Economics of Weather Risk Management Using Climate Prediction Models

Amy Cheung and Tiho Ancev, University of Sydney

Abstract

Considerable uncertainties, especially those relating to the weather, are present among Australian grazing enterprises. Existing climate prediction tools are not being used effectively in aiding farmers to decide the optimal stocking rate and the levels of other management variables on their pastures. The paper aims to link a biophysical climate simulation model, Aussie GRASS, with an economic model of farm decision making under uncertainty. This model will be used to analyse farmers' behaviour with respect to weather risk, and to derive optimal pasture management options that result in profitable and sustainable natural resource management on a farm level.

Keywords

Grazing management, production uncertainty, weather risk

---

1. Introduction

Australian grazing enterprises are subject to severe uncertainties, especially regarding the future weather conditions. In a benchmarking survey reported in Paull *et al* (2001), only 37% of participants were currently using seasonal climate forecast in decision making. It was recognised that graziers are not making the fullest use of their valuable rainfall records, and other climate records. A total of 75% of participants do not currently use long-term climatic records to assist in decision making. It was also recognised that the farming community have some reservations about product accuracy and forecasting ability of climate prediction tools.

The survey concluded that, future extensions for the Aussie GRASS project, should recognise the need to provide more customized decision-support information, and the need for Aussie GRASS outputs to be continually linked with related information products/tools in order to make the best management decisions (Paull *et al* 2001).

In the light of these findings, this paper aims to link this biophysical climate simulation model, Aussie GRASS, with an economic model of farm decision making under uncertainty. This will require the use of Aussie GRASS pasture growth output as an input, to produce information regarding the "optimal" stocking rate. This model will be used to analyse farmers' behaviour with respect to weather risk, and to derive optimal pasture management options that result in profitable and sustainable natural resource management on a farm level. This will enable the determination of economic gains from a risky enterprise (grazing) by the alteration of farmer behaviour through the use of an existing climate prediction model.

If profit maximising graziers have perfect knowledge of the weather state for the forthcoming seasons, they will be able to determine the level of pasture growth for the different rainfall levels, and thus, hold the optimum number of livestock in the current season to prepare for the following seasons. The optimal stocking decision refers to a profit maximising livestock quantity subject to fixed pasture size, labour supply, and land degradation considerations. That is, a stocking rate that would ensure long-term viability of the industry, at the same time yielding the highest returns to graziers[1].

In practice, graziers are not certain of the future weather condition. Grazing operations in Australian rangeland are characterised by extreme climate variability. As a result, grazing operations typically involve a significant level of weather uncertainty and subsequent risk. Graziers need advance warning on extreme weather conditions to plan their daily activities, and seasonal outlooks to plan their management strategies such as reducing the stocking rate on an area of pasture. A thorough understanding of the risks faced by graziers and the ability to manage those risks not only has the potential to increase profits in the short run but also to improve the viability of the grazing operation in the long run (ABARE 1998).

Graziers are typically exposed to two types of risk[2]. The first type concerns commodity marketing. This comprises commodity trade and price fluctuations, or “price risks”, that reflects the market dynamics in both the domestic and international markets. The second type is the production or supply-side risk that is affected by the level of pasture growth. Naturally, this type of risk may be better known as “weather risk” as it reflects the weather variability that results in major climatic extremities that result in significant economic and environmental damages. According to ABARE (1998) it is likely that much of the production risk throughout Australia can be attributed in some way to the El Nino Southern Oscillation (ENSO). ENSO has a direct effect on Australian soil moisture level and therefore, pasture growth. Indirectly, climatic extremities can lead to pest and parasites infestation and disease outbreaks.

Consequently, there are substantial costs associated with managerial decisions based on uncertain weather predictions. The phenomenon of global climatic change implies that past weather records may not be a reliable source to predict the future (Henry *et al.* 2004). This results in a loss in efficiency in the production process.

[1] Note that it is possible that the (long-term) profit maximising output is not consistent with long-term sustainability. It will, naturally, depend on the discount rate.

[2] For simplicity we will only consider two types of risk. Graziers do have their own specific risk(s) – but they cancel each other out if we consider the case at an industry level.

2. Aussie GRASS, pasture growth and stocking decision

In response to uncertain weather conditions, various tools, including financial instruments or specific climate prediction models, have been developed and tailored for tactical decision-making to ensure the smoothing of farm income over good and bad seasons. They include hedging using options and futures for farm commodities, weather derivatives and agricultural insurances, where available, and of particular interest to this paper, biophysical climate prediction tools, such as Rainman and Aussie GRASS.

Aussie GRASS (The Australian Grassland and Rangeland Assessment by Spatial Simulation) is a national biophysical modelling framework. Over the last decade, this modelling framework has operationally provided simulations of biophysical indicators of the grazed resource, enabling assessment of current pasture and soil moisture relative to historical conditions, and outlooks for the season ahead (Henry *et al.* 2004). Much of the impetus for the development of Aussie GRASS arose in response to the need for accurate near-real time data in order to make timely management decisions (CVAP 2004). Aussie GRASS delivers a range of client-focused products for resource managers to make more effective decisions, especially regarding drought and land degradation risk. The power of this simulation approach is the ability to see the trend, and accurately place the current situation in its historical context (CVAP 2004).

Efficient utilisation of timely forecasts by climate prediction tools enables graziers to set more economically viable production objectives. These objectives include: the provision of income flow after an extended drought, the ability to better plan their marketing activities - for example, to handle and transport various production levels, or the ability to exploit expected future livestock prices; and to adopt more sustainable farm practices through determination of pasture growth levels and thus, the optimal stocking rates in the livestock industry.

3. The grazing problem

The need for a good forecast framework becomes apparent when we compare the flexibility of graziers' management decisions to those of crop farmers. Graziers generally have a less flexible management plan than a typical crop farmer. For example, while it is possible for crop farmers to plant a crop almost immediately after a wet season, a grazier's breeding stocks requires time to be re-established. Graziers, therefore, have a tendency to hang on to their breeding stock to prepare for a (hopefully) wet season after a dry season[3]. If the drought continues, then significant economic costs will result from the loss of years of breeding decisions when their breeding stocks are scattered[4] [5]. Hence

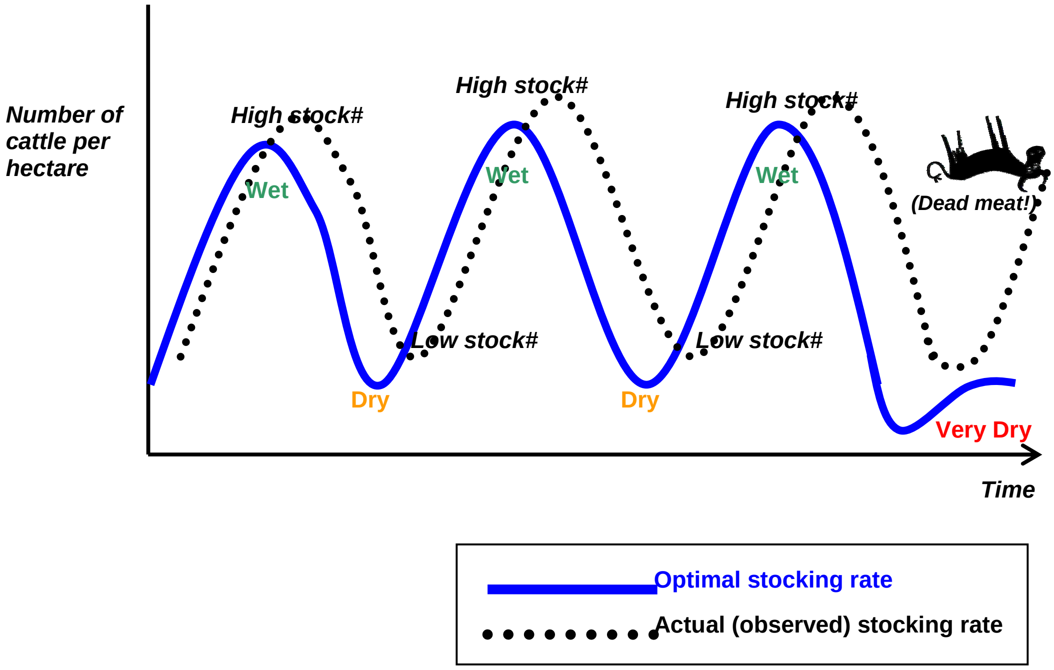
[3] Note that, hanging on to a high stock in expectations for a wet season has been found to be a worthwhile risk to take because if graziers do not take full advantage of the coming wet season then they are at risk of bankruptcy if the dry season persists.

[4] This issue has become a major concern in terms of compensation payouts under the current National Drought Policy (O'Meagher 2003).

[5] Note also that graziers tend to hold on to their stocks through the drought is because (a) selling stock during a drought usually yields a low price due to a large supply and lack of demand for stock in a drought times, and (b) livestock price tends to be much higher after a drought and (c) they want better control over the purity of the breeding stocks.

graziers have the problem of suboptimal stocking rate. *Figure 1* is an illustration of the problem.

Figure 1: Deviation between the optimal stocking rate and the actual (observed) stocking rate



There appears to be a deviation between the optimal stocking rate and the observed or actual stocking rate (Kokic *et al* 2004). The uncertainty of weather conditions is reflected through graziers understocking when weather conditions are favourable (for example, during wet years where there is an abundance of pasture feed), and overstocking during less favourable years with below-average rainfall.

Consequence from an overgrazed pasture from overstocking include a shortage or no standing forage later in the season, a reduction in the better pasture grass varieties, soil erosion and dust storms, and possible contribution to future degradation episodes[6]. Note that degraded land may not necessarily regenerate. As a result, overstocking may result in loss of capital grazing pasture thereby reducing future revenue. On the other hand, understocking results in lost revenues, an abundance of mature forage through the season will result in old pasture of poor quality and unpalatable to stock later in the season. Therefore, it is important to stock pasture optimally to efficiently utilise available feed but not overgraze.

The emerging question is, why does the stocking sub-optimality problem persists even with advancements in climate prediction technology? As addressed in past literature such as Hammer (2004), Henry *et al* (2004), and Kokic *et al* (2004), existing climate

[6] See Henry *et al* (2004) and McKeon *et al* (2004) for further information on degradation episodes.

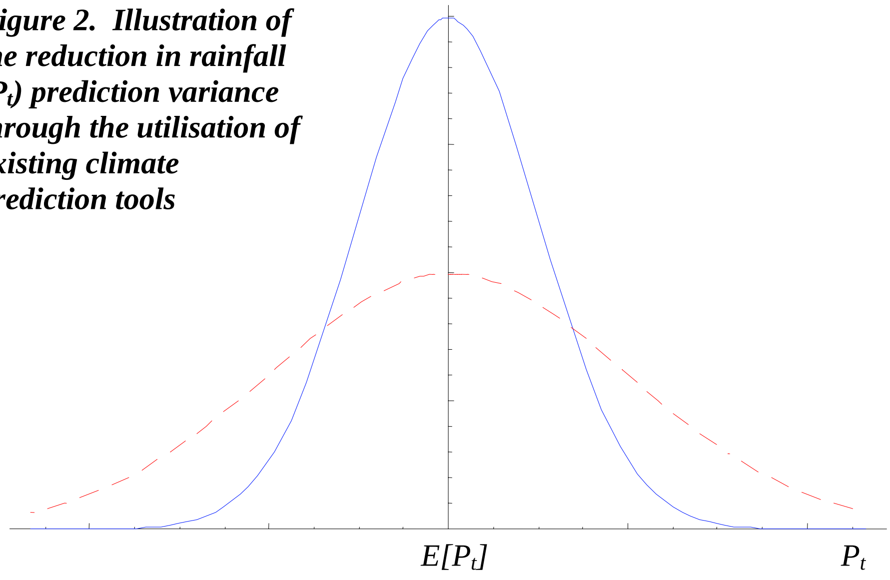
prediction tools have not achieved maximum effectiveness in aiding farmers to decide the optimal stocking rate and the levels of other management variables on their pastures. Henry (2004) suggested that there is scope to increase acceptance of the need to incorporate weather uncertainties into decision making, and to improve the quality of the information for management and policy making. In addition, Kokic et al (2004) suggested the need to incorporate considerations of both livestock production and pasture growth in farm decision making. Previously the focus has been primarily on pasture growth and considerations of animal livestock production have been largely neglected. What is needed in the future modeling efforts is incorporating the two models, an economic model of decision making, and a biophysical simulation model of climate prediction.

4. Theory and model

Biophysical models are models that utilise the theory and principles of physics and chemistry and methods of mathematical analysis and computer modelling to examine the mechanisms of biological systems. Economic models are models that utilise the theory and principles of economics to examine the mechanisms of the economic systems.

In essence, climate prediction models provide a greater level of certainty about future realised climate variables. This can be envisaged as a variance reduction of the prediction. *Figure 2* is an illustration of the reduction in the variance of rainfall prediction through the utilisation of the climate prediction tools.

Figure 2. Illustration of the reduction in rainfall (P_t) prediction variance through the utilisation of existing climate prediction tools



- - - - - Distribution of rainfall without climate prediction tool
——— Distribution of rainfall with climate prediction tool

Precipitation is an important variable in every farm analysis. However, according to Paull *et al* (2001), while precipitation explains only 40% of pasture growth variation, models of soil water and pasture growth explained 50-70% of observed variation. So using pasture growth as an input instead of solely precipitation provides a more accurate simulation.

If we let precipitation P be a continuous random variable with some unknown distribution $P \sim D(\mu, \sigma_p^2)$, pasture growth G, which depends on precipitation, will also follow a similar distribution $G \sim D(\psi, \sigma_g^2)$.

We assumed the aim of the grazing entrepreneur is to maximise profit. The objective function is to maximise profit π over time interval t. This is essentially the difference of the total revenue and total cost of stocking cattle over the choice of the stocking rate per hectare q_t. Hence we have the profit maximisation as:

$$Max_{q_t} \pi = Max_{q_t} \int e^{-rt} E[\pi] t dt \qquad (1)$$

Where π is total profit, maximised over q_t, and r is the discount rate. The expected profit may be defined as:

$$E[\pi] = p_t y_t - C(q_t) \qquad (2)$$

Where y_t is liveweight (kg) per hectare, p_t is price of cattle per cent (c) assumed to be exogenous, and C is the associated cost with stocking q cattle. Hence at this point the expected value will be evaluated.

y_t here is a function of q_t and G_t. Pasture growth G_t is given in kilograms of dry matter per hectare at time t:

$$y_t = \psi(G_t, q_t) \qquad (3)$$

Essentially y_t is:

$$y_t = G_t q_t V \qquad (4)$$

Where V is some conversion rate from pasture biomass to cattle liveweight.

Because pasture growth is a function of rainfall, we need a link between G_t and rainfall P_t:

$$G_t = f(P_t, ...) \qquad (5)$$

G_t is the calculated pasture growth by Aussie GRASS. It is an evaluation of how good or bad the seasonal conditions have been for pasture growth. It is a function of soil moisture S_t , and land degradation L_t , plus other factors γ_t . Thus:

$$G_t = g(S_t, L_t, \gamma_t) \tag{6}$$

G_t does not account the feed carried over from the previous year, or feed consumed. Therefore, it may not reflect the current existing feed reserves $\sum_{n=1}^{t} G_{t-n}$.

Stocking rate at time *t*, q_t , is a function of expected pasture growth at time ***t***, and expected precipitation P_t at time *t*:

$$q_t = \varphi\left(E\left[G_t\right], E\left[P_t\right]\right) \tag{7}$$

Using (6) we can obtain:

$$q_t = \varphi\left(E\left[g(S_t, L_t, \gamma_t)\right], E\left[P_t\right]\right) \tag{8}$$

Soil moisture S_t , is of course, some function of precipitation P_t :

$$S_t = s(P_t) \tag{9}$$

Note that, even under high precipitation, a profit maximising agent may not want to stock the maximum level of stock. Reasons for this behaviour include demand constraints, soil moisture constraints (i.e. growth optimality constraint), and environmental considerations, such that preserving a piece of grazing land in the first period would perhaps help to maximise profit in the subsequent period.

5. Methodology

A methodology for analysing the economics of weather risk using climate prediction models is presented as follow. The calculation procedure is based on the premise of risk neutrality in grazing. Hence at this point only the expected value of the profit will be computed.

The study will aim to compute expected profit from 1996 to 2004. For the computation of expected value we require data from three sources. They include expected pasture growth as produced by the simulation biophysical model Aussie GRASS, general rainfall predictions, and the actual recorded rainfall from Bureau of Meteorology (BoM), and observed data commodity prices (ABARE).

The study will simulate profit from two scenarios:

Scenario A involve graziers using own daily rainfall record and the general BoM forecast. This scenario will require predicted rainfall, observed rainfall, and commodity prices. The outcome will be simulated profit outcome without using Aussie GRASS as an aid in farm decision making.

Scenario B involves graziers using Aussie GRASS in farm decision making. This scenario requires simulated expected pasture growth output by Aussie GRASS, and commodity prices. The outcome will be simulated profit outcome from the adaptation of Aussie GRASS in stocking decisions. Note that, simulation from Aussie GRASS will facilitate grazing management decision to reduce future degradation risk.

6. Policy implications and Conclusions

Policy direction will be dependent of the significance in adopting a new simulation system in grazing decision making.

If potential improvement from the use of Aussie GRASS is found to be significant, then policy should be directed to encourage the use of this climate prediction model in farm decision making. This can be implemented through community workshops, subsidised use of models, and improve accessibility by upgrading the telecommunications infrastructure as required in remote areas and increase the user-friendliness of the simulation system. This reflects the current drought policy which encourages farmers to assume greater responsibility in drought management, rather than relying on relief packages.

If improvement is found to be insignificant then there is a need to understand why. Is it due to the cost of acquiring new technology; is it an issue of reliability of simulation systems, discount rate and graziers' attitude, and understanding the tradeoff between degradation issues and profit maximisation objectives? Either way the result will be of interest to the rural community, researchers, and policymakers.

[*Work in progress*]

7. REFERENCE

ABARE 1998, *Seasonal Climate Variability and Agricultural Yield Forecasting: Occasional paper CV01/98 - Climate Variability Series*, Land and Water Resources Research and Development Corporation, Canberra.

CVAP 2004, http://www.cvap.gov.au/climag5.html

Hammer, G. 2004, 'Economic applications of seasonal climate forecasting at farm level', *Outlook 2004 Speaker Papers*, Canberra

Henry, B. *et al.* 2004, 'Management of climate variability in extensive grazing systems', *Outlook 2004 Speaker Papers*, Canberra.

Kokic, P. *et al.* 2004, 'An enhanced ABARE system for predicting farm performance', *ABARE eReport 04.6*, Canberra.

Mckeon, G., et al 2004, 'Pasture degradation and recovery in Australia's rangelands: Learning from history, Natural Resource Science, Queensland Department of Natural Resources, Mine and Energy, Queensland.

O'Meagher, B. 2003, 'Economic aspects of drought and drought policy', in L.C. Botteril and M. Fisher (eds), *Beyond Drought: People, Policy and Perspectives*, CSIRO Publishing, Collingwood.

Paull, C. Cliffe, N. and Hall, W. 2001, *Australian Grassland and Rangeland Assessment by Spatial Simulation (Aussie GRASS) Extension Sub-project QNR9 Final Report for the Climate Variability in Agriculture Program April 2001*, Department of Natural Resources and Mines, Queensland.