 = \$100$$

However, the real option value without fodder conservation is:

$$ENB = 0 + ¼ \cdot 200 + ¾\ 40 = \$80$$

Therefore, in the current season, the real option value is $100. In this simple example, a grazier will adapt to climate change. If fodder conservation was not an option, the real option value would decline by $40, from $120 before climate change to $80 after climate change. With fodder conservation, the real option value declines by only $20, from $120 to $100.

Yield Index Insurance

Farmers routinely share financial risks by using futures markets and grain pools and by purchasing options. None of these financial contracts are perfectly correlated with farm-gate prices, but the correlation is enough to make risk-sharing practical. In the future, farmers may also purchase yield index insurance. The index is a prediction of harvest depending upon the weather. If the prediction is highly correlated with actual harvest, yield index insurance will also become practical. Figure 8 shows a very simple example for a yield index based on growing season rainfall.

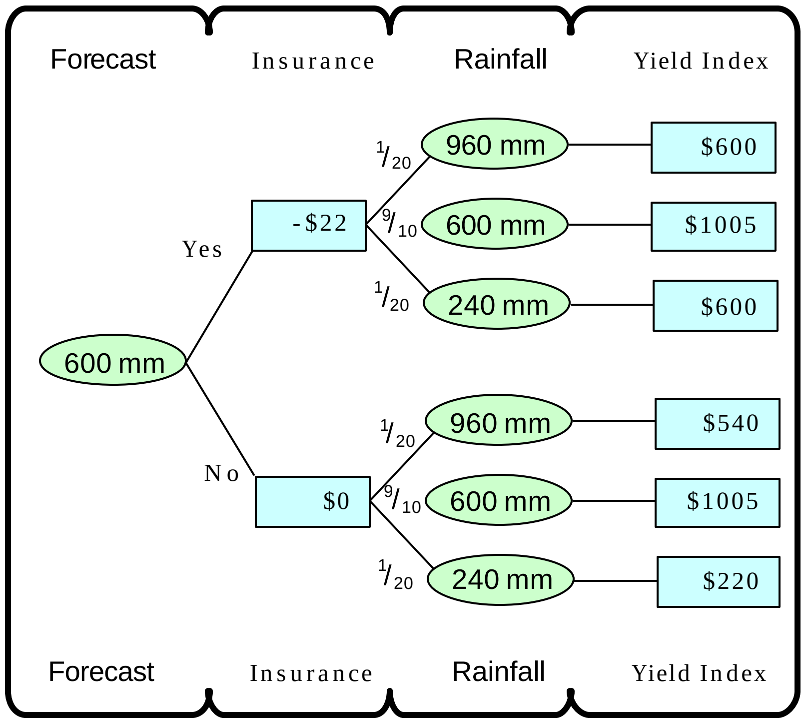

Figure 8: Pricing of yield index insurance.

The forecast is for 600 mm of rain. Actual rainfall may be 960 mm, 600 mm or 240 mm. For these rainfalls, the yield index predicts outcomes of $540, $1,005 and $220, respectively. If insurance is purchased, a minimum outcome of $600 is guaranteed. Nine in ten seasons the actual rainfall will be 600 mm and there will be no insurance payout. One in 20 seasons, rainfall will be 960 mm, the yield index predicts low yields and the insurance payout will be 600 – 540 = $60. Also, one in 20 seasons, rainfall will be 240 mm, the index predicts even lower yields and the insurance payout will be 600 – 220 = $380. The price of yield index insurance that equates the real option value with and without insurance is $22. This is the actuarially fair price. In practice, insurers charge more to cover their costs and receive a return on investment in a risky business. Farmers may still buy insurance, however, if they are averse to risk or if sharing the risks is more economical than retaining risks and adapting the farming system.

Decision diagrams are an excellent method for thinking about systems subject to climate change and climate risks. They incorporate states of nature and probabilities that depend upon the states of nature. They make clear that decisions and outcomes are adaptive, and irreversible. However, the diagrams have gaps. For example, a yield index could predict outcomes for all possible levels of growing season rainfall, not just 960 mm, 600 mm and 240 mm. Similarly, the forecast for rainfall need not be 600 mm. It could be 590 mm or 743 mm or any other level. More subtly, yield index insurance could be purchased at different times during the growing season for different prices. Additional levels and times could be drawn in a much bigger decision diagram. An alternate approach would keep the decision diagrams simple and use the mathematical power of real options to fill in the gaps (Duffie 1996, Hertzler 2004).

Conclusions

Adapting to climate change and sharing climate risks is a challenge for Australia. Farmers have proven themselves to be adaptable and, if better climate forecasts, new methods of farming and new methods of sharing climate risks can be developed using weather derivatives and yield index insurance, agriculture and its support industries may continue to prosper. However this will require collaboration between researchers and producers. The real options framework provides a way to think about adapting and sharing risks and give us a language for communicating about a complex problem.

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