Rainfall Variability and its Impact on Dryland Cropping in Victoria[1]

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ABSTRACT

Conventional wisdom holds that rainfall variability represents a significant source of agriculture production risk. Surprisingly, there have been very few economic analyses exploring the link between rainfall variability and agriculture production. This paper is intended to investigate the factual basis of this assumption and to inform future government policy in such areas as drought, climate change adaptation and water policy. We investigate whether rainfall variability has had an actual impact on agricultural production, specifically dryland cropping in Victorian regions during the period 1982-83 to 2004-05.

1 BACKGROUND

Australia has one of the most variable rainfall climates in the world. Over the past decade, most parts of the country have experienced relatively low rainfall. This situation has fuelled renewed interest in the effects of climate variability on the agricultural sector. The aim of this paper is to analyze the impact of climate variability on broadacre agriculture in Victoria. Given the current drought context, a closer look will be given to the impact of rainfall variability.

Agricultural production is affected by many uncontrollable climatic factors, the number one being rainfall. The role of rainfall as a resource in crop production has been an area of interest for many researchers studying the major droughts in Australia (Foley, 1957; Gibbs and Maher, 1967; Smith et al., 1993; White and O'Meagher, 1995; Horridge et al, 2005). In order to understand the impact of rainfall on agricultural production, it is necessary to understand its seasonal variability. This paper analyses the rainfall variability and then uses this to assess its impact on agricultural production in Victoria. We also analyse solar radiation, evaporation and temperature to investigate if other climatic variables have a significant effect on crop production.

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[1] Paper presented at the 52nd Annual Conference of the Australian Agricultural and Resource Economics Society (AARES), Canberra, 2008

Acknowledgements: We would like to thank Walter Shafron and Milly Lubulwa from ABARE for providing data. We would also like to thank James Darragh and Sarah Reichert from ABS, and Mark Taylor from DPI Statistical Services for organizing the provision of ABS data.

The rest of the paper is divided as follows. Section two discusses some methods available for quantifying rainfall variability. Data sources, limitations and methodology are discussed in section three while the results of the analysis are presented in section four. This section starts by demonstrating the variability of historical rainfall in cropping regions of Victoria and then continues presenting the impact of this variability on agricultural industries. The final section concludes.

2 METHODS FOR QUANTIFYING RAINFALL VARIABILITY

Several statistical methods for assessing rainfall variability have traditionally been used by meteorologists and hydrologists; the most common in Australia include deciles, quartiles and Standard Precipitation Index (SPI) (Coughlan, 1987; Smith et al., 1993; Khan and Short, 2001). This section provides a brief review of these statistical methods as well as giving an insight into the Rainfall Anomaly Index which is used in this study.

2.1 Decile analysis

The method of rainfall decile analysis was developed by Gibbs and Maher (1967) as a drought indicator. It consists of ranking the annual rainfall data in descending order to construct a cumulative frequency distribution. The distribution is then split into 10 ranges (tenths of distribution or deciles). The degree of wetness or dryness associated with each decile range is determined as in Table 1.

Table 1: Definitions of Decile bands that result from a Decile analysis

DEFINITION OF DECILE BANDS	
Decile Range 1	Very much below average
Decile Range 2	Much below average
Decile Range 3	Below average
Decile Range 4	Slightly below average
Decile Ranges 5 & 6	Average
Decile Range 7	Slightly above average
Decile Range 8	Above average
Decile Range 9	Much above average
Decile Range 10	Very much above average

Source: Gibbs and Maher (1967)

The decile analysis has the advantage that it is simple, and its computation requires less data and fewer assumptions than the other methods (Smith et al. 1993)[2]. The main drawback of using rainfall deciles is that accurate calculations require a long climatic data record (100-years). Also, deciles cannot assess the severity of a drought. The analysis can only distinguish between high and low rainfall values, but the relative dryness of a particular period cannot be implicitly assessed as a continuous function.

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[2] This method is used by the Australian Bureau of Meteorology as the measurement of drought. It has also been adopted by the Australian Drought Watch System to act as an indicator of the eligibility for drought assistance. Farmers can only request government assistance if the drought is shown to be an event that occurs only once in 20-25 years (deciles 1 and 2 over a 100-year record) and has lasted longer than 12 months (Botterill, 2003b).

2.2 Quartile analysis

The quartile method is very similar to the decile analysis, in terms of computation, strengths and limitations. However, it is not commonly used. In this method (Edwards 1979) the annual rainfall data is ranked from the highest to the lowest, divided into four bands of 25 percent each. Definitions for weather severity based on quartiles are described as in Table 2.

Table 2: Definitions of quartile values and quartile analysis results

QUARTILE VALUES	
0	Minimum
< 1st	Below Average
2nd	Median
1st to 3rd	Average
> 3rd	Above Average
4th	Maximum

Source: Edwards (1979)

2.3 Standardized Precipitation Index analysis

The Standardized Precipitation Index (SPI) method was developed by Mckee et al., (1993). This method is based on the probability distribution of precipitation. The SPI is calculated by fitting a long-term precipitation record for a given station to a probability distribution which is then transformed into a normal distribution with a zero mean (Khan and Short, 2001). Positive SPI values indicate greater than median precipitation and negative values indicate less than normal precipitation as indicated in Table 3. This index is mostly used by drought planners. It has the advantage of being a versatile indicator, it can be computed for different time scales, and it can provide early warning of drought and help assess the severity of drought. The main drawback of SPI however, is that its values based on a data set up to a particular year are likely to change in future when the data set is extended.

Table 3: Definitions of SPI values and SPI analysis results

SPI VALUES	
2.0+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2.0 and less	Extremely dry

Source: NDMC (2006)

2.4 Rainfall Anomaly Index analysis

The rainfall anomaly index (RAI) has been commonly used to monitor precipitation in drought-prone regions such as the Brazilian North-east (Hastenrath, 1984; Hastenrath et al., 1984) and West African Sahel (Katz, 1978; Hulme, 1992). The construction of RAI involves standardizing the annual or seasonal total rainfall for an individual station by subtracting the station's mean and dividing by its mean (or standard deviation), with the mean and standard deviation being computed from the station's historical record.[3]

Assume, x_{ij} represents total rainfall for station *i* in year *j*. To construct RAI, annual (seasonal or monthly) rainfall total is normalized as follows:

$$x'_{ij} = \frac{x_{ij} - \bar{x}_i}{\bar{x}_i} \qquad (1)$$

or

$$x'_{ij} = \frac{x_{ij} - \bar{x}_i}{s_i} \qquad (2)$$

where x'_{ij} is the normalized annual (seasonal or monthly) rainfall total for station *i* in year *j*; $\bar{x}_i$ and s_i the mean and standard deviation of the rainfall total during a specified reference period. The normalized rainfall totals x'_{ij} are then used to compute RAI as follows:

$$\bar{X}_j = \frac{1}{n}\sum_i x'_{ij} \qquad (3)$$

where $\bar{X}_j$ is the RAI value for year j and n, the number of stations.

Unlike the SPI, each RAI value is a point estimate of the corresponding true area average. In this study, the raw rainfall data are normalized using equation (1) and averaged across stations within a region as per equation (3) to yield time series of annual RAI values.

3 DATA SOURCES AND METHODOLOGY

Daily rainfall and other climatic records were obtained for 21 rainfall stations across 6 regions in Victoria. These regions include the Mallee, Wimmera, North East, North-central, South West and Gippsland. Raw data on rainfall and other climate variables are daily observations from 01/01/1889 to 31/12/2006. The other climate variables include daily maximum temperature, solar radiation and evaporation. The daily rainfall data were then summed-up using user-defined functions in Excel, to calculate total annual and total growing season rainfall (GSR) over the calendar year. The GSR is the total of April to October rainfall. The other climate data (i.e., maximum or minimum temperature, solar radiation and evaporation) were averaged over the calendar year.

The rainfall variability at each rainfall station was determined using the "rainfall anomaly" or percent departure from the mean method as discussed in section 2. An index for each region was then constructed, following equation (3) above. A similar index was calculated for the annual average of daily maximum temperature, solar radiation and evaporation. The annual averages were calculated from daily data using user-defined functions in Excel.

Daily rainfall and other climate data were expressed in terms of calendar year. Production and financial data (explained below) are on the basis of the financial year. This is reasonable

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[3] In comparing RAI derived using the mean as denominator and the one using the standard deviation as denominator, Kraus (1977) concludes that both measures yield similar results given that in dry climates the mean and the standard deviation are correlated.

especially for grain cropping, because production and financial data collected for 2004-05 for example, depends on the crops harvested at the end of 2004 and this crop depends on the growing season that commences in April 2004 (before start of the financial year 2004-05). In other words, climate data is expressed in calendar years to match the impact of rainfall on crop production.

Agricultural production and financial data were obtained from Australian Bureau of Statistics (ABS) and Australian Bureau of Agricultural and Resource Economics (ABARE). Every attempt was made to obtain the data on production, costs and income disaggregated to regional level. There have been inevitable constraints in the availability of disaggregated data. One limitation is the lack of breakdown between irrigated and dryland agriculture.

ABS collects crop area and production data through its annual agricultural surveys and agricultural census that is now conducted every five years. The ABS data are collected at farm-level and are published annually as aggregate data for four hierarchical levels of geographical regions (ABS, 2007). These regions, in the descending order, include State (or Territory), Statistical Division (SD), Statistical Sub Division (SSD) and Statistical Local Area (SLA). Except in the census years, the ABS data are not reported generally beyond the level of SD's.

ABARE data are collected through an annual farm survey and are published as average per farm. The disaggregation of this data within each state/territory is limited only to a single hierarchical level of geographical regions. One limitation with ABARE data is that the regions to which state/territory-level survey data are disaggregated are larger than the SD's of the ABS. There are only four ABARE regions covering Victoria whereas ABS has got eleven SD's for the state.

Farm financial data such as input costs, farm income and capital value are collected only by ABARE. Data on the area and production of grains are collected by both ABS and ABARE. The area and production of total cereals data are collected by the ABS. Data on specific crops such as wheat and barley were sourced from ABARE. These data based on SD's of the ABS were aggregated up to ABARE regions, using an area-based concordance as shown in Table 4 (Darragh, J., ABS, pers com, 2007).

Table 4: Area-based aggregation of data from SD's of the ABS to ABARE regions

ABARE region	Proportion of each SD of the ABS							
221 Mallee	94% of Mallee	11% of Wimmera						
222 Wimmera	82% of Wimmera	6% of Mallee						
223 Central north	67% of Loddon	61% of Goulburn	24% of Ovens-Murray	7% of Wimmera				
231 Southern & eastern	100% of Barwon	100% of Central highlands	100% of East Gippsland	100% of Gippsland	100% of Western district	76% of Ovens-Murray	39% of Goulburn	33% of Loddon

Source: Darragh, J., ABS, pers com, 2007

Although historical data on rainfall and other climate variables are available for 109 years, ABS and ABARE data were purchased for a period starting from 1982-83 and 1977-78, respectively. Only the period from 1982-83 to 2004-05 has been considered in the analysis, in order to create a complete pool dataset.

In addition to agricultural production and financial data on a regional basis, the market price of wheat for Australia was obtained for the same period (ABARE, various years). Fluctuations in commodity prices, as analysed historically by Kingwell (1997), is another significant off-farm factor that impacts on farm financial performance (see Wimalasuriya, 1999; Wimalasuriya et al., 2003). The market price of wheat, which is the main grain crop that the majority of farmers grow, has also been included in the analysis to check for its impact on cropping in comparison with rainfall and other climate variables. All the financial data and commodity prices have been deflated using the producers paid index and producers received index (ABARE, various years).

To examine the impact of the variability in rainfall and other climatic factors on dryland cropping, we use statistical correlations and econometric modeling. All these analyses were conducted separately for the three ABARE regions in the northern portion of Victoria, namely, the Mallee, Wimmera and Central North regions. Amount of rainfall (mm) was used instead of RAI for the statistical and econometric analysis because any data with negative values cannot be used for econometric analysis.

3.1 Statistical correlations

The correlation between two variables can be thought of as a measure of the strength and direction of their linear relationship. The correlation coefficient is between -1 and 1. The sign of the coefficient indicates the direction of the relationship (Hill, et al, 2001). Correlation does not imply causation, it only provides an indication of a linear relationship. Additionally, there is the potential for variables with a nonlinear relationship or no relationship at all to show some correlation. For our purposes we will consider .1-.29 as a weak relationship, .3-.49 as medium and .5-1.0 as strong (Cohen, 1988). We choose these because there are many factors in agriculture that may interfere with a linear relationship.

The correlation between each climate variable and each agricultural production or financial parameter was estimated. The climate variables include annual rainfall, average maximum temperature, radiation and evaporation. The agricultural production and financial parameters include cereal area and production, wheat and barley area and production, crop gross receipts, farm business profit, farm cash income and wheat and barley receipts.

Further correlations were estimated between the production and area sown of the two main cereal crops, wheat and barley. This is to check for any differences between the two crops, in terms of their tolerance to climate variability.

3.2 Econometric modeling

We complement the correlation analysis with econometric analysis. Specifically, we want to investigate the significance of rainfall to grains cropping in Victoria's Mallee, Wimmera and Central North regions. This has implications for drought policy which is based on a climatic definition of drought used to trigger Exceptional Circumstances assistance (see Footnote 2).

Given the regional level nature of our dataset, we decided to use pool estimation techniques to allow the generation of results by cross-sections. This allows the identification of regional differences that may exist in the data. We use "EViews" pooled estimation features for our analysis.

In the following analysis, we use what is called 'log-log' or 'double log' specification of the regional production functions. The advantage of using this specification is that it allows us to interpret coefficient estimates as elasticities (Ramanathan 1995). We did not choose a more 'flexible' approach such as translog because of the lack of degrees of freedom if we had to include a large number of interaction terms (Greene 2000; Guan, Oude Lansink, Van Ittersum and Wossink 2006). Recall, that we have 23 years of data. In pooled estimation this becomes 69 (23*3) observations but because each variable is estimated for each cross-section, 3 observations are used every time one is added. Essentially, the expansion in usable observations is illusory because the number of observations used for each variable used also expands at the same rate. Thus, the use of a translog specification as interaction terms are estimated for each combination of variables. For example, if we used 5 variables, in pooled estimation for 3 cross-sections, 15 degrees of freedom would be used. Assuming we only have two variable combinations, the number of interactions would be $\left(\frac{5!}{(5-2)!}\right)\times 3 = 30$ degrees of freedom. In all, 45 degrees of freedom (ignoring the constant) would be used to implement a translog specification for a 5 variable model. As a result, a relatively small number of variables could conceivably use up all the degrees of freedom especially if the interaction terms are greater than two variables. Given this concern, we chose the less intensive double log specification. We used least squares estimation because there was no compelling reason to use a different estimation technique.

We estimated three models for wheat, barley and cereal production. We chose to model wheat and barley individually because they comprise the largest proportion of cereal crops. We chose to model cereals in totality to capture any differences in estimates that may have occurred that are not apparent from modelling individual crops. For example, one might suspect the impact of rain to be lower for cereals production than for wheat because farmers are able to change their cropping mix towards less rain-dependent crops. As such, modelling of individual crops may overstate the impact of climate.

4 IMPACT OF RAINFALL VARIABILITY ON DRYLAND CROPPING IN VICTORIA

Before analysing our results with respect to the RAI, we begin this section with a brief overview of some characteristics of the dryland cropping regions in Victoria. Traditionally, broadacre cropping has mainly been confined to the northern parts of the state, which are mainly the ABARE regions refered to as the Mallee, Wimmera and Central North. These three regions together contribute to more than 90 per cent of the total grains area of Victoria, but this has been decreasing since early 1990's. This is because some of the traditional livestock farming areas in the Southern and Eastern region have more than doubled the area under grain growing over this period.

Continuous cropping is practiced mainly on the good quality grey clay soils of the Wimmera region while grain-growing in the Mallee and Central North regions are mainly based on crop-pasture rotations. Therefore, most of the grain-growing farms in the latter regions are mixed crop/livestock farms. The livestock component in these mixed farms is predominantly sheep, specializing in either lamb or wool production. The pasture types that are rotated with grain crops are annual pasture types, mainly subclover or medic species. These annual pasture species are either under-sown with the last crop of the cropping phase of the crop-pasture rotation (mainly subclover in the Central North) or are allowed to regenerate from the naturally occurring seed bank in the soil (mainly medics in the Mallee). Some farmers also establish Lucerne pasture after the cropping phase and maintain it for three to five years before returning to cropping.

The impact of rainfall variability on agriculture can be assessed by at least two broad methods. Firstly, agricultural operators can be surveyed with the objective of capturing their views on how their specific farming activities are affected by variability in rainfall. This self-assessment method has commonly been used to evaluate drought preparedness and management among farmers in the United States (Harwood et al.,1999) and in Australia (Webb and Mazur, 2004)[4]. As noted by Topp and Shafron (2006), the subjectivity of this method constitute one of its major weaknesses. For instance the results of studies using this approach are likely to be biased to reflect farmers' belief regarding risk management and/or mitigation. Further, since this approach is in essence carried out ex ante, farmers may respond to ex ante survey types with their best intentions, whereas in reality their actions may be different.

Secondly, a direct evaluation can be carried out by analyzing the extent of co-movement between rainfall variability indicators and key farm performance variables over a specified period of time. This approach avoids the subjectivity of the self-assessment method and is likely to be relatively accurate. However, it requires detailed and accurate data on rainfall variability as well as farm performance indicators over a specified period of time. Direct evaluation of agricultural effects of rainfall variability can involve econometric estimations as in Barrios *et al.* (2004).

In what follows below, some results of this direct evaluation method are presented. However, this section begins with the analysis of rainfall variability in Victorian agricultural regions across time.

4. 1 Analysis of rainfall variability across Victorian agricultural regions

Observation of rainfall variability using the RAI in Figure 1 reveals that between 1898 and approximately 1943, all three regions experienced a relatively stable pattern of rainfall relative to the long term average. From 1943 all regions show evidence of relatively higher variability with pronounced wetting in the Mallee region. When growing season rainfall is considered (Figure 2), there is no substantial difference in the RAI trend over the years compared to that of annual rainfall.

The RAI based on the long-term average for a given year, reveals by what percentage that the rainfall in that year was either higher than or lower than the average. Rainfall in a given year appears to have varied generally, between sixty per cent lower and sixty per cent higher than the long-term average. Out of the three regions, the Mallee exhibits the most profound rainfall variability (8 years with more than +40%, 12 with less than -40%) while the Wimmera shows the least profound (3 years with more than +40%, 5 with less than -40%).

The Mallee region has had a couple of years with less than sixty per cent less than the average, -65% in 1982 and -62% in 1967. The highest rainfalls on record for this region are +106% in 1973, +63% in 1974 and +62% in 1956. The two lowest annual rainfalls for the Wimmera had been -51% in 2006 and -50% in both years 1967 and 1982. The years 1973 and 1974 in the Wimmera have received the highest rainfalls of +67% and +61%, respectively. In the North-central region, the two driest years have been 1982 and 1967 with RAI values of -60% and -54%, respectively. The wettest years in this region so far have been 1973 with +103%, 1956 with +65% and 1974 with +63%.

It is interesting to see that our measure of rainfall variability (RAI) captures the current drought. Both figures 1 and 2 indicate an increasing dry regime relative to the long term average, from 1997 in all regions. Further, the RAI analysis confirms with previous studies (for eg, Botterill and Chapman, 2002; Botterill, 2003a) that droughts are part and parcel of

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[4] It is important to note that studies using this method generally focus on drought management. Meanwhile in this paper, the discussion is carried out in terms of rainfall variability.

life in Australia. Specifically, the so called "federation drought" from 1895-1902 can easily be identified in figure 1 for all three regions. This is also true for the 1937-1945 drought.

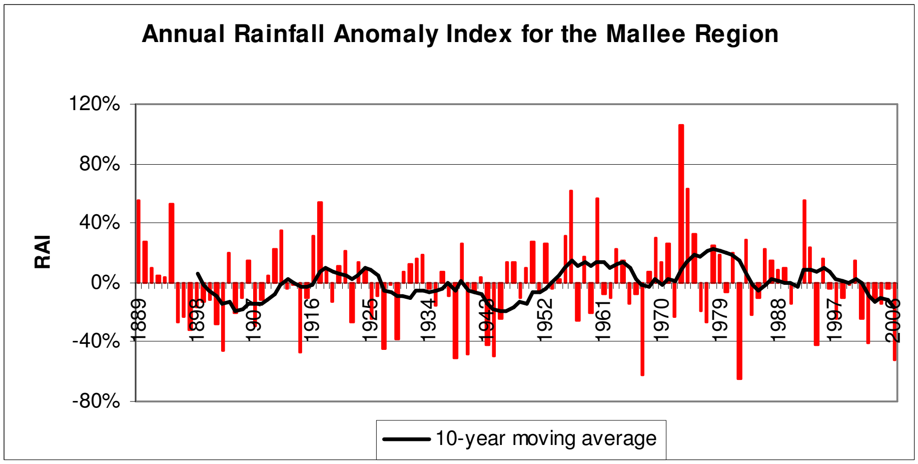
The ten-year moving average line in Figure 1 reveals a completely different perspective to the analysis of droughts. If this medium-term trend line appears close to the long-term average (or the 0% RAI line in Figure 1) in a particular year, this means the ten-year period up to this year is average, overall. This period may consist of single years of dry, wet and average rainfall years, but the cumulative impact on agriculture and hydrology should be neutral. If the ten-year average trend line goes down significantly, down to ten per cent less than the long-term average for example, this may tell you that the cumulative negative impact on agriculture and hydrology may be substantial. If this fallen trend line either moves down further or stays over several years, this negative impact may even be more profound. In addition to agriculture, the hydrology may also be affected by this stage.

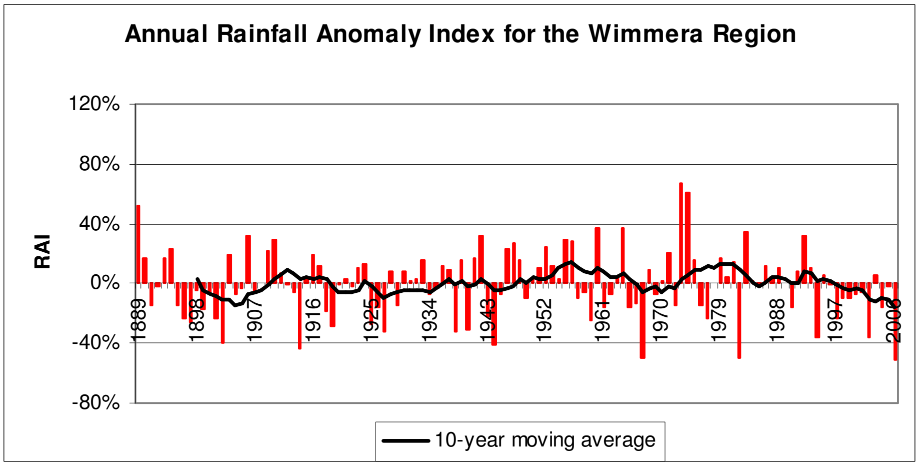
The historical data on rainfall shows that a single year or two of below-average rainfall is obviously a natural part of life. This type of a drought, when the soils are too dry and agricultural production is affected, is generally referred to as an "agricultural drought". If the rainfall across a significant area stays substantially below average for more than a year or two resulting in reduced stream flows and groundwater recharge, an agricultural drought may develop into its next level up, a "hydrological drought" (IWMI, 2005). This stage is reached when the reservoir and groundwater aquifer levels drop.

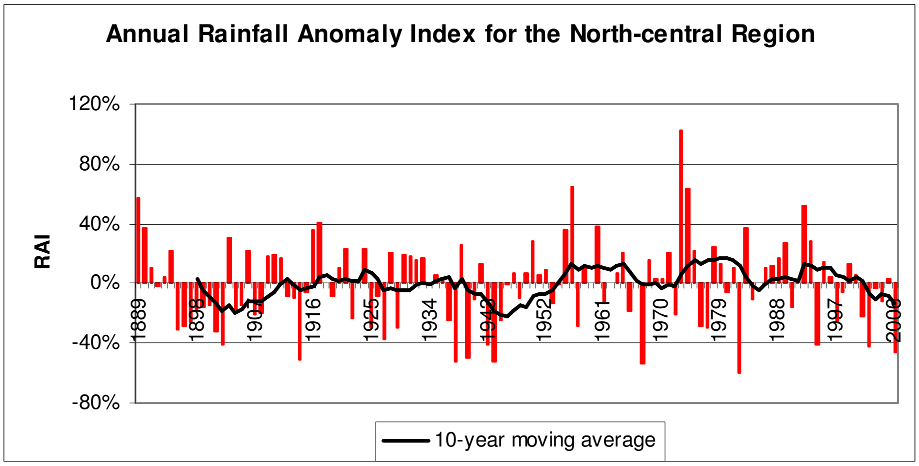
The Mallee region has experienced ten-year average trends of ten per cent or more lower than the long-term average for several consecutive years, twice during the last century. These are an eight year period from 1902 to 1909 and the seven years from 1943 to 1949. A four-year period from 1902 to 1905 has been the only such period for the Wimmera, while 1900 to 1908 and 1943 to 1949 have been similar for the North-central region. The above-mentioned periods of the ten-year average rainfall being consistently and significantly below the long-term average for several years in a row, may have been hydrological droughts. The last five or six years have shown a similar pattern in most of Victoria except in the North-central region (see the trend line in Figure 1).

However, there appears to be a lack of a suitable simple, quantitative measure to determine whether an agricultural drought has progressed into a hydrological drought.

Figure 1: Annual Rainfall Anomaly index for three Regions in Victoria (expressed with respect to the 1889-2006 mean)

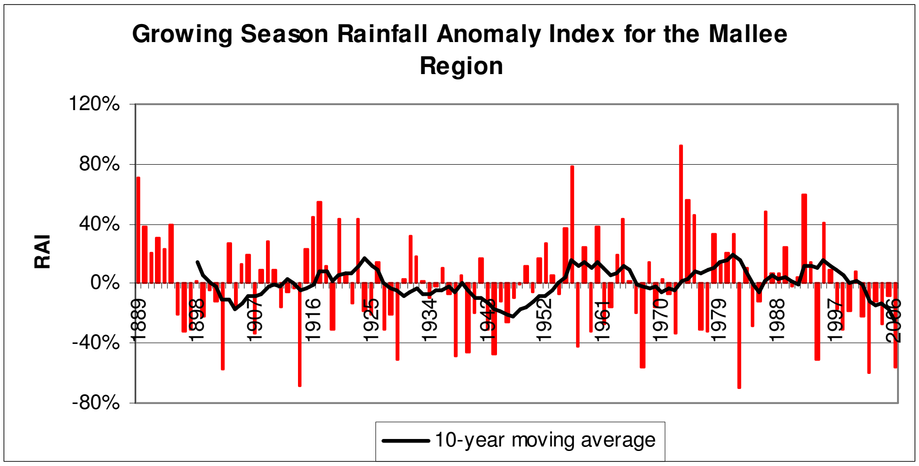


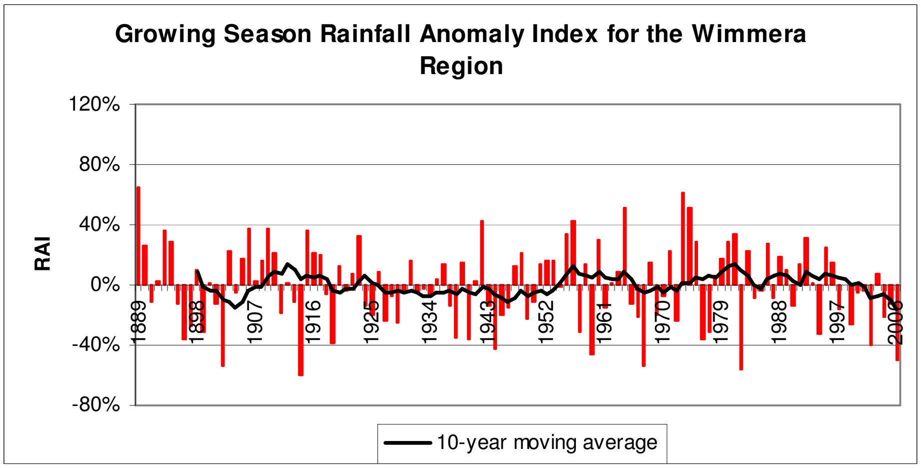


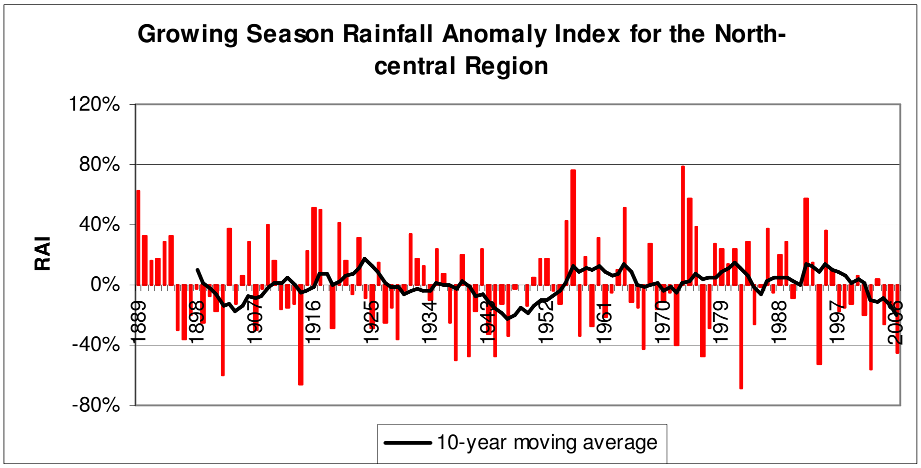


Source: Author's computation

Figure 2: Growing Season Rainfall Anomaly index for three Regions in Victoria (expressed with respect to the 1889-2006 mean)







Source: Authors' computation

4.2 Correlation between rainfall variability and agricultural variables across Victorian cropping regions

4.2.1 Correlations for the Mallee region

The correlation coefficients for the statistical correlation between climate variables and agricultural production and financial parameters for the Mallee region are shown in Table 5. Annual rainfall exhibits a positive, medium to strong correlation with all except three production/financial parameters. These exceptions are areas sown under wheat, barley and total cereals. Total cereals and wheat produced, and farm business profit show strong correlations with annual rainfall.

Table 5: Correlation coefficients for the Mallee region, using data from 1982-83 to 2004-05

Agricultural production / financial variable	Average daily maximum temperature (°C)	Radiation Anomaly Index	Evaporation Anomaly Index	Annual Rainfall (mm)
Cereal area sown (ha)	0.25	0.23	0.19	-0.15
Cereal production (t)	-0.40	-0.47	-0.23	0.60
Total crop gross receipts ($)	-0.36	-0.41	-0.25	0.42
Wheat receipts ($)	-0.15	-0.35	-0.06	0.40
Barley receipts ($)	-0.24	-0.31	0.01	0.39
Farm business profit ($)	-0.40	-0.46	-0.09	0.55
Farm cash income ($)	-0.21	-0.35	0.03	0.41
Wheat produced (t)	-0.35	-0.48	-0.22	0.59
Barley produced (t)	-0.23	-0.30	-0.10	0.46
Wheat area sown (ha)	0.37	0.38	0.28	-0.27
Barley area sown (ha)	0.14	0.10	0.20	0.04

Maximum temperature and radiation appear to show small to medium, but negative correlations with all production/financial parameters, except the areas sown to wheat, barley and total cereals. These two climate variables show a medium, but positive correlation with only wheat area. Evaporation follows approximately the same pattern as the other two climate variables, but the correlations are not that strong. This may be due to the high occurrence of short and long fallow phases between planting crops, which conserve moisture in the soil from previous summer rains.

4.2.2 Correlations for the Wimmera region

Compared to the Mallee region, the results for the Wimmera region (Table 6) show a marked difference with regard to rainfall. Total crop gross receipts and barley produced relate to rainfall only with weak correlations while barley receipts do not show any relationship. Also, barley area sown has got a weak, but negative correlation with rainfall.

Out of other climate variables, maximum temperature and radiation show a similar trend as in the Mallee, with two exceptions. The existing correlations are weaker than in the Mallee, and the barley receipts and produced show no to weak, positive correlations while barley area sown shows medium to strong, positive correlation. Evaporation is negatively correlated to most of the parameters in a stronger manner than in the Mallee. This may be due to the reduced occurrence of fallow phases between crops that conserve soil moisture for crop growth.

Table 6: Correlation coefficients for the Wimmera region, using data from 1982-83 to 2004-05

Agricultural production / financial variable	Average daily maximum temperature (°C)	Radiation Anomaly Index	Evaporation Anomaly Index	Annual Rainfall (mm)
Cereal area sown (ha)	0.21	0.18	-0.03	-0.06
Cereal production (t)	-0.28	-0.23	-0.32	0.54
Total crop gross receipts ($)	-0.11	-0.06	-0.31	0.23
Wheat receipts ($)	-0.26	-0.38	-0.45	0.49
Barley receipts ($)	0.06	0.14	-0.21	0.09
Farm business profit ($)	-0.30	-0.29	-0.25	0.45
Farm cash income ($)	-0.08	-0.08	-0.15	0.27
Wheat produced (t)	-0.37	-0.43	-0.43	0.66
Barley produced (t)	0.07	0.19	-0.16	0.16
Wheat area sown (ha)	0.21	0.05	-0.02	-0.05
Barley area sown (ha)	0.40	0.47	0.03	-0.23

All the parameters with regard to barley in the Wimmera have behaved differently. This behaviour reveals that more barley is sown when the rainfall is relatively low and temperature and radiation are relatively high, basically as a more drought-tollerent crop compared to wheat.

4.2.3 Correlations for the Central North region

The Central North region follows a similar pattern to the Wimmera in general (Table 7), but most of the correlations are weaker than the other two regions. Rainfall shows a medium, positive correlation with only farm business profit and wheat produced. It also shows a medium, negative correlation with cereal area and weak, negative correlations with wheat and barley areas. This may be revealing the problem of water logging in high-rainfall years and some ability of grain-growers in the Central North region to adjust the area cropped unlike in other regions.

Table 7: Correlation coefficients for the Central North region, using data from 1982-83 to 2004-05

Agricultural production / financial variable	Average daily maximum temperature (°C)	Radiation Anomaly Index	Evaporation Anomaly Index	Annual Rainfall (mm)
Cereal area sown (ha)	0.28	0.29	0.11	-0.26
Cereal production (t)	-0.14	-0.08	-0.26	0.23
Total crop gross receipts ($)	-0.20	0.04	-0.18	0.04
Wheat receipts ($)	-0.20	-0.12	-0.16	0.19
Barley receipts ($)	-0.14	0.04	-0.22	0.09
Farm business profit ($)	-0.29	-0.20	-0.19	0.34
Farm cash income ($)	-0.10	0.10	0.01	0.01
Wheat produced (t)	-0.36	-0.31	-0.33	0.39
Barley produced (t)	-0.03	0.13	-0.18	0.08
Wheat area sown (ha)	0.03	-0.01	0.15	-0.13
Barley area sown (ha)	0.22	0.35	-0.02	-0.19

The correlations between other climate variables and production/financial parameters in the region do not differ much from the Wimmera. Medium, negative correlations are seen only between maximum temperature and farm business profit, maximum temperature and wheat produced, radiation and wheat produced, evaporation and wheat produced, and evaporation and cereal production. Both the maximum temperature and radiation are positively correlated with cereal area to a medium degree while radiation also correlates positively to barley area to the same degree.

4.2.4 Correlations between area and production of wheat and barley

Although the amount of grain produced and the area sown are strongly correlated (> 0.7) for barley in all three regions, the same for wheat show only medium correlation (Table 8). This is due to the ability of the barley crop to produce a stable yield throughout the years despite receiving variable rainfall. Wheat yield appears to be less stable than barley in all three regions.

Table 8: Correlations between area and production of wheat and barley

		Barley area sown (ha)	Wheat area sown (ha)
Mallee	Barley produced (t)	0.73	0.12
	Wheat produced (t)	0.32	0.38
Wimmera	Barley produced (t)	0.77	0.22
	Wheat produced (t)	0.17	0.45
Central North	Barley produced (t)	0.84	-0.11
	Wheat produced (t)	0.32	0.46

4.2.5 Summary of correlation results

In summary, variability of annual rainfall over the years on grains farms does have a medium to strong impact on the variability of farm business profit and cereal production, especially wheat production. This relationship however, is relatively weaker in the Central North region. Crop areas are comparatively independent of fluctuations in rainfall and other climate variables, except in the Central North.

Other climate variables used in the analysis generally impacts on agricultural and financial variables in an opposite direction compared to rainfall. There also appears to be some regional differences. Agricultural impacts of rainfall variability are less profound in the Central North. Barley in the Wimmera appears to be used as a relatively drought-tolerant crop. Mallee shows the highest impact of the variability of rainfall as well as the other climate variables. The impact of fluctuating evaporation is less in the Mallee and the Central North is able to adjust its crop areas to some extent.

4.3 Results of the econometric analysis

Table 9, Table 10 and

Table 11 contains results of wheat, barley and cereals production, respectively. For wheat and barley, 9 models were estimated for each crop:

Model 1: Basic model.

Model 2: With cross-sectional fixed effects.

Model 3: With cross-sectional fixed effects and current-year wheat and barley prices.

Model 4: With current-year wheat and barley prices.

Model 5: With lagged wheat and barley prices.

Model 6: With cross-sectional fixed effects and lagged wheat and barley prices.

Model 7: With current-year and lagged wheat and barley prices.

Model 8: With cross-sectional fixed effects, current-year and lagged wheat and barley prices.

Model 9: With cross-sectional fixed effects, current-year and lagged wheat and barley prices and lagged annual rainfall.

For the cereal production model, we estimated the following four models.

Cereal Model 1: Basic model.

Cereal Model 2: Cross-sectional fixed effects.

Cereal Model 3: Lagged rainfall.

Cereal Model 4: Lagged rainfall and cross-sectional fixed effects.

In all models, the following variables were included (i.e. the 'basic model'):

- Annual total rainfall (mm);
- Average maximum temperature (°C);
- Wheat area sown (ha) (for wheat production model only):
- Barley area sown (ha) (for barley production model only);
- Cereals area sown (ha) for cereal production model only);
- Crop and pasture chemicals cost ($);
- Fertilizer cost ($);
- Total closing capital value ($); and
- Annual imputed labour cost ($).

These variables are all basic estimators that form the basis of our models. We also used the following variables in various combinations to investigate specific theories:

- Deflated wheat and barley prices ($/t), current-year and lagged;
- Lagged annual total rainfall (mm); and
- Cross-sectional fixed effects.

Note that we take the log of all variables in the modelling (except for the cross-sectional fixed effects). For this reason, we do not use the RAI because of the presence of negative values. Taking the log of negative values results in an undefined value being returned which in turn reduces the number of usable observations available for estimation. Given this, we use annual rainfall rather than the RAI. Also, note that prices (current-year and lagged) are included in the basic model of the cereals model. Finally, we used cross-sectional fixed effects because we are using a consistent dataset for the Mallee, Wimmera and Central North from the years 1982-83 to 2004-05.

All coefficient estimates will be presented for individual regions. As mentioned before, this is a useful feature of the pooled estimation functions as this allows us to analyse the difference between regional crop production. We will report statistics for goodness of fit, specifically R^2 and adjusted R^2. We report the Akaike information criterion (AIC) to provide comparative information on models' relative explanatory power. Finally, we also present Durbin-Watson statistic to see if serial correlation was a problem in the models.

In the following discussion, we will first provide an overview of the results. Secondly, we discuss the results especially in terms of drought and the ability of dryland crop farmers to cope with climate change. We will first discuss wheat and barley production as there are some similarities that can be discussed jointly. Then we will discuss total cereals production.

4.3.1 Wheat and Barley Production

Starting from the first variable listed in Table 9 and Table 10, annual rainfall is positive and significant at the 90% level for all nine of our specifications for wheat and for eight of nine of the barley specifications. The elasticity of wheat and barley production varies with specification and region. Estimates for wheat production elasticity with regard to annual total rainfall range from less than 1% (model 7) to over 2.8% (model 2) increase in production with a 1% increase in annual rainfall, both results from the Wimmera (Table 9). For barley, elasticity estimates range from less than 0.6% (and insignificant) from the Central North (model 7) to over 4% from the Wimmera (model 2) increase in production for a 1% increase in annual rainfall (Table 10). In terms of regional impacts, it is ambiguous whether wheat in the Wimmera or the Mallee is more sensitive to rainfall variability. For barley, our results do not provide an unambiguous finding on which region is likely to be most affected. However, the key result is that both wheat and barley are sensitive to changes in rainfall and this finding is robust to specification.

The impact of average maximum temperature on wheat and barley production is ambiguous. In specifications where cross-sectional fixed effects were not specified, average maximum temperature was found to be significant and negative (models 1, 4, 5 and 7). However, when cross-sectional fixed effects are included, the average maximum temperature variable was found to be insignificant. This suggests that the average maximum temperature variable is correlated with the fixed effects. One reason may be that the temperature data may be correlated to regional-specific features such as soil type, geographic features or local government policies. As a result, when we include cross-sectional fixed effects to any of the models, average maximum temperature is no longer significant for both wheat and barley production.

Area sown to barley and wheat, like annual rainfall, is expected to be an important determinant of production. Our results support this. For both wheat and barley, all regions and specifications, we find that area sown is significant and positive. Elasticity estimates for wheat range from over 1% in the Wimmera (model 4) to nearly 3.5% (model 3) increase in production with a 1% increase in area sown (Table 9). For barley, elasticity estimates range from less than 1% (model 5) to nearly 1.6% (model 2) increase in production for a 1% increase in area sown to barley (Table 10). To some extent, maintaining area sown to crops may offset a decrease in rainfall.

For the other crop inputs – crop and pasture chemicals, fertilizer, capital and imputed labour cost – these were generally insignificant. However, there was one regional-specific results that may be worth mentioning. Central North barley production appeared to be significantly related to fertilizer cost (positively), capital (negatively) and imputed labour cost (negatively) until lagged prices were included (i.e. models 5 to 9). This may reflect the less specialised nature of Central North broadacre farms relative to the Wimmera and the Mallee, hence the negative estimates for capital and imputed labour. Such regional-specific effects did not appear to diminish when cross-sectional fixed effects were included.

Cross-sectional fixed effects appear to be more important for wheat production than barley production. Specifically, including fixed effects appear to improve the AIC of wheat production models. Conversely, the inclusion of fixed effects actually worsened the AIC unless lagged prices and lagged rainfalls were also included in the models (i.e. models 8 and 9). This may reflect wheat production's sensitivity to local features such as soil type. In particular, cross-sectional fixed effects were significant and negative for the Wimmera in all the models that it was included.

Lagged annual rainfall was only included in model 9 but was found to have generated significant improvement in the AIC, especially for wheat production. Lagged annual rainfall can be seen as a proxy for the amount of retained soil moisture which is an important determinant of production (Alexander and Kokic 2005). For wheat production, estimates for lagged rainfall is positive and significant whereas for barley, it is significant only for the Wimmera region.

Prices and lagged prices for wheat and barley had ambiguous effects on production. These variables were included to improve the model's explanatory power. Current-year wheat prices were significant and positive for wheat production in models 8 and 9 and for models 7-9 for barley production. Lagged wheat prices were significant but negative for wheat and barley production in models 5 to 7. Current-year and lagged barley prices were insignificant for all specifications and both crops. The fact that the elasticity estimates had similar effects for both crops suggests that wheat prices may determine both barley and wheat planting decisions. As such, when farmers observe higher wheat prices, they may expect higher production in the current season so they may rationally anticipate lower prices. As a result, they may reduce plantings of both crops. As such, wheat is the only relevant price. With current-year prices, this may suggest an opportunistic motive which may be supported by the higher sensitivity of wheat and barley producers to lagged wheat prices than current-year prices.

Finally, all models exhibit high goodness of fit of around 0.9. Serial correlation is not a problem as all models' Durbin-Watson statistics approximate to 2.

4.3.2 Cereal Production

The cereal production model generates several different results to the wheat and barley production models. First, annual rainfall is not significant for all regions across specifications. Specifically, the Central North's estimates are not significant in models 1 and 2. This may reflect the possibility that crop farmers in the Central North may use irrigation to water their crops.

Secondly, the elasticity estimates of cereal production to rainfall are usually below 1%. A possible reason may be that crop farmers may switch out of rain-dependent crops to hardier varieties during drought. As a result, overall cereal production is less sensitive because farmers may employ crop selection strategies that minimise the costs of low rainfall years. Another reason for lower elasticitly estimates may be farmers' ability to maximize production in high rainfall years and minimize production losses in low-rainfall years.

Third, cereal area sown is not significant for all model specifications for the Wimmera and the Mallee. However, this variable was significant and positive when lagged rainfall was included. This lack of robustness to specification may be due to the relatively constant amount of land used for cropping in the Wimmera and Mallee. Given that these regions specialize in cropping, variation is unlikely to be significant.

Fourth, imputed labour cost is positive and significant for the Mallee and the Wimmera for all specifications. This may reflect the farmers' ability to manage cereal production given climate risk. Such farmers may have strategies in place to deal with different weather conditions and are able to generate higher cereal production in all types of weather.

In terms of similarities, the most important one to point out is that the average maximum temperature is only significant and negative when cross-sectional fixed effects are not included.

4.3.3 Discussion of econometric results

Our modelling results strongly suggest that Victorian dryland cropping is sensitive to rainfall but not average maximum temperature variability. Area sown is generally important for wheat and barley production but not so important for overall cereal production. Farm inputs (e.g. fertilizer and chemicals) appear to be less important than rainfall.

These results suggest that rainfall is a reasonable measure of dryland crop production. However, the degree of sensitivity to rainfall variability may differ significantly between regions. Also, it is not clear that farmers are not capable of anticipating or managing rainfall variability. For example, total cereal production is less sensitive than wheat or barley production to rainfall, which may suggest analysing crop production by individual crops would overstate the effects of a drought. Farmers may change their crop mix to minimise any expected drought-related losses.

Our results also indicate that Victorian dryland agriculture may be less vulnerable to climate change than previously thought. Specifically, the higher average maximum temperatures expected from climate change may have little or no effect on crop production. However, rainfall variability will continue to pose a threat to dryland cropping if climate change results in lower average rainfall.

Given the clear link between rainfall and wheat and barley production, one way to reduce the impact of rainfall variability on farmers may be to encourage the greater use of weather related insurance or derivatives. At the moment, the market is very small but there are some measures that can be used to lower the cost of weather derivatives in particular. Australia, unlike the US or India, does not have an exchange for weather derivative contracts. This increases the transaction costs of entering a weather derivative contract to levels equivalent to more than the value of most farms' wheat and barley production (i.e. around $1-$2 million). Obviously, such contracts are too expensive for the average farmer. Given the robust link between crops and rainfall, we suggest there is a ready market for rainfall related derivatives or insurance provided the cost of derivative contracts can be reduced.

CONCLUSIONS

Annual rainfall in Victoria could be highly variable over the years. Based on the historical data in general, a given year's rainfall may be anywhere between sixty per cent lower and sixty per cent higher than the long-term average. This variability of rainfall resulting in droughts as well as floods or water-logging, is a natural part of Australian life. Having a dry year or a "drought" is not an exceptional circumstance.

The ten-year moving average trend-line of historical annual rainfall provides a different insight to the above-mentioned rainfall variability. The ten-year average has been persistently less than ten per cent below the long-term average over seven to ten years, at least twice in a century except in the Wimmera region. This is the type of situation that Victoria is experiencing currently. It is this type of a multi-year drought which could be seen as exceptional. This is not only an agricultural drought, but it has developed into a hydrological drought where stream flows, dam levels and even groundwater levels have fallen (IWMI, 2005).

Further research is needed however, to determine the most appropriate indicator for defining a hydrological drought. First, what's the most suitable number of years to calculate the medium-term average of annual rainfall? By what percentage should the multi-year moving average be lower than the long-term average annual rainfall? For how many years should it stay at that level continuously? These are critical factors for defining the demarcation between an agricultural and a hydrological drought.

Dryland cropping in Victoria is sensitive to rainfall variability, but not to the inter-annual variability of average maximum temperature. Rainfall plays a more significant role than other farm inputs. Area under a particular crop is important in determining the production from that crop, but total cereal production appears to be less sensitive to rainfall fluctuations than for individual crop production. This reduced sensitivity at the overall cereals production level may suggest that farmers have, to some extent, been able to anticipate climatic conditions and have adopted their crop mix to reduce vulnerability to rainfall variability. This requires further research to confirm that dryland crop producers are able to adapt to climate variability. If true, this has implications for the design of the National Drought Policy and the future development of agriculture's adaptation to climate change.

Further research may also be required to examine the links between rainfall variability and other agriculture sectors, particularly dairy, beef, sheep and horticulture. As mentioned before, multi-year droughts could proceed from an agricultural drought to a hydrological drought. The latter may have significant implications for irrigation-dependent industries such as horticulture. Understanding how rainfall variability has affected this industry will allow policy-makers to develop policies that support on-farm adaptation effort.

Another important area of research is to analyse the effect of rainfall variability on farm income. As the above correlations show, there is a weak to medium correlation between income variables and climate variables. Understanding why this is the case may help policy-makers improve climate-related agriculture policies to take account of how climate affects farm incomes.

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Table 9: Wheat Production Double Log Models Results, 1982-83 to 2004-05

Variable	Region	1	2	3	4	5	6	7	8	9
Annual Total Rainfall (mm)	Mallee	1.334*** _7.106_	1.676*** _5.424_	1.577*** _5.216_	1.166*** _5.569_	1.354*** _5.922_	1.521*** _4.915_	1.14*** _4.6_	1.388*** _4.852_	1.674*** _6.009_
	Wimmera	1.973*** _6.887_	2.845*** _6.611_	2.536*** _5.781_	1.716*** _5.378_	1.39*** _3.581_	1.963*** _3.944_	0.93** _2.095_	1.403** _2.873_	1.556*** _3.748_
	Central North	1.1606*** _5.352_	1.425*** _4.291_	1.235*** _3.731_	0.991*** _4.159_	0.836** _2.538_	1.01*** _2.829_	0.587* _1.702_	0.712** _2.099_	0.844*** _2.845_
Average Maximum Temperature (°C)	Mallee	-3.9756*** _-2.784_	0.366 _0.105_	1.4 _0.409_	-4.321*** _-3.04_	-3.356** _-2.519_	-0.784 _-0.242_	-3.822*** _-2.871_	1.38 _0.454_	3.008 _1.13_
	Wimmera	-3.768* _-1.766_	4.214 _1.148_	4.033 _1.133_	-3.935* _-1.864_	-4.228* _-1.977_	0.82 _0.232_	-5.005** _-2.352_	0.975 _0.301_	0.504 _0.185_
	Central North	-3.947** _-2.12_	-1.004 _-0.295_	-0.209 _-0.063_	-3.652* _-1.975_	-4.861** _-2.406_	-2.174 _-0.692_	-4.839** _-2.432_	-0.689 _-0.237_	-0.033 _-0.013_
Wheat Area Sown (ha)	Mallee	0.999** _2.352_	0.94** _2.347_	2.771*** _2.771_	1.125** _2.64_	0.794* _1.976_	0.775* _1.952_	0.94** _2.349_	0.967** _2.635_	1.586*** _3.843_
	Wimmera	1.074** _2.776_	1.149*** _3.156_	3.076*** _3.076_	1.051*** _2.728_	1.079*** _3.191_	1.138*** _3.424_	1.053*** _3.161_	1.104*** _3.616_	1.232*** _4.714_
	Central North	0.657* _2.999_	0.718*** _3.352_	3.488*** _3.488_	0.656*** _3.036_	0.783*** _3.935_	0.809*** _3.956_	0.766*** _3.932_	0.798*** _4.276_	0.832*** _5.27_
Crop and Pasture Chemicals ($)	Mallee	-0.03 _-0.18_	-0.1 _-0.608_	0.0479 _0.277_	0.089 _0.486_	-0.113 _-0.705_	-0.134 _-0.822_	0.024 _0.14_	0.052 _0.324_	-0.208 _-1.097_
	Wimmera	-0.037 _-0.165_	-0.334 _-1.39_	-0.071 _-0.275_	0.166 _0.649_	-0.34 _-1.419_	-0.515* _-2.02_	-0.177 _-0.713_	-0.297 _-1.227_	-0.209 _-1.006_
	Central North	0.109 _0.341_	0.208 _0.658_	0.309 _0.998_	0.167 _0.523_	0.274 _0.954_	0.36 _1.193_	0.335 _1.179_	0.51* _1.816_	0.433* _1.766_
Fertilizer ($)	Mallee	0.101 _0.415_	0.085 _0.374_	0.017 _0.077_	0.065 _0.268_	-0.01 _-0.043_	-0.003 _-0.012_	-0.052 _-0.234_	-0.083 _-0.24_	0.424 _1.39_
	Wimmera	0.448 _1.603_	0.735** _2.582_	0.523* _1.806_	0.281 _0.958_	0.433* _1.71_	0.621** _2.315_	0.252 _0.954_	0.386 _1.51_	0.266 _1.209_
	Central North	0.425 _0.998_	0.221 _0.495_	0.308 _0.712_	0.513 _1.214_	-0.174 _-0.37_	-0.41 _-0.751_	-0.092 _-0.199_	-0.403 _-0.81_	-0.233 _-0.536_
Total Closing Capital Value ($)	Mallee	-0.28 _-0.613_	-0.291 _-0.68_	-0.257 _-0.622_	-0.255 _-0.566_	-0.164 _-0.381_	-0.153 _-0.364_	-0.132 _-0.313_	-0.092 _-0.24_	-0.643 _-1.563_
	Wimmera	-0.445 _-1.272_	-0.516 _-1.567_	-0.462 _-1.447_	-0.417 _-1.2_	-0.348 _-1.096_	-0.363 _-1.166_	-0.252 _-0.803_	-0.206 _-0.715_	-0.135 _-0.55_

Variable	Region	1	2	3	4	5	6	7	8	9
	Central North	0.086 *0.191*	0.079 *0.187*	0.049 *0.12*	0.063 *0.142*	0.377 *0.783*	0.538 *1.114*	0.414 *0.878*	0.668 *1.507*	0.547 *1.457*
Imputed Labour Cost ($)	Mallee	0.785 *1.239*	1.087 *1.712*	0.697 *1.087*	0.454 *0.674*	1.019* *1.696*	1.163* *1.874*	0.645 *1.035*	0.739 *1.262*	0.546 *1.1*
	Wimmera	0.217 *0.304*	0.542 *0.796*	0.237 *0.352*	0.002 *0.002*	1.129 *1.547*	1.341* *1.853*	1.093 *1.525*	1.325* *1.999*	1.627*** *2.86*
	Central North	0.126 *0.292*	0.499 *0.909*	-0.072 *-0.121*	-0.315 *-0.602*	0.834 *1.491*	1.302* *1.75*	0.374 *0.623*	0.791 *1.128*	0.649 *1.088*
Cross-sectional Fixed Effects	Mallee		-17.526 *-1.347*	-23.204* *-1.803*			-11.827 *-0.945*		-24.126* *-2*	-29.809*** *-2.811*
	Wimmera		-32.48** *-2.594*	-32.868** *-2.692*			-22.748* *-1.822*		-29.386** *-2.532*	-37.039*** *-3.571*
	Central North		-13.707 *-1.008*	-15.414 *-1.17*			-16.502 *-1.204*		-24.931* *-1.951*	-26.848** *-2.472*
Lagged Annual Rainfall (mm)	Mallee									0.592** *2.186*
	Wimmera									0.742*** *3.217*
	Central North									0.343** *2.264*
Wheat Price ($/t)					0.592 *1.466*	0.671 1.535			0.617 *1.494*	0.881** *2.27*
Barley Price ($/t)					0.366 *0.768*	0.021 0.042			0.172 *0.385*	0.4 *0.967*
Lagged Wheat Prices ($/t)							-1.195*** *-3.319*	-0.772* *-1.919*	-0.962** *-2.571*	-0.219 *-0.535*
Lagged Barley Prices ($/t)							0.642 *1.349*	0.458 *0.959*	0.454 *0.956*	0.079 *0.174*
Summary Statistics										
R2		0.919	0.919	0.933	0.94	0.924	0.933	0.941	0.94	0.953
Adjusted R2		0.885	0.885	0.899	0.906	0.888	0.9	0.904	0.904	0.92
Akaike information criterion		0.533	0.533	0.427	0.369	0.521	0.281	0.257	0.249	0.083
Durbin-Watson statistic		2.2	2.2	2.313	2.111	1.969	2.157	2.308	1.935	2.008

Note: T-statistics in italics. '***' denotes significance at the 99% level, '**' denotes significance at 95% level and '*' denotes significance at 90% level.

Table 10: Barley Production Double Log Models Results, 1982-83 to 2004-05

Variable	Region	1	2	3	4	5	6	7	8	9
Annual Total Rainfall (mm)	Mallee	1.1*** *3.741*	1.561*** *2.958*	1.491*** *2.766*	0.95*** *2.789*	1.39*** *5.753*	1.573*** *4.368*	1.062*** *3.931*	1.375*** *4.143*	1.1*** *3.741*
	Wimmera	3.571*** *7.839*	4.141*** *5.553*	3.891*** *4.886*	3.351*** *6.433*	1.761*** *3.967*	1.965*** *3.321*	1.151** *2.309*	1.239** *2.135*	3.571*** *7.839*
	Central North	2.725*** *7.534*	2.566*** *4.654*	2.4*** *4.174*	2.559*** *6.268*	0.931** *2.418*	1.087** *2.565*	0.588 *1.477*	0.715* *1.786*	2.725*** *7.534*
Average Maximum Temperature (°C)	Mallee	-5.191** *-2.199*	0.696 *0.115*	1.783 *0.289*	-5.521** *-2.283*	-3.856** *-2.444*	-1.253 *-0.321*	-4.696*** *-3.011*	1.45 *0.398*	-5.191** *-2.199*
	Wimmera	-2.494 *-0.66*	3.153 *0.453*	2.662 *0.379*	-3.018 *-0.779*	-4.158 *-1.549*	-2.489 *-0.553*	-5.772** *-2.161*	-3.62 *-0.885*	-2.494 *-0.66*
	Central North	3.567 *1.25*	1.746 *0.315*	2.674 *0.474*	3.92 *1.347*	-3.462 *-1.54*	-1.014 *-0.287*	-3.377 *-1.554*	1.12 *0.343*	3.567 *1.25*
Barley Area Sown (ha)	Mallee	1.17** *2.614*	1.114** *2.453*	1.217*** *2.612*	1.255*** *2.708*	1.078*** *3.827*	1.068*** *3.709*	1.203*** *4.316*	1.237*** *4.617*	1.17** *2.614*
	Wimmera	1.35** *2.533*	1.22** *2.202*	1.348** *2.368*	1.445** *2.615*	0.769** *2.167*	0.787** *2.149*	0.952** *2.689*	1.097*** *3.153*	1.35** *2.533*
	Central North	1.542*** *5.695*	1.57*** *5.557*	1.561*** *5.354*	1.533*** *5.46*	1.245*** *6.874*	1.227*** *6.446*	1.2439*** *7.02*	1.226*** *6.966*	1.542*** *5.695*
Crop and Pasture Chemicals ($)	Mallee	0.073 *0.309*	-0.026 *-0.102*	0.132 *0.452*	0.215 *0.758*	0.06 *0.341*	0.027 *0.147*	0.259 *1.365*	0.271 *1.463*	0.073 *0.309*
	Wimmera	0.225 *0.317*	0.176 *0.246*	0.274 *0.373*	0.314 *0.43*	0.174 *0.361*	0.097 *0.196*	0.193 *0.414*	0.042 *0.094*	0.225 *0.317*
	Central North	-0.827 *-1.648*	-0.885 *-1.675*	-0.766 *-1.41*	-0.742 *-1.436*	-0.319 *-0.985*	-0.24 *-0.689*	-0.212 *-0.676*	-0.029 *-0.092*	-0.827 *-1.648*
Fertilizer ($)	Mallee	-0.023 *-0.052*	-0.008 *-0.017*	-0.155 *-0.337*	-0.134 *-0.292*	0.000 *0.001*	0.008 *0.03*	-0.153 *-0.548*	-0.215 *-0.802*	-0.023 *-0.052*
	Wimmera	0.594 *1.266*	0.742 *1.492*	0.597 *1.144*	0.471 *0.951*	0.33 1.075	0.4 *1.21*	0.142 *0.463*	0.185 *0.603*	0.594 *1.266*
	Central North	2.287*** *3.447*	2.411*** *3.244*	2.473*** *3.298*	2.358*** *3.49*	0.4 *0.768*	0.166 *0.268*	0.498 *0.989*	0.144 *0.258*	2.287*** *3.447*
Total Closing Capital Value ($)	Mallee	-0.396 *-0.827*	-0.484 *-0.988*	-0.323 *-0.63*	-0.254 *-0.5*	-0.513 *-1.668*	-0.531 *-1.682*	-0.279 *-0.893*	-0.218 *-0.724*	-0.396 *-0.827*
	Wimmera	-0.595 *-1.581*	-0.614 *-1.617*	-0.599 *-1.564*	-0.581 *-1.526*	-0.183 *-0.708*	-0.164 *-0.622*	-0.07 *-0.277*	0.022 *0.091*	-0.595 *-1.581*
	Central	-2.031***	-2.068***	-2.09***	-2.054***	-0.127	0.043	-0.096	0.217	0.17

Variable	Region	1	2	3	4	5	6	7	8	9
	North	_-3.037_	_-3.036_	_-3.05_	_-3.031_	_-0.242_	_0.076_	_-0.188_	_0.416_	_0.334_
Imputed Labour Cost ($)	Mallee	1.351 _1.446_	1.786* _1.736_	1.328 _1.203_	0.918 _0.873_	1.306* _1.964_	1.478** _2.043_	0.741 _1.075_	0.899 _1.32_	0.817 _1.209_
	Wimmera	-1.353 _-1.057_	-1.308 _-1.013_	-1.438 _-1.1_	-1.463 _-1.124_	0.456 _0.505_	0.543 _0.588_	0.608 _0.698_	0.85 _1.012_	0.987 _1.197_
	Central North	-1.326* _-1.921_	-1.564 _-1.679_	-2.12** _-2.024_	-1.802** _-2.092_	0.879 _1.381_	1.337 _1.562_	0.239 _0.353_	0.726 _0.903_	0.536 _0.677_
Cross-sectional Fixed Effects	Mallee		-23.481 _-1.055_	-29.42 _-1.282_			-11.38 _-0.766_		-28.121 _-1.952_	-26.403* _-1.817_
	Wimmera		-21.34 _-0.97_	-22.231 _-0.997_			-8.41 _-0.563_		-15.44 _-1.124_	-24.6* _-1.73_
	Central North		8.846 _0.384_	6.582 _0.283_			-14.995 _-0.9352_		-27.192* _-1.815_	-27.945* _-1.885_
Lagged Annual Rainfall (mm)	Mallee									-0.055 _-0.192_
	Wimmera									0.662** _2.114_
	Central North									0.154 _0.745_
Wheat Price ($/t)					0.223 _0.304_	0.259 _0.357_			0.79* _1.699_	1.094** _2.369_
Barley Price ($/t)					0.721 _0.823_	0.468 _0.547_			0.306 _0.59_	0.548 _1.076_
Lagged Wheat Prices ($/t)							-1.663*** _-3.631_	-1.402** _-2.702_	-1.289*** _-2.757_	-0.582 _-1.095_
Lagged Barley Prices ($/t)							1.074* _1.897_	0.964 _1.654_	0.76 _1.349_	0.388 _0.693_
Summary Statistics										
R2		0.929	0.929	0.932	0.934	0.93	0.955	0.956	0.96	0.966
Adjusted R2		0.899	0.899	0.897	0.896	0.897	0.931	0.929	0.937	0.942
Akaike information criterion		1.461	1.461	1.5	1.525	1.5	0.547	0.6	0.48	0.41
Durbin-Watson statistic		2.079	2.079	2.175	2.114	2.014	2.297	2.435	2.066	2.265

Note: T-statistics in italics. ‘***’ denotes significance at the 99% level, ‘**’ denotes significance at 95% level and ‘*’ denotes significance at 90% level.

Table 11: Cereal Production Double Log Model Results, 1982-83 to 2004-05

Variable	Region	1	2	3	4
Annual Total Rainfall (mm)	Mallee	0.914*** *4.597*	0.987*** *3.768*	0.96*** *5.056*	1.282*** *4.897*
	Wimmera	0.716* *1.783*	0.819* *1.836*	0.716* *1.876*	0.861** *2.177*
	Central North	0.373 *1.302*	0.483 *1.565*	0.537* *1.889*	0.645** *2.235*
Average Maximum Temperature (°C)	Mallee	-3.028** *-2.063*	-1.32 *-0.477*	-3.534** *-2.473*	1.155 *0.443*
	Wimmera	-4.313** *-2.326*	-2.126 *-0.707*	-5.328*** *-2.771*	-2.186 *-0.825*
	Central North	-3.945** *-2.445*	-1.252 *-0.502*	-3.616** *-2.361*	-0.455 *-0.204*
Cereal Area Sown (ha)	Mallee	0.535 *1.508*	0.672 *1.65*	0.822** *2.277*	1.372*** *3.123*
	Wimmera	0.774 *1.354*	1.036 *1.543*	0.927* *1.688*	1.371** *2.289*
	Central North	0.838*** *3.762*	0.875*** *3.904*	1.017*** *4.433*	1.106*** *5.104*
Crop and Pasture Chemicals ($)	Mallee	0.023 *0.155*	0.02 *0.128*	-0.143 *-0.865*	-0.289 *-1.564*
	Wimmera	0.113 *0.535*	0.091 *0.415*	0.166 *0.797*	0.159 *0.806*
	Central North	0.279 *1.4*	0.376* *1.8*	0.2 *1.01*	0.316 *1.663*
Fertilizer ($)	Mallee	-0.115 *-0.652*	-0.135 *-0.762*	0.151 *0.643*	0.255 *1.092*
	Wimmera	-0.036 *-0.158*	-0.02 *-0.086*	-0.126 *-0.557*	-0.137 *-0.648*
	Central North	-0.139 *-0.381*	-0.39 *-0.946*	-0.027 *-0.074*	-0.279 *-0.749*
Total Closing Capital Value ($)	Mallee	-0.019 *-0.07*	-0.048 *-0.17*	-0.18 *-0.677*	-0.4 *-1.416*
	Wimmera	-0.051 *-0.137*	-0.162 *-0.384*	-0.08 *-0.217*	-0.25 *-0.668*
	Central	0.435	0.591	0.214	0.345

Variable	Region	1	2	3	4
	North	*1.076*	*1.411*	*0.536*	*0.905*
Imputed Labour Cost ($)	Mallee	1.095** *2.107*	1.171** *2.11*	0.934* *1.873*	1.184** *2.415*
	Wimmera	1.137* *1.938*	1.256** *2.08*	1.263** *2.262*	1.481*** *2.741*
	Central North	0.478 *0.932*	0.866 *1.393*	0.365 *0.707*	0.681 *1.224*
Cross-sectional Fixed Effects	Mallee		-9.653 *-0.773*		-27.242** *-2.102*
	Wimmera		-12.256 *-1.008*		-19.588* *-1.727*
	Central North		-16.033 *-1.432*		-18.324* *-1.826*
Lagged Annual Rainfall (mm)	Mallee			0.388* *1.825*	0.596** *2.534*
	Wimmera			0.4* *1.808*	0.521** *2.387*
	Central North			0.272 *1.642*	0.32** *2.043*
Wheat Price ($/t)		0.153 *0.445*	0.153 *0.445*	0.305 *0.854*	-0.037 *-0.111*
Barley Price ($/t)		0.455 *1.227*	0.455 *1.227*	0.541 *1.426*	0.708* *1.907*
Lagged Wheat Prices ($/t)		-0.887*** *-2.867*	-0.887*** *-2.867*	-0.56 *-1.519*	-1.275*** *-3.934*
Lagged Barley Prices ($/t)		0.385 *0.96*	0.385 *0.96*	0.152 *0.356*	0.37 *0.972*
Summary Statistics					
R2		0.945	0.949	0.954	0.964
Adjusted R2		0.913	0.913	0.922	0.932
Akaike information criterion		-0.131	-0.115	-0.227	-0.36
Durbin-Watson statistic		2.153	2.288	1.806	2.14

Note: T-statistics in italics. '***' denotes significance at the 99% level, '**' denotes significance at 95% level and '*' denotes significance at 90% level.