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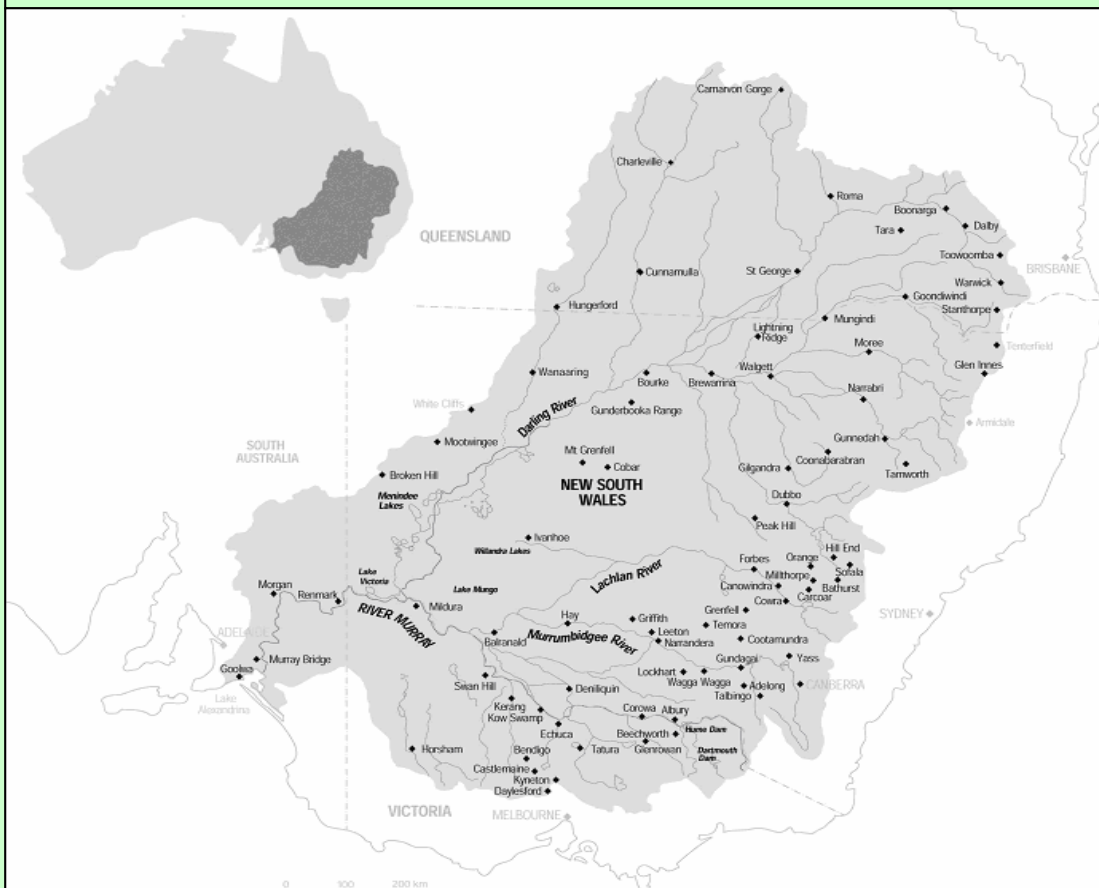
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Climate change and climate uncertainty in the Murray-Darling Basin

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Abstract

Human activity has modified the environment at all scales from the smallest ecosystems to the global climate systems. In the analysis of the Murray-Darling Basin, it is necessary to take account of effects of human activity ranging from local changes in water tables and soil structure through basin-level effects of the expansion of irrigation to changes in precipitation pattern arising from the accumulation of greenhouse gases in the atmosphere. In this paper, we analyse the impact of, and adjustments to, climate change in the Murray-Darling Basin, using a simulation model that incorporates a state-contingent representation of uncertainty.

Climate change and climate uncertainty in the Murray-Darling Basin

Human activity has modified the environment at all scales from the smallest ecosystems to the global climate systems. In the analysis of the Murray-Darling Basin, it is necessary to take account of effects of human activity ranging from local changes in water tables and soil structure through basin-level effects of the expansion of irrigation to changes in precipitation pattern arising from the accumulation of greenhouse gases in the atmosphere.

Analysis of the effects of such changes is complicated by high levels of variability and uncertainty in natural inflows to and outflows from the system. Among the world's major river systems, the Murray-Darling has both the lowest average rainfall and the greatest proportional variability.

Analysis of the impact of climate change on the Murray-Darling Basin must, therefore take appropriate account of uncertainty. A state-contingent representation of production under uncertainty (Chambers and Quiggin 2000) is naturally well-suited to this task, since different states of nature (droughts, normal rainfall and flood events) are represented explicitly, as are the responses of water users to the uncertainty they face. Different systems of property rights may also be represented.

In this paper, we examine the impact of projections of climate change in which higher temperatures and reduced precipitation combine to reduce average levels of runoff, and increase the variability of flows. Such changes may be represented by changing the state-contingent distribution of inflows to the system. A question of particular interest is the relationship between climate change and policy variables such as the Cap on aggregate average extractions of water from catchments, which was introduced in 1995.

The paper is organised as follows. Section 1 deals with climate change and uncertainty, and introduces a number of distinctions that are important in understanding the issues. Climate change scenarios for the Murray-Darling Basin are described, along with the relationship between precipitation, evaporation and runoff. Section 2 summarises the state-contingent model of land and water allocation in the Murray–Darling Basin developed by Adamson, Mallawaarachchi and Quiggin (2007) and shows how climate change may be incorporated in the model. In Section 3, estimates of the impact of climate change for two alternative solutions for the model are presented and discussed. Finally, some concluding comments are offered.

1. Climate change and uncertainty

Variability and uncertainty regarding natural flows is central to the analysis of irrigated agriculture. When considering climate change, it is useful to distinguish between predictable variation (for example, seasonal patterns) and uncertainty, and to further distinguish two kinds of uncertainty: risk and ambiguity. Risk arises when the probability distribution of a given variable is known. Ambiguity, also sometimes referred to as Knightian uncertainty (Ellsberg 1961, Knight 1921) arises when probabilities are unknown, or when it is not possible to describe all possible outcomes in advance.

The simplest case is that of predictable seasonal variability. Dams allow water to be captured when it is readily available, and used when it would otherwise be scarce. In the Murray-Darling Basin, the natural pattern was one of high flows in spring, caused by the melting of snows in the Snowy Mountains, followed by low flows in summer and autumn. Even under stable long-term climatic conditions, the probability distribution of inflows to the Murray-Darling Basin displays high levels of risk compared to other major river systems. Management of the river has produced a more even seasonal pattern with peak flows in summer when demand for irrigation water is highest. This change has potential adverse effects on environmental flows.

Farmers and other water users do not respond passively to risk, but choose production strategies to manage risk. To represent this appropriately, it is necessary to analyse production under uncertainty in state-contingent terms. A general theory of state-contingent production is developed by Chambers and Quiggin (2000) and applied to the modelling of the Murray-Darling Basin by Adamson, Mallawaarachchi and Quiggin (2007).

Climate change may be expected to increase climatic risk, by raising the probability of extreme events and also to introduce ambiguity arising from the fact that our understanding of changes in climatic patterns remains limited, particularly at regional scales. Thus, while we know that the probability distribution of climatic variables will change from the historically observed levels, we cannot yet determine the probability distribution that will be applicable in the future. This is a classic case of ambiguity (Ellsberg 1961)

Most discussion of ambiguity in economic choice under uncertainty has focused on the case of an unknown probability distribution over a known set of possible outcome. Increasingly, however, attention has been focused on the more fundamental problem that some relevant future events are not foreseen adequately in advance.

Climate change itself provides an illustration. When concern about the sustainability of irrigation policy first emerged in the 1980s, the possibility of climate change was not seriously considered in this or others of public policy. Even as late as 1994, the COAG Water Policy took little account of climate change.

Although a good deal of attention has now been paid to climate change, new and unexpected implications continue to emerge. For example, the implications of more frequent and severe bushfires came to prominence following the fires in Canberra in January 2003.

Climate change scenarios

Considerable uncertainty surrounds the likely impact of climate change on the Murray-Darling Basin. Jones et al (2001) gave on overview of modelling research concluded (p 3)

Recent projections of rainfall change for the MDB suggest a decline in winter and spring rainfall by the year 2030. In summer, rainfall may either decrease or increase, with increases slightly more likely, while in autumn the direction of rainfall change is uncertain. Possible rainfall increases are largest towards the north of the MDB and decreases are largest to the south. Temperature is expected to increase in all areas. Potential evaporation is also highly likely to increase in all areas due to higher temperatures. These increases will be larger in regions and seasons in which rainfall decreases. Increases in open water evaporation will affect wetlands and water storages.

The combination of generally declining rainfall and increased evaporation imply that the availability of water will, in general be reduced. However, this outcome is not certain.

Jones et al (2001) present a number of possible scenarios for regional impacts of climate change. As noted above, allthough all simulations include an increase in mean temperatures and evaporation, there is considerable uncertainty surrounding projections of both rainfall and runoff.

Since the aim of this paper is to model adaptation to climate change, attention in this paper will be focused on the high-impact projections in which climate change leads to higher temperatures and lower rainfall. Recent experience suggests that the probability of such an outcome may be greater than was indicated by preliminary regional modelling.

Climate change and runoff

Jones et al use a simple model relating proportional changes in mean annual runoff (Q) to proportional changes in mean annual precipitation (P) and potential evapotranspiration (Ep)

δQ = A δP + B δEp

Here A is the elasticity of catchment runoff with respect to changes in precipitation, P and B are the elasticity of catchment runoff with respect to changes in evaporation, Ep. When applied to the Macquarie catchment, this simple relationship fitted observed change to mean annual flow with a standard

error of ±2% mean annual flow (Jones and Page 2001). For any given catchment, these elasticities depend on Qc; the ratio of annual rainfall to runoff. The fitted relationship

A Factor = 3.5 + -0.04*(Qc) and;

B Factor = -0.81 + 0.007*(Qc)

The A factor is particularly noticeable with an elasticity in excess of 3.5, indicating that a 10 per cent reduction in rainfall will generate a reduction in runoff of at least 35 per cent. Similarly a 10 per cent increase in evaporation will reduce runoff by around 8 per cent. Thus, quite modest changes in rainfall and evaporation could reduce runoff by up to 50 per cent.

2. Model

The model is based on that presented in Adamson, Mallawaarachchi and Quiggin (2007). The river system is divided into catchments $k = 1...K$. The system is modelled as a directed network. The catchments are linked by endogenously determined, state-contingent, flows of salt and water. Water flows out of a given catchment are equal to inflows (net of evaporation and seepage) less extractions (net of return flows). Extractions are determined endogenously by land use decisions as described above, subject to limits imposed by the availability of both surface and ground water.

Agricultural land and water use in each region is modelled by a representative farmer with agricultural land area Lk. The model includes 18 catchments corresponding to Catchment Management Authority regions within the Basin. The catchments are sequentially linked on the basis of existing flow patterns. The network captures the cumulative water volume and salt loads from Condamine-Balonne catchment of southern Queensland to the Lower Murray– Darling Catchment that encompasses the South Australian portion of the Basin where the river system joins the sea.

There are S possible states of nature corresponding to different levels of

rainfall/snowmelt and other climatic conditions. In the present simulations, S=3. That is, there are three states of nature corresponding to low, normal and high rainfall.

The status of the river in each catchment and state of nature is measured by a flow variable and Q water quality variables. The $(Q+1) \times K \times S$ vector of status variables is determined endogenously by upstream water use decisions. In the present simulations, the only water quality variable is salinity. The interaction between producers arises from the fact that changes in salinity levels, arising from the decisions of upstream water users, affect crop yields for downstream irrigators. The model therefore incorporates adverse effects of salinity on yields, derived from agronomic data.

There are M distinct agricultural production systems, and therefore $M \times S$ different state-contingent commodities. In the present simulations, M=14. The commodities are listed in table 1 along with the type of technology and the level of water use.

Table 1 Commodities Investigated

	Technology & Water Use	
Commodity	Standard	High & Low
Citrus		Yes
Cotton	Yes	
Cotton mix		
Grains	Yes	
Grapes		Yes
Dairy		Yes
Rice	Yes	
Sheep/Wheat		
Rice mix		

Stone Fruit		Yes
Vegetables	Yes	
Dryland Option		

There are N inputs, committed before the state of nature is known. In the present version, N=4. In addition to water, the model inputs include the three classical factors of production: land, labour and capital, and a generic cash input. A variety of constraints are considered on inputs. Land is constrained by total area, and by soil type for particular commodities. In addition, constraints may be imposed on changes in the total area under irrigation and on the total volume of irrigation consistent with the MDBC Cap. The supply of operator and household labour is assumed to be constrained in short run versions of the model, but contract labour is incorporated in the generic cash input.

In general, input and output prices are assumed to be the same in all regions. However, the model allows for various different rules for setting water prices to reflect property rigths.

Activities

In each region land is allocated across Ak different activities. For one hectare of land an activity is represented by:

(i) state-contingent outputs of a single commodity (dimension S);

(ii) water use in each state of nature (dimension S); and

(iii) other inputs (dimension N).

Hence, for each region k, the matrix of activity coefficients has dimensions Ak × (N+2S). As in Quiggin (1988), there may be more than one technology used to produce a given commodity.

Productivity in a given state of nature will depend on salinity, which in turn will be determined by upstream water use. Constraints on water availability will be determined by the interaction between upstream water use, institutional arrangements and policy variables.

The extended model uses region-specific gross margin budgets, reflecting differences in production conditions between regions. In addition, information on soil type is used to constrain production areas for specific commodities within regions. In this and other respects, geographical information system (GIS) technology has proved valuable in integrating data from different sources, based on inconsistent and overlapping divisions of the study area into data units.

Because the model is solved on an annual basis, the process of capital investment is modelled as an annuity representing the amortised value of the capital costs over the lifespan of the development activity. This provides the flexibility to permit the modelling a range of pricing rules for capital from short run marginal cost (operating cost only) to long run average cost, and to allow the imposition of appropriate constraints on adjustment, to derive both short-run and long-run solutions.

Solution concepts

The model allows a variety of solution concepts. Two broad classes of solution may be considered.

In sequential solutions, water users at each stage of the system maximize private returns from water use, subject to land, labour and constraints arising from regulation or the allocation of water rights, including the salinity of incoming water, but without taking direct account of the effects of their actions on downstream water users.

In global solutions, the allocation of water is chosen to maximise the surplus for the Basin as a whole, possibly subject to institutional constraints. The solution procedure, analogous to dynamic programming, involves determining the value of water at the final stage of the system and determining optimal upstream allocations by a recursive backward induction.

In the present paper, all solutions are derived subject to constraints on water use chosen to match the Cap on extractions imposed in 1995 For regions in Queensland, individual caps have not yet been agreed, water use is constrained not to exceed average levels for 2000 determined from ABS data.

Modelling climate change

In the present paper, climate change is modelled as a change in inflows of water to the catchments in the Murray-Darling Basin, using the projections of Jones et al. The implications of higher temperatures for yields and for the water requirements of crops are not taken into account. Some analysis taking these variables into account has been undertaken by Trang (2006), but only for a limited range of crops and regions.

Two probability distributions are considered: a baseline distribution derived from historical observations and a projection based on the warm dry case considered by Jones et al.

3. Results and discussion

The analysis yields four sets of results, representing the sequential and global (CAP-constrained) solutions for both the baseline and climate change simulations.

Baseline simulations

The results of the baseline simulations are presented in Tables 2 and 3. Tables 2a and 2b show water use, salinity and economic returns for each of the regions in each state of nature. As in Adamson, Mallawaarachchi and Quiggin (2006), the sequential solution involves higher extractive water use than the global solution. Relative to the global solution, the sequential solution yields higher returns in upstream regions, and lower regions in the downstream regions, particularly the South Australian section of the Murray–Darling Basin and in urban use in Adelaide.

In addition, the global solution involves more flexible use of water, involving opportunity cropping using irrigation in periods of high availability, reverting to dryland in periods of water shortage. In this version of the model, as in Adamson, Mallawaarachchi and Quiggin (2006), the most important use of opportunity cropping arises in the production of cotton. The 'cotton fixed' activity involves a fixed rotation plan requiring a stable water input. The 'cotton flexible' activity is based on an opportunity cropping approach, incurring higher costs in return for greater flexibility.

However, the two simulations reported here differ less than do the unconstrained global and sequential solutions considered by Adamson, Mallawaarachchi and Quiggin (2006). The imposition of the CAP brings the sequential solution closer to the global optimum, restricting low-value water use in upstream catchments. On the other hand, the fact that the global solution is also constrained by the CAP necessarily reduces the value of the target variable relative to the unconstrained optimum. Moreover, the imposition of the CAP constraints produces an allocation of land and water that is closer to the current pattern of use. Since the pattern of use prevailing in the mid-1990s was the basis of the CAP, this is unsurprising.

Climate change simulations

The climate change simulations indicate that reduced runoff arising from climate change would impose significant social costs. Total social value, in terms of value added in agriculture, declines by about $250 million in the global solution and $280 million in the proportional solution.

In the proportional solution, the costs of warming are incurred mainly in the downstream regions, such as the South Australian section of the Murray-Darling Basin, and in Adelaide. This outcome reflects the model assumption that the Cap on extractions remains unchanged, so that only modest adjustment is required in upstream regions.

Similarly, in this solution, the area allocated to irrigation declines only modestly, and the allocation of land between activities is broadly similar before and after climate change. The costs of climate change are reflected in reduced flows and lower water quality in downstream regions.

By contrast, in the global solution the costs of global warming are distributed more evenly.

State-contingent effects

It is important to consider how the effects of climate change will differ in different states of nature. In the baseline simulations, the global solution involves considerably more flexibility in agricultural water use than the proportional solution. The adoption of flexible technologies means that water use

is reduced significantly in low flow years. This flexibility implies greater reliability of urban water supply for Adelaide, and a pattern of flows that more closely approximates natural patterns and is therefore likely to be beneficial for the environment.

Because water use in the dry state is already relatively low in the global solution, the effect of climate change on the state-contingent pattern of allocation is relatively modest. By contrast, climate change tends to encourage the adoption of more flexible technologies in the proportional solution.

The impact modelled here depends on the representation of climate change that has been adopted. In the simulations reported here, rainfall and runoff are reduced uniformly in all states of nature. However, some evidence suggests that the most important impact of climate change will be to increase the frequency of severe drought conditions.

Discussion

The responses to global climate change have been characterized as 'mitigate, adapt, or suffer' (Weber 2007). For water users in the Murray-Darling Basin, the global level of mitigation (including Australia's contribution) may be regarded as exogenous, and the rate and pattern of climate change as both exogenous and uncertain.

The analysis presented here focuses on adaptation to climate change through changes in land and water use. However, even with substantial adaptation, water users as a group will suffer significant losses from climate changes leading to decreased precipitation and increased evaporation, if these are realised as modelled here.

It is important to note that the analysis here is based on the assumption that land use patterns have adjusted completely to climate change, as in the analysis of Mallawaarachchi et al (2006). This issue is discussed further by Mendelsohn, Nordhaus and Shaw (1994, 1999). As Quiggin and Horowitz (1999, 2003) observe, a large proportion of the costs of global climate change consists of adjustment costs. As long as the climate continues to change, adjustment costs will continue. Hence, the analysis presented here may be regarded as representing the impact of a policy under which global temperatures are

stabilised at a new and higher level.

4. Concluding comments

Climate change is a complex process of which an increase in global mean temperatures is only one of the consequences. Changes in the geographical seasonal and probabilistic distribution of rainfall may be equally important for agriculture. Interactions between these changes, affecting runoff and evapotranspiration add further complexity. These changes can only be modelled satisfactorily if uncertainty is taken into account explicitly.

The modelling presented above shows that if, as is now generally expected, climate change is associated with reduced rainfall in southeastern Australia, the cost to irrigated agriculture and to urban users of water from the Murray-Darling Basin will be substantial. Adaptation through changes in land and water use, in ways that provides the greatest returns to all factors of production, as modelled in this paper, can reduce, but not eliminate, these costs.

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