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# Explaining permanent and temporary water market trade patterns within local areas in the southern Murray–Darling Basin\*

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The southern Murray–Darling Basin of Australia has the world’s largest and most sophisticated water markets. However, there has been little study on the drivers of permanent and temporary water market movements within local areas, or the substitution effects between groundwater and surface-water extraction over time. This topic is important as it is often claimed that water market trade patterns (especially selling large amounts of permanent water) are associated with rural decline. This study uses random-effects tobit panel models to investigate the association of regional and spatial socio-economic characteristics with temporary and permanent southern Murray–Darling Basin water market trade, using a broker panel database at postcode level from 2010/11 to 2013/14. Overall, results suggest there is no statistical significant evidence that more disadvantaged communities sold larger amounts of permanent water. Permanent water selling was statistically more likely to be associated with other spatial and land productivity characteristics, while temporary water market trade volumes were more related to water scarcity factors. In addition, there was evidence to suggest a substitution effect between rural areas selling higher volumes of permanent water and using higher volumes of groundwater.

**Key words:** irrigation, rural decline, socio-economic effects, substitution effects, water trading.

## 1. Introduction

Water crises have consistently been identified as one of the world’s top five global risks in terms of impact since 2012 (WEF 2019). A variety of water demand management strategies and economic instruments are being introduced globally to deal with water scarcity problems, and many countries are considering adopting water markets (Wheeler *et al.* 2017).

In Australia’s Murray–Darling Basin (MDB), concern over long-term low water availability, water over-allocation, environmental problems and predicted increased rainfall variability prompted a series of water policy changes from the 1980s onwards, ultimately introducing formal water

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trading<sup>1</sup> and water markets (Quiggin 2001; Crase *et al.* 2004; Lee and Ancev 2009). Major policies and funding schemes (e.g. the Basin Plan) that primarily affected the irrigation industry were announced during the Millennium Drought (2001/02–2009/10). At the same time, many rural MDB communities have faced substantial socio-economic changes – resulting in a reduction of jobs, services, farm numbers and population sizes. This is attributed to changes in agricultural production, labour market restructuring and a withdrawal of public and private sector services (Alston 2004; Wheeler, Xu and Zuo 2020), although this result is not homogenous across all areas (Pritchard and McManus 2000; Wheeler *et al.* 2018).

Today Australia's water market is mature and ranks high in terms of institutional foundations, economic efficiency and environmental sustainability (Grafton *et al.* 2011). Water trading in the MDB has become an important tool to manage water scarcity and is widely adopted by irrigators as an adaptation strategy (Wheeler *et al.* 2014). Water trading has also become increasingly part of a broader farm business strategy in the southern MDB, where water entitlement and allocation trading (and water carry-over decisions between farming seasons) are complementary activities and, thus, should be considered collectively. Irrigators may decide to substitute the use of water entitlements and allocations – or surface water and groundwater (where viable resources are available) – to adapt to environmental (e.g. decreasing water quantity/quality) or financial (e.g. increasing water/crop prices) issues (Mukherjee and Schwabe 2015). As a result, regions may experience major water and land use changes (e.g. increased groundwater extraction, change in the number of annual/perennial plantings).

Although water markets have the ability to provide a flexible, voluntary and efficient allocation of a scarce resource (e.g. Howe *et al.* 1986), they are subject to market failures and are heavily dependent upon both strong governance and institutions (Wheeler *et al.* 2017). Recent studies have highlighted numerous issues that remain within both the southern and northern MDB's water markets and how market failures need to be addressed (Seidl *et al.* 2020; Wheeler and Garrick 2020). An ongoing issue surrounding water markets in Australia is the association between water trading and socio-economic developments in rural communities. Outward permanent

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<sup>1</sup> Two major types of water rights are traded in Australia, namely water entitlements (permanent rights to a share of water and referred to as *permanent trading*) and water allocations (seasonal and proportional access to a share of water and referred to as *temporary trading*) (COAG 2004). The majority of water entitlements are owned by irrigators; however, following the unbundling of water from land, there has been increased non-landholder and foreign ownership (Seidl *et al.* 2020). The security type of water entitlements describes the probability of the water being fully available from year to year. High security water entitlements provide a highly reliable water supply (usually full allocation 90–95 years out of 100) with little variation between years. Low/general security water entitlements provide a variable or uncertain water supply.

water trading has been often blamed for reduced agricultural production, economic activity and employment in some regions (e.g. Kiem 2013), causing pressure and stress for some farmers. However, as severe drought conditions had often led to this scenario, it is difficult to discern the real drivers of negative change in communities.

Studies suggest that the overall effect of water markets on rural communities is minimal and current socio-economic trends in those communities do not vary much under a non-water trading scenario (e.g. NWC 2012). Wheeler *et al.* (2020) modelled agricultural and population census data in the MDB from 1991 to 2011 and found no statistically significant relationship between declining total farm numbers (including dryland and irrigated farms) and water trade movements.

Other economic modelling studies show that decreased irrigation water extraction caused relatively small impacts on agricultural production (e.g. Connor *et al.* 2009; Wittwer 2011). For example, Kirby *et al.* (2014) showed that a 70 per cent reduction in irrigation water use during the Millennium Drought led to a 10 per cent decline in irrigation production value. Furthermore, selling temporary water can be associated with higher farm net income and rate of return, and while selling permanent water can result in reduced farm production, it can also reduce debt in farming communities (Wheeler, Zuo and Hughes 2014).

This study investigates key characteristics associated with four main types of water trading behaviour, namely purchase and sale decisions across both temporary and permanent water trades. Water trading data are aggregated at the community (postcode area) level – this study being the first to employ such data in the southern MDB. We are specifically interested in the association of regional socio-economic measures with community-level water trading transactions and other regional (substitution) effects. Given that many of the arguments by lobby groups focus on the importance of ‘community water’ – and that communities’ economic fortunes are irrevocably linked with a certain level of irrigation water extraction<sup>2</sup> – then conducting empirical analysis at the community level provides the opportunity to better understand how water trading movements on a smaller scale are associated with specific regional effects (e.g. potential substitution effects with groundwater extraction). Results may help to better understand the interconnectedness of regional demographic, economic and social changes, along with irrigators’ water trading decision-making – and whether there is a link between ‘community water extractions’ and regional economies.

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<sup>2</sup> For example, see submissions to the Independent assessment of social and economic conditions in the MDB, available at <https://www.mdba.gov.au/publications/independent-reports/independent-assessment-social-economic-conditions-basin>.

## 2. Conceptual framework and literature review

### 2.1 Water trading effects and behaviour

Irrigators' water trading decision-making has been increasingly studied, especially within Australia's MDB. Various determinants affect water trading behaviour for different water rights. In general, *temporary water trading* has been found to be associated with irrigators' personal characteristics and short-term considerations in response to seasonal fluctuations of prices or water availability (to manage risk and uncertainty within and between seasons) (e.g. Bjornlund 2004; Loch *et al.* 2012; Zuo, Nauges, and Wheeler 2015). This has also been found internationally. For example, in Spain it was found that water markets decreased risk and vulnerability during water scarcity conditions (Calatrava and Garrido 2005). Studies suggest that temporary water traders in Australia have particularly become more advanced over time in their use of water market information (NWC 2012; Zuo, Brooks *et al.* 2014; de Bonviller, Zuo and Wheeler 2019). *Permanent water trading* has been found to be influenced by long-term considerations largely relating to farm and environmental/spatial characteristics (e.g. Isé and Sunding 1998; Wheeler *et al.* 2012; Haensch *et al.* 2016). US studies have found negative associations between selling water and the value of agricultural land; between leasing out water and the value of agricultural production (Hansen *et al.* 2014); and the impact of transfer costs (i.e. transaction and water conveyance costs) on water markets (Regnacq *et al.* 2016). There has also been increasing literature considering the role of environmental water holders in Australian water markets (e.g. NWC 2012; Ancev 2015).

Most of the water market literature to date has focused either on the micro-scale (farm-level survey data) (e.g. Isé and Sunding 1998; Wheeler *et al.* 2012; Giannoccaro *et al.* 2015) or macro-scale (e.g. time-series data at the water district or county/state level) (e.g. Brown 2006; Haensch *et al.* 2016; Regnacq *et al.* 2016; Zuo *et al.* 2019). However, examining water trading decision-making at the meso-scale (i.e. regional, community or postcode level) has been the object of much less attention – because water trading data were previously not available at this spatial scale. Macro-scale analysis commonly produces policy relevant findings, which are generalisable across a broader region or a country. Conversely, micro-level analysis is used to gain in-depth contextual knowledge, but with limited validity across space and time. At the meso-scale, macro-level external driving forces may still be detectable, which can be less obvious at the individual level – and also local conditions are not as aggregated compared to the macro-level, where they may not be detected (Messerli *et al.* 2015). Thus, a meso-scale analysis provides the opportunity to better understand water trading movements and to capture more specific regional influences. Other opportunities include being able to identify more local areas where water extraction (surface-water and groundwater) can be

expected to decrease or increase; or when land use is potentially changing and where communities have specific adaptation needs.

## 2.2 Regional socio-economic and substitution effects

The impact of rural socio-economic development and population dynamics on (water) resource use, agriculture and environment has been a continuing topical issue globally (e.g. de Sherbinin *et al.* 2007; Hibbard and Lurie 2013) – largely due to declining rural populations (e.g. Winkler *et al.* 2012). Multiple and complex processes lead to rural decline, which are often referred back to push factors, such as loss of employment opportunities – but also the perceived attractiveness of living in bigger cities causes noticeable out-migration (Argent and Walmsley 2008). However, conversely, some rural areas have experienced major economic transformations resulting in improved rural economic diversity, rural–urban interdependence/income parity, emergent exurban areas and amenity-led rural growth (Irwin *et al.* 2010). In Australia, rural (youth) out-migration and associated regional socio-economic decline has been a long-term issue. However, diverse patterns of rural decline may be apparent if different spatial (e.g. small-scale instead of broad-scale data) and temporal scales are analysed (Carson *et al.* 2016).

Empirical research on how regional socio-economic changes affect farming businesses, water trade decisions and activities in Australia is growing, but still limited (e.g. see Barr 2009; McManus *et al.* 2012; Pritchard *et al.* 2012; Wheeler *et al.* 2020b). A recent study found no statistically significant association between water entitlement sales and regional decline in the MDB (Haensch *et al.* 2019). Wheeler *et al.* (2020b) analysed the drivers of MDB farm exit decisions at the statistical local area level from 1991 to 2011, and found statistically significant associations between increased net farm exits and decreased commodity output prices, increased urbanisation, higher temperatures and higher unemployment. However, the study also found no statistically significant link between net farm exit and changes in irrigation water diversions and water trade movements.

This study focuses on the following regional socio-economic measures: regional socio-economic index (SEIFA index); population density; distance to cities; net primary production business income; and government benefit payments. The agricultural economics literature has shown the importance of some of these measures in agricultural land use decisions. For example, von Thünen's (1826) agricultural location theory was the first to show how and why land uses vary with market distance. Though mostly studied in regional/urban economics research (Wu *et al.* 2017), regional socio-economic characteristics (e.g. population density) are also pivotal in the critical mass and agricultural infrastructure framework (Lynch 2006). For example, population growth is related to several positive (e.g. increased demand for farm produce) and negative (e.g. increased regulation) impacts on agriculture (Lopez *et al.* 1988; Wu *et al.* 2011). Increased population (in

some cases urbanisation) is likely to increase off-farm work opportunities and the cultivation of high value crops – because of a new customer base – which in turn may lead to either farm exit or increased farm income (Gellrich *et al.* 2007; Wu *et al.* 2011). Moreover, population growth may result in increased input costs (because of less agricultural activity in the area in favour of off-farm jobs) and labour costs (because of increased competition for labour) (Wu *et al.* 2011). Thus, the effect of population on agricultural infrastructure (number of input supplier/output processors affecting agricultural prices, e.g. input prices or transportation costs) and farmers' profit function varies with local institutional and other factors – for example local land availability, property taxes and environmental regulations (Roe *et al.* 2002).

In the empirical literature, studies have found positive associations between population growth/density and farmland abandonment (Goetz and Debertin 2001; Gellrich *et al.* 2007); farmland value (Mukherjee and Schwabe 2015; Dall'erba and Domínguez 2016); off-farm work participation (Lim-Applegate *et al.* 2002); and farm production costs and net farm income (Wu *et al.* 2011). A similar variable of distance to markets/roads significantly affects land use decisions (Nelson and Hellerstein 1997; Marcos-Martinez *et al.* 2017), rural/agricultural growth and agricultural land prices (Cho and Newman 2005; Polyakov *et al.* 2014). We are interested if distance to market and similar factors have an influence on water market trading patterns in the MDB. Following the critical mass and agricultural infrastructure literature, we hypothesise that irrigators' profit functions are influenced by the state of, and changes to, regional socio-economic factors, depending on how agricultural prices change.

Another aim of this study was to analyse potential regional substitution effects. Farmers' ability to substitute farm inputs can improve farm productivity when facing external shocks, such as input cost increases (Vincent 1977; Sheng *et al.* 2016). Farmers may substitute feed inputs (farm-grown forages/grains for purchased feed) on dairy farms in response to prices (Moschini 1988); or substitute land for energy in response to increases in electricity prices (Edwards *et al.* 1996). Similarly, irrigators may adjust their water input mix to meet new environmental and economic conditions (Mukherjee and Schwabe 2015). Nieswiadomy (1988) found that water demand has a negative elasticity in response to increasing pump costs and is substitutable with labour and technology. There is also evidence for crop substitution (from irrigated to dryland crops) when energy prices increase (Edwards *et al.* 1996; Konyar and Howitt 2000). Irrigators may respond similarly to environmental changes, such as substituting crops (e.g. reducing the area planted with rain-fed crops such as pasture and soybeans) or increasing groundwater extraction in response to lower precipitation, depending on irrigators' abilities (Maneta *et al.* 2009; Wheeler *et al.*, 2020c). Additionally, substitutions between water and other crop inputs can

depend on cropping patterns and profitability (e.g. there are lower levels of substitution in low-value crops areas) (Cai *et al.* 2008).

This study examines different irrigation water substitution effects, focusing on regional/community-level water input substitutability – in terms of water resources (substitutability between surface and groundwater) and water rights (substitutability between water entitlements and allocations). The substitution of surface-water or groundwater has become a common response to the respective over-allocation of these resources in Australia (Wheeler *et al.*, 2020c). However, there is little knowledge about the consequences of increased groundwater extraction and how to manage surface-water and groundwater conjunctively (e.g. Ross 2018). In addition, over the years, irrigators in the MDB became highly experienced in the use of the water market. There is evidence of irrigators using water entitlements and water allocations as complements (e.g. Delorit *et al.* 2019; Wheeler *et al.*, 2020c); and water trading in the southern MDB increasingly becoming part of a broader farm business strategy (NWC 2012).

### 3. Methodology

#### 3.1 Water market data and study area

Water entitlement and allocation trading data by postcode area, over four years, were compiled and sourced from a leading private water broker (Waterfind) for the southern MDB. The data include irrigation districts in southern New South Wales (NSW), northern Victoria (VIC) and South Australia (SA). The southern MDB is located in southeast Australia and was selected as a case study because water markets are connected in this area, and have been operating since the 1990s. Over the study time-period, some water trading restrictions were in place in the southern MDB – for example, an annual 4 per cent limit on the volume of water entitlements traded out of irrigation districts in northern VIC (2007-2014) (Grafton and Wheeler 2018).

Water trading and several spatial datasets (described in the following section) were analysed and plotted using a Geographic Information System (GIS). This analysis focuses on postcode areas that have their centroid within the boundaries of the southern MDB ( $n = 383$ ). Because of the size of the southern MDB (471,427 km<sup>2</sup>), there are postcode areas where water trading is unlikely to occur (e.g. no farming area or no water entitlements issued). Thus, the analyses are based on postcode areas that have had at least one water allocation and entitlement transaction, respectively, in at least one of the years considered.

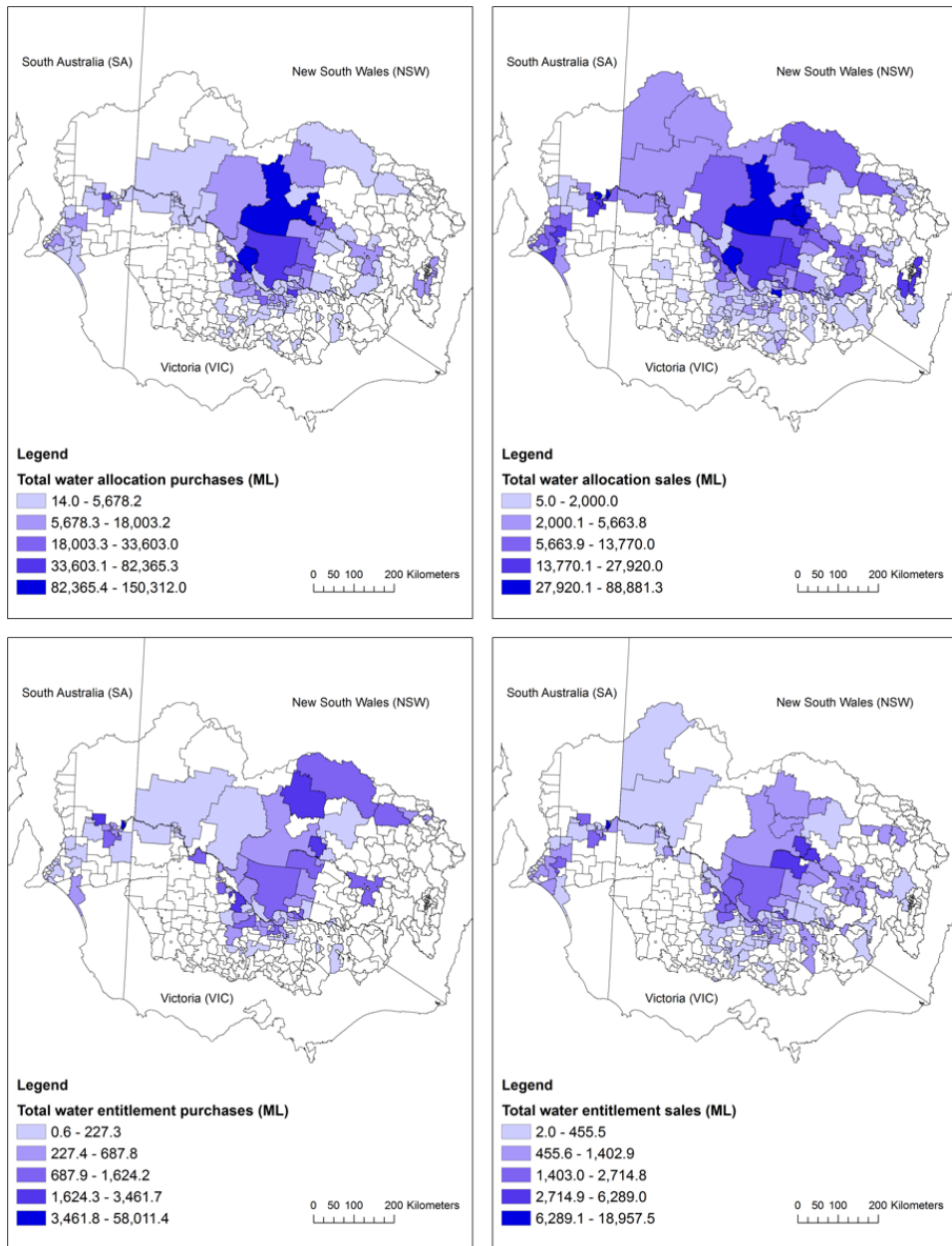
It has been suggested that basing spatial research on administrative boundaries may not be suitable for all types of research questions (Logan 2016). However, for the purposes of a regional analysis, postcode areas are typically the smallest geographic area that can be associated with individual farms (Roberts and Key 2008). The postcode area boundaries used in this

study are based on statistical areas level 1 (SA1), created by the Australian Bureau of Statistics (ABS), which are designed to contain broadly similar population sizes (ABS 2011). Thus, postcode areas vary in area size – but much less in population size – which fits the purpose of this analysis.

Data were provided from 2003/04 onwards until 2013/14, from a private water market broker. Given the private water market broker reached market dominance from 2010/11 onwards, particularly from 2012, when a competitor in VIC ceased business (NWC 2013) – we only used water market trading data from 2010/11 to 2013/14. When comparing the dataset from Waterfind with publicly available water market data from the BOM (2020), it was found that Waterfind accounted for 10.3 per cent of total surface-water entitlement trade and 10.5 per cent of total water allocation trade in the study time-period of 2010/10-2013/14 in the southern MDB. Unfortunately, the Waterfind dataset provided no information about whether the purchase or sale was an intra- or inter-trade within postcode areas. Thus, we used a different water trade database from BOM (2020) to test and provide evidence whether total water entitlement or allocation trade was a good proxy of net water entitlement or allocation trade at a broader level (i.e. water trading zones). The BOM database included whether the transaction took place inside or outside of the trading zone. Water trading zones in the southern MDB are generally larger than postcode areas and located along major water systems. We excluded groundwater trade data and calculated the correlation between total and net water entitlement and allocation trade. The average correlation between net and total water allocation trade was found to be 0.97. Overall, 6,542 water allocation transactions were classified as occurring outside of the trading zone and 27,761 inside the trading zone, between 2010/11 and 2013/14. Water entitlement trading data showed that, out of a total of 9,629 entitlement trades in our four-year study period, only very few transactions were traded outside of the trading zone. We were therefore able to conclude that, at the broader/regional level, total water entitlement and allocation trade data are a satisfactory proxy for net water entitlement and allocation trade data.

Figure 1 shows the total water allocation and water entitlement trading activities (in megalitres (ML)) in the southern MDB (total number of observations:  $n = 1,839$ ). Water entitlement trading data included high, general and low security water entitlements.

Other data related to water markets and extraction include water prices, groundwater extraction, water entitlements on issue (i.e. amount of water made available to water users) and water allocation levels. These data were primarily sourced from relevant water authorities within each state, the Murray–Darling Basin Authority (MDBA), the Bureau of Meteorology (BOM) and the National Water Commission (NWC) and are typically only available at the river valley level. Thus, postcode areas were assigned to relevant river valleys if they were located inside or closest to it. Water allocation level data indicate the percentage of an irrigator's water



**Figure 1** Total Water Trading Volume (ML) in the southern MDB Postcode Areas, 2010/11–2013/14. Source: Created from data provided by Waterfind. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

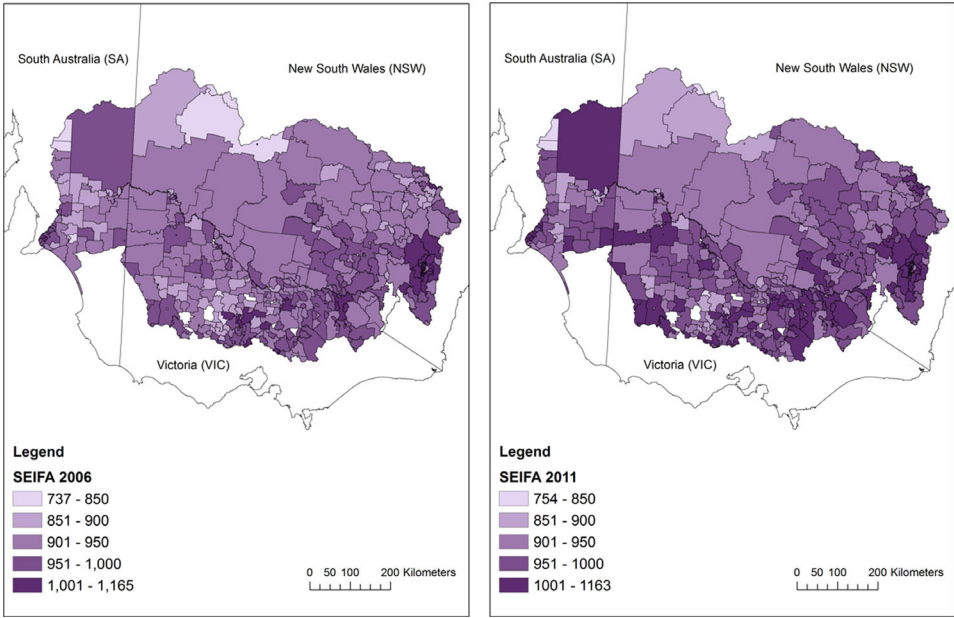
entitlement expected to be available for use within a farming season – depending on the water availability in the specific water resource to prevent water over-allocation. This variable indicates water scarcity levels per season and region.

### 3.2 Spatial and other regional data

A GIS database was compiled by collecting secondary spatial data, covering biophysical, land use and regional socio-economic information. Biophysical data comprised information of soil texture sourced from the Commonwealth Scientific and Industrial Research Organization (CSIRO); dryland salinity collected from the National Land and Water Resources Audit (NLWRA); and rainfall and evapotranspiration data (e.g. Raupach *et al.* 2009) – as well as a calculation of the distance to the downstream area of the River Murray. Land use data were sourced from a composite dataset via the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES 2012).

Variables that reflect regional socio-economic factors (i.e. location of cities, population density, socio-economic index) were sourced from the ABS. The regional socio-economic index (Index of Relative Socio-Economic Advantage and Disadvantage (IRSAD)) from the Socio-Economic Indexes for Areas (SEIFA) ranks areas according to relative socio-economic advantage and disadvantage, based on the five-yearly Census. An area with a high score has a relatively high incidence of advantage and a relatively low incidence of disadvantage. The index is built on the basis of several variables relating to income, education, housing, employment, occupation and other (ABS 2013). Figure 2 shows the geographic pattern of the SEIFA for 2006 and 2011 in the southern MDB. Overall, the SEIFA increased slightly between the Census years in the southern MDB (the mean was 946.93 in 2006 and 970.77 in 2011). Furthermore, the distance to cities (with population greater than 1,000) was calculated and is used as a proxy for distance to markets, and other infrastructure and services. The ABS defines urban centres as population clusters of greater than 1,000 people (population centres with 1,000 to 19,999 people are defined as small towns), while areas below a population of 1,000 are defined as rural (ABS 1998). Distance to cities with population greater than 10,000 was also calculated and tested. The Australian Taxation Office (ATO) provided the net business income/loss for primary production and the number of primary production businesses per postcode area for the relevant financial years. Primary production activities include plant or animal cultivation, fishing or pearling, and tree farming or felling (ATO 2016). The same source provided government benefits data, which comprise Australian Government allowances and payments, such as Newstart, youth allowance and Austudy payment, per postcode area for the relevant financial years.

This study comprises several time-variant and time-invariant variables because of data collection constraints. Time-invariant variables are soil texture, distance to cities, dryland salinity and land use. Though land use and salinity are prone to changes over time, such information was not available on an annual basis for our four-year period. Table 1 provides the descriptive statistics.



**Figure 2** Geographic Pattern of Socio-Economic Ranking in the Southern MDB Postcode Areas for 2006 and 2011. *Note:* A high index is relatively more advantageous. Data source: ABS (2013). [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

### 3.3 Regression Analysis

To analyse the relationship between water trading and various regional socio-economic and spatial factors over time, several random-effects tobit panel models (censored regression/limited dependent variable models) were employed, allowing for inclusion of time-invariant variables. The tobit panel models treated postcode areas for which no transactions were observed as not reported (censored) observations (Greene 2003, p. 764):

$$y_i^* = x_i'\beta + \varepsilon_i,$$

$$y_i = 0 \text{ if } y_i^* \leq 0,$$

$$y_i = y_i^* \text{ if } y_i^* > 0.$$

The dependent variable  $y$  represents four water trade measures for a given postcode area, namely volume of: i) water entitlement purchases; ii) water entitlement sales; iii) water allocation purchases; and iv) water allocation sales. These were estimated by summing the volumes of all approved water entitlement and allocation sales/purchases within a postcode area for each year, which resulted in different numbers of observations for the years and models. The location variables (e.g. distance to cities, distance to downstream area) account for potential spatial correlations in the dataset – because

**Table 1** Variable description and descriptive statistics

Variable	Details	Mean	Std. Dev.
<i>Dependent variables</i>			
Water entitlement sales (log ML)	Total water entitlements sold/purchased per year between 2010/11 and 2013/14	2.50	2.62
Water entitlement purchases (log ML)		2.20	2.61
Water allocation sales (log ML)	Total water allocations sold/purchased per year between 2010/11 and 2013/14	4.21	3.33
Water allocation purchases (log ML)		4.41	3.45
<i>Independent variables</i>			
Water entitlements owned (log ML)	Total water entitlements owned per year between 2010/11 and 2013/14 (namely it is based on high security water entitlements for VIC and SA; high and general security for NSW) per river valley	13.03	1.56
Water allocation level (%)	Final seasonal irrigation water allocation levels between 2010/11 and 2013/14 and average for the previous 5 years (2005/06–2012/13) per river valley (this indicates the percentage of a water entitlement made available for use within a farming season depending on the water availability in the specific water resource)	90.95 <sup>†</sup>	20.17
Water allocation level previous 5 years (%)		54.04	22.09
Groundwater extraction (log ML)	Annual groundwater extraction between 2010/11 and 2013/14 (long-term average annual figures were used where data were not available) per river valley	9.31	2.98
Entitlement price (log \$/ML)	Market prices (volume weighted average AUD\$/ML) of high security water entitlements (general security for Lachlan, NSW), per year and for the previous year (2009/10–2012/13) per river valley (nominal prices) <sup>‡</sup>	7.37	0.29
Entitlement price previous year (log \$/ML)		7.47	0.29
Allocation price (log \$/ML)	Prices for water allocations (volume weighted average AUD\$/ML), per year and for the previous season (2009/10–2012/13) per river valley	3.59	0.51
Allocation price previous year (log \$/ML)		3.79	0.82
Irrigated cropping (%)	Percentage of land under:	1.75	3.51
Irrigated horticulture (%)	• Irrigated cropping (e.g. cereals, hay, silage, oil seeds, sugar, cotton, pulses)	3.33	8.52
Irrigated grazing (%)	• Irrigated horticulture (perennial and seasonal) • irrigated grazing/modified pastures (e.g. fodder plants, pasture legumes, legume/grass mixture)	4.06	9.80
Net rainfall (mm/year)	Rainfall minus evapotranspiration (mean mm/year), spatial resolution: 5km, for the same year and averaged for the previous 5 years (e.g. 2005/06–2009/10 for 2010/11)	95.17	130.05
Net rainfall previous 5 years (mm/year)		54.29	60.32
Soil texture (index)	Index of soil texture in the soil layer 1 (mean): 1 = sands, 2 = sandy loams, 3 = loams, 4 = clay loams/light clays, 5 = clays (spatial resolution: 1.1 km)	3.12	1.01

**Table 1** (Continued)

Variable	Details	Mean	Std. Dev.
Dryland salinity (dummy)	1 = Percentage of dryland salinity risk/hazard area per total agricultural area is greater than 4%; 0 = otherwise§	0.44	0.50
Distance to cities 1000 (km)	Mean Euclidean distance to cities within the postcode area with population greater than 1,000	17.89	20.46
Distance to cities 10000 (km)	Mean Euclidean distance to cities within the postcode area with population greater than 10,000	52.53	45.28
Population density (log)	Population size per km <sup>2</sup> for previous year and averaged for the previous 5 years (linear interpolation using the Census years 2006, 2011 and 2016)	2.23	1.67
Population density previous 5 years (log)		2.23	1.66
SEIFA index (2006, 2011)	Index of Relative Socio-Economic Advantage and Disadvantage from 2006 and 2011. A high index is relatively more advantageous.	952.15	55.13
SEIFA index (2011)		962.43	55.02
Distance to downstream area (km)	Euclidean distance to downstream area/River Murray mouth (km)	497.98	245.32
Primary production business income	Net business income/loss (\$AUD) for primary production businesses in the previous year (2009/10–2012/13) by business numbers (in thousands)	−0.74	26.48
Primary production business income previous 5 years		−0.63	13.43
Government benefits (log)	Australian Government allowances and payments like Newstart, youth allowance and Austudy payment (\$AUD).	8.63	0.26
Government benefits previous 5 years (log)		8.61	0.27
Years (2010/11 – omitted; 2011/12; 2012/13; 2013/14)	Dummy variables for farming seasons (e.g. 2010/11 = 1 if farming season 2010/11, 0 = otherwise)	0.25	0.43

Note: Variables are based on postcode area level unless otherwise specified.

†Some areas fall inside river valley Lachlan, which received over 100% allocation in 2010/11 and 2011/12.

‡For smaller river valleys (e.g. Kiewa, Ovens, Broken), price data are not available for all years. In this case, prices for VIC Murray above or below Barmah Choke were used.

§The dryland salinity dataset is now dated. However, some regional and more recent studies confirm the continued occurrence of dryland salinity in some areas of the southern MDB (e.g. Fawcett, 2013).

random-effects tobit models cannot be estimated using spatial econometrics. Spatial panel models also require a balanced panel (which our dataset cannot produce) and no missing trade data in neighbouring postcode areas to define an appropriate spatial matrix (there are missing postcode areas because of no trade). We tested the quadratic terms of the regional socio-economic variables to identify any potential threshold effects and non-linear relationships. Similar non-linear relationships were found in related studies (e.g. Wu *et al.* 2011).

While the marginal effects in tobit models have three forms (on the latent dependent variable  $y_i^*$ , on the unconditional dependent variable  $y_i$ , and on the

uncensored conditional dependent variable,  $y_{it}|y_i > 0$ ); the marginal effects of our interest are on the unconditional dependent variable  $y_i$  – since we are mainly concerned with factors affecting the level of water traded by all observed postcodes (including zero volume). Variance inflation factor (VIF) statistics and correlation matrices were checked for serious multicollinearity issues (independent variables that had correlation factors above 0.7 and VIFs above 5 were excluded).

In the water entitlement trading models, time-variant variables were required to be lagged (e.g. previous five years) to reflect long-term issues, which are more relevant for permanent water trading decision-making, and to account for potential endogeneity issues. Time-variant regional socio-economic variables (i.e. population density, SEIFA index), to some extent, might be endogenous to water entitlement sales (e.g. in the case of farm exits and farmers moving out of the region). We addressed this by using the average population density of the previous five years (interpolated using the data from three Census years) and the SEIFA index from the previous Census. Similarly, water entitlement and allocation prices were lagged (previous year) in each respective model (e.g. water allocation prices were lagged in the water allocation volume models), to account for potential endogeneity between volume and prices. However, water price was expected not to be endogenous as the volume of water traded was measured on a postcode level, while water prices are only made available based on a more regional trading zone level. Hence, water trading volume within a postcode area was not likely to be influential on water prices of a trading zone. Additionally, water price is influenced by the demand and supply of the whole connected southern MDB.

Initially, water allocation trading models were estimated using the same long-term (lagged based on the previous five years) variables used in the water entitlement trading models. As it was expected, the majority of those long-term variables had no influence on temporary water allocation trading and were then replaced by the current year variables to improve the water allocation model fitness. Year dummy variables were excluded in the water entitlement models, as current year's water allocation prices in these models reflect the effects of different years, resulting in severe multicollinearity (high correlations greater than 0.7). In the water allocation models, year dummy variables account for other important differences between the years that are not based on weather or prices (e.g. irrigators' increased adoption and experience with allocation trade).<sup>3</sup>

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<sup>3</sup> Not including annual dummy variables in the water allocation models resulted in lower model Wald-Chi-square test results and the results for water prices do not follow economic theory.

## 4. Results and discussion

### 4.1 Regional socio-economic effects

One of our aims was to test for an association between different measures of regional socio-economic characteristics (population, distance/access to markets and infrastructure, regional socio-economic indexes, net primary production business income and government benefits payments) and water trading behaviour. The results under Table 2 indicate that most of these regional socio-economic effects were more likely to be associated with water entitlement selling and allocation purchasing, rather than water entitlement purchasing and water allocation selling decisions.

An overall measure of regional socio-economics (the SEIFA index) was not found to be associated with water entitlement selling decisions (although it was found that more disadvantaged areas purchase larger volumes of water entitlements and allocations). But results further show significant relationships between increased volumes of water entitlement sales in regions with increased primary production business incomes and lower government benefits. Overall, there is little evidence that indicators of poor rural community socio-economics was associated with higher water entitlement sales.

However, larger volumes of water entitlements were more likely to be sold from areas further away from cities (population over 1,000), but at a decreasing rate, as shown by the squared term. In other words, remote areas with greater distances to markets, infrastructure and other services were associated with larger volumes of water entitlement sales – but only up to a certain distance point (as shown in Figure 3). Irrigated agriculture in rural areas may be more cost intensive and disadvantaged, for example in terms of the connection to water and other infrastructure, resources and services. Thus, farmers may need to adapt to external changes; meet farm business needs (e.g. clearing debt); or facilitate a structural adjustment process. This result supports findings from other empirical studies, linking closer distances to markets with agricultural growth and land values (e.g. Cho and Newman 2005). At the same time, model results also suggest that areas with higher population density (over the previous 5 years) are associated with larger volumes of water entitlement sales. This may reflect the impact of growing urbanisation (e.g. higher competition with urban labour markets) on fewer remaining farms – and consequently a sale of their water entitlements. Thus, model results reflect the multifaceted effects of regional socio-economic factors for agriculture, as discussed earlier.

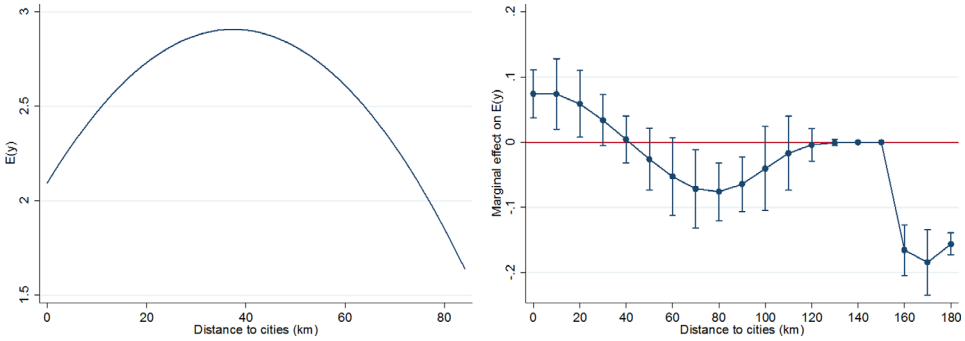
Figures 3 and 4 show the quadratic relationships of distance to cities in the models (quadratic prediction and average marginal effects), when they were found significant.

Conversely, distance to cities showed a significant non-linear relationship with water allocation purchases (Figure 4). This may indicate a substitution

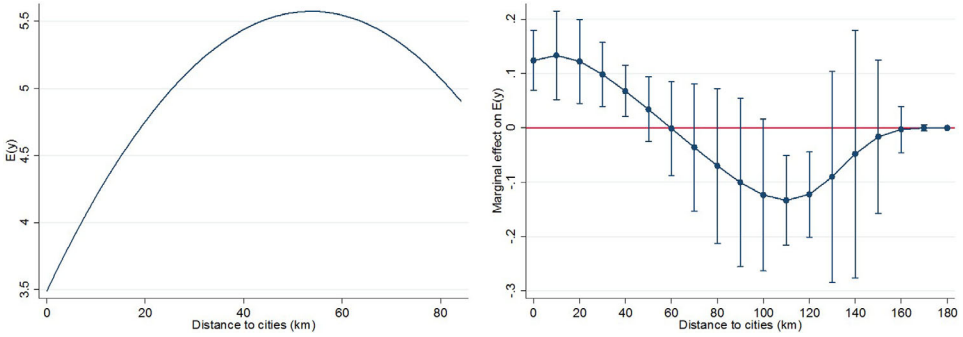
**Table 2** Tobit random-effects panel models of water entitlement (permanent) and allocation (temporary) trading (volume) at Postcode Levels across the southern MDB, 2010/11–2013/14

	Entitlement sale		Entitlement purchase		Allocation sale		Allocation purchase	
	coefficient	dy/dx	coefficient	dy/dx	coefficient	dy/dx	coefficient	dy/dx
Entitlements owned (log ML)	-0.042	-0.025	-0.095	-0.050	0.704***	0.536	-0.018	-0.014
Groundwater extraction (log ML)	0.341***	0.201	0.075	0.040	-0.013	-0.010	-0.032	-0.025
Allocation level (%)	0.013	0.007	0.007	0.003	0.001	0.001	-0.028**	-0.021
Entitlement price (log \$/ML)†	-0.795	-0.469	-3.229**	-1.708	-2.005**	-1.525	-0.374	0.288
Allocation price (log \$/ML)†	0.083	0.049	2.281***	1.206	-0.224	-0.170	-1.391	-1.069
Irrigated cropping (%)	0.350***	0.206	0.148*	0.078	0.144*	0.109	0.307***	0.236
Irrigated horticulture (%)	-0.009	-0.005	-0.006	-0.003	-0.038	-0.029	0.013	0.010
Irrigated grazing (%)	-0.014	-0.008	-0.014	-0.007	-0.035	-0.027	0.069**	0.053
Net rainfall (mm/year)	-0.017***	-0.010	-0.005	-0.002	-0.008***	-0.006	0.0001	0.0001
Soil texture	0.047	0.028	0.686	0.363	0.124	0.094	0.443	0.340
Dryland salinity (dummy)	1.127**	0.665	-1.140*	-0.603	0.765	0.582	0.873	0.671
Distance to downstream area (km)	-0.001	-0.001	-0.005**	-0.003	-0.003***	-0.002	-0.005***	-0.004
Distance to cities 1000 (km)	0.210***	0.079	0.058	0.018	0.049	0.023	0.203**	0.106
Distance to cities 1000 squared (km)	-0.002***		-0.001		-0.001		-0.002*	
Population density (log)	0.557**	0.329	0.341	0.180	0.158	0.120	0.624	0.479
SEIFA index	-0.007	-0.004	-0.022**	-0.011	-0.008	-0.006	-0.024***	-0.019
Primary production business income	0.030*	0.018	0.010	0.005	0.001	0.001	0.001	0.0005
Government benefits (log)	-3.777**	-2.228	0.170	0.090	-0.030	-0.023	1.591	1.223
2011/12					-0.283	-0.215	-0.570	-0.438
2012/13					1.253	0.953	0.181	0.139
2013/14					2.616***	1.990	2.819***	2.167
Constant	39.54**		34.21		17.58		13.18	
Observations	475		315		605		434	
Left-censored observations	224		163		207		146	
Wald chi <sup>2</sup>	71.79		46.05		188.93		134.52	

Note: †Entitlement prices are lagged in the entitlement trade volume models, and allocation prices are lagged in the allocation trade volume models. \*  $P < 0.10$ , \*\*  $P < 0.05$  and \*\*\*  $P < 0.01$  indicate significance at the 10%, 5% and 1% levels, respectively. The coefficient estimates are presented in the first column and the marginal effects are presented in the adjacent column. All estimated models are highly statistically significant, shown by the results of Wald-Chi-square tests ( $P < 0.001$ ). No marginal effects are reported for non-linear variables; instead, the marginal effects at the mean value are reported for the linear term. Standard errors are shown in Tables IV and V in the Appendix.



**Figure 3** Effects of Distance to Cities on Water Entitlement Sales (quadratic prediction (left) and average marginal effects with 95 per cent confidence intervals (right)).



**Figure 4** Effects of Distance to Cities on Water Allocation Purchases (quadratic prediction (left) and average marginal effects (right) with 95 per cent confidence intervals).

effect between selling water entitlements and purchasing water allocations in rural areas further away from larger cities (until a certain threshold point). This result was, however, not consistent in the robustness test model of net water allocation purchases (see Table I).

In the robustness test models in the Appendix, we also re-estimated the models using alternative measures of distance to cities (e.g. different functional forms; distance to cities with population greater than 10,000). Distance to cities with populations greater than 1,000 modelled as a linear term did not statistically significantly influence water entitlement sales (Table II). Other key results remained the same, when also testing distance to cities with populations greater than 10,000 (squared) (Table III). Furthermore, we tested the remoteness index from ABS (which classifies areas into outer regional, inner regional, major cities and remote). However, this was not included in the final models, given lower Wald-Chi-square test results and no statistically significant relationships found.

## 4.2 Groundwater and other substitution effects

Our results found increased water entitlement sales where larger amounts of groundwater were extracted. This confirms a potential substitution effect between groundwater and surface water entitlement trade (i.e. where groundwater resources are available and of sufficient quality, surface-water entitlements seem to be sold on the market as surplus water) (Haensch *et al.* 2016; Wheeler *et al.* 2016; Wheeler *et al.* 2020c). There has been slow progress towards conjunctive management of connected groundwater and surface-water resources in Australia (Ross 2018), and thus, evidence of substitution effects underpin the importance of developing conjunctive water management practices.

We conducted further analysis to investigate a potential substitution effect between water entitlement sales and water allocation purchases. We included water entitlement trade sale behaviour (lagged and current) in water allocation purchase models (and water allocation purchase volumes in water entitlement trade sale models) and did not find any statistically significant influence, indicating that there seemed to be no detected substitution effect between entitlement sales and allocation purchases within our time-period.

## 4.3 Other climate/environment relationships

Results confirmed findings from previous studies regarding other environmental spatial impacts. There is a statistically significant and negative association between net rainfall (over the previous five years) and water entitlement and allocation sales. Thus, water scarcity drives water sales – for example irrigators may change land uses or terminate irrigation as a result of lower water availability, or buy temporary water to make up rainfall shortfall. Furthermore, as expected, there is a statistically significant negative association between water allocation levels received and water allocation purchases. Hence, water scarcity drives the need to purchase more water on the temporary water market, and irrigators are using this market to respond to seasonal fluctuations in water allocation levels (Loch *et al.* 2012). This variable showed no statistically significant effect in the net water allocation purchase model of the robustness check (Table I).

Moreover, increased water entitlement sales occurred where dryland salinity was present. Irrigators affected by dryland salinity typically may not generate sufficient profits – leading to land use changes or irrigation exits, which is reflected in higher water entitlement sales (Haensch *et al.* 2016). Similarly, increased volumes of water entitlements were purchased where dryland salinity did not occur.

Finally, land use variables have various impacts on water trading activity. Areas with a higher percentage of irrigated croppers and grazers were more likely to be buying higher volumes of water allocations.

#### 4.4 Robustness testing

Sensitivity checks of the tobit model results regarding the quadrature approximation used in random-effects estimators were undertaken in order to achieve stable coefficient estimates. Linear fixed effects panel models on the time-variant variables and pooled regression models were estimated, and models were tested by state as a robustness check. The alternative specifications also found the key results presented previously.

As an additional robustness check, we calculated net volumes of water entitlement and allocation trading per postcode area for the dependent variables. Specifically, net water entitlement or allocation purchase (sale) was defined as the net volume of water entitlement or allocation purchased (sold) by a postcode area, and if an area was not a net purchaser (seller), the value for this variable was zero. Both variables are positive and censored at zero. The results of the models with net volumes of water trading as the dependent variable are included in Appendix (Table I). This robustness check finds similar results to the total water entitlement and allocation trade models (Table 2) and suggests there are no major differences in factors associated with total and net water entitlement and allocation trade in local areas in the southern MDB.<sup>4</sup>

#### 4.5 Overall summary and limitations

Overall, regional socio-economic factors and other spatial biophysical variables, such as net rainfall, groundwater extraction and dryland salinity, were statistically significant influences on water entitlement sale decisions, but not water entitlement purchase decisions. Water entitlement volume purchases by local areas were much more likely to be associated with water market prices, location and soil productivity. Given past literature findings, major differences in the determinants of water entitlement selling and purchasing were expected. Water sale decisions are often connected to major life or farm changes (e.g. decreasing or exiting farm production, converting to dryland agriculture) and irrigators often place a high value on their water entitlements as they have a strong connection to the land – whereas water purchasing often means either continuing or expanding farm production levels (Haensch, Wheeler and Zuo 2019).

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<sup>4</sup> One main reason for the similar results between *total* and *net* models is that a postcode generally covers a small geographic area within which there may not be many sales and purchases existing at the same time. Therefore, total sales (purchases) are not greatly offset by total purchases (sales) within a postcode in a given year, and the *total* and *net* values would be very close. The correlation coefficients between them are all reasonably large in magnitude and statistically significant at the 0.01 significance level (0.99 between total entitlement purchase and net entitlement purchase; 0.40 between total entitlement sale and net entitlement sale; 0.87 between total allocation purchase and net allocation purchase; and 0.69 between total allocation sale and net allocation sale).

As expected, water allocation trading was less likely to be affected by spatial/land biophysical factors, than water entitlement trading – rather, temporary trading was more associated with surplus water (such as water entitlements owned within the area), rainfall and seasonal water allocation levels. Conversely, longer-term characteristics (e.g. dryland salinity) appear to mainly affect water entitlement trading activity, due to the long-term investment characteristic of water entitlements.

The identification of substitution of surface-water for groundwater is a concern for water governance in the future, especially given that many groundwater bores are poorly monitored, and reform in all water sources of monitoring, measurement and enforcement will be needed (Wheeler *et al.* 2020; Wheeler *et al.*, 2020c).

There are multifaceted impacts of regional socio-economic aspects on agriculture – and ultimately irrigators' water trading decision-making (Crase and Merton 2013; Wheeler *et al.*, 2020b). Indeed, the history of the placement of irrigation districts has also played a role in driving the influence of water trading on regional socio-economics. These impacts depend on the effects of more urban and more rural/isolated areas on agricultural input and output prices. Our results do not find any evidence of worsening rural socio-economic measures driving greater water entitlement sales. However, it is important to note the limitations of our analysis. We only had access to complete water market trading data from one broker at the postcode level up to 2013/14. Future studies should consider merging water trading data from various sources at longer time scales and various spatial scales, as well as investigating the historical aspects of the location of irrigation districts on regional land values. Furthermore, modelling various measures of rural socio-economics as dependent variables at the postcode level would reveal further insights regarding the relationships between water market dynamics and rural socio-economic change.

Wittwer and Young (2020) highlight the huge opportunity cost of investing in irrigation infrastructure as a form of water recovery, and the subsequent trade-offs for regional economies if money had been invested in services instead. In addition, the current policy of providing grants for mainly infrastructure development (e.g. see the Murray–Darling Basin Economic Development Program) as the key way to stimulate regional outcomes needs careful assessment. Overall, our results support more spatially refined and targeted approaches in policy-making – akin to Crossman *et al.* (2010) – detailing a land use reconfiguration policy approach, using spatial planning to optimise local environmental and socio-economic outcomes. In the case of water resources management, spatial planning and spatial prioritisation problems arise when deciding on irrigation infrastructure investments, irrigator support programs, ecosystem service payments, drought assistance, water quality improvements, water extraction/trading regulations and government's water purchases.

## 5. Conclusions

Based on an extensive and unique community postcode-level dataset from multiple sources, this study investigated influences on water trading behaviour, by analysing the volume of permanent and temporary water purchased and sold in the southern MDB. By controlling for a variety of regional socio-economic factors (such as distance to cities, population density, a regional socio-economic classification index, net primary production income and government benefits), along with other spatial/biophysical characteristics – important new insights on permanent and temporary water trade were revealed.

Our model results found that very remote areas, and areas with lower socio-economic classifications, were not statistically significantly associated with higher volumes of water entitlements sold. Overall, there is little evidence that indicators of poor rural community socio-economics was associated with higher water entitlement sales.

The model results of water entitlement volumes sold suggested irrigators switched between groundwater and surface-water extraction. In areas where sufficient groundwater quality and quantity is available, irrigators increasingly sold water entitlements as surplus water to adapt to external changes, meet water demands or meet farm business needs. Evidence of such substitution effects underpins the importance of developing conjunctive water and land management plans that require robust measurement, monitoring and enforcement of water extraction.

Overall, key spatial influences such as net rainfall, groundwater extraction and dryland salinity were determining influences on the volumes of water entitlements sold – while water entitlement purchase volumes were much more likely to be associated with water market prices, location and soil productivity. As expected from previous literature, volumes of water allocation trading were more associated with water scarcity factors, confirming that water markets provide an important adaptive tool for irrigators in response to unfavourable conditions.

### Data availability statement

The water trading data were collected from a private water broker (Waterfind). Their policies do not allow providing the data.

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Appendix

**Table 1** Robustness check: Tobit Random-Effects Panel Models of Net Water Entitlement and Allocation Trading (volume) at Postcode Levels across the southern MDB, 2010/11–2013/14

	Net entitlement sale		Net entitlement purchase		Net allocation sale		Net allocation purchase	
	Coefficient	dy/dx	Coefficient	dy/dx	Coefficient	dy/dx	Coefficient	dy/dx
Entitlements owned (log ML)	-2.926	-1.152	-49.8	-10.693	486.3***	189.472	100.6	33.487
Groundwater extraction (log ML)	34.89**	13.739	-137.8	-29.578	-81.92	0.674	96.29	-12.836
Allocation level (%)	1.241	0.489	-39.12	-8.399	1.73	-31.923	-38.57	32.046
Entitlement price (log \$/ML) <sup>†</sup>	-46.84	-18.448	-6466.8***	-1388.420	-1149	-447.705	1719.9	572.358
Allocation price (log \$/ML) <sup>†</sup>	-81.72	-32.183	2947.0*	632.723	75.43	-18.351	-1185.4	84.386
Irrigated cropping (%)	55.17**	21.728	-74.42	-15.977	-47.1	-3.568	253.6*	-3.007
Irrigated horticulture (%)	0.275	0.108	70.5	15.136	-9.156	-35.007	-9.036	30.950
Irrigated grazing (%)	-3.224	-1.270	-11.84	-2.541	-89.84***	-2.857	93.00**	5.133
Net rainfall (mm/year)	-1.247*	-0.491	11.77	2.527	-7.333***	-63.850	15.42**	866.127
Soil texture	-28.47	-11.211	952.4	204.474	-163.9	82.309	2602.6***	-232.035
Dryland salinity (dummy)	139.3**	54.843	-2043.9*	-438.825	211.2	-13.738	-697.2	56.796
Distance to downstream area (km)	-0.005	-0.002	-5.294	-1.137	-0.574	7.052	-10.90***	-78.568
Distance to cities 1000 (km)	32.59**	7.611	-50.38	-10.816	-33.48	-3.508	251.3	-5.585
Distance to cities 1000 squared (km)	-0.413***		0.00009		-0.054		-1.868	
Population density (log)	81.43**	32.069	-199.1	-42.753	18.1	29.393	-236.1	-394.483
SEIFA index	-0.52	-0.205	-35.26**	-7.571	-9.002	-0.224	-16.78	-3.628
Primary prod. business income	3.972**	1.564	45.36	9.740	8.674	3.380	-4.953	-1.648
Government benefits (log)	-434.6**	-171.165	1324.6	284.398	-136.9	-53.329	-757.9	-252.219
2011/12					-1012.9	-394.672	2531.6	842.479
2012/13	3840.9*		59397.9*		-422.8	-164.752	2369.3	788.470
2013/14	475		315		118.4	2777.1	1152.3	924.201
Constant					13809.1	46.120		
Observations					605		434	
Wald chi2					53.59		56.34	

Note: <sup>†</sup>Entitlement prices are lagged in the entitlement trade volume models, and allocation prices are lagged in the allocation trade volume models. \*  $P < 0.10$ , \*\*  $P < 0.05$  and \*\*\*  $P < 0.01$  indicate significance at the 10%, 5% and 1% levels, respectively. The coefficient estimates are presented in the first column, and the marginal effects are presented in the adjacent column. All estimated models are highly statistically significant, shown by the results of Wald-Chi-square tests ( $P < 0.001$ ). No marginal effects are reported for non-linear variables; instead, the marginal effects at the mean value are reported for the linear term.

**Table II** Test Tobit Random-Effects Panel Model (including the variable distance to cities with populations greater than 1,000 (linear term))

	Entitlement sale		Entitlement purchase		Allocation sale		Allocation purchase	
	Coefficient	dy/dx	Coefficient	dy/dx	Coefficient	dy/dx	Coefficient	dy/dx
Entitlements owned (log ML)	-0.004	-0.003	-0.085	-0.045	0.724***	0.551	-0.043	-0.033
Groundwater extraction (log ML)	0.355***	0.210	0.081	0.043	-0.022	-0.017	-0.046	-0.035
Allocation level (%)	0.013	0.008	0.006	0.003	0.0001	0.0001	-0.030**	-0.023
Entitlement price (log \$/ML) <sup>†</sup>	0.155	0.091	-3.003**	-1.588	-1.824*	-1.387	1.138	0.875
Allocation price (log \$/ML) <sup>†</sup>	0.191	0.113	2.332***	1.233	-0.259	-0.197	-1.424	-1.095
Irrigated cropping (%)	0.331***	0.195	0.137*	0.072	0.126	0.096	0.281***	0.216
Irrigated horticulture (%)	-0.016	-0.010	-0.008	-0.004	-0.041	-0.031	0.010	0.008
Irrigated grazing (%)	-0.026	-0.015	-0.017	-0.009	-0.041	-0.031	0.065**	0.050
Net rainfall (mm/year)	-0.017***	-0.010	-0.004	-0.002	-0.008***	-0.006	-0.0001	-0.00005
Soil texture	-0.071	-0.042	0.701	0.371	0.168	0.128	0.474	0.364
Dryland salinity (dummy)	1.333***	0.786	-1.074	-0.568	0.745	0.566	0.927	0.712
Distance to downstream area (km)	-0.001	-0.001	-0.005**	-0.003	-0.003**	-0.002	-0.005**	-0.004
Distance to cities 1000 (km)	0.034	0.020	0.006	0.003	-0.011	-0.008	0.065**	0.050
Population density (log)	0.145	0.085	0.165	0.087	-0.056	-0.042	0.202	0.155
SEIFA index	-0.008	-0.005	-0.022**	-0.012	-	-0.007	-0.026***	-0.020
Primary production business income	0.031*	0.019	0.011	0.006	0.001	0.001	0.0005	0.0004
Government benefits (log)	-2.768*	-1.632	0.206	0.109	0.061	0.046	1.573	1.210
2011/12					-0.298	-0.226	-0.544	-0.418
2012/13					1.256	0.955	0.289	0.222
2013/14					2.677***	2.035	3.040***	2.337
Constant	26.37		33.03		17.53		11.79	
Observations	475		315		605		434	
Wald chi <sup>2</sup>	62.40		45.79		187.95		130.72	

Note: <sup>†</sup>Entitlement prices are lagged in the allocation trade volume models, and allocation prices are lagged in the entitlement trade volume models. \*  $P < 0.10$ , \*\*  $P < 0.05$  and \*\*\*  $P < 0.01$  indicate significance at the 10%, 5% and 1% levels, respectively. No marginal effects are reported for non-linear variables; instead, the marginal effects at the mean value are reported for the linear term.

**Table III** Test Tobit Random-Effects Panel Model (including the variable distance to cities with populations greater than 10,000 (squared))

	Entitlement sale		Entitlement purchase		Allocation sale		Allocation purchase	
	Coefficient	dy/dx	Coefficient	dy/dx	Coefficient	dy/dx	Coefficient	dy/dx
Entitlements owned (log ML)	-0.076	-0.028	-0.210	-0.094	0.682***	0.536	-0.066	-0.069
Groundwater extraction (log ML)	0.327***	0.202	0.058	0.039	-0.011	-0.016	-0.029	-0.034
Allocation level (%)	0.013	0.008	0.001	0.003	0.002	0.0004	-0.026**	-0.022
Entitlement price (log \$/ML)†	-0.586	0.242	-3.029**	-1.220	-1.995**	-1.393	0.222	0.889
Allocation price (log \$/ML)‡	0.072	0.097	2.235***	1.222	-0.189	-0.173	-1.290	-1.034
Irrigated cropping (%)	0.397***	0.223	0.249***	0.122	0.168**	0.112	0.362***	0.251
Irrigated horticulture (%)	-0.027	-0.019	-0.013	-0.010	-0.048	-0.037	0.0008	-0.001
Irrigated grazing (%)	0.002	-0.008	0.009	0.004	-0.032	-0.029	0.079***	0.057
Net rainfall (mm/year)	-0.014**	-0.008	-0.003	-0.001	-0.008***	-0.006	0.0004	0.0002
Soil texture	-0.057	-0.106	0.358	0.226	0.060	0.085	0.261	0.246
Dryland salinity (dummy)	1.426***	0.940	-0.389	-0.092	0.908*	0.658	1.194*	0.946
Distance to downstream area (km)	-0.001	-0.0005	-0.004*	-0.002	-0.003**	-0.002	-0.005***	-0.004
Distance to cities 1000 (km)	0.217***	0.021	0.076	0.005	0.048	-0.011	0.208***	0.046
Distance to cities 1000 squared (km)	-0.002***		-0.0007		-0.0006		-0.002*	
Distance to cities 10000 (km)	-0.016	0.008	0.070*	0.015	0.004	0.005	0.023	0.010
Distance to cities 10000 squared (km)	0.0002		-0.0003		0.00002		-0.00005	
Population density (log)	0.570*	0.175	1.144*	0.342	0.221	0.001	0.887**	0.294
SEIFA index	-0.007	-0.003	-0.012	-0.007	-0.007	-0.006	-0.020**	-0.017
Primary production business income	0.032*	0.019	-0.002	0.001	0.0006	0.0008	0.0001	0.00007
Government benefits (log)	-4.056***	-1.757	-0.159	-0.045	-0.071	0.020	1.528	1.171
2011/12					-0.207	-0.178	-0.406	-0.304
2012/13					1.362	1.022	0.374	0.372
2013/14					2.672***	2.068	2.894***	2.419
Constant	40.09**		24.44		16.18		9.034	
Observations	475		315		605		434	
Wald chi <sup>2</sup>	67.38		54.79		188.98		133.25	

Note: Entitlement prices are lagged in the allocation trade volume models, and allocation prices are lagged in the entitlement trade volume models. \*  $P < 0.10$ , \*\*  $P < 0.05$  and \*\*\*  $P < 0.01$  indicate significance at the 10%, 5% and 1% levels, respectively. No marginal effects are reported for non-linear variables; instead, the marginal effects at the mean value are reported for the linear term

**Table IV** Standard errors (and coefficients) for Table 2

	Entitlement sale		Entitlement purchase		Allocation sale		Allocation purchase	
	Coefficients	Standard errors	Coefficients	Standard errors	Coefficients	Standard errors	Coefficients	Standard errors
Entitlements owned (log ML)	-0.042	0.194	-0.095	0.332	0.704***	0.194	-0.018	0.268
Groundwater extraction (log ML)	0.341***	0.115	0.075	0.145	-0.013	0.079	-0.032	0.096
Allocation level (%)	0.013	0.013	0.007	0.020	0.001	0.009	-0.028**	0.012
Entitlement price (log \$/ML)†	-0.795	1.165	-3.229**	1.489	-2.005**	0.982	0.374	1.417
Allocation price (log \$/ML)†	0.083	0.484	2.281***	0.675	-0.224	0.656	-1.391	0.865
Irrigated cropping (%)	0.350***	0.068	0.148*	0.084	0.144*	0.080	0.307***	0.083
Irrigated horticulture (%)	-0.009	0.024	-0.006	0.039	-0.038	0.029	0.013	0.042
Irrigated grazing (%)	-0.014	0.027	-0.014	0.030	-0.035	0.030	0.069**	0.027
Net rainfall (mm/year)	-0.017***	0.006	-0.005	0.008	-0.008***	0.002	0.0001	0.003
Soil texture	0.047	0.302	0.686	0.444	0.124	0.313	0.443	0.390
Dryland salinity (dummy)	1.127**	0.478	-1.140*	0.693	0.765	0.527	0.873	0.657
Distance to downstream area (km)	-0.001	0.001	-0.005**	0.002	-0.003**	0.001	-0.005***	0.002
Distance to cities 1000 (km)	0.210***	0.071	0.058	0.102	0.049	0.043	0.203**	0.085
Distance to cities 1000 squared (km)	-0.002***	0.001	-0.001	0.001	-0.001	0.000	-0.002*	0.001
Population density (log)	0.557**	0.276	0.341	0.524	0.158	0.254	0.624	0.387
SEIFA index	-0.007	0.006	-0.022**	0.009	-0.008	0.006	-0.024***	0.008
Primary production business income	0.030*	0.017	0.010	0.020	0.001	0.005	0.001	0.005
Government benefits (log)	-3.777**	1.495	0.170	1.983	-0.030	0.833	-0.570	0.997
2011/12					-0.283	1.039	-0.570	1.382
2012/13					1.253	1.350	0.181	1.800
2013/14					2.616***	0.836	2.819***	1.093
Constant	39.54**	17.043	34.21	21.879	17.58	11.890	13.18	14.645

Note: \*  $P < 0.10$ , \*\*  $P < 0.05$  and \*\*\*  $P < 0.01$  indicate significance at the 10%, 5% and 1% levels, respectively.

**Table V** Standard errors (and marginal effects) for Table 2

	Entitlement Sale		Entitlement purchase		Allocation sale		Allocation purchase	
	Marginal effects	Standard errors	Marginal effects	Standard errors	Marginal effects	Standard errors	Marginal effects	Standard errors
Entitlements owned (log ML)	-0.025	0.114	-0.050	0.176	0.536	0.146	-0.014	0.206
Groundwater extraction (log ML)	0.201	0.067	0.040	0.077	-0.010	0.060	-0.025	0.074
Allocation level (%)	0.007	0.008	0.003	0.011	0.001	0.007	-0.021	0.010
Entitlement price (log \$/ML) <sup>†</sup>	-0.469	0.687	-1.708	0.787	-1.525	0.744	0.288	1.089
Allocation price (log \$/ML) <sup>†</sup>	0.049	0.285	1.206	0.354	-0.170	0.499	-1.069	0.664
Irrigated cropping (%)	0.206	0.039	0.078	0.044	0.109	0.061	0.236	0.063
Irrigated horticulture (%)	-0.005	0.014	-0.003	0.021	-0.029	0.022	0.010	0.032
Irrigated grazing (%)	-0.008	0.016	-0.007	0.016	-0.027	0.023	0.053	0.021
Net rainfall (mm/year)	-0.010	0.004	-0.002	0.004	-0.006	0.002	0.0001	0.002
Soil texture	0.028	0.178	0.363	0.235	0.094	0.239	0.340	0.3
Dryland salinity (dummy)	0.665	0.281	-0.603	0.366	0.582	0.400	0.671	0.504
Distance to downstream area (km)	-0.001	0.001	-0.003	0.001	-0.002	0.001	-0.004	0.001
Distance to cities 1000 (km)	0.079	0.026	0.018	0.032	0.023	0.024	0.106	0.038
Distance to cities 1000 squared (km)						0.193		
Population density (log)	0.329	0.163	0.180	0.277	0.120		0.479	0.297
SEIFA index	-0.004	0.004	-0.011	0.005	-0.006	0.005	-0.019	0.006
Primary production business income	0.018	0.010	0.005	0.0107	0.001	0.004	0.0005	0.004
Government benefits (log)	-2.228	0.878	0.090	1.049	-0.023	0.634	1.223	0.765
2011/12					-0.215	0.791	-0.438	1.062
2012/13					0.953	1.027	0.139	1.383
2013/14					1.990	0.635	2.167	0.838
Constant								

Note: For significance levels of marginal effects, please refer to Table IV.