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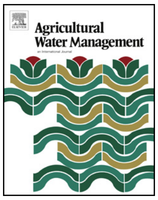

Irrigation revenue loss in Murray–Darling Basin drought: An econometric assessment

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ABSTRACT

This article presents an econometric analysis of irrigation commodity area and revenue responses to varying commodity prices, water availability and climate conditions for the second half of a decade long drought in the Murray–Darling Basin, Australia. We find statistically significant evidence of irrigation area decline with reductions in water allocations and irrigation revenue shrinking with area irrigated. Results also indicate hotter drier weather conditions experienced in the drought effected crops differently: some crop revenues suffered, while higher evapotranspiration and yield potential appeared to support higher revenue outcomes for other crops. Comparison revealed that marginal revenue changes in response to water allocations estimated are much less than those implicit in other economic assessments of water scarcity impacts for the same basin that used different methods. We find that triangulation of results between methods provides confidence in consistent results and reveals possible avenues for future research and methodological development.

1. Introduction

Irrigation is expected to play a major role in meeting future world food demand (McCarthy et al., 2001). Yet, much of the world's irrigated area is in arid and semi-arid regions where droughts are common, and are anticipated to be more common and severe under future climate change (Schwabe and Connor, 2012; Schwabe et al., 2013). Many irrigated food production regions including parts of Australia and the USA face a compounding challenge as water is increasingly reallocated away from irrigation to in-stream flows for water dependent ecosystems (Garrick et al., 2012).

A number of studies have used mathematical programming models to forecast irrigation sector economic responses to reduced water availability (Iglesias et al., 2003; Calatrava and Garrido, 2005; Peck and Adams, 2010). Specific to our study region, Qureshi et al. (2007) assessed Murray–Darling Basin (MDB) irrigation sector impacts from environmental water reallocation and Connor et al. (2009, 2012) assessed climate change and salinity impacts on southern MDB irrigation. Computable general equilibrium (CGE) modelling is another common approach to economic assessment of drought and water scarcity (Goodman, 2000; Berrittella et al., 2007). Wittwer and Griffith (2011) used CGE modelling to assess both the impact of drought and water resource reallocation in the MDB. An advantage with mathematical programming and CGE models is that they allow assessment of scenarios that are outside actual experience. For instance, Harou et al. (2010) assess California irrigation sector impacts from a 72-year-long drought that is consistent with geologic records but much longer than any drought in the hydrologic record. One challenge with programming and CGE models is the specification of technical coefficients characterising yield, land use, revenue and cost changes in response to changes in available water. Misspecification, for example under representation of the true range of adaptation options, or the overspecialisation in a single crop, can lead to erroneous conclusions with respect to policy or future climate assessments.

Econometric simulation is an alternative to programming models which has been used to assess factors driving irrigation response to drought and water reallocation at the level of an irrigation district (Lorite et al., 2007), irrigated farm (Rubio-Calvo et al., 2006) or single crop (Quiroga and Iglesias, 2009). A potential advantage with econometric study of drought is that it provides a basis for modelling coefficients that is grounded in revealed responses to actual reductions in water available for irrigation. A challenge that can arise with small sample panel datasets can be statistically estimating significant marginal effects reliably (Hox, 2002, 2010). This is potentially an issue in our case study as the available survey and

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census data involves a small unbalanced panel dataset. Another issue with the data are missing explanatory variables including capital and labour inputs to production. Despite these limitations, a strong drought signal and irrigation adaptive response do allow identification of significant marginal impacts of reduced water availability for most MDB irrigated commodities.

In what follows, we describe our case study, the conceptual basis for our regression model, the data sources, prior hypotheses, model specification, testing, and results. We then compare our econometrically estimated responses to those from other recent MDB irrigation sector drought economic impact assessments that used programming or CGE models and discuss reasons for the differences. We end with a discussion about the advantages of comparing different methodologies both in providing evidence for consistent results and where results differ, for future research agendas and method development.

2. Case study

Situated in the south-eastern part of Australia, the MDB covers about 1 million square kilometres or 14 percent of Australia. There are 23 river valleys and climatic zones range from cool temperate rainforests in the northeast to hot dry arid plains in the west and semi-arid plains in the south. Nearly two million people live in the Basin and it provides municipal industrial water to an additional 1.3 million people outside of the Basin (Loch et al., 2012).

Agricultural production, both irrigated and dryland is a significant economic activity throughout the Basin accounting for 34 per cent of Australia's gross value of agricultural production and 65 percent of Australia's irrigated land (Bryan and Marvanek, 2004). In response to a deepening drought water diverted for irrigation in the Basin declined between 2000 and 2010 (Kirby et al., In Press). Reductions in water allocations (annual water allocations tied to a water entitlement vary with inflow and storage) were more severe in the second half of the drought and severity of reductions varied by region. For example, in the South Australian (SA) Murray irrigation region 2008/09 allocations were just 18 percent of the long term average (Wheeler et al., In Press). During the drought dry, hot conditions affected crop evapotranspiration and yield potential and during this period irrigated commodity prices were highly variable (Kirby et al., In Press). These characteristics make the drought a useful case study to examine observed irrigation sector adaptation with the objective to better understand the economic impacts of water scarcity.

Data gathered for this study for five growing seasons; 2005/06 to 2009/10 was retrieved from publically available databases for 16 Australian Bureau of Statistics (ABS) Natural Resource Management (NRM) regions within the MDB, see Fig. 1. Dependent variable observations are irrigated land area and irrigated revenue for nine major commodities that represent more than 90 percent of the value of Basin irrigated production. These commodities are: beef, dairy, sheep, wine, perennial horticulture (fruit and nuts), cereal (wheat and other broadacre crops such as barley), cotton, and vegetables.

3. Model specification and estimation approach

The conceptual basis for the econometric specification in the modelling is the micro-economic theory of production. Observed output, and variable inputs are assumed to be profit maximizing responses. They are estimated as responses to input and output prices, climatic conditions, and fixed inputs. Other econometric studies of climate impacts on irrigation are also underpinned by this conceptual model (Kumar and Parikh, 2001; Gbetibouo and Hassan, 2005; Seo and Mendelsohn, 2008). The choice of dependent variables is partially determined by the availability of empirical data. Used observations of county level land rental value to assess climate impacts on irrigation value, while Seo and Mendelsohn (2008) used observations of farm level returns and livestock stocking levels. Available data allowed us to estimate demand for irrigated land area (IRRIGN_AREA) with water allocation (ALLOCN), commodity prices (PRICE), and an irrigation water demand proxy (IRRIGN_D, calculated as evaporation minus rainfall) as explanatory variables, see Eq. (1). We also estimate irrigation revenue (IRRIGN_REV) as a function of irrigated land area (IRRIGN_AREA), PRICE and IRRIGN_D, see Eq. (2).

Table 1
Regression dependent and explanatory variables.

Name	Description	Units
Dependent variables		
IRRIGN_AREA	Logits of land area	Logits
IRRIGN_REV	Revenues from irrigated agricultural production	AU$ × 10^6
Explanatory variables		
ALLOCN	Regional irrigation water allocation measured as the reported percentage of full regional entitlement	%
IRRIGN_AREA	Area irrigated	hectares
PRICE	Commodity price	$/t
IRRIGN_D	Variable measuring climatic influence on crop irrigation demand calculated as crop potential evapo-transpiration less crop available rainfall	Mm

$$A_{i,j,y} = \alpha_i^0 + \alpha_i^{wa} \times wa_{i,j,y} + \alpha_i^p \times p_{i,y} + \alpha_i^c \times c_{i,j,y} + e1_{i,j,y} \quad (1)$$

$$R_{i,j,y} = \varphi_i^0 + \varphi_i^a \times area_{i,j,y} + \varphi_i^p \times p_{i,y} + \varphi_i^c \times c_{i,j,y} + e2_{i,j,y} \quad (2)$$

where, subscript i indicates commodity, j indicates region, and y indicates year. Terms α, and φ are regression coefficients with superscript 0 indicating the regression intercepts, a indicating the IRRIGN_AREA coefficients, p indicating the PRICE coefficients, c the IRRIGN_D coefficient, and the terms $e1_{i,j,y}$, and $e2_{i,j,y}$ are the error vectors for the two equations. The explanatory variables are described in Table 1. Note that we have organised the regions into a northern and southern catchments as this has been shown to be relevant in discussion of irrigation responses to drought in the Basin (Kirby et al., In Press). Summary statistics for all variables are reported in Table 2.

Intuitively, it would seem logical to have estimated IRRIGN_REV as a direct function of ALLOCN and other relevant explanatory factors. However, we found that including ALLOCN directly in the IRRIGN_REV regression yielded relatively poorer explanatory power (lower R^2 values and fewer significant marginal effects) than our less direct approach explaining IRRIGN_AREA as a function of water allocations in Eq. (1), and IRRIGN_REV as function of IRRIGN_AREA in Eq. (2). For detailed results of the direct regression of IRRIGN_REV on ALLOCN, PRICE, and IRRIGN_D see Table A1 in the online Support material.

Consistent with past econometric studies of land use change, we used a logistical functional form as the dependent variable in the IRRIGN_AREA regressions (Eq. (1)). This form is popular because it precludes the possibility of negative areas by bounding IRRIGN_AREA estimates between zero and 100 per cent of potential irrigation area (Lubowski et al., 2006; Lewis et al., 2011). The explained observations in the IRRIGN_AREA regressions are the logits of irrigated area as a proportion of the maximum area for each crop and region, where the maximum area was assumed to be the maximum extent in the historic data for the region in the period 1997 to 2010.

We tested the explanatory power of our choice of linear functional form for all explanatory variables in both the IRRIGN_AREA and IRRIGN_REV regressions using Ramsay Equation Specification Error Tests (RESET) to determine whether nonlinear combinations

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