A Thirst for Efficiency:
Finding the Relationship between Water Trading and Agricultural Water Use Efficiency in the Murray-Darling Basin

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Declaration

Except when appropriately acknowledged this thesis is my own work, has been expressed in my own words and has not been previously submitted for assessment.

____________________________ Date: 26/10/2012

Signed

Roger Hassan

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Abstract

The Australian government has put forward many policies in the past three decades with the aim of increasing water market activity. Water trading is widely thought to transfer water to its highest productive use in order to extract the greatest benefit to society. This paper employs an empirical analysis of the agricultural water market in the Southern Murray-Darling Basin in order to determine whether trading has indeed induced agricultural water use efficiency. This thesis focuses on technical water use efficiency as it searches for evidence that water trade has induced innovation in minimizing water use at the farm level. This research is done on three different scales in order to test the relationship between water trade and the efficiency of its use in several situations.

First a cross-sectional analysis of the Goulburn Murray Irrigation District shows an increasing trend in water use efficiency between 1998/99 and 2010/11, although only a weak relationship with trade is found. Second a panel-data regression is performed across the four Murray-Darling Basin states in order to estimate the relationship that both permanent and temporary trade has on water use efficiency. The results of the panel regression conclude that while a 1GL increase in permanent water entitlement trade has led to a 0.00089ML/Ha increase in water use efficiency over the past 15 years, there is no hard evidence that temporary trade has had the same effect. Finally a case study of the dairy industry in the Goulburn region models the incentives faced by farmers who can substitute between feed grain and water for pastured grass as production inputs. Given water and grain prices it is possible to illustrate the optimal decision making of farmers in 2007/08 to see the positive impact of water trading in promoting economic efficiency.

This thesis makes an important empirical contribution to the current literature on water markets. The analysis done determines the relative success of permanent water entitlement trade in inducing innovation in water use; this innovation in water use increases technical water use efficiency.

Word Count: 10,658

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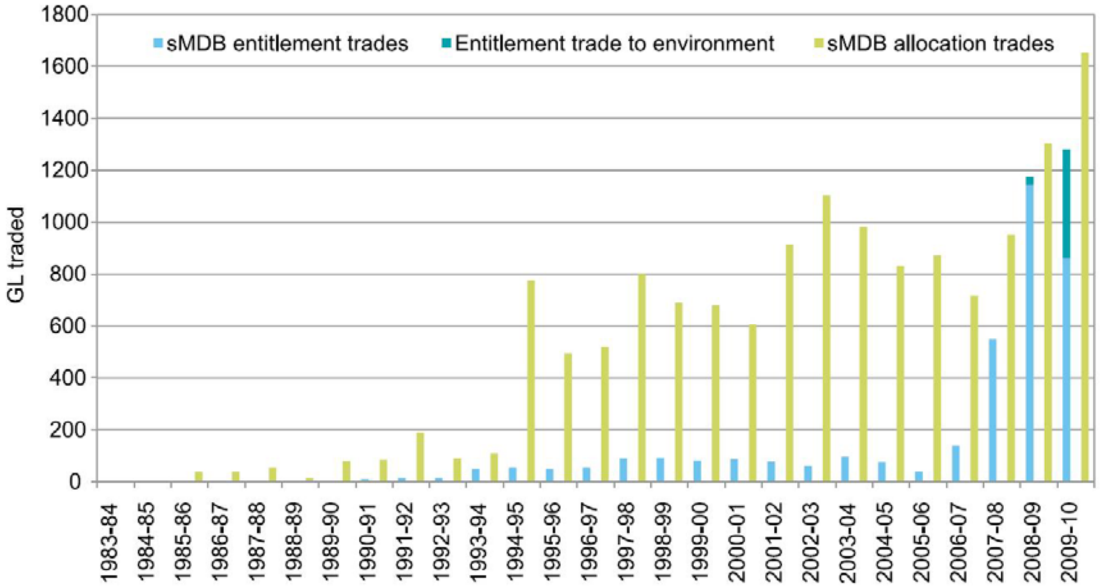
1 Introduction

As the world develops and populations continue to grow, water is becoming a more scarce and valuable resource than ever before. It is becoming increasingly important to manage water in an efficient manner so as to extract the highest benefit from existing supplies and water markets have a large role to play in promoting this efficiency. Basic economic theory suggests that the introduction of water property rights enables a market for trade in water entitlements and allocations. Water trading is an important economic mechanism which can be used to transfer water to its highest valued use at any point in time (Peterson, Dwyer, Appels, & Fry, 2004). It is this movement of water which promotes efficient investment and innovation in water use which maximises the value of water to society. Although this relationship is theoretically clear, there is little information regarding the true impact of water trade on the efficiency of its use. Utilising the theoretical model of trade this paper aims to determine the empirical relationship between trade in water and its effect on agricultural water use efficiency.[1]

FIGURE 1.1 TOTAL ENTITLEMENT & ALLOCATION TRADES ALONG SOUTHERN MDB, 1983/84 TO 2009/10



Source: National Water Commission (Water Markets in Australia - A Short History, 2011)

Australia’s water use is in a phase of maturity whereby most sources of water supply are being exploited and it is this limited supply of water which has made it possible for markets to emerge (Randall, 1981). This paper examines the water market for the Murray-Darling Basin (MDB) due to its standing as one of the most developed in the world. The history of water trading along the Southern MDB is illustrated in Figure 1.1 which illustrates an increasing trend of both permanent (entitlement) and temporary (allocation) trades since 1983/84. Government policies have been instrumental in the

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[1] Water use efficiency has no standard definition and is measured in this paper via different performance indicators of the value of water in a productive capacity.

introduction and facilitation of the water market as illustrated by the spike in allocation trades after the 1994 Council of Australian Governments (COAG) Water Reform Framework policy. Similarly there was a dramatic increase in entitlement trade following the introduction of the 2007 Water Act. Government buybacks of water for the environment have increased since 2008/09 to become a large portion of entitlement trade in 2009/10 and illustrates the high valued use of water in being returned to the environment.

The COAG framework (1994) outlined the formal structure of the MDB water market with its aim for *"a system of tradeable entitlements to allow water to flow to higher value uses subject to social, physical and environmental constraints."* Although the market for water now exists it is important to determine whether greater market activity in the Southern MDB has indeed made some headway towards achieving its goal of greater water use efficiency.

This thesis is divided into three main sections which analyse the impact of the water market on different scales. First a cross sectional analysis of the Goulburn Murray Irrigation District (GMID) is performed in order to determine how water use efficiency has changed from the introductory period of water trading to recent time. Taking a snapshot of the GMID in 1998/99 and 2010/11 the analysis finds an increase in the efficiency of water use between these periods; however the causal relationship is undetermined.

Second a more comprehensive analysis is performed using a panel regression at the state level in order to determine if an empirical relationship between water trading and efficiency exists. The results of this model predict a significant positive relationship between permanent water entitlement trading and water use efficiency and are largely robust to potential endogeniety problems. It is found that although there is a positive relationship between temporary water allocation trade and efficiency these results are not significant.

Finally a case study of the Goulburn dairy industry is undertaken to model the incentives faced by farmers in the presence of water markets. The case study employs a model which views water for pasture growth as a substitute for dairy cattle feed grain. The model is then matched with real grain and water prices in the Goulburn region in an attempt to explain the nature of water being traded to a higher valued use at the farm level. The analyses performed in this paper provide evidence that water trading along the MDB has led to an increase in water use efficiency as hypothesised. However it is clear that more can be done to further liberalise trade so as to obtain greater gains from water markets.

The remainder of the thesis is structured as follows. Section 2 reviews relevant literature surrounding water trade theory and provides a brief history of water markets to appropriately inform the motive for this research. Sections 3, 4 and 5 describe the methodologies and results of the three main segments outlined above respectively. Section 6 concludes, discussing the findings and implications of this research.

2 Review of Relevant Literature and History

2.1 Water Trading: A Theoretical Analysis

The COAG Water Reform Framework in 1994 was the necessary first step which made considerable headway in placing the government view on water as an economic good. It is widely thought that water markets are an additional tool which can be used by irrigators in managing water availability uncertainty. Markets are also able to introduce flexibility into an irrigator's production and water decisions by allowing them to respond effectively to exogenous factor changes such as drought, input prices and business objectives (National Water Commission, 2011).

Water markets operating in a shared river (such as the MDB) set a cap on the total sustainable diversion of water for consumptive and productive use and individuals are given the right to a share of this diversion. In Australia this right to extract water from a certain point along the MDB is referred to as an e*ntitlement*. Each entitlement is bundled with a particular share of water allocated for diversion, defined as an *allocation*, which may change from season to season. These entitlements and allocations represent legal ownership, control and use of a packet of water and must be voluntarily tradable at a market determined price which represents the value of the water by both sellers and buyers (National Water Commission, 2011).

The cap and trade system relies heavily on the correct measurement of the cap. The cap must be set at the maximum limit of water that can be diverted from the total resource pool considering the long-term environmental sustainability of the resource's production ability. The trade aspect of this market allocation method is the main focus of this paper and as such the relevant economic theory regarding water trade is presented as a basis for the empirical research conducted. Water trading relies on the same economic principles of trade as any other market based trade mechanism whereby the market will price water to represent its marginal value. This pricing allows buyers and sellers to reallocate water to those uses which are valued more highly in both the short and long term.

Bjornlund & McKay (2002) clarify the trade of temporary allocations as being a response to temporal, often climatic, changes and the transfer of permanent entitlements as a restructuring of water demand in favour of higher valued uses over the long term. Formal water markets include both temporary and permanent trades which are registered by a formal water authority.[2] Water entitlements are classed in two main categories; high and general securities (State Water, 2012). High security entitlements grant its users an allocation of water which is guaranteed irrespective of circumstance. General security

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[2] The trade of temporary water is defined as the transfer of an allocation for the duration of no more than one year. Permanent trade refers to the transfer of water entitlements for periods longer than one year, with trades usually occurring on a permanent basis for the foreseeable future. For example the trade data for 2007/08 includes all temporary trades ranging from July 1 2007 to June 30 2008 as well as any permanent transfers within this time period.

entitlements provide allocations subject to demand circumstances. This paper focuses on high security entitlements (the majority of entitlements) due to their reliability.[3]

In the short term, temporary seasonal allocations can be traded to allow water to move across different crops, irrigators and locations with differing demands in response to changing environmental conditions. The existence of the cap means that only a finite amount of entitlements are available, therefore trade in these entitlements in the long term facilitates structural adjustment of different water use industries. This dynamic efficiency often comes in the form of more water efficient firms tending to enter the market in the place of the less efficient firms or expand the market further (National Water Commission, 2011). The market based system can promote productive efficiency whereby the water price signal provides incentives for firms to make efficient use of its inputs by increasing the farm water use efficiency as a result of the firms being confronted with the opportunity cost of their water use decisions.

This thesis makes the distinction between technical and economic efficiency brought about by water trade. The economic efficiency outlined below illustrates efficiency as the achieving the maximum value of water use across different irrigators. This efficiency is achieved through the reallocation of water to uses where it is more productive. This paper recognises the importance of economic efficiency in maximising the productive surplus to society. Technical efficiency involves the production capacity of water as induced by innovation in its productive process. The methodologies outlined in this paper generally focus on the technical efficiency which is naturally linked to trade in entitlements. Trade in entitlements signify the movement of water permanently to those processes which gain the greatest benefit from a particular volume of water. This incentive to use water more efficiently encourages innovation by farmers to retrieve greater production yield per drop of water.

Figure 2.1 illustrates the possible gains from trade in the water market in the absence of barriers to trade using basic microeconomic principles. The horizontal axis illustrates the cap aspect of the system whereby there is a finite volume of water which can be shared between the two regions. Both vertical axes represent the price of water which reflects the marginal product of water. Region 1 has a value of marginal product (VMP) which is downward sloping to represent the diminishing marginal product of water. Region 2 has a VMP which is also downward sloping originating from the right vertical axis; essentially mirroring the VMP faced by region 1.

If trade is not possible, the quantity of water used by both regions lies at the point $Q_{no\ trade}$. At this quantity region 1 uses more water however the VMP of water earned at this quantity is lower than if it were used by region 2. At this point region 1 has a surplus equal to the area $a + b + c + d$ and region 2 has a surplus area of $f + g$. If trade is possible region 2 would be willing to purchase water from

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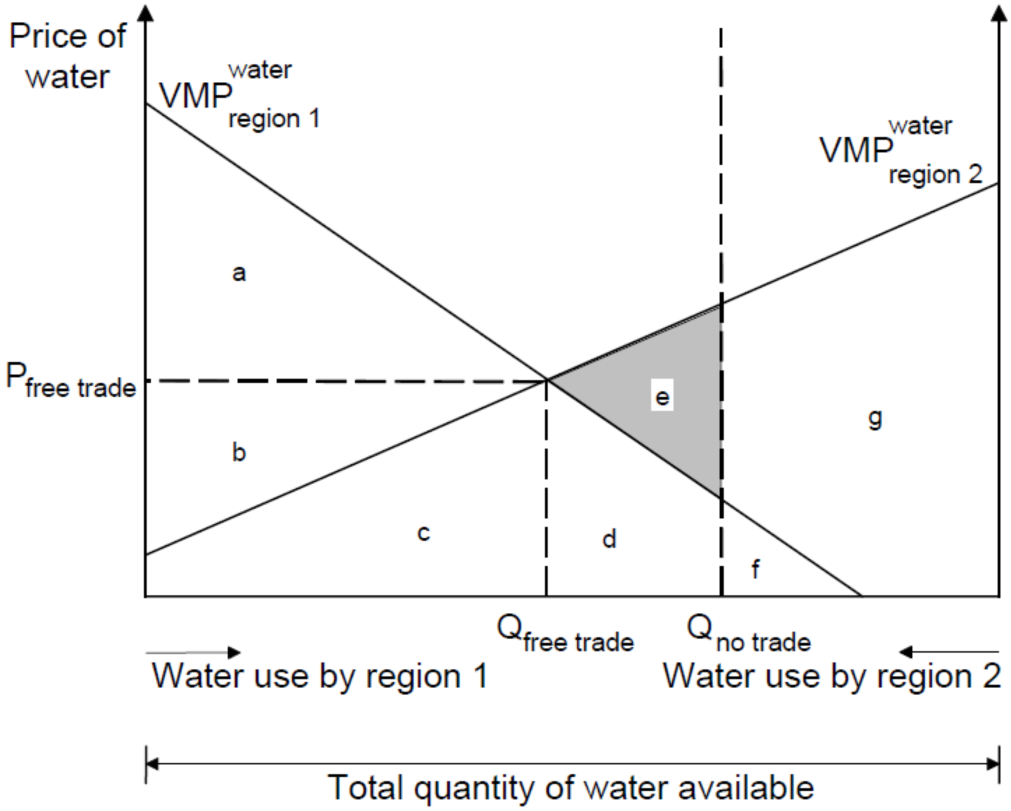
[3] The term general security applies to New South Wales whereas Queensland refers to the same entitlements as medium security. Both Victoria and South Australia use the term low security (Porter, 2009). This paper uses the term general security in place of the other possible names.

region 1 as the VMP from water is greater for this region. Region 2 would compensate region 1 for this additional water traded until the VMP are equal for both regions at which point neither party has any incentive to trade further.

FIGURE 2.1 ILLUSTRATIVE GAINS FROM TRADE IN WATER



Source: Productivity Commission (Peterson, Dwyer, Appels, & Fry, 2004, p. 26)

The market arrives at the point $Q_{free\ trade}$ where the VMP of both regions are equal. Region 1 is now left with the surplus area $a + b + c$ and region 2 is left with the area $d + e + f + g$. Therefore there is a net gain of surplus area e to the market which represents the total gains from trade. This model is useful under the assumptions of zero transaction costs in trading and that the VMP corresponds to both the social and private valuations (Peterson, Dwyer, Appels, & Fry, 2004). Although these assumptions are not accurate in the real world the lessons in trade remain true.

The main elements of water market design outlined by the NWC (2011) are addressed by the Council of Australia Governments Water Reform Framework (1994). There are three main aspects of the framework which are believed by Turral et al (2005) to have been the main catalysts in furthering development of an Australian water market. Section 4.a of the COAG framework determines the need to separate water property rights from land title. This key action aims to fulfil a major market precondition being the clear specification of property rights; in this case the motivation in determining clear rules of entitlements is necessary in removing barriers to trade. This separation of land and water rights dramatically reduced the transaction costs associated with trade, prior to this separation individuals who wished to purchase water also had to purchase the land associated with the water entitlement. The framework outlines the property rights necessary for an efficient market as having *"clear specification of entitlements in terms of ownership, volume, reliability, transferability and, if appropriate, quality"*.

Section 4.b of the COAG framework outlined the need for the environment to become a separate and genuine user of water through the inclusion of allocations for environmental flow. This element reflects the need for the cap set the following year to ensure the threshold of water available for environmental sustainability is not crossed. This element's importance cannot be understated, if the environmental sustainability limit is breached, the long term health risk of the river increases future uncertainty for farmers. This risk can lead farmers to use their water inputs inefficiently due to the reduced future security of their entitlements and allocations. Section 5.a of the framework states the proposition that water must be traded in order to bring maximum benefit to national welfare subject to social, physical and environmental constraints illustrating the motivation towards a more comprehensive and efficient market for water.

2.2 History of Water Trading: Globally

There are several papers which attempt to outline the success of water markets around the world in promoting efficient water management practices. This section reviews relevant literature and experiences which use empirical analyses to identify whether water trading increases farm water use efficiency. A move toward free-market water trading followed the 1973 military coup in Chile, formalising secure property rights and reintroducing markets in the following years. By 1981 the National Water Code led to a separation of water rights from land, making them freely tradable and introducing obligatory registration of all water transfers (Bjornlund & McKay, 2002, p. 774). These were similar strategies as outlined over a decade later in Australia by the COAG framework mentioned above. While temporary trade in water allocations occur frequently, the extent of permanent trading has been quite low in the decades following the introduction of the Water Code. Bjornlund and McKay outline the main impediments to trade in the Chilean water market, these include: the physical cost of water redistribution following a transfer, legal uncertainty in the registry of water rights, social values and the availability of cheaper options such as ground water or dams.

Hearne and Easter (1997) surveyed several areas in Chile as case studies in order to assess the impact of water markets. The authors calculated net gains from trade in the Elqui Valley as being approximately US$1265.13[4] per share on average for 712 shares of the river as well as higher net rents produced from inter-sectoral trade rather than trade between farmers. In the Limarí Valley there was an estimated average net gain from trade of approximately US$3.84 per m^3/year transferred and it is mentioned that some permanent transfers of water use rights moved from traditional crops towards higher valued fruit

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[4] 1993 prices adjusted for inflation to 2012 prices using the CPI index of 160.

crops. It is difficult to separate the effect of the Water Code on the agricultural sector from the general liberalisation of trade and secured land rights, however this irrigation dependent sector managed to expand despite lack of investments in irrigation infrastructure.

Recently Pujol et al (2006) aimed to *"evaluate to what extent water markets may contribute to the improvement of the efficiency of water allocation and to the profitability of irrigated agriculture."* The authors used linear program modelling of profit-maximising farms with fixed and variable transaction costs in Southern Italy and Spain water markets, comparing between a market and non-market situation in two study areas. With no transaction costs the model results in a maximum increase of approximately 176€/ha[5] in Low Ter (Spain) with generated benefits by the water market increasing by up to 30%, and an increase of approximately 107€/ha in Foggia (Italy). The paper found that proportional transaction costs mainly impact the amount of water sold and fixed transaction costs impact market entry or exit. The paper concludes with the message of the potential for water markets to improve economic efficiency of water use and that the extent of benefits gained has a vital dependence on the level of transaction costs.

Texas has been another example of the successful impact of water markets on the increase in water use efficiency. The Water Rights Adjudication Act introduced in 1967 clearly specified water rights by converting surface rights into a permit system which are adjudicated by the Texas Water Commission. This market is found to have moved water from its traditional agricultural use to municipal and industrial purposes in the valley where its benefits surpass the opportunity cost of some agricultural activities (Chang & Griffin, 1992).

2.3 History of Water Trading: Australia

It is believed that the Australian water economy began to enter its phase of maturity by the 1980s after decades of expansion (Randall, 1981). Of the Southern MDB states, South Australia began formal water trading in 1983, with New South Wales following in 1989 and Victoria in 1991 (Olmstead, 2010). Although informal water trading has occurred along the MDB in the past (Turral, et al., 2005), it was the Water Reform Framework in 1994 which recognised the use of market principles in determining effective water policy (Council of Australian Governments, 1994). This reform made necessary changes to the way in which water was handled and was instrumental to the successful development and growth of the Australian water market.

In 1995 the Murray-Darling Basin Ministerial Council (MDBMC) implemented a water audit reporting a significant increase in water diversions from the MDB which could lead to poor river health (Murray Darling Basin Ministerial Council, 1995). The states agreed to placing a cap on the volume of water diverted from the MDB at the 1993/94 levels of development. The cap became an establishing feature

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[5] 2006 prices adjusted for inflation to 2012 prices using the CPI index of 113.

of the management of the health and sustainability of the river system. The inclusion of the cap meant that any future developments along the river should come from improved efficiency of water use or the purchase of water from already existing developments; this was likely to increase growth in water trade (Independent Audit Group, 1996).

In 2000 water transfers were difficult to trade interstate due to the differing licensing systems between states. However after the first interstate trade in 1998, 9.8GL of water was traded inter-state in the following two years (Young, MacDonald, Stringer, & Bjornlund, 2000). In 2004 the MDB states later agreed to the National Water Initiative (NWI) set out by COAG whose reform extended that of the 1994 Water Reform Framework and solidified specific commitments to expand the trade in water among the overall objective to *"achieve a nationally compatible market, regulatory and planning based system of managing surface and groundwater resources for rural and urban use that optimises economic, social and environmental outcomes"* (National Water Commission, 2011).

A key action of the NWI had the states implement public and reliable registers of all permanent and temporary water entitlements and trades, this objective led to the establishment of a Water Registers Working Group by the National Water Commission (NWC) to implement this action. The NWI also lead to action by the Water Trading Group and the Murray-Darling Basin Commission (MDBC) on the removal of institutional barriers to trade within and between states (Australian Government, 2006). The Water Act 2007 further bolstered the responsibilities of the NWC in contributing to the further development of the national water market and established the Murray Darling Basin Authority (MDBA). Advised by the Australian Competition and Consumer Commission, the NWC and MDBA were tasked with *"the creation of water charge, water market and water trading rules"* all reforms of which were enacted by 2010 (National Water Commission, 2011). In 2008 Water Amendment Act led to the transfer of MDBC functions to the MDBA. One of the key roles of the newly formed authority was to facilitate water trading across the MDB through the development of an information service for water rights as well as the measuring and monitoring of basin water resources (Australian Government: DSEWPC, 2011).

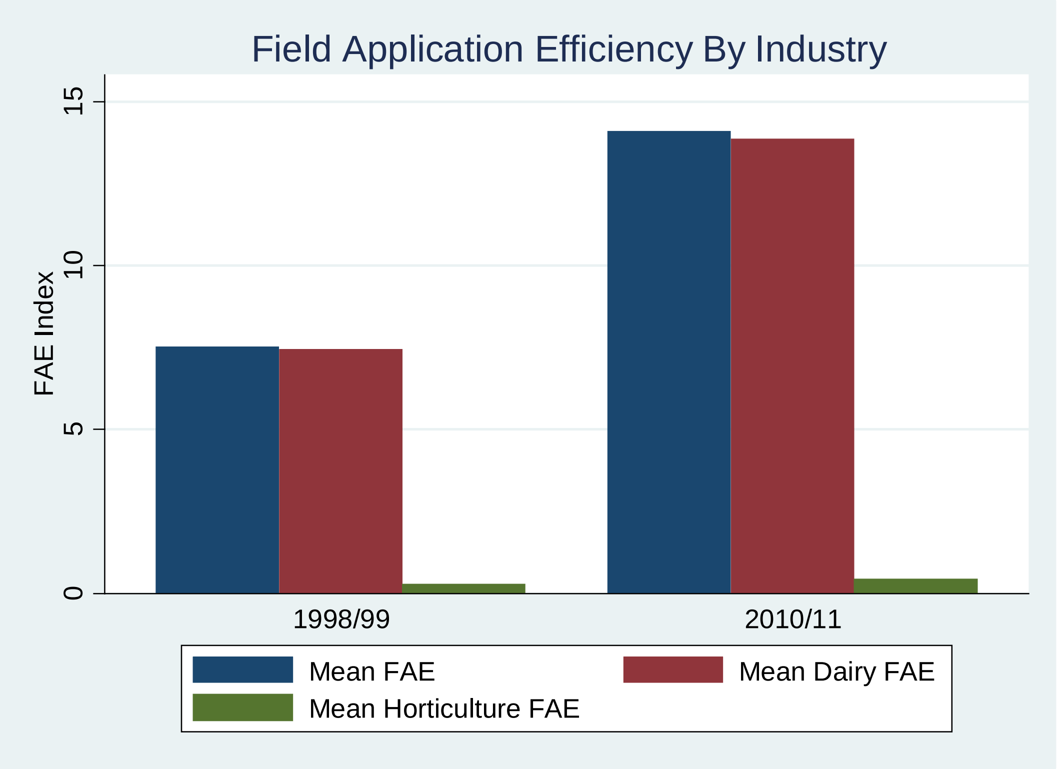
Water trading has not been a major determinant in socio-economic change along the MDB however it has been considered a mechanism for assisting change. There is evidence of water trading having increased the rate of industry adjustment in communities which are dependent on irrigation. For example increased volumes of water have moved out of the dairy industry in northern Victoria and rice industry in NSW (National Water Commission, 2010, p. 100). Intraregional trade has benefited regions as the value of agricultural production has increased despite reductions in aggregate water use between 2001 and 2006 (Australian Bureau of Statistics, 2012). Modelling by the Productivity Commission (Peterson, Dwyer, Appels, & Fry, 2004) indicates that intraregional trade accounts to more than 50% of the economic benefits and that trade is viewed positively in the community.

3 Cross Sectional Analysis

3.1 Descriptive Statistics

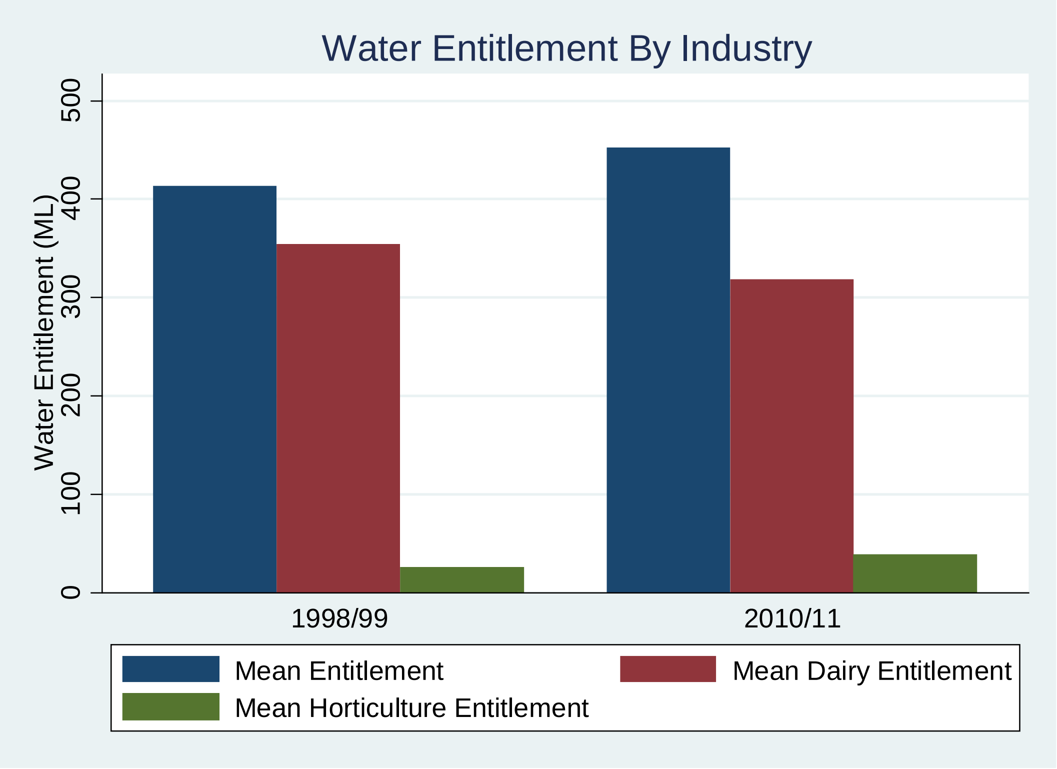
In order to determine if there is a relationship between the rising activity of water markets and an increase in farm water use efficiency it is important to first see how water use behaviour has changed over time. The cross sectional analysis of the Goulburn Murray Irrigation District (GMID) drew on farm survey data sourced from Sarah Wheeler and Henning Bjornlund at the University of South Australia. The data used in this section utilises farm survey data in both 1998/99 and 2010/11 with the aim of illustrating the evolution of farm level water use behaviour over the past decade. The information used focuses on the dairy and horticulture industries as these are the major agricultural enterprises in the GMID and help shed light on the behaviour of water use in different industries.

FIGURE 3.1 INDEX OF EFFICIENCY BY INDUSTRY IN 1998/99 & 2010/11



Simply looking at the average values of several important variables can describe how water use has changed on farms as well as illustrating trading behaviour. Figure 3.1 shows the increase in the average of the efficiency index (explained in Section 3.2 below) signifying that the efficiency in which farmers divert water to crops/dairy relative to their respective requirements has increased since 1998/99. It can be seen that the dairy industry is the primary driver of increased efficiency in the GMID, likely due to the large scale of dairy production relative to horticulture in this region. Figure 3.2 illustrates a statistically significant increase at the 1% level from an average of 413ML of maximum high security water entitlements in 1998/99 to 452ML in 2010/11. This increase in average entitlements likely comes from the horticulture industry (significant at 6%) as the dairy industry had lower water entitlements (significant at 1%) in 2010/11.[6]

FIGURE 3.2 WATER ENTITLEMENT BY INDUSTRY IN 1998/99 & 2010/11



Interestingly despite an increase in entitlements, Figure 3.3 shows that there has been a highly statistically significant decrease at 1% in the average amount of water used, from 476ML in 1998/99 to 240ML in 2010/11. Most of this decrease in average water use has come from the dairy industry (significant at 1%) which illustrates the general trend that will be illustrated in Section 5.2 of a net export of water out of this industry. This increase in average water entitlements coupled with a decrease in water use can be explained in part due to the unbundling of water entitlements in Victoria in 2007 (Victorian Water Register, 2012). This policy allowed the separation of entitlements to water shares which could be traded elsewhere, presumably to a higher valued use.

Figure 3.4 illustrates the average net allocation traded by industry between 1998/99 and 2010/11. Therefore positive values signify a net import of water into the industry and negative values a net export of water from the industry. The graph shows an increase in the average net allocation trade between both horticulture and dairy industries, however deconstructing the industries shows that most of this increase came from the horticulture industry; the dairy industry actually showed a decrease in the average net allocation traded. It is important to note however that the average total and dairy net

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[6] Results of the respective significance tests are available in Appendix C.

allocation trade is insignificantly different between years, however the difference between horticulture net allocation trade between years is significantly different at the 6% level.

FIGURE 3.3 WATER USE BY INDUSTRY IN 1998/99 & 2010/11

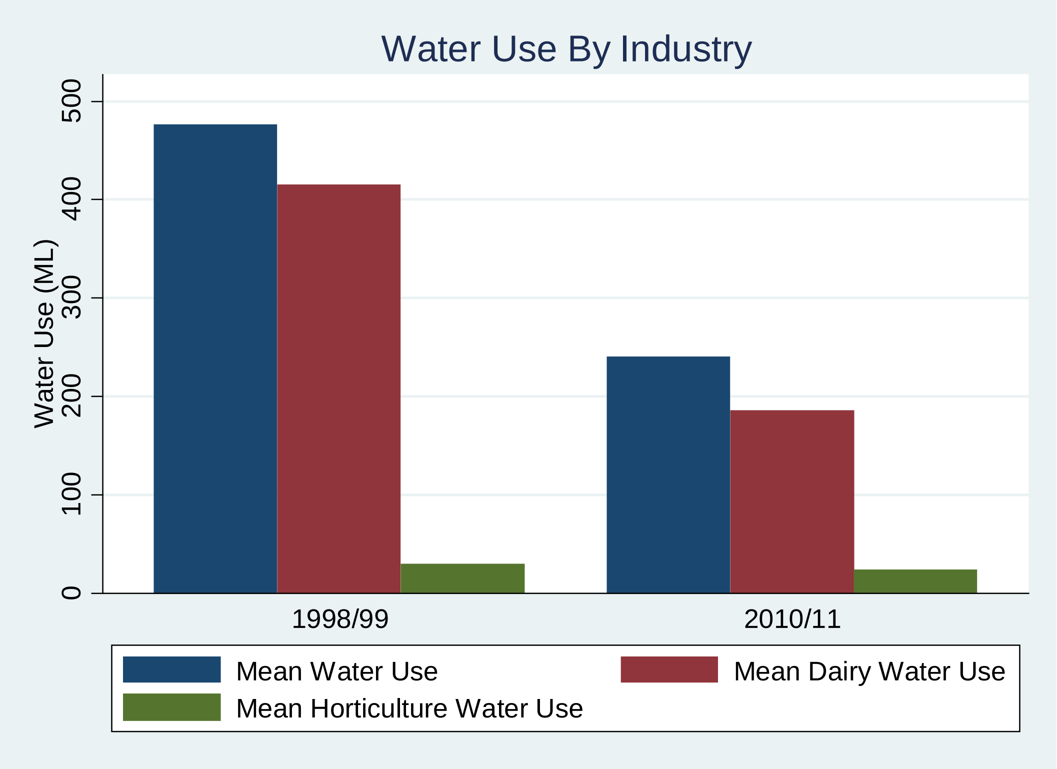
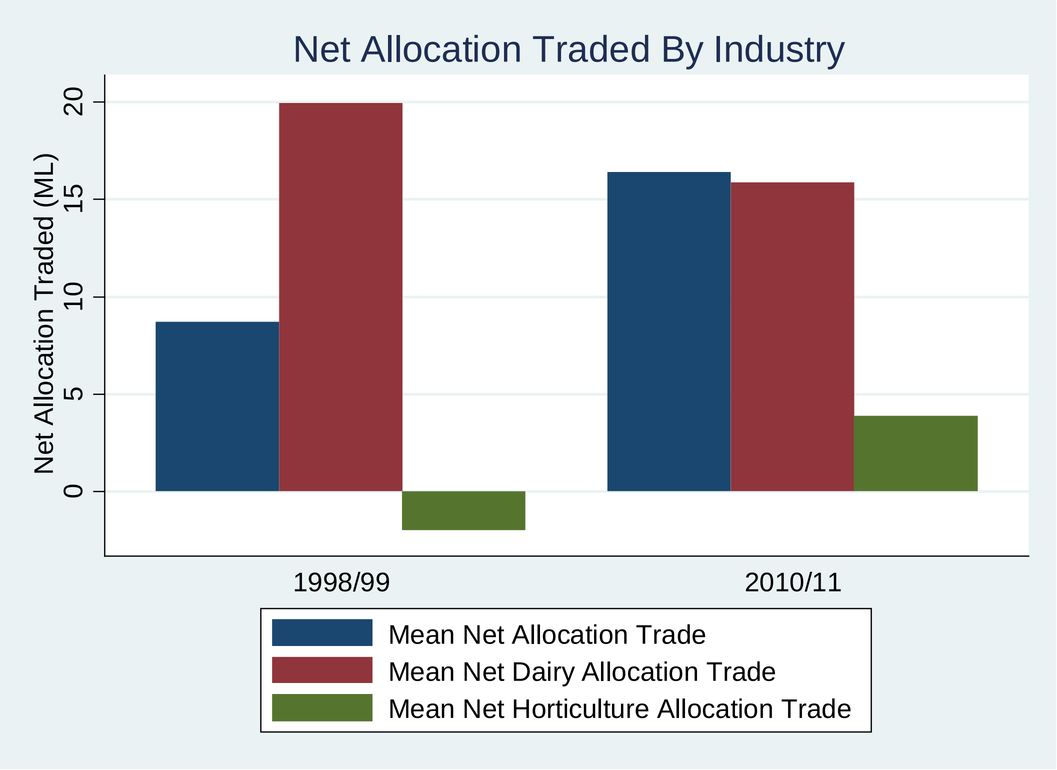


FIGURE 3.4 NET ALLOCATION TRADED BY INDUSTRY IN 1998/99 & 2010/11



3.2 Methodology

The first task of this analysis was to choose an appropriate index to resemble efficiency. Constrained by data availability, the FAE index was used as the measure of technical irrigation efficiency. A similar approach had been by adopted elsewhere in the literature (Wheeler, Zuo, & Bjornlund, 2010). The FAE index is calculated as the ratio of the crop irrigation water requirement (WR) to the amount of water delivered (WD) to the field as outlined by Bos et al (1994, p. 244):

$$FAE = \frac{WR}{WD}$$

In order to find the crop irrigation requirement it was necessary to use the different water requirements for both dairy and horticulture products. Wheeler et al outlined the water irrigation requirement for several agricultural industries as calculated by the Victorian Department of Primary Industries (DPI). The water irrigation required for the dairy industry in the Central Goulburn Irrigation Area was estimated at 11 ML/Ha in 2004. The Victorian DPI also estimated the water requirement for the horticulture industry at 5.84 ML/Ha in the Shepparton Irrigation Region in the same year. The total water requirement for the entire area of product irrigation was therefore calculated using the total irrigated grazing area for dairy cattle and horticulture respectively:[7]

$$WR = 11 \times Area_{dairy} + 5.84 \times Area_{horticulture}$$

The water delivery (WD) to field is utilised straight from the farm survey data as the amount of water used in the given year applied to the field. The FAE index is very intuitive in its interpretation as the index characterises an increase in the FAE ratio as an increase in efficiency. Two different regression analyses were tested in order to find out how behaviour towards water use efficiency has changed over the past decade or so. The analysis first begins with a standard Ordinary Least Squares (OLS) model which regressed on the FAE index a constant (α), the error term (ε). A vector of 27 independent variables (X) encompassing variety of farm, irrigation, social and economic properties were chosen as theoretically likely candidates which may be of interest in determining possible changes in water use behaviour:

$$FAE = \alpha + \beta X + \varepsilon \qquad (3.1)$$

The OLS model experienced high variability in the FAE index which could possibly have the results influenced by outlying data. Wheeler et al (Wheeler, Zuo, & Bjornlund, 2010) also tested a binary probit model in order to reduce this variability. This model was chosen in order to account for the possible overestimation of water use by farmers, however in doing so does remove some information from the FAE index. Therefore the binary probit model is primarily used to check the robustness of the OLS

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[7] Calculation of the water requirement followed a similar method as outlined in the Draft Report to the NWC.

model. The use of a binary probit model meant the index had to be coded using a dummy variable subject to the following values:

$$FAE = \begin{cases} 1\ if\ FAE_i^* > 1 \\ 0\ otherwise \end{cases}$$

$$FAE_i^* = \alpha + \beta X + \varepsilon \qquad (3.2)$$

The probit regression outlined in equation 3.2 follows a general probit model using the same vector of independent variables (X) used in the OLS regression. The probit model was chosen over the comparative logit model due to the probit regression following a normal rather than logistic distribution which more appropriately describes the use of the collected survey data.

3.3 Results

The OLS and binary probit regressions outlined above provide an important picture on the efficiency in which these farms have operated between 1998/99 and 2010/11.[8] Table 3.1 below shows the results for OLS and probit regressions as well as a check of the robustness of the results. Column 1 states the OLS results of a 1998/99 year dummy variable's effects on the FAE index. This column states that being a farm in 1998/99 leads to a 6.6 point decrease in the FAE index, suggesting that farms in 1998/99 were less technically efficient on average than those in 2010/11; however this result is insignificant. The second column includes many possible omitted variables such as temporary water bought as well as percentage of irrigated area by industry. The inclusion of these variables increases the negative effect of the year dummy to become an 11.9 point decrease in the index which is now significant at 10%. This result suggests that farms have innovated over this time period to increase technical efficiency of waters productive capacity.

Column 3 shows the initial probit regression resulting in a 0.108 increase in the FAE dummy in the existence of the 1998/99 year dummy. This result presents a counter argument to the OLS results as well as the figures above suggesting that being a farmer in 1998/99 is associated with greater efficiency than that of 2010/11. After adding in the same variables used in the second OLS regression there is a large shift in the results with the 1998/99 year dummy now showing a highly statistically significant decrease of 0.801 on the FAE dummy. The implementation of this robustness check implies that this initial probit result likely suffered from omitted variable bias. This change reaffirms the OLS results that farms were more technically water efficient in 2010/11 relative to 1998/99.

The sign of the 1998/99 year dummy is considerably more important than the magnitude mentioned above and it is this negative relationship between the year dummy and FAE which is most interesting. In order to further strengthen the findings of these regressions the variance inflation factors were calculated and a correlation analysis conducted. The mean variance inflation factor reported of 1.56

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[8] A table of summary statistics for the 27 variables used can be found in Appendix C.

implies very little existence of multicollinearity in the OLS regression. The correlation analysis performed reported low correlation between all significant variables and the standard errors were robust to any heteroskedasticity further strengthening the significance of the regression results.

Perhaps the most important result of these OLS and probit regressions is the overwhelming notion that farms have increased their water efficiency from 1998/99 to 2010/11. The dummy signifying temporary water bought in the respective year yields an unexpected result whereby more farms purchasing water has led to a decrease in FAE. This is likely due to the nature of the efficiency index used as the purchase of water is for the purpose of increasing the amount of water used on the farm, decreasing the FAE index value for that particular farm.

TABLE 3.1 OLS & PROBIT REGRESSIONS ON EFFICIENCY IN GOULBURN

	(1)	(2)	(3)	(4)
VARIABLES	OLS1 FAE	OLS2 FAE	Probit1 FAEdummy	Probit2 FAEdummy
Year 1998/99	-6.581	-11.88*	0.108	-0.801***
	(5.063)	(6.660)	(0.138)	(0.291)
Temporary Water Bought		-8.439**		-0.652***
		(3.443)		(0.216)
Irrigated Area (Ha)		0.0931*		0.0206***
		(0.0512)		(0.00464)
Irrigated Area (% Grazing)		0.175*		0.0436***
		(0.0964)		(0.00531)
Irrigated Area (% Horticulture)		0.0445		0.0236***
		(0.0567)		(0.00374)
Entitlement Water (ML)		-0.0203*		-0.00167***
		(0.0106)		(0.000534)
Total Water Use (ML)		-0.0121		-0.00228***
		(0.00918)		(0.000686)
Constant	14.10***	4.521	0.981***	-1.419***
	(4.722)	(5.082)	(0.0947)	(0.336)
Observations	497	497	497	497
R-squared	0.003	0.130		
Wald Chi2	.	.	0.611	86.95
Prob > chi2	0.194	0.0302	0.434	0
Pseudo R-squared	.	.	0.00145	0.534

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The variable for entitlement water yields an interesting result whereby an increase in the amount of entitlement water is associated with a decrease in the FAE index of 0.0203. This result suggests that farms with a larger entitlement are using water in a way which is less technically efficient than those with a smaller entitlement. This outcome can be explained by the notion that farms which have innovated to become more technically efficient in their productive capacity of water do not require large water entitlements due to this increased technical efficiency.

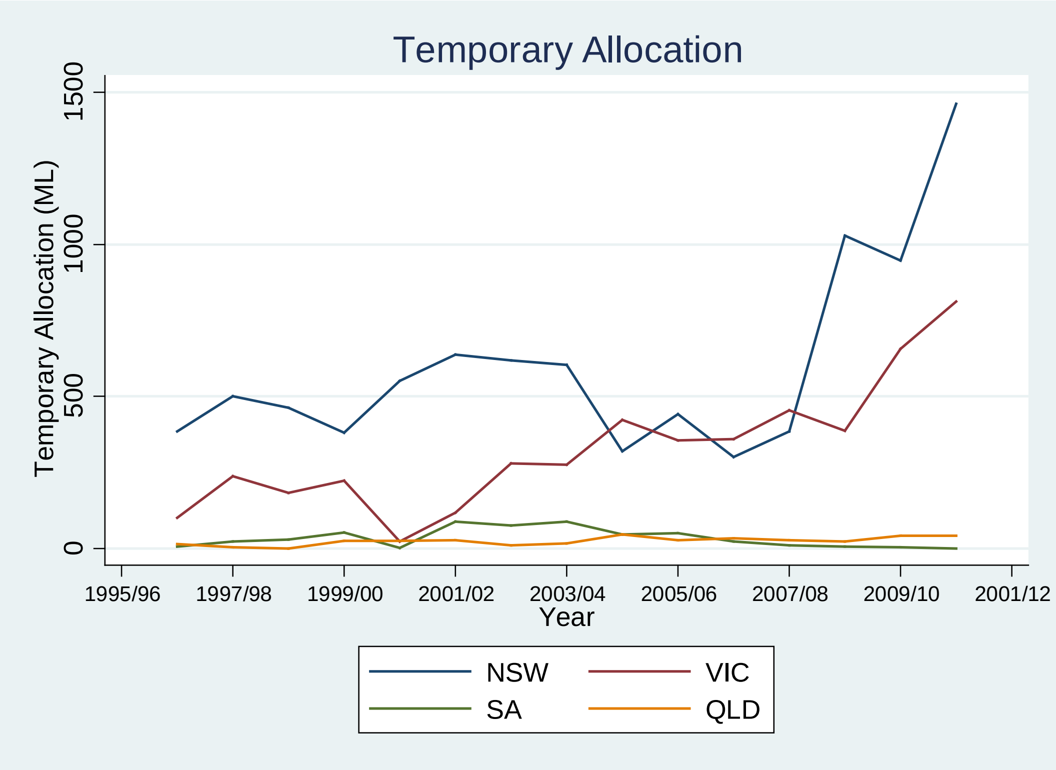
Although this cross sectional analysis has been helpful in painting a picture of water use behaviour at the micro level, the regressions did not show any significant impact of allocation traded on FAE. This effect may have been warped by the amount of rainfall in the survey years. Ideally a time-series could be used to show the evolution of allocation trading over this period, however due to data unavailability this paper is unable to comment further on the effect of water trading on FAE from these results.

4 Panel Data Analysis

4.1 Descriptive Statistics

In addition to the cross-sectional analysis this paper utilises a state level panel data analysis in order to estimate a relationship between water trading and on farm water use efficiency. A state level panel is used due to a lack of necessary trading and efficiency variables on a smaller scale over a substantial period of time. Water trading data comes from the MDBA (Water Audit Monitoring Report) from 1996/7 to 2010/11 which reports detailed data on trading within and between the four MDB states. This data is aggregated at the state level in order to remain consistent with irrigation and water volume application data sourced from the Australian Bureau of Statistics (ABS) by state over the same time period.[9]

FIGURE 4.1 TEMPORARY ALLOCATION TRADE BY STATE



This section provides a brief picture of the evolution of the water market in the four MDB states. With water trade data only beginning to trickle in from 1996/97 onwards, the four states, New South Wales and Victoria in particular began seeing an increase in temporary water allocations being traded within states as illustrated by Figure 4.1. Shortly after the introduction of the Water Act in 2007 (with the aim of further liberalising trade) the basin states began to see a large increase in permanent entitlements traded as seen in Figure 4.2 as well as a further increase in the transfer of temporary allocations.

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[9] A table of summary statistics for the variables used in the panel-data regression can be found in Appendix C.

FIGURE 4.2 PERMANENT ENTITLEMENT TRADE BY STATE

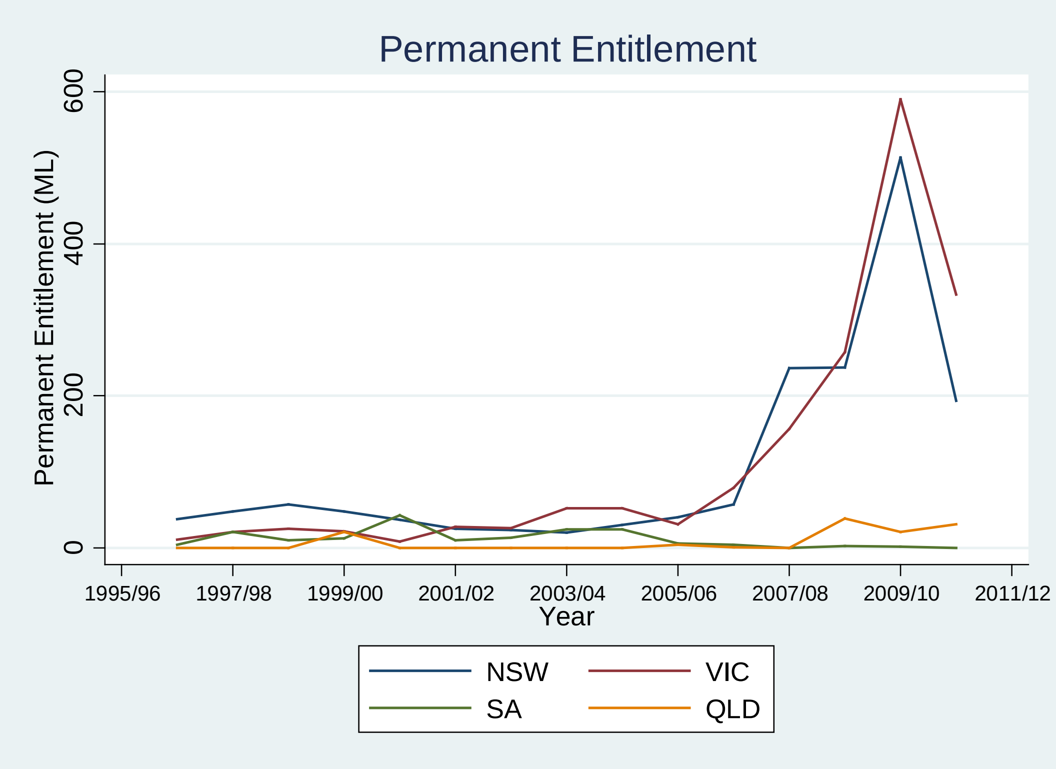
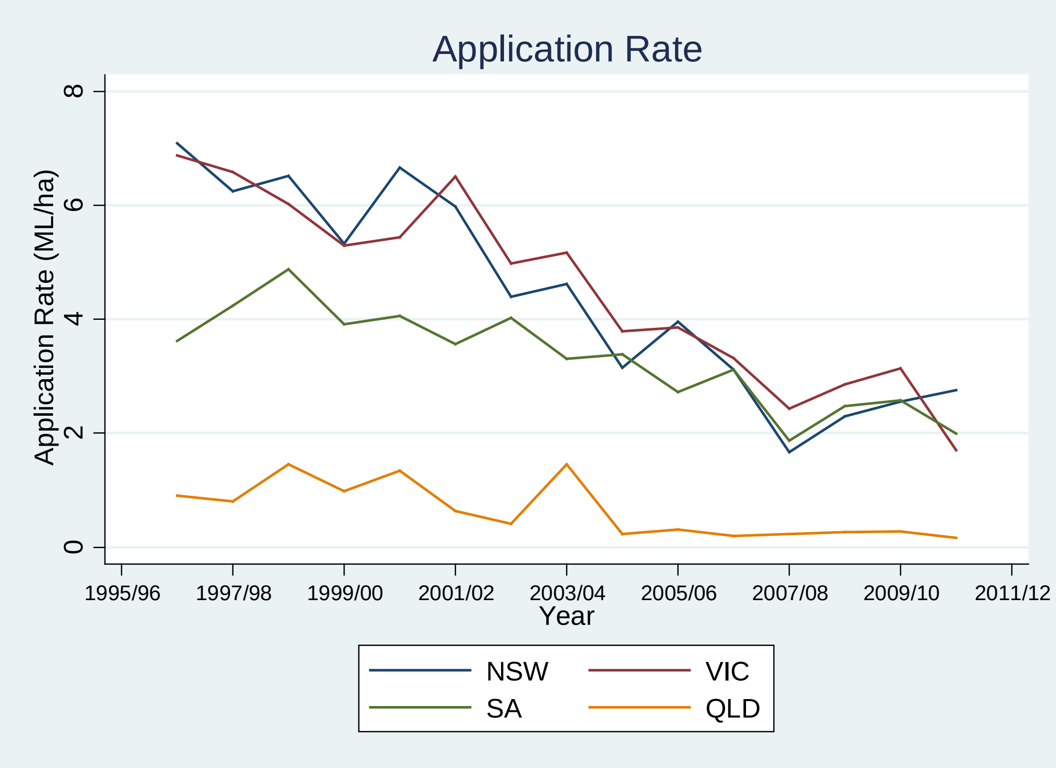


FIGURE 4.3 APPLICATION RATE BY STATE



Most increased trade activity in the MDB was experienced in New South Wales and Victoria due to the large percentage of each state covering the basin, 75% and 60% respectively (Murray Darling Basin Commission, 2006). Figure 4.3 illustrates the various states' application rates since 1996/97 which is used as the measure of technical water use efficiency in each state for this analysis. The application rate[10] measures the total amount of water used with respect to the total area of irrigated agriculture in each state (explained below). It is important to note the general downward trend across all states signifying the increased technical water use efficiency of each state over the past 15 years.

4.2 Methodology

The state level panel regression was chosen as the most appropriate model with which to test the relationship between water trading and water use efficiency due to the lack of finer scale data. The initial goal of this section involved the use of a large panel containing data at the statistical local area[11] level however this data for use as variables is essentially non-existent for most years. The necessary data is available at the National Resource Management (NRM) level; however, there is only a short time series available as the data is reported between 2005/06 and 2009/10. It is important to note the limitations of this model due to the large scale of data used. The analysis models the general picture of trade over time but cannot comment on the noise surrounding the relationship in question. As mentioned above the application rate (AR) is used as the measure of irrigated water use efficiency and works the opposite way to the FAE index mentioned in Section 3.2 above:

$$Application\ Rate = \frac{Water\ Allocation\ Used\ in\ Area(ML)}{Irrigated\ Area\ (Ha)}$$

The application rate increases as the water allocation used in the area increases or the area being irrigated decreases. Therefore a lower value of the application rate is associated with greater technical efficiency of water use. It is important to note that rainfall acts as an exogenous shock and will supplement irrigation water; hence the application rate is subject to environmental market shocks which are assumed to be constant over long time periods. The application rate is used as the dependent variable (measure of efficiency) in the state panel and is regressed on permanent and temporary entitlement trades made during that year. The state panel therefore follows the standard panel regression model:

$$AR_{i,t} = \alpha + \beta trade_{i,t} + \mu_i + \mu_t + \varepsilon_{it} \qquad (4.1)$$

In this form $AR_{i,t}$ is the application rate in state i and year t and $trade_{i,t}$ is permanent entitlement or temporary allocation trade. The μ_i variable catches the state fixed effects such as different state laws being passed which may affect the application rate differently across states. The μ_t variable captures

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[10] Application rate is calculated in the same manner as the ABS.

[11] ABS standard area as defined by the Australian Standard Geographical Classification as similar to Local Government Areas.

year fixed effects being those factors which may change over time and the idiosyncratic state-year disturbance term ε_{it} is included as well.

The regression of equation 4.1 uses the state clustered standard errors which relaxes the assumption of independence between the errors of the observations with the requirement that the observations be independent across clusters (states). These standard errors were used due to the likely assumption that the state observations are likely not completely independent as much of the water market reform has come from the federal government which affects the states in similar ways. This was compared to the robust standard errors which in fact had higher statistical significance thereby supporting the results.

Equation 4.1 above creates a potential endogeniety problem stemming from possible reverse causality coming from the application rate to the trade variable. The calculation of the application rate includes the variable for water volume applied to the field which may affect the amount of water traded in the following period. Therefore the notion that AR in period $t-1$ causes trade in period t implies correlation between these two variables over time. It is possible to control for this endogeniety issue by including AR_{t-1} in the regression. This paper uses the Arellano-Bond difference General Method of Moments (GMM) estimators first proposed by Holtz-Eakin, Newey & Harvey (1988) in order to first difference the equation. The following regression model follows similar steps outlined in Roodman (2009) and Mileva (2007). In equation 4.1 the error term would have included the past year's volume of water used. This is illustrated in equation 4.2 which includes the expansion of the error term:

$$AR_{i,t} = \alpha + \beta trade_{i,t} + \mu_i + \mu_t + \delta AR_{i,t-1} + v_{i,t} \qquad (4.2)$$

As there exist possible state fixed effects mentioned above which may be correlated with water trade this paper uses the difference GMM process of the Arellano-Bond methodology and takes the first-differences of equation 4.2:

$$\Delta AR_{i,t} = \beta \Delta trade_{i,t} + \delta \Delta AR_{i,t-1} + \Delta v_{i,t} \qquad (4.3)$$

The effect of first differencing equation 4.2 is to have the first-differenced lagged dependent variable ($\Delta AR_{i,t-1}$) instrumented with its past levels (i.e. $\Delta AR_{i,t-2}$) as well as removing fixed effects from the model. The second lag of application rate is used as an instrument as it is not correlated with the current error term unlike the first lag. Deeper lags are experimented with however this reduces the sample size which is already quite low. It is important to note that the Arellano-Bond dynamic panel estimators are ideally used with a small T, large N panel. The above panel has a larger time series than number of groups and therefore the original panel results may still hold some important value as stated by Roodman (2009, p. 128) "if T is large, dynamic panel bias becomes insignificant, and a more straight forward fixed-effects estimator works".

4.3 Results

The estimate results of the initial state panel regression are similar to the Arellano-Bond dynamic panel estimator's results. The results of the first panel regression can be seen below in Table 4.1 which reports the results using equation 4.1. The regression equation looks at the separate effect of both permanent and temporary entitlement trade on the application rate and includes a robustness check with the inclusion of fixed effects. This paper decided against the rescaling of the data into teralitres in order to maintain a more intuitive basis in which to interpret the results of the regressions; hence the values of the results are quite low in size but more intuitive in their explanation.

Panel A states the estimated effect of permanent entitlement trade on the application rate. Column 1 of Panel A reports a 1 GL increase in permanent entitlement trade is associated with an estimated 0.00084ML/ha decrease in the application rate. Column 2 reports the estimate with the inclusion of a pan evaporation variable which measures the pooled effects of a variety of climate elements such as temperature, humidity and rainfall etc, a variable which theoretically has an additional effect on the dependent variable.[12]

TABLE 4.1 STATE PANEL REGRESSION

VARIABLES	(1) App Rate	(2) App Rate	(3) App Rate	(4) App Rate
Panel A				
Permanent Entitlement Trade	-0.000839	-0.00582*	-0.00748**	-0.0048**
	(0.00368)	(0.00189)	(0.00130)	(0.00115)
Pan Evaporation	No	Yes	Yes	Yes
State Fixed Effects	No	No	Yes	Yes
Year Fixed Effects	No	No	No	Yes
Observations	60	60	60	60
R-squared	0.002	0.286	0.739	0.928
Panel B				
Temporary Allocation Trade	0.00172	0.000224	-0.00343	-0.00156
	(0.00183)	(0.00171)	(0.00166)	(0.00116)
Pan Evaporation	No	Yes	Yes	Yes
State Fixed Effects	No	No	Yes	Yes
Year Fixed Effects	No	No	No	Yes
Observations	60	60	60	60
R-squared	0.066	0.201	0.701	0.911

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

With the inclusion of pan evaporation there is a large increase in the value of the parameter which also becomes significant at the 10% level. With the inclusion of state fixed effects (e.g. irrigation infrastructure systems, different commodities, and differing state laws) the estimate maintains its negative relationship and increases slightly in magnitude. Finally including the year fixed effects leads to

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[12] Annual pan evaporation data was sourced from the BOM website and was included in the robustness check due to the high theoretical effect the variable would have on water trading.

a very important result of this paper, reporting that a 1 GL increase in permanent entitlement trade is associated with a 0.0048ML/ha decrease in the application rate. It is important to note the increasing model strength of the regressions as more variables are included for the state and year fixed effects. This is likely due to the calculation effect of the R^2 value which increases as more variables are included.

The results in Panel B report the regression results of temporary entitlement trade and can be interpreted in the same way as Panel A. Initially the results report that a 1 GL increase in allocation trade leads to a 0.00172ML/ha increase in the application rate. With the inclusion of the pan evaporation variable the estimate is still positive; however this has now reduced in size to 0.00022ML/ha. After accounting for state fixed effects the estimate turns negative and is marginally insignificant at 13%, suggesting the presence of some omitted variables captured by these fixed effects. The inclusion of the year fixed effects reduces the size of the estimate to have a 1 GL increase in allocation traded being associated with a 0.00156ML/ha decrease in the application rate. This estimate is not significant likely due to the large scale of the model which is ultimately less sensitive to subtle variations in trade within years rather than across years.

These results show that throughout both panels, after having accounted for fixed effects there is a general negative relationship between the amount of entitlement/allocation traded and the application rate. This suggests that water trading has had a positive effect on efficiency; one must recall that a lower application rate is associated with increased water use efficiency. One possible issue is the small number of observations coming from the four different MDB states over 15 years. Ideally this paper would have used a larger data set, however as mentioned above, the regressions were constrained by the lack of data availability and collection. Another possible issue with these results is the existence of an endogeniety problem as mentioned above in Section 4.2 and accounted for in the following Arellano-Bond regression results below.

It is interesting to note the greater significance associated with permanent rather than temporary trade. This is likely due to the specification of the model as finding the impact of trade over a long time period, whereas allocation trading occurs within years. This specification leads to the potential for improvement by determining a model which tests for this intra-year trading of allocations and how it may affect trade separately to entitlement trades. A model searching for the effect of allocation trade on water use efficiency would require day to day water transfer data which is historically difficult to find. Although both entitlements and allocations are associated with a positive relationship between trade and efficiency, there is a greater effect coming from permanent trade that typically involves long term rather than short term decisions. This result suggests that perhaps the structural adjustment associated with permanent movement of water rights between regions has a greater impact on farm water use efficiency than do temporary movements.

The results for the Arellano-Bond difference GMM dynamic estimators are reported in Table 4.2 below. Columns 1 and 2 report the estimators for permanent entitlement trade with and without pan evaporation whose inclusion checks for robustness. Column 1 states that an increase in the reduction in the application rate of 1 GL last period will lead to a 0.786ML/ha decrease in the application rate this period. The result of the estimate is to be expected as this year's application rate will move closely with the rate of the previous year. The estimate barely changes with the inclusion of pan evaporation and remains highly statistically significant across permanent and temporary trade regressions. Column 1 also reports that an increase in the change of permanent entitlement trade by 1 GL is associated with a 0.00089ML/ha decrease in the application rate and is highly significant. This result is similar in magnitude and direction to Column 1 of Table 4.1 (the first panel regression) and does not change significantly with the inclusion of pan evaporation. This outcome provides strong evidence of the positive effect that permanent entitlement trade has on water use efficiency. This positive relationship suggests that over time this trade in permanent entitlements has induced innovation to improve the technical efficiency of water use.

TABLE 4.2 ARELLANO-BOND DYNAMIC PANEL REGRESSION

VARIABLES	(1) App Rate	(2) App Rate	(3) App Rate	(4) App Rate
1st Lag of Application Rate	0.786***	0.784***	0.814***	0.809***
	(0.0406)	(0.0495)	(0.0386)	(0.0418)
Permanent Entitlement Trade	-0.000890***	-0.00094*		
	(0.000256)	(0.000502)		
Pan Evaporation		-6.78e-05		-0.000222
		(0.000329)		(0.000183)
Temporary Allocation Trade			-0.000369	-0.000492
			(0.000912)	(0.000920)
Observations	52	52	52	52
Number of state	4	4	4	4
Prob > chi2	0	0	0	0
Arellano-Bond test AR(1): Pr > z	0.0583	0.0584	0.0664	0.0688
Arellano-Bond test AR(2): Pr > z	0.107	0.109	0.0841	0.0777

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Looking at the temporary allocation trade effects in columns 3 and 4 similar results are found to that of Table 4.1; the sign and magnitude of the estimates are alike however they still lack statistical significance. As noted previously the insignificance of the temporary allocation traded variable is likely due to the specification of the model as a regression across years which naturally points to entitlement trade. Further research must still be performed on the relationship allocation trades have in promoting economic water use efficiency through the transfer of water to a temporarily higher valued use.

The regression reports the Arellano-Bond test for AR(1) process in first differences and rejects the null hypothesis of no autocorrelation between differenced residuals at the 10% level. This is to be expected as mathematically $\Delta v_{i,t}$is related to $\Delta v_{i,t-1}$ through the shared term $v_{i,t-1}$ (Roodman, 2009, p. 119). The Arellano-Bond test for AR(2) process does however fail to reject the null hypothesis that no autocorrelation in levels exists. Roodman (2009, p. 128) mentions that a small number of states could affect the cluster-robust standard errors possibly making the Arellano-Bond test for autocorrelation unreliable.

5 Dairy Case Study

5.1 Farm Model

The intrinsic value of water trading may be difficult to see at the state level explored in the previous section. In order to understand the benefits of water trading it is necessary to look in-depth at how the water market can affect users at the farm level. This section models a case study outlining the incentives faced by dairy farmers. Assuming that dairy farmers are profit maximising, the model is used to explore the change in dairy farmer behaviour in relation to various price changes. This relationship helps illustrate the tradeoffs that farmer's face in the presence of a water market. Farmers can feed their dairy cows in two ways, either growing irrigated grass which the cows can eat or purchasing feed grain from the market to supplement/replace the grass as a production input. In practice grass and feed grain are near perfect substitutes as inputs for milk production. This paper will often refer to water as being the substitute for grain as water is the main input needed for grass production in this model. The farmer's profit function therefore resembles the following equation:

$$Max\ \Pi = P_m f(w,g) - P_g g - P_w(w_1 + w_2) + P_w E$$

The profit function includes the total revenue calculated as the price of milk (P_m) multiplied by the total milk produced $f(w,g)$ being a function of water for grass and grain purchased. The cost aspect of the profit function includes both the total cost of grain inputs ($P_g g$) as well as total cost of water inputs for grass; the water inputs come in two distinct terms for illustrative purposes. The term w_1 considers water as a revenue source for the farmer and carries net values in terms of buying (positive) and selling (negative) water allocations; this can be thought of as a separate investment vehicle. The second water term w_2 is water used to produce grass as a dairy input and the final term E expresses the revenue possibilities from the total water entitlements held by the farmer. It is noted here that although rainfall is a free alternative to the purchase of water, the amount of effective rainfall shall be reflected in the price of water along with the market for allocations. If both water terms are aggregated into a term which signifies the total tradable water the following profit function variant is then:

$$Max\ \Pi = P_m f(w,g) - P_g g - P_w w + P_w E \qquad (5.1)$$

It is important to note that the entitlement held by the farmer has a levelling effect on the profit function and does not dictate the marginal cost of trading water and grain. Therefore differentiating equation 5.1 illustrates that the marginal product of water and grain are equal to their price:

$$f_w(w,g) = P_w \quad \& \quad f_g(w,g) = P_g$$

This model assumes a competitive market for grain and carries with it the zero profit condition that the total revenue from grain is equal to the total costs of water and labour:

$$P_g = P_w \frac{w}{g} + P_l \frac{l}{g} \qquad (5.2)$$

There is an interesting relationship between these two substitutes due to the nature of feed grain as a substitute for water due to the reliance on water as an input in the grain market; therefore the price of grain must be considered to be some function of the price of water multiplied by the change in water with respect to the change in grain. Therefore the price ratio between water and grain is equal to the change in grain production with respect to the change in water use:

$$\frac{\partial g}{\partial w} = \frac{P_w}{P_g}$$

In order to determine the incentives faced by dairy farmers it is also necessary to analyse the market for grain. This model uses a Constant Elasticity of Substitution production function for grain due to it being a standard function to model the substitutes of inputs and is determined by water and labour inputs:

$$g = \left(\frac{1}{\sigma_w} w^\alpha + \frac{1}{\sigma_l} l^\alpha\right)^{\frac{1}{\alpha}}$$

Using the grain production function it is possible to determine the effect that water has on grain:

$$\frac{\partial g}{\partial w} = \frac{1}{\alpha}\left(\frac{1}{\sigma_w} w^\alpha + \frac{1}{\sigma_l} l^\alpha\right)^{\frac{1}{\alpha}-1} \alpha \frac{1}{\sigma_w} w^{\alpha-1}$$

Solving through and inserting the price ratio in the place of the partial derivate of grain with respect to water gives the following expression for use in the zero profit condition in equation 5.2:

$$\frac{w}{g} = \left(\frac{P_w}{P_g}\right)^{\frac{1}{\alpha-1}} \sigma_w{}^{\frac{1}{\alpha-1}} \qquad (5.3)$$

By symmetry:

$$\frac{l}{g} = \left(\frac{P_l}{P_g}\right)^{\frac{1}{\alpha-1}} \sigma_l{}^{\frac{1}{\alpha-1}} \qquad (5.4)$$

It is now possible to insert equation 5.3 and 5.4 into the zero profit condition above in order to find the price of grain as a function of the prices of both water and labour:

$$P_g = P_w \left(\frac{P_w}{P_g}\right)^{\frac{1}{\alpha-1}} \sigma_w{}^{\frac{1}{\alpha-1}} + P_l \left(\frac{P_l}{P_g}\right)^{\frac{1}{\alpha-1}} \sigma_l{}^{\frac{1}{\alpha-1}}$$

After collecting like terms and totally differentiating we find the elasticity of the price grain with respect to the price of water. This price elasticity measures the responsiveness of the price of grain to a change in the price of water:

$$\frac{\partial P_g}{\partial P_w} \cdot \frac{P_w}{P_g} = \epsilon_w = \left(\frac{P_w}{P_g}\right)^{\frac{\alpha}{\alpha-1}} \sigma_w{}^{\frac{1}{\alpha-1}} \qquad (5.5)$$

This expression of the price elasticity of grain and water gives rise to some interesting incentives which may be faced by farmers. The natural log of equation 5.5 is taken in order to distil the different conditions under which the price of grain will change with respect to the price of water:

$$\ln(\epsilon_w) = \frac{\alpha}{\alpha-1}\left(\ln P_w - \ln P_g\right) + \frac{1}{\alpha-1}\ln(\sigma_w) \qquad (5.6)$$

As $0 < \alpha < 1$, both terms in equation 5.6 will be negative. However if the price of grain is greater than the price of water then the first term will become positive. Therefore if the price differential of grain to water is large enough, the log of the price elasticity can be positive, therefore illustrating a situation in which the price elasticity of grain to water could be greater than 1. In this unique situation, an increase in the price of water will lead to a larger increase in the price of grain. Given this condition, there is a possible situation in which an increase in the price of water will lead dairy farmers to actually buy more water rather than feed grain as a substitute due to the price of grain increasing even more. The necessary condition is outlined below suggesting that the price of water must be significantly lower than the price of grain in order for this situation to arise:

$$if \ \left|\frac{\alpha}{\alpha-1}\left(\ln P_w - \ln P_g\right)\right| > \left|\frac{1}{\alpha-1}\ln(\sigma_w)\right|$$

$$then \ \ln(\epsilon_w) > 0, \therefore \epsilon_w > 1$$

By symmetry this condition holds true of the price of labour as well; however this paper takes the price of labour as given and assumes no change due to our primary interest in the effect of water trading. The theory behind this case study illustrates the use of water markets in promoting the transfer of water to its highest marginal value of production in the dairy industry at the farm level. Under ordinary conditions (a price elasticity less than 1), if the price of water is greater than the price of grain then farmers will be better off selling water to where it is more highly valued, perhaps to another industry for crop irrigation purposes, and purchase feed grain instead. The efficiency in which the water is used will then have increased as the buyer is paying a higher price signalling the higher value of the water.

5.2 Goulburn District Analysis

In order to extend this theoretical analysis of dairy farming, the Goulburn Valley in the MDB was again chosen to further illustrate the real world implications of the water market at the farm level. Dairy farming comprises a large portion of the Goulburn Valley agriculture industry which is home to almost 3,000 commercial dairy farms (Deparment of Primary Industries, 2012). This section focuses on the grain and water prices changed in 2008 and how this may have affected the composition of inputs in the production of milk. Analysis from this case study is done in part due to the observations made by Wittwer and Griffith (2012, p. 130) who found that water use in the dairy industry in 2008 decreased by 64.4% relative to 2006 whereas output decreased by just 26.5%. The large decrease in water use is likely in part due to the lingering drought in 2007/08 which decreased the amount of water allocations traded as illustrated in Figure 1.1, but not necessarily the volume of water traded as a proportion of total allocations. However the fact that output declined much less than water use suggests that the substitution of grain as a production input was likely to occur.

FIGURE 5.1 WATER & GRAIN AS INELASTIC SUBSTITUTES FOR DAIRY INPUTS

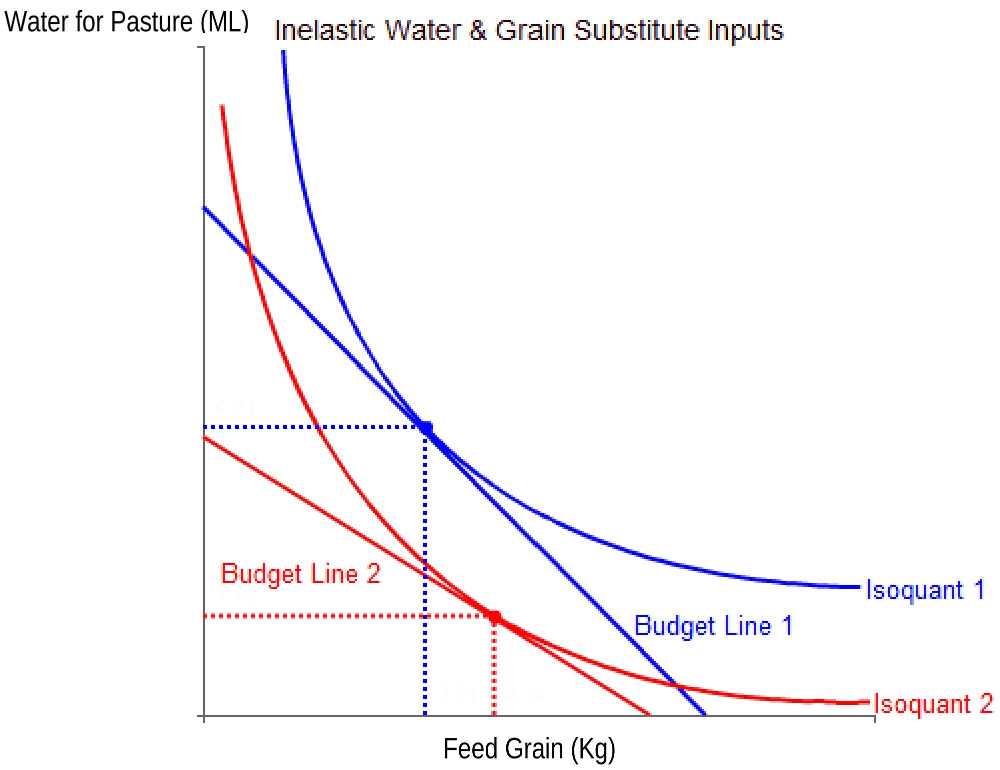
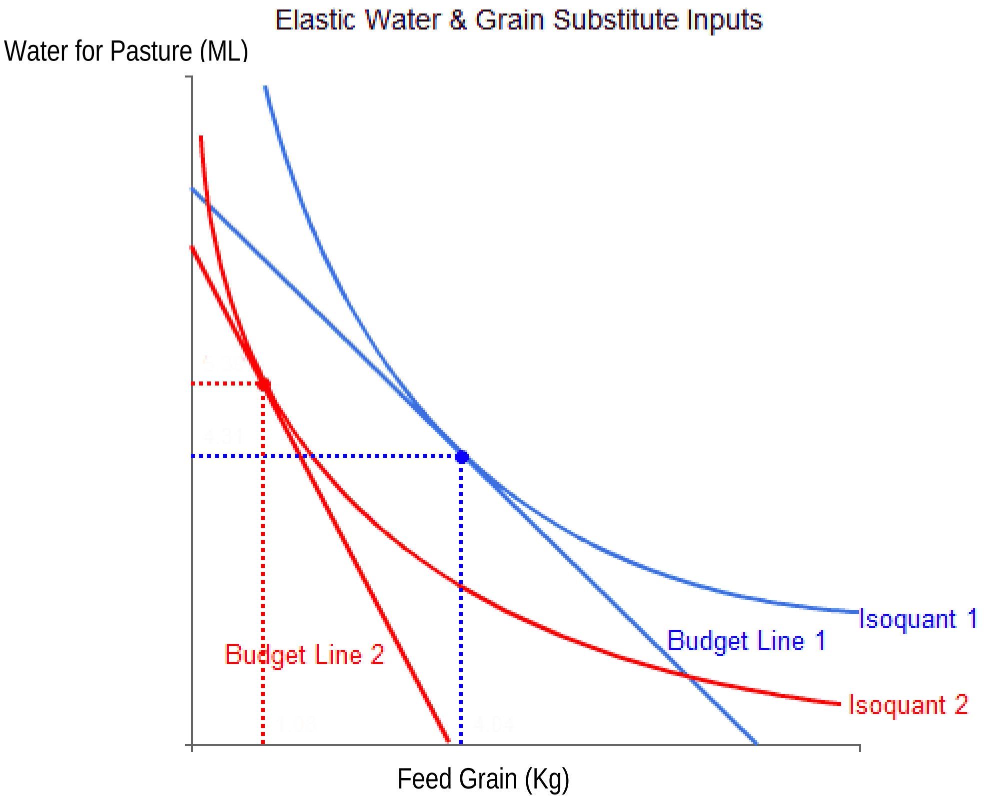


Figure 5.1 illustrates a basic cost minimisation situation in which an increase in the price of water leads to a smaller increase in the price of grain. The water price increase is illustrated by the reduction of Budget Line 1 to Budget Line 2 which signifies the situation in which the price elasticity of water with respect to the price of grain is less than 1 and therefore relatively inelastic. In this situation the increase in the price of water leads to a large decrease in the amount of water used in production and an increase in its substitute feed grain. The graph also illustrates the Isoquants being the maximum level of

milk production which can be attained at the lowest cost. This figure can help illustrate the framework behind the findings of Wittwer and Griffith as the decrease in output illustrated by the move from Isoquant 1 to Isoquant 2 is less than the decrease in water used. This is possible due to the existence of grain as a substitute for water.

Figure 5.2 illustrates the unusual situation outlined above in which the elasticity of the price of water with respect to the price of grain is relatively elastic. In this case it is possible to see that an increase in the price of water leads to a larger increase in the price of grain. In this situation a decrease in the price of water has actually led to an increase in the amount of water used for pasture and a decrease in the amount of grain.

FIGURE 5.2 WATER & GRAIN AS ELASTIC SUBSTITUTES FOR DAIRY INPUTS

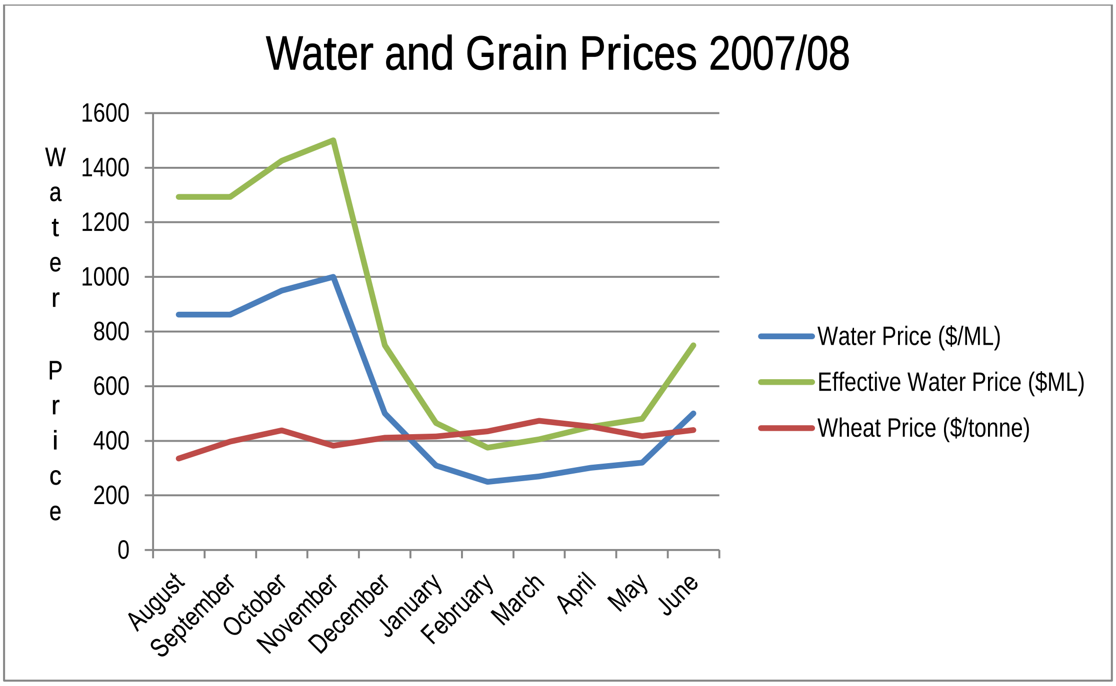


This study uses wheat as a proxy for grain input for dairy farms due to the similarity in price movements and levels of many pasture substitute grains. Perennial ryegrass is used as the generic water-intensive pasture land alternative to feed grains due to its widespread use on dairy farms. Figure 5.3 illustrates the high price of water relative to wheat prior to the beginning of 2008. Using the model outlined in section 5.1 this high price of water would lead to the substitution of wheat grain for water as a production input in dairy farms. Farmers faced increasing pressure towards changing their production input mix to include more wheat as feed for dairy cows until mid-November. When the price of water began to drop and eventually fell below the price of wheat, farmers faced new incentives which would lead to the use of more water for pasture and purchasing of less wheat.

It is important to note that the price of water may not accurately reflect the same production yield of the price of wheat. Therefore the figure also includes what this paper refers to as the effective water price which normalises the price of water to the level of ryegrass production that matches the same amount of grain production.[13] Farmers face the same incentives with regard to the effective water price although this has been dulled somewhat.

Figure 5.3 further illustrates the model outlined in Figure 5.1 as a large increase in the price of water is met with a smaller increase in the price of grain. The water price data in Figure 5.3 was sourced from the Victorian Water Register (VWR) and is illustrated against the Melbourne wheat grain price data from Dairy Australia. This situation suggests the incentives faced by farmers to purchase grain as a substitute could have actually driven the price higher as demand for feed grain is increasing; this can be seen in figure 5.3. Unfortunately due to a lack of available data reporting actual grain traded into the Goulburn it is not possible to identify this substitution effect for certain, however all of the available evidence points in this direction.

FIGURE 5.3 WATER & GRAIN PRICES 2007/08



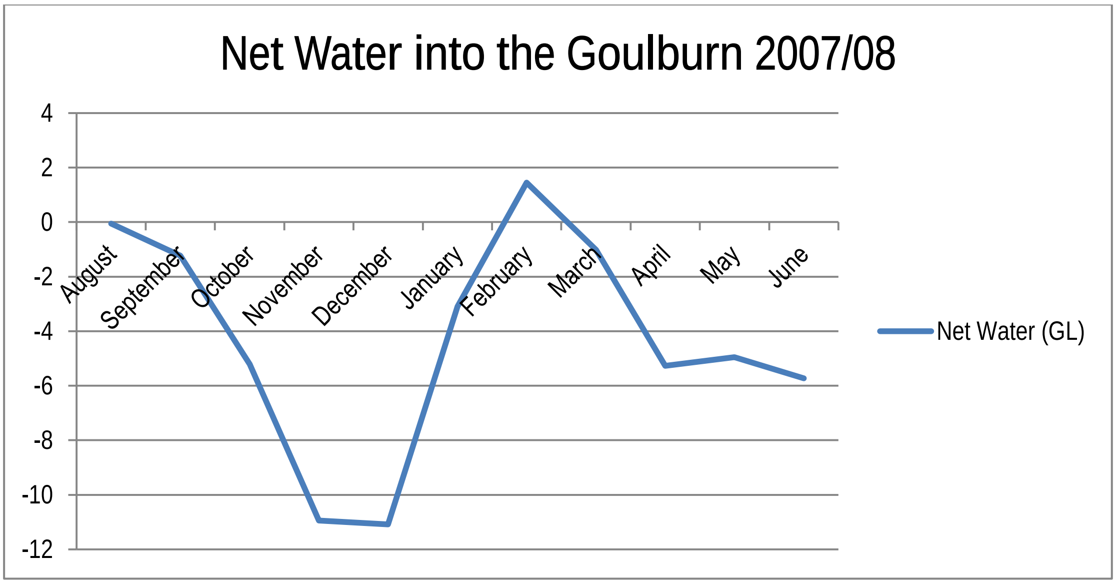
Data from the VWR was used in Figure 5.4 which illustrates the net water traded into the Greater Goulburn region. The Goulburn generally saw a net trade of water out of the region suggesting the substitution from ryegrass to wheat as feed grain. This suggests that water moved out of the region which is has a large dairy industry to other regions where the marginal product of water was relatively higher.

---

[13] The effective water price was calculated by multiplying the average WUE of ryegrass in the previous two years to the original water price in order to determine the water needs in producing 1 tonne of ryegrass to match 1 tonne of wheat. (Farran)

This case study has so far assumed that perennial ryegrass and wheat are both perfectly substitutable as feed for dairy cows; this is does not hold perfectly in the real world however. The differences in nutritional value between these production inputs mean they cannot be perfect substitutes. The metabolisable energy (ME) obtained from wheat and ryegrass is not necessarily the same in all circumstances with wheat producing between 10.9 to 14.7 mega-joules (MJ) (Dairy Australia, 2010) and ryegrass producing between 7.8 to 12.3 MJ (Sanford, 2012, p. 2) per kilogram of dry matter; this difference however is not too substantial. Another issue could include the use of rainfall as an alternative to purchasing water for ryegrass production as this is free. There are however risks attached to the use of rainfall as a substitute due to its nature of variability and insecurity. These issues of ME and rainfall are assumed to be reflected in the prices of the production inputs and hence the model should still provide credible insight into the trading of water in the Goulburn dairy industry.

FIGURE 5.4 NET WATER TRADED INTO THE GOULBURN 2007/08



6 Conclusion

The need for managing water effectively and efficiently is an important issue affecting nations around the world. Through the establishment of property rights a market for water is able to emerge transferring water to more productive uses. This paper has sought to determine if there is in fact an empirical relationship between water trade and an increase in agricultural water use efficiency as hypothesised by basic economic theory. Over the past three decades Australia has slowly introduced policies such as the COAG Water Reform Framework (1994) and the Water Act (2007) which has opened up the market for water trading through the removal of barriers to trade. Using data from the highly developed water market in Murray-Darling Basin three different empirical methods were used across different scales in the search for evidence of this relationship between water trade and efficiency of its use. Trade in temporary water allocations has been hypothesised to provide an increase in economic water use efficiency by transferring water to its highest marginal value. This paper also identifies the purpose of trade in permanent water entitlements as inducing innovation over the longer term which can lead to an increase in the technical efficiency of water use in a productive capacity.

A cross-sectional analysis looking at the main drivers of water use efficiency in both 1998/99 and 2010/11 in the GMID concluded that water use efficiency has appeared to have increased between these time periods. This study also concluded that no significant association with allocation traded could be found. The results also showed that a larger water entitlement was associated with lower technical efficiency, likely explained by the reduction in entitlements needed by innovative farms in their production.

The panel regression of the four main MDB states over 15 years led to a strong conclusion that a 1 GL increase in permanent entitlement trade is associated with a 0.00089 ML/ha point decrease in the application rate. This provides strong evidence that entitlement trade has led farmers to innovate in their water production methods improving technical water use efficiency in the long term. Temporary allocations traded also led to a decrease in the application rate; however this result was marginally insignificant. The model specification using panel data of trade over many years meant that trade in water allocations may not have been appropriately predicted by the model used. Allocations are traded within a year by construction and therefore the impact of these trades may not show up in the results against technical water use efficiency over time. The state panel illustrated the very important outcome that an increase in the amount of permanent entitlement trading can lead to structural adjustment of water demand by different industries as induced by farm innovation in water use.

The dairy industry in the Goulburn region was used to model incentives faced by farmers in the presence of water for pasture as a substitute for feed grain as an input for milk production. The price data collected for 2008 led to the conclusion that the price of water relative to the price of grain was relatively inelastic which can aid in explaining the reason for the much larger decrease in water use compared to the decrease in output between 2005/6 and 2007/08 in the dairy industry. This model suggested that farmers were faced with incentives to substitute water for feed grain. Hence the marginal product of water would have been higher in another use outside the region due to the net movement of water out of the Goulburn over this time.

A lack of detailed data at the smaller scale meant that fewer observations could be made use of, it is therefore suggested that this work continue in the future with the use of a greater scope of data. It is clear that there is still more research that must be done in order to determine whether allocation trading during the year has actually had a positive impact on increasing economic water use efficiency.

This paper has provided evidence for the continued move towards greater water market activity in being a factor towards improving water use efficiency. On a large scale there is evidence pointing towards the significant impact that entitlement trades appear to have on technical water use efficiency. Entitlement trades are relatively small compared to allocations but their role is significant. Another area for further research involves determining the channels in which trade in entitlements does in fact promote innovation in technical water use efficiency. Future research in this field can provide useful processes to be put in place by water policy aimed at increasing technical efficiency in water use. The results of this paper have skimmed the surface of the empirical relationship between water markets and efficiency but future analysis must continue to explore the depths of this relationship.

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Appendix A. Abbreviations

AR	Application Rate
ABS	Australian Bureau of Statistics
BOM	Bureau of Meteorology
COAG	Council of Australian Governments
DPI	Department of Primary Industries
FAE	Field Application Efficiency
GMID	Goulburn Murray Irrigation District
GMM	General Method of Moments
MDB	Murray Darling Basin
MDBA	Murray Darling Basin Authority
MDBC	Murray Darling Basin Commission
MDBMC	Murray Darling Basin Ministerial Council
ME	Metabolisable Energy
MJ	Mega-Joules
NRM	Natural Resource Management
NWC	National Water Commission
NWI	National Water Initiative
VMP	Value of Marginal Product
VWR	Victorian Water Register
WD	Water Delivered
WR	Water Requirement

Appendix B. Case Study Calculations

The following appendix shows the in-depth calculations used in the model outlined in section 5.1. The model illustrates the incentives faced by dairy farmers which use water as both an input in dairy production as well as a tradable investment. Beginning with the farmer's profit function we have the standard total revenue less total cost of output (Y).

$$\pi = P_y Y - cY$$

The farmer's utility function consists of the profits they make from milk production which is some function of the water and grain as substitute production inputs. Utility also depends on the net profits made from sales of water (w_1) coming from their initial entitlement (E).

$$u = \pi(w, g) + P_w(E - w_1)$$

The farmer's profit function with the inclusion of the substitute input goods is therefore made up of the price of milk (P_m) multiplied by some milk production function. From this revenue the cost of inputs are then deducted being grain and water, with water being split into water for use in production (w_2) and the net revenue left over from the original entitlement (E) less the water taken out of this entitlement (w_1).

$$Max\ \pi = P_m f(w, g) - P_g g - P_w(w_2) + P_w E - P_w(w_1)$$

$$Max\ \pi = P_m f(w, g) - P_g g - P_w(w_2 + w_1) + P_w E$$

$$Max\ \pi = P_m f(w, g) - P_g g - P_w(w) + P_w E$$

Maximising the profit function yields the marginal product of water and grain respectively.

$$\frac{\partial \Pi}{\partial w} = f_w(w, g) - P_w = 0 \qquad \rightarrow \qquad f_w(w, g) = P_w$$

$$\frac{\partial \Pi}{\partial w} = f_g(w, g) - P_g = 0 \qquad \rightarrow \qquad f_g(w, g) = P_g$$

Here it is important to note that the original entitlement is not included in the marginal product of water and therefore only plays the role of creating a levelling effect on profit rather than a marginal effect. Section 5.1 pointed out that the price of grain is in fact dependent on the price of water due to the nature of water as an input for grain production.

$$P_g \frac{\partial g}{\partial w} = P_w$$

$$\frac{\partial g}{\partial w} = \frac{P_w}{P_g}$$

It is therefore assumed that water and labour are considered inputs for grain production and using a Constant Elasticity of Substitution production function due to its unique characteristics it is possible to find the effect that water has on grain prices.

$$g = \left(\frac{1}{\sigma_w} w^{\alpha} + \frac{1}{\sigma_l} l^{\alpha}\right)^{\frac{1}{\alpha}}$$

It is now possible to determine the marginal effect that water has on grain.

$$\frac{\partial g}{\partial w} = \frac{1}{\alpha}\left(\frac{1}{\sigma_w} w^{\alpha} + \frac{1}{\sigma_l} l^{\alpha}\right)^{\frac{1}{\alpha}-1} \alpha \frac{1}{\sigma_w} w^{\alpha-1}$$

$$\frac{\partial g}{\partial w} = \left(\frac{1}{\sigma_w} w^{\alpha} + \frac{1}{\sigma_l} l^{\alpha}\right)^{\frac{1}{\alpha}(1-\alpha)} \frac{1}{\sigma_w} w^{\alpha-1}$$

$$\frac{\partial g}{\partial w} = g^{1-\alpha} \frac{1}{\sigma_w} w^{\alpha-1}$$

$$\frac{\partial g}{\partial w} = \frac{1}{\sigma_w}\left(\frac{w}{g}\right)^{\alpha-1}$$

$$\frac{\partial g}{\partial w}\sigma_w = \left(\frac{w}{g}\right)^{\alpha-1}$$

$$\frac{w}{g} = \left(\frac{\partial g}{\partial w}\right)^{\frac{1}{\alpha-1}} \sigma_w{}^{\frac{1}{\alpha-1}}$$

The price ratio is then inserted in place of the partial derivate of grain with respect to water to give an expression which yields only the prices of goods.

$$\frac{w}{g} = \left(\frac{P_w}{P_g}\right)^{\frac{1}{\alpha-1}} \sigma_w{}^{\frac{1}{\alpha-1}}$$

By symmetry:

$$\frac{l}{g} = \left(\frac{P_l}{P_g}\right)^{\frac{1}{\alpha-1}} \sigma_l{}^{\frac{1}{\alpha-1}}$$

This model assumes a competitive market for grain and will therefore use a long run zero economic profit condition.

$$P_g g = P_w w + P_l l$$

$$\therefore P_g = P_w \frac{w}{g} + P_l \frac{l}{g}$$

Inserting the water-grain and labour-grain ratios into the zero profit condition yields the price of grain as a function of the prices of both water and labour.

$$P_g = P_w \left(\frac{P_w}{P_g}\right)^{\frac{1}{\alpha-1}} {\sigma_w}^{\frac{1}{\alpha-1}} + P_l \left(\frac{P_l}{P_g}\right)^{\frac{1}{\alpha-1}} {\sigma_l}^{\frac{1}{\alpha-1}}$$

$${P_g}^{\frac{\alpha}{\alpha-1}} = {P_w}^{\frac{\alpha}{\alpha-1}} {\sigma_w}^{\frac{1}{\alpha-1}} + {P_l}^{\frac{\alpha}{\alpha-1}} {\sigma_l}^{\frac{1}{\alpha-1}}$$

It is then necessary to totally differentiate the above equation in order to find the elasticity of the price of water with respect to the price of grain.

$$dP_g \frac{\alpha}{\alpha-1} {P_g}^{\frac{\alpha}{\alpha-1}-1} = dP_w \frac{\alpha}{\alpha-1} {P_w}^{\frac{\alpha}{\alpha-1}-1} {\sigma_w}^{\frac{1}{\alpha-1}} + dP_l \frac{\alpha}{\alpha-1} {P_l}^{\frac{\alpha}{\alpha-1}-1} {\sigma_l}^{\frac{1}{\alpha-1}}$$

$$dP_g {P_g}^{\frac{1}{\alpha-1}} = dP_w {P_w}^{\frac{1}{\alpha-1}} {\sigma_w}^{\frac{1}{\alpha-1}} + dP_l {P_l}^{\frac{1}{\alpha-1}} {\sigma_l}^{\frac{1}{\alpha-1}}$$

For the purpose of this model it is assumed that the price of labour is constant so as to find the elasticity of the price of grain with respect to the price of water, i.e. $dP_l = 0$:

$$\frac{dP_g}{dP_w} = \left(\frac{P_w}{P_g}\right)^{\frac{1}{\alpha-1}} {\sigma_w}^{\frac{1}{\alpha-1}}$$

$$\frac{dP_g}{dP_w} \cdot \frac{P_w}{P_g} = \frac{P_w}{P_g} \cdot \left(\frac{P_w}{P_g}\right)^{\frac{1}{\alpha-1}} {\sigma_w}^{\frac{1}{\alpha-1}}$$

$$\frac{dP_g}{dP_w}\left(\frac{P_w}{P_g}\right) = {P_w}^{\frac{\alpha}{\alpha-1}} {P_g}^{\frac{-\alpha}{\alpha-1}} {\sigma_w}^{\frac{1}{\alpha-1}}$$

$$\frac{\partial P_g}{\partial P_w} \cdot \frac{P_w}{P_g} = \epsilon_w = \left(\frac{P_w}{P_g}\right)^{\frac{\alpha}{\alpha-1}} {\sigma_w}^{\frac{1}{\alpha-1}}$$

This price elasticity (ϵ_w) measures the responsiveness of the price of grain to a change in the price of water. The natural log of equation is then taken in order to distil the different conditions under which the price of grain will change with respect to the price of water:

$$\ln(\epsilon_w) = \frac{a}{\alpha-1}\left(\ln P_w - \ln P_g\right) + \frac{1}{\alpha-1}\ln(\sigma_w)$$

This expression of the price elasticity of grain and water gives rise to some interesting incentives which may be faced by farmers. As $0 < \alpha < 1$, both terms in the logged equation will be negative. However if the price of grain is greater than the price of water then the first term will become positive. Therefore if the price differential of grain to water is large enough, the log of the price elasticity can be positive, therefore illustrating a situation in which the price elasticity of grain to water could be greater than 1. In this unique situation, an increase in the price of water will lead to a larger increase in the price of grain. Given this condition, there is a possible situation in which an increase in the price of water will lead dairy farmers to actually buy more water rather than feed grain as a substitute due to the price of grain increasing even more. The necessary condition is outlined below suggesting that the price of water must be significantly lower than the price of grain in order for this situation to arise:

$$if \ \left|\frac{a}{\alpha - 1}\left(\ln P_w - \ln P_g\right)\right| > \left|\frac{1}{\alpha - 1}\ln(\sigma_w)\right|$$

$$then \ \ln(\epsilon_w) > 0, \therefore \epsilon_w > 1$$

Appendix C. Cross-Sectional & Panel Data Descriptive Statistics

TABLE C.1 MEAN FAE SIGNIFICANCE TEST RESULTS

```
. *Mean FAE Significance Test*
. ttest FAE10=aveFAE98

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
   FAE10 |     251    14.10257    4.722129    74.81259    4.802343    23.40279
aveFAE98 |     251    7.521137           0           0    7.521137    7.521137
---------+--------------------------------------------------------------------
    diff |     251     6.58143    4.722129    74.81259   -2.718795    15.88166
------------------------------------------------------------------------------
     mean(diff) = mean(FAE10 - aveFAE98)                          t =   1.3937
 Ho: mean(diff) = 0                              degrees of freedom =      250

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.9177         Pr(|T| > |t|) = 0.1646          Pr(T > t) = 0.0823

. ******************************************************************************
. *Mean Dairy FAE Significance Test*
. ttest FAEdairy10=aveFAEdairy98

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FAEda~10 |     251    13.85333    4.724903    74.85654    4.547642    23.15902
aveF~y98 |     251    7.440137           0           0    7.440137    7.440137
---------+--------------------------------------------------------------------
    diff |     251    6.413193    4.724903    74.85654   -2.892495    15.71888
------------------------------------------------------------------------------
     mean(diff) = mean(FAEdairy10 - aveFAEdairy98)                t =   1.3573
 Ho: mean(diff) = 0                              degrees of freedom =      250

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.9120         Pr(|T| > |t|) = 0.1759          Pr(T > t) = 0.0880

. ******************************************************************************
. *Mean Horticulture FAE Significance Test*
. ttest FAEhortic10=aveFAEhortic98

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FAEho~10 |     251     .448194    .1004051    1.590716    .2504463    .6459416
aveF~c98 |     251     .284757           0           0     .284757     .284757
---------+--------------------------------------------------------------------
    diff |     251     .163437    .1004051    1.590716   -.0343107    .3611847
------------------------------------------------------------------------------
     mean(diff) = mean(FAEhortic10 - aveFAEhortic98)              t =   1.6278
 Ho: mean(diff) = 0                              degrees of freedom =      250

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.9476         Pr(|T| > |t|) = 0.1048          Pr(T > t) = 0.0524
```

TABLE C.2 MEAN ENTITLEMENT SIGNIFICANCE TEST RESULTS

```
. *Mean Entitlement Significance Test*
. ttest entitlement10=aveentitlement98

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
entit~10 |     359    452.3682     29.9732     567.911    393.4226    511.3139
aveen~98 |     359     413.424           0           0     413.424     413.424
---------+--------------------------------------------------------------------
    diff |     359    38.94423     29.9732     567.911   -20.00143     97.8899
------------------------------------------------------------------------------
     mean(diff) = mean(entitlement10 - aveentitlement98)          t =   1.2993
 Ho: mean(diff) = 0                              degrees of freedom =      358

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.9027         Pr(|T| > |t|) = 0.1947          Pr(T > t) = 0.0973

. ******************************************************************************
. *Mean Dairy Entitlement Significance Test*
. ttest dairyentitlement10=avedairyentitlement98

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
dairye~0 |     359    318.3546    26.94914    510.6134    265.3561    371.3531
aved~t98 |     359    353.9347           0           0    353.9347    353.9347
---------+--------------------------------------------------------------------
    diff |     359   -35.58007    26.94914    510.6134   -88.57859    17.41846
------------------------------------------------------------------------------
     mean(diff) = mean(dairyentitlem~10 - avedairyentit~98)       t =  -1.3203
 Ho: mean(diff) = 0                              degrees of freedom =      358

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.0938         Pr(|T| > |t|) = 0.1876          Pr(T > t) = 0.9062

. ******************************************************************************
. *Mean Horticulture Entitlement Significance Test*
. ttest horticentitlement10=avehorticentitlement98

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
hortic~0 |     359    38.53036    8.155673    154.5279    22.49131    54.56941
aveh~t98 |     359    25.68933           0           0    25.68933    25.68933
---------+--------------------------------------------------------------------
    diff |     359    12.84103    8.155673    154.5279   -3.198019    28.88008
------------------------------------------------------------------------------
     mean(diff) = mean(horticentitle~10 - avehorticenti~98)       t =   1.5745
 Ho: mean(diff) = 0                              degrees of freedom =      358

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.9419         Pr(|T| > |t|) = 0.1163          Pr(T > t) = 0.0581
```

TABLE C.3 MEAN WATER USE SIGNIFICANCE TEST RESULTS

```
. *Mean Water Use Significance Test*
. ttest wateruse10=avewateruse98

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
water~10 |     359    240.4577    30.91787      585.81    179.6542    301.2611
avewa~98 |     359     476.295           0           0     476.295     476.295
---------+--------------------------------------------------------------------
    diff |     359   -235.8373    30.91787      585.81   -296.6408   -175.0339
------------------------------------------------------------------------------
     mean(diff) = mean(wateruse10 - avewateruse98)                t =  -7.6279
 Ho: mean(diff) = 0                              degrees of freedom =      358

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000

. ****************************************************************************
. *Mean Dairy Water Use Significance Test*
. ttest dairywateruse10=avedairywateruse98

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
dairyw~0 |     359    116.0686    18.53841    351.2528    79.61075    152.5265
aved~e98 |     359    382.6835           0           0    382.6835    382.6835
---------+--------------------------------------------------------------------
    diff |     359   -266.6149    18.53841    351.2528   -303.0728    -230.157
------------------------------------------------------------------------------
     mean(diff) = mean(dairywateruse10 - avedairywater~98)        t = -14.3818
 Ho: mean(diff) = 0                              degrees of freedom =      358

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000

. ****************************************************************************
. *Mean Horticulture Water Use Significance Test*
. ttest hortiwateruse10=avehortiwateruse98

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
hortiw~0 |     359    19.94131    4.800362    90.95388    10.50086    29.38176
aveh~e98 |     359    15.85578           0           0    15.85578    15.85578
---------+--------------------------------------------------------------------
    diff |     359    4.085532    4.800362    90.95388   -5.354921    13.52598
------------------------------------------------------------------------------
     mean(diff) = mean(hortiwateruse10 - avehortiwater~98)        t =   0.8511
 Ho: mean(diff) = 0                              degrees of freedom =      358

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.8024         Pr(|T| > |t|) = 0.3953          Pr(T > t) = 0.1976
```

TABLE C.4 MEAN ALLOCATION TRADED SIGNIFICANCE TEST RESULTS

```
. *Mean Allocation Traded Significance Test*
. ttest alloc_trade10=avealloctrade98

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
alloc_~0 |     359     16.3844    7.256218    137.4857    2.114231    30.65457
avea~e98 |     359    8.703333           0           0    8.703333    8.703333
---------+--------------------------------------------------------------------
    diff |     359    7.681068    7.256218    137.4857   -6.589102    21.95124
------------------------------------------------------------------------------
     mean(diff) = mean(alloc_trade10 - avealloctrade98)           t =   1.0585
 Ho: mean(diff) = 0                              degrees of freedom =      358

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.8547         Pr(|T| > |t|) = 0.2905          Pr(T > t) = 0.1453

. ****************************************************************************
. *Mean Dairy Allocation Traded Significance Test*
. ttest alloctrddairy10=avealloctrddairy98

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
allo~y10 |     359    15.85515    6.004497     113.769    4.046634    27.66367
avea~y98 |     359    19.90667           0           0    19.90667    19.90667
---------+--------------------------------------------------------------------
    diff |     359   -4.051513    6.004497     113.769   -15.86003    7.757007
------------------------------------------------------------------------------
     mean(diff) = mean(alloctrddairy10 - avealloctrdda~98)        t =  -0.6747
 Ho: mean(diff) = 0                              degrees of freedom =      358

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.2501         Pr(|T| > |t|) = 0.5003          Pr(T > t) = 0.7499

. ****************************************************************************
. *Mean Horticulture Allocation Traded Significance Test*
. ttest alloctrdhortic10=avealloctrdhortic98

Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
allo~c10 |     359    3.877437    3.713644    70.36351   -3.425862    11.18074
avea~c98 |     359   -1.936667           0           0   -1.936667   -1.936667
---------+--------------------------------------------------------------------
    diff |     359    5.814104    3.713644    70.36351   -1.489195     13.1174
------------------------------------------------------------------------------
     mean(diff) = mean(alloctrdhortic10 - avealloctrdho~98)       t =   1.5656
 Ho: mean(diff) = 0                              degrees of freedom =      358

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.9408         Pr(|T| > |t|) = 0.1183          Pr(T > t) = 0.0592
```

TABLE C.5 SUMMARY OF CROSS-SECTIONAL DATA

Variable	Obs	Mean	Std. Dev.	Min	Max
tb	659	.2822458	.4504342	0	1
ts	659	.3004552	.4588042	0	1
year98	659	.4552352	.4983704	0	1
proppcla	642	64.476	38.87836	0	100
proppcru	642	45.04538	43.1796	0	100
propwfp	657	.6864536	.4642878	0	1
sucessor	622	1.025723	.9269523	0	3
houage	656	53.21646	10.73499	24	86
farmyears	655	34.27786	14.52886	1	80
lutohair	659	165.2671	256.6026	0	3000
grazing	659	55.06603	43.38163	0	100
hviv	659	9.327309	28.00645	0	100
entitlement	659	434.6395	487.1785	0	6300
water~otrade	646	89.3356	131.3746	0	1999.4
water~htrade	659	85.11184	106.4036	-186.6	1430
wateruse	658	347.6239	551.2079	0	9497.2
lowedu	658	.2325228	.4227618	0	1
extservice	659	.2139605	.4104108	0	1
propdev	658	2.823708	1.268726	1	5
commugroup	659	.3414264	.4745484	0	1
opsur1000	586	29.19369	25.28006	0	100
offfarm_per	651	30.33333	37.15383	0	100
alloc_open	659	54.62822	59.80444	0	120
alloc_end	659	84.20182	14.45274	71	100
tprice	659	126.3953	61.85872	58.778	182.9
pprice	659	1479.642	738.4388	672.46	2154.167
alloc_trade	659	12.88771	148.9718	-1130	1100

TABLE C.6 SUMMARY OF PANEL-DATA

Variable	Obs	Mean	Std. Dev.	Min	Max
year97	60	8	4.356954	1	15
state	60	2.5	1.127469	1	4
permenttran	60	59.6345	115.6839	0	590
tempenttran	60	245.8537	303.9253	0	1462
netperment~n	60	-.0043333	3.213781	-14.57	14.02
nettempent~n	60	-.0076667	112.0405	-562.3	336.4
allocuse	60	1905.533	2006.578	93	7148
irha	60	528.8667	268.1508	137	1126
irhaper	60	1.597667	1.66334	.23	5.26
panevap	60	2245.553	557.7019	1220.58	3031.2
applicrate	60	3.229892	2.031136	.1646884	7.093719