Risk & Sustainable Management Group

Australian Public Policy Program Working Paper: C08#3

Research supported by an Australian Research Council Federation Fellowship and Discovery Project
http://www.arc.gov.au/grant_programs/discovery_federation.htm

The impact of climate change on agriculture

John Quiggin
Australian Research Council Federation Fellow, University of Queensland

Schools of Economics and Political Science
University of Queensland
Brisbane, 4072
rsmg@uq.edu.au
http://www.uq.edu.au/economics/rsmg

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

This version:August 19, 2008

The impact of climate change on agriculture

Paper presented to Australian Institute of Agricultural Science and Technology workshop, Brisbane, 3 September 2008

John Quiggin

Australian Research Council Federation Fellow

School of Economics and School of Political Science and International Studies

University of Queensland

EMAIL j.quiggin@uq.edu.au

PHONE + 61 7 3346 9646

FAX +61 7 3365 7299

http://www.uq.edu.au/economics/johnquiggin

I thank Nancy Wallace for helpful comments and criticism.

This research was supported by an Australian Research Council Federation Fellowship.

The impact of climate change on agriculture

It is now virtually certain that Australia and the world will experience significant climate change over the next century, as a result of human-caused emissions of carbon dioxide (CO_2) and other greenhouse gases.

This note is a brief discussion of the projected effects of climate change on agriculture, under 'business as usual' conditions in which global concentrations of CO_2 grow steadily and under the assumption that a global mitigation effort successfully stabilises global concentrations of CO_2 and slows the climate change. Both global effects and effects on Australian agriculture are considered, with a particular focus on irrigated agriculture in the Murray–Darling Basin.

Baseline

Comparisons in which the baseline simulation involves no climate change are not particularly useful. A more appropriate basis for analysis is a comparison between 'business as usual' and a stabilisation option, in which policy responses ensure that the atmospheric concentration of greenhouse gases is stabilised at a level consistent with moderate eventual climate change. Although the latter definition is somewhat vague, a target of 550 ppm has been proposed on a number of occasions (Stern 2007). For typical estimates of climate sensitivity, this target implies temperature change of around 0.2 degrees per decade over the next century, with stabilization thereafter.

Direct effects of higher temperatures

The Intergovernmental Panel on Climate Change (2007) summarises a large number of studies of the impact of higher temperatures on crop yields. Unsurprisingly, for small changes in temperature, these effects are generally unfavorable at low (tropical) latitudes and favorable at high latitudes. The most important beneficial effects are on the growth of wheat in Canada, Northern Europe and Russia (Smit, Ludlow and Brklacich 1988; Parry, Rosenzweig, and Livermore 2005).

The aggregate effects of modest warming are likely to be small, but the losers are likely to be concentrated in poor countries, particularly in the tropics. As Parry, Rosenzweig, and Livermore (2005) conclude

> while one may be reasonably optimistic about the prospects of adapting the agricultural production system to the early stages of global warming, the distribution of the vulnerability among the regions and people are likely to be uneven.

Because losses are concentrated in developing countries, global warming implies a significant increase in the number of people at risk of hunger, although this risk may be mitigated by expansion of trade.

For warming of more than 2 degrees C, the marginal effects of additional warming are unambigously negative. Studies of wheat yields in mid-to-high latitudes, summarised in Figure 5.2b(c) of IPCC

(2007) show that the benefits of warming reach their maximum value for warming of 2 degrees C, while at lower latitudes, and for rice, the effects of warming greater than 2 degrees are clearly negative. For temperature increases of more than 3 degrees C, average impacts are stressful to all crops assessed and to all regions.

Rainfall and evapotranspiration

Water, derived from natural precipitation, from irrigation or from groundwater, is a crucial input to agricultural production. IPCC (2007, Chapter 3, p175) concludes, with high confidence, that the negative effects of climate change on freshwater systems outweigh its benefits. This negative finding arises from a number of features of projected climate change.

First, climate change is likely to exacerbate the spatial variation of precipitation, with average precipitation increasing in high rainfall areas such as the wet tropics, and decreasing in most arid and semi-arid areas (Milly, Dunne and Vecchia 2005).

Second, climate change is likely to increase the variability and uncertainty of precipitation (Trenberth et al 2003). The frequency and geographical extent of severe droughts are likely to increase by multiples ranging from two to ten, depending on the measure (Burke, Brown, and Nikolaos 2006) and high intensity rainfall events are likely to become more prevalent (IPCC 2007a).

Third, higher temperatures will lead to higher rates of evaporation and evapotranspiration, and therefore to increased demand for water for given levels of crop production (Döll 2002). Water stress (the ratio of irrigation withdrawals to renewable water resources) is likely to increase in many parts of the world. Water stress may be reduced in some areas, but the benefits of increased precipitation will be offset by the fact that the increases in runoff generally occur during high flow (wet) seasons, and may not alleviate dry season problems if this extra water is not stored (Arnell 2004).

CO_2 fertilisation

Increases in atmospheric concentrations of CO_2 will, other things being equal, enhance plant growth through a range of effects including stomatal conductance and transpiration, improved water-use efficiency, higher rates of photosynthesis, and increased light-use efficiency (Drake, Gonzalez-Meler, and Long 1997). However only modest increases in yields can be expected from increases in CO_2 beyond 550 ppm. Temperature and precipitation changes associated with climate change will modify, and often limit, direct CO_2 effects on plants. For instance, high temperatures during flowering may lower CO_2 effects by reducing grain number, size and quality. Some of these effects may be overcome by appropriate selection of cultivars (Baker, 2004). Increased temperatures may also reduce CO_2 effects indirectly, by increasing water demand. Xiao et al. (2005) found that, for given availability of water, the yield of wheat declined for temperature increases greater than 1.5 degrees C. Additional irrigation was needed to counterbalance these negative effects.

Aggregate global impacts

In assessing the aggregate impact of climate change on agriculture it is necessary to take account of the interaction between production systems and markets. In general, demand for agricultural products is inelastic. Conversely, the elasticity of equilibrium prices with respect to exogenous shifts in aggregate supply is typically greater than 1. That is, a reduction in global agricultural output caused by an exogenous shock such as climate change will increase the aggregate revenue of the agricultural sector.

This general result must be qualified, however, by the observation that global markets are not frictionless. If, as most projections suggest, moderate warming will increase output in temperate-zone developed countries while reducing output in (mainly tropical) developing countries, the net impact is ambiguous.

A number of studies have attempted to estimate the impact of global warming on agricultural output and on aggregate returns to the agricultural sector. Fischer et al. (2002) estimate that, under a 'business as usual' projection, global output of cereals will decline by between 0.7 per cent and 2.0 per cent, relative to the case of no change in climate, while the estimated change in agricultural GDP ranges from -1.5 per cent to +2.6 per cent.

Darwin (1999) estimates that world welfare may increase if the average surface land temperature does not increase by more than 1.0 or 2.0 C, as is likely under stabilisation If the average surface land temperature increases by 3.0 C or more, however, world welfare may decline. Similarly, Parry, Rosenzweig, and Livermore (2005) find that stabilisation at 550 ppm avoids most of the risk of increased global hunger associated with a 'business as usual' projection.

Impact on Australian agriculture- the case of the Murray–Darling Basin

Australian agriculture has always been subject to climatic change and variability. Over the course of the 21st century, climate change arising from human action will have increasingly significant effects. The effects of climate change will depend both on the extent to which action to mitigate climate change is effective and on the response of global and regional climatic systems.

The most detailed analysis of the economic effects of climate change on Australian agriculture is the modelling of effects on irrigated agriculture in the Murray–Darling Basin undertaken by Quiggin et al (2008) for the Garnaut Review.

Irrigated agriculture is particularly sensitive to climate change. Relatively modest changes in precipitation and temperature can have substantial effects of inflows of water to river systems and therefore on the availability of water for irrigation. In the the Murray-Darling Basin, effects of this kind arising from the recent prolonged drought are already being observed.

To assess the impact of climate change, with or without global agreement on mitigation, it is necessary to model the responses of farmers and other users of land and water to changes in the

availability of water arising from climate change. Particularly in the case of systems like the Murray-Darling Basin where natural variability is high, modelling must take account of uncertainty.

Quiggin et al (2008) projected the effects of climate change under a range of scenarios, taking account of resulting changes in patterns of land and water use under uncertainty. Quiggin et al considered a baseline scenario without climate change and two sets of alternative scenarios. The 'business-as-usual' scenarios were based on projections in which emissions grow rapidly. The range of variation reflects uncertainty in models of the regional impact of climate change on the Murray-Darling Basin. In the mitigation scenarios, it was assumed that atmospheric concentrations of CO2 and other greenhouse gases are stabilised at levels of 450 or 550 ppm CO2 equivalent.

The analysis distinguishes three factors that determine the severity of the impact of climate change. The modelling work here determines the impact climate change may have on rainfall and consequently inflow inflows to the basin. Under 'business as usual', both 'median' and 'dry' scenarios show significant reductions in inflows to the Basin. As shown in Figure I the reductions in inflows projected by 2100 would make irrigated agriculture economically infeasible.

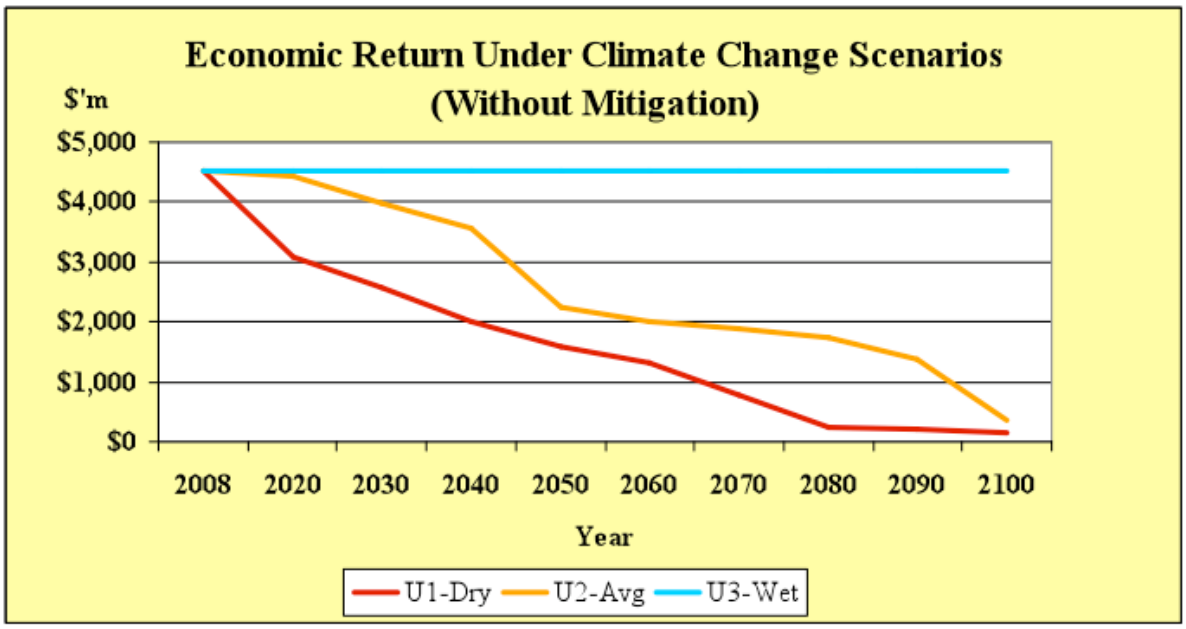

Figure I Policy Inaction on Climate Change

The second factor is the extent to which there is effective international action to mitigate climate change, resulting in stabilisation of atmospheric concentrations of greenhouse gases. The analysis here considers the implications of stabilization at 450 ppm or 550 ppm. As shown in Figure II, most damage can be avoided in the median scenarios with stabilization at 450 ppm. Stabilization at 550 ppm is sufficient to avoid severe damage in the median scenario, and to delay, but not permanently prevent, damage in the dry scenario. No projections were available for the case of stabilization at 450

ppm in a dry scenario, but it appears likely that damage would be reduced substantially relative to the 'business as usual' and 550 ppm scenarios.

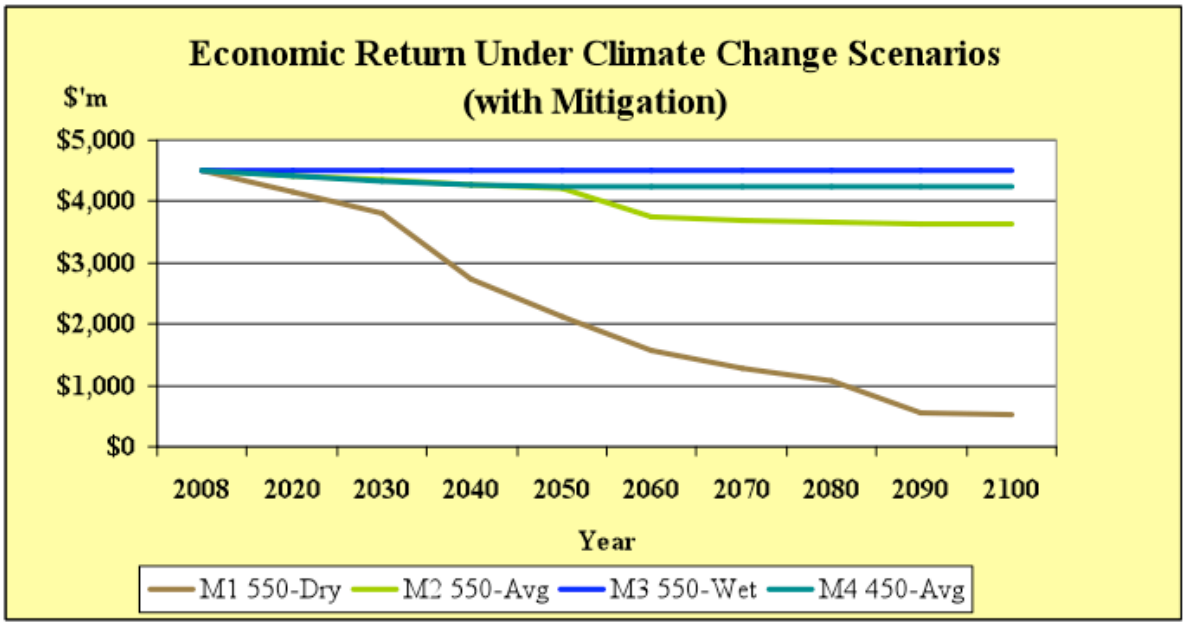

Figure II Policy Inaction on Climate Change

The final factor is the extent to which land and water users adapt to climate change. The model analysis incorporates optimal adaptation to changing conditions by farmers and other water users, given the constraints under which they operate. These constraints reflect existing institutional arrangements. Other work undertaken by the Group indicates that improved institutional arrangements could increase the economic and social value derived from water use, and improve capacity to adapt to climate change.

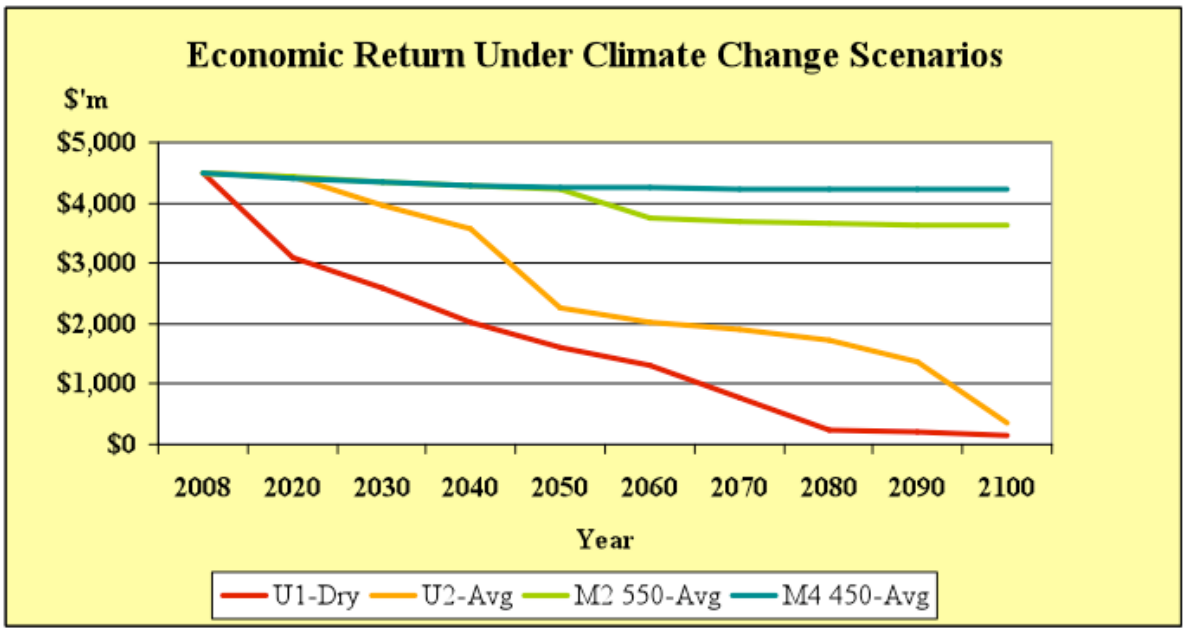

Figure III Benefits from Policy Action

The results are summarised by the Garnaut Review (p. 170)

> In an unmitigated case, irrigation will continue in the Basin in the immediate term. Later in the century, decreasing runoff and increased variation in runoff are likely to limit the Basin's ability to recharge storages. By 2030 economic production falls by 12 per cent. By 2050 this loss increases to 49 per cent and, by 2100, 92 per cent has been lost due to climate change. Beyond 2050 fundamental restructuring of the irrigated agriculture industry will be required.
>
> If the world were to achieve ambitious stabilisation of greenhouse gas concentrations to 450 ppm CO2-e by 2100, it is very likely that producers would be able to adjust their production systems with greater efficiency and technological improvement (not modelled) to adapt with little cost to overall economic output from the Basin under this scenario. By 2030 economic production falls by 3 per cent. By 2050, this loss increases to 6 per cent. By 2100, 20 per cent has been lost due to climate change.

Concluding comments

Agriculture is the economic activity in which human dependence on natural biological and climatic systems is most direct and fundamental. Unsurprisingly, it is the activity most vulnerable to climate change. The results derived above show that a 'business as usual' approach will lead to substantial

losses in agricultural productivity, relative to the alternative of mitigation and stabilisation. If human food needs are to be met, this will require the diversion of significant resources into agricultural production.

The worst-case scenarios for the Murray–Darling Basin, if repeated globally, would raise the possibility that, even with substantial diversion of resources into agriculture, it would be difficult or impossible to provide a secure food supply to the world population. The need to rule out such worst-case outcomes is one reason early action on climate change is necessary, even in the absence of a comprehensive international agreement.

References

Arnell, N.W. (2004), 'Climate change and global water resources: Sres emissions and socio–economic scenarios', *Global Environmental Change*, 14(1) Climate Change, 31–52.

Baker, J.T. (2004), 'Yield responses of southern US rice cultivars to CO_2 and temperature', *Agricultural and Forest Meteorology*, 122(3–4), 129–37.

Burke, E., Brown, S. and Nikolaos, C. (2006), 'Modeling the recent evolution of global drought and projections for the twenty–first century with the Hadley Centre Climate Model, *Journal of Hydrometeorology*, 7(5), 1113–1125.

Darwin, R. (2004), 'Effects of greenhouse gas emissions on world agriculture, food consumption, and economic welfare', *Climatic Change*, 66(1), 191–238.

Döll, P. (2002), 'Impact of climate change and variability on irrigation requirements: a global perspective', *Climatic Change*, 54(3), 269–93.

Drake, B.G., Gonzalez–Meler, M.A. and Long, S.P. (1997), 'More efficient plants: A consequence of rising atmospheric CO_2?', *Annual Review of Plant Physiology and Plant Molecular Biology*, 48, 609–39.

Fischer, G., Shah, M. and van Velthuizen, H. (2002), 'Climate Change and Agricultural Vulnerability', Working Paper, International Institute for Applied Systems Analysis, Laxenberg, Austria.

Garnaut Climate Change Review (2008), 'Draft Report', Commonwealth of Australia, Melbourne.

Intergovernmental Panel on Climate Change (2007b), *Working Group II Report (WGII): Climate Change 2007: Impacts, Adaptation and Vulnerability*, IPCC, Geneva.

Milly, P.C., Dunne, K.A. and Vecchia, A.V. (2005), 'Global pattern of trends in streamflow and water availability in a changing climate', *Nature*, 438(7066), 347–50.

Parry, M., Rosenzweig, C. and Livermore, M. (2005), 'Climate change, global food supply and risk of hunger.', *Philosophical Transactions of the Royal Society London B Biological Sciences*, 360(1463), 2125–38.

Quiggin, J., Adamson, D., Schrobback, P. and Chambers, S. (2008), 'Report to Garnaut Review: The Implications of Climate Change for Irrigation in the Murray Darling Basin'Risk and Sustainable Management Group (RSMG), School of Economics and School of Political Science and International Studies, University of Queensland .

Smit, B., Ludlow, L. and Brklacich, M. (1988), 'Implications of a global climatic warming for agriculture: A review and appraisal', *Journal of Environmental Quality*, 17 (4), 519–27.

Trenberth, K.E. et al. (2003), 'The changing character of precipitation', *Bulletin of the American Meteorological Society*, 84(9), 1205–17.

Xiao, G., Weixiang, L., Qiang, X., and Zhaojun, S. (2005), 'Effects of temperature increase and elevated CO_2 concentration, with supplemental irrigation, on the yield of rain–fed spring wheat in a semiarid region of China', *Agricultural Water Management*, 74(3), 243–55.

PREVIOUS WORKING PAPERS IN THE SERIES

CLIMATE CHANGE

C05_1	Counting the cost of climate change at an agricultural level, John Quiggin (October, 2005).
C06_1	Fiddling while carbon burns: why climate policy needs pervasive emission pricing as well as technology promotion, John C.V. Pezzey, Frank Jotzo and John Quiggin (December, 2006).
C07_1	Stern and his critics on discounting and climate change, John Quiggin (June, 2007).
C07_2	Declining inflows and more frequent droughts in the Murray-Darling Basin: climate change, impacts and adaption, John Quiggin (2007).
C07_3	Complexity, climate change and the precautionary principle, John Quiggin (2007).
C07_4	The practicalities of emissions trading, Joshua Gans and John Quiggin (August 2007).
C08_1	Equity between overlapping generations, John Quiggin (June, 2008).
C08_2	Uncertainty and climate change policy, John Quiggin (2008).
C08_3	The impact of climate change on agriculture, John Quiggin (August, 2008).
C08_4	Grandfathering and greenhouse: the roles of compensation and adjustment assistance in the introduction of a carbon emissions trading scheme for Australia, Flavio Menezes, John Quiggin and Liam Wagner (December, 2008).
C09_1	Agriculture and global climate stabilization: a public good analysis, John Quiggin (August, 2009).
C10_1	Climate change, uncertainty and adaption: the case of irrigated agriculture in the Murray-Darling Basin in Australia, John Quiggin, David Adamson, Sarah Chambers and Peggy Schrobback (2010).
C11_1	Stabilizing the global climate: a simple and robust benefit cost analysis, John Quiggin (2011).
C13_1	Carbon pricing and the precautionary principle, John Quiggin (March 2013).
C13_2	How I learned to stop worrying and love the RET, John Quiggin (May 2013).