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The responsiveness of Australian farm performance to changes in irrigation water use and trade

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The flexibility of farms to respond to changing economic or environmental conditions has received attention in recent years, particularly in the context of changes in the availability and pricing of irrigation water. This study uses a new unit record data set of Australian farms and a generalised profit-function framework to assess the links between farm performance and water use practices, involvement in water trading and other farm characteristics. Amongst other findings, the study provides experimental estimates of the responsiveness of the demand for irrigation water to price changes and the impact of farmers either buying or selling water on farm profits, after controlling for other factors.

The responsiveness of Australian farm performance to changes in irrigation water use and trade

1. Introduction[1]

The performance of Australia's agricultural industries is inextricably linked to regional agronomic and seasonal conditions, and to developments in the markets for both agricultural commodities and key inputs such as labour and irrigation water supplies. Over recent years, drought conditions coupled with growth in competing demands for available water supplies, has drawn attention to the capacity of farms to respond to changes in economic or environmental conditions that impact on production, and particularly to the influence of changes affecting irrigation water use and trade. The more responsive are farms to changes in the availability, usage practices and pricing of key factors such as irrigation water, the greater may be their potential to maintain or improve performance.

Most empirical studies to date have either been commodity, industry or regional level analyses of performance or — in the few cases in which farm-level data have been examined — have been based on a relatively small sample of farms. In part, this has reflect the limited farm–level information that has been available for factors such as water use volumes and trading activity, and for water charges and other costs incurred in the use of irrigation water. This information gap has restricted assessments of the impact of policy and other changes on agriculture and farm performance.

This paper makes a start towards filling this information gap. It uses a new comprehensive farm–level panel data set to provide exploratory estimates of the impact of a range of production, institutional, seasonal and environmental factors on farm performance. It is intended that this empirical analysis will contribute to assessments of factors influencing farm activity, including the implications of alternative water prices on water use and expanding water markets on farm performance.

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The farm-level panel data set (described in box 1) was prepared as part of a joint ABS–Productivity Commission project to provide analysis of data collected on natural resource use in Australian agriculture. The first descriptive results from this study were reported in *Characteristics of Australia's Irrigated Farms* (ABS–PC 2006). This report examined the diversity of farm irrigation practices and management. The current study by the Commission extends the use of this information to examine links between farm characteristics and farm performance.

The analysis presented in this paper focuses on the activities of Australian farms over the period 2000-01 to 2003-04. For the purpose of this study, farms are classified to an industry according to their predominant activity under the Australia New Zealand Standard Industry Classification (ANZSIC), and then grouped into one of 12 agricultural industry groups (table 1). In forming these industry groups, some ANZSIC industry classes have been combined, taking account of the participation of sample farms in each of the ABS surveys and the availability of key water use data. The agricultural industry groups included in the analysis cover over 90 per cent of the Australian agricultural sector's gross value of production and represent major agricultural industries from all States and Territories.

Each industry group contains a mix of irrigated and non-irrigated farms and the importance of water trade is varied between these groups. In the analysis, control variables are used to distinguish farms that irrigate from those that do not, and farms which are able to trade from those which do not hold a tradeable entitlement. In this way, the analysis of the relationship between trade and farm performance was confined to those farms which irrigate and for which water trade may be a relevant consideration.

In this paper, some background information about water use and trade in the agricultural sector is provided, together with broad information on farm 'profits' by agricultural industry group and some commentary about potential influences on performance. A standard empirical framework is then applied to enable an examination of the impact of water use and participation in water trading on farm profit performance. Finally, some exploratory results estimated using this framework are provided.

Box 1 **Outline of the farm–level panel data set used for the analysis**

The panel data set for this project covers the four year period 2000-01 to 2003-04 and is referred to as the Agricultural Statistics Unit Record Data File (ASURF).

The core of ASURF is production data for farms represented in the ABS's Agricultural Census (2000-01) and the Agricultural Surveys (2001-02 to 2003-04); and natural resource and land management data for farms represented in the Land Management and Salinity Survey (2002) and the Water Survey Agriculture (2002-03). These collections cover the activity of selected agricultural establishments (farms) which have an Estimated Value of Agricultural Output (EVAO) greater than $5 000. The core ABS data in ASURF is described in detail in ABS-PC (2006).

The panel data set includes all farms covered in the 2000-01 Census year *and* in a subsequent Agricultural Survey. Because the panel does not cover every farm in each year of the four year period, it is an 'unbalanced' panel data set. Further, not all data items are available for every farm as not all farms that responded to an Agricultural Survey were also included in the Land Management and Salinity Survey or the Water Survey Agriculture. To complete the data set it was necessary to extrapolate available information to fill some farm–level data gaps. For example, for a number of farms, the volume of water used is estimated for the first two years of the panel based on areas irrigated in these years and water application rates in 2002–03 and 2003-04.

The local value of production was estimated using ABS farm–level production data and ABS output price information for each State and Territory. Farm variable costs were derived using information on the usage of fertiliser, paid labour and irrigation water from the Agricultural Census and Surveys; supplemented by farm input cost data from the ABS Agricultural Finance Survey for 1999-00, and price data from ABARE, ANCID and other ABS collections. For example, the cost of irrigation water per megalitre used was estimated for 2002-03 using farm–level information from the Water Survey (2002-03). This unit cost was then imputed for the remaining three years using annual trends in volumetric charges by state for high security allocations (ANCID 2005).

The farm–level data in ASURF were also augmented by selected climate and land condition data classified according to Statistical Local Area (SLA) by the Bureau of Rural Sciences. The original sources of these data included the Bureau of Meteorology, McTainsh, Leys and Kenn Tews (2005) and the National Land and Water Resources Audit.

Because the resulting panel data set combines data from a number of different sources and, of necessity, involves some imputation of data and approximations, caution is necessary in using it to answer very specific policy questions, and in interpretation of results.

Table 1 **Agricultural industry groupings**

Industry group in analysis	*ANZSIC codes*	*ANZSIC industries*
Nurseries	111	Plant nurseries
	112	Cut flower and flower seed growing
Vegetables	113	Vegetable growing
Grapes	114	Grape growing
Fruit	115	Apple and pear growing
	116	Stone fruit growing
	117	Kiwi fruit growing
	119	Fruit growing n.e.c.
Grains & other crops	121	Grain growing
	169	Crop and plant growing n.e.c
Mixed crops & livestock	122	Grain-sheep and grain-beef cattle farming
	123	Sheep-beef cattle farming
Sheep	124	Sheep farming
Beef	125	Beef cattle farming
Dairy	130	Dairy cattle farming
Other livestock	141	Poultry farming (meat)
	142	Poultry farming (eggs)
	151	Pig farming
	152	Horse farming
	153	Deer farming
	159	Livestock farming n.e.c.
Sugar	161	Sugar cane growing
Cotton	162	Cotton growing

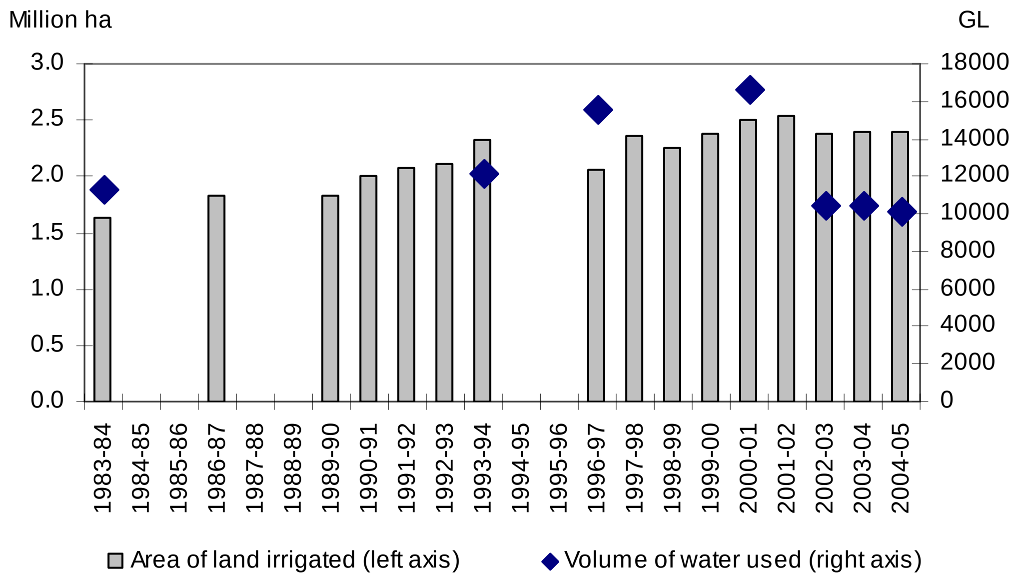
Source: ABS (ANZSIC 1993, Cat. no. 1292.0).

2. Background

Agricultural water use increased substantially over the 1990s to reach a recorded peak of 16 600 gigalitres (GL) in 2000-01 (figure 1). About 90 per cent of this was used for irrigation of agriculture activities. The remainder was accounted for by water for livestock, other on-farm activities, and seepage and evaporation losses.

By 2003-04, the quantity of water used for irrigation had declined substantially to around 10 000 GL — although not strictly comparable, this was similar to the early 1980s levels. Much of that decline reflects the temporary influence of drought. While reduced supplies in recent years have lowered agricultural water use, irrigated areas have remained at around 2.4 million hectares in Australia in 2003-04. Although, this represented only 0.5 per cent of all agricultural land, irrigated farms generate around one quarter of the gross value of Australia's agricultural production (ABS-PC 2006).

Figure 1 **Water use in agriculture and irrigated land areas, 1983–84 to 2004–05**

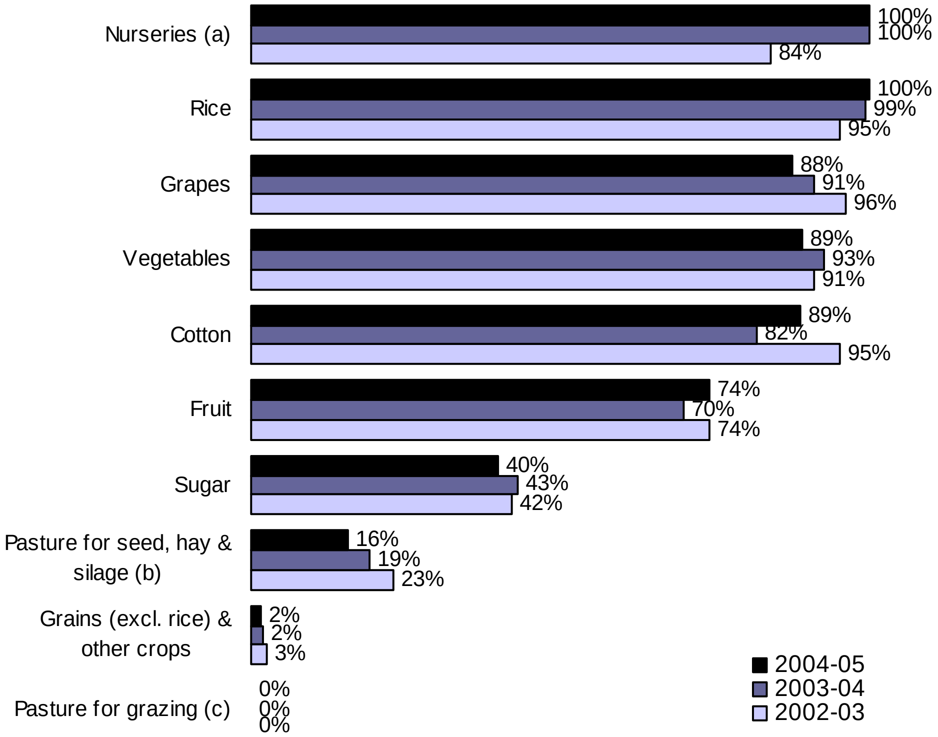


Source: ABS–PC 2006, ABS 2006.

The importance of irrigation and water trade

Irrigation is more important for some agricultural industry groups than for others (ABS–PC 2006). More than 80 per cent of land used for rice, cotton, grapes, vegetables and nursery production is irrigated (figure 2). Typically farms would not produce these crops without irrigation water. At the other end of the scale, crops such as pasture rely mainly on rainfall and can be produced with little or no irrigation. Reflecting these differences in reliance on irrigation, the volume of water used also varies widely between industries. Farms in the Cotton, Grains and Dairy industry groups were the major users of irrigation water during the period under analysis (ABS–PC 2006).

Figure 2 **Proportion of land irrigated by activity, 2002-03 to 2004-05[a]**



[a] The format of survey questions in 2002-03 is likely to have downwardly biased the proportion of land irrigated for Nurseries in that year. [b] Irrigated pasture for seed, hay and silage is predominantly on farms in the dairy industry. [c] The proportion of land irrigated for 'Pasture' is dominated by a substantial area of dryland pasture for grazing.

Source: ABS–PC 2006; ABS 2006.

A range of factors potentially influence the likelihood and extent to which a farm engages in irrigation.

At a broad level, irrigation provides a means of meeting seasonal demand for water when rainfall and soil moisture are relatively low. However, for many farms the use of irrigation is influenced by longer-run factors such as the availability of streams or groundwater, allocations from irrigation authorities and access to water markets. The combination of seasonal and longer-run factors underlies farm decisions about investment in irrigation equipment and other capital.

Farms that irrigate generate, on average, 55 per cent more output, measured by gross value of production, per farm than farms that do not irrigate, although the land area of irrigated farms is smaller on average, than that of non-irrigated farms (ABS–PC 2006). The contribution made by irrigation income to the value of agricultural production also increased, on average, with farm size. For example, 25 per cent of the gross value of production on large farms (ranked by gross value of production) was generated by irrigated activities in 2003-04, while on the smallest farms, 16 per cent of gross production income came from irrigated activities. The use of irrigation water by farms with higher average production incomes from their main irrigated activity, was also more likely to be continued over successive years.

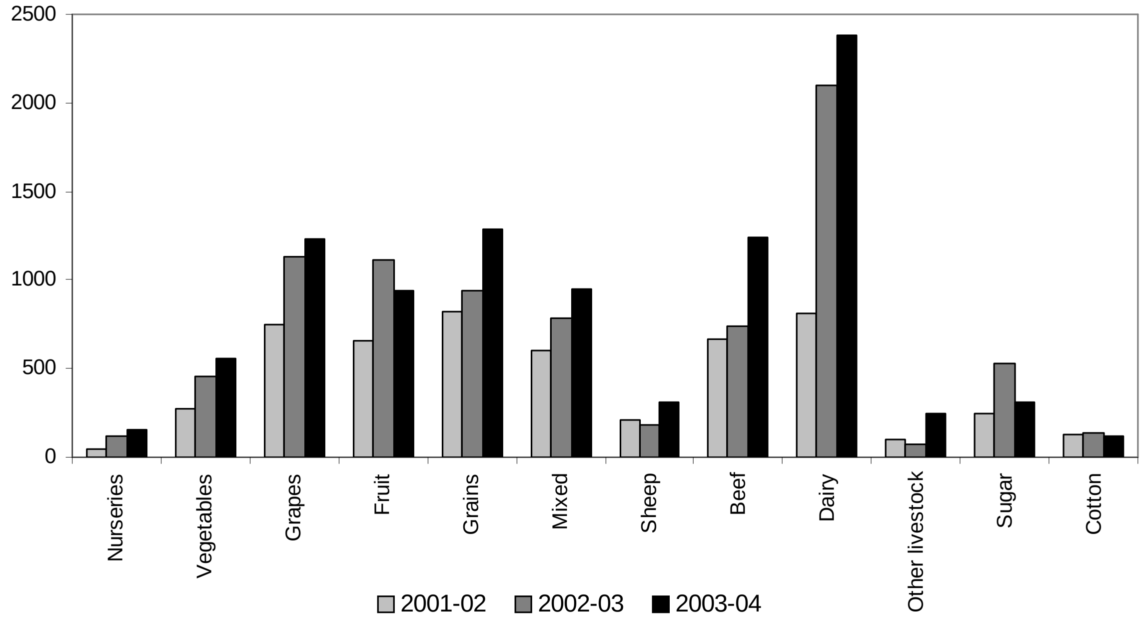
In parallel with the greater use of water by higher income farms, the use of water markets either to source additional irrigation supplies or to sell water entitlements (on a temporary or permanent basis) was also more likely for higher income farms (ABS-PC 2006). Since 2000-01, at least one-third of Australia's irrigators have participated in some form of water trade. While few farms engaged in trade on a regular basis (less than 15 per cent traded in each of the three years to 2003-04), trade participation has steadily increased in most industry groups over time (figure 3). Farms in the Dairy, Grains, Fruit and Grapes industry groups were the most active in water trade during 2001-02 to 2003-04.

Trade was also evident by farms in those industry groups that have a lower reliance on irrigation, such as Sheep and Beef. A number of farms in these industry groups hold water rights, which may be traded or used for irrigated cropping or activities such as the fattening of prime lambs on irrigated pastures.

More generally, the extent of water use and the likelihood of trade partly reflect the relative responsiveness of irrigation water demand in each activity to water prices and the value of an additional unit of irrigation water in production. Where activities can adapt to changes in irrigation water availability, an increase in water prices may reduce irrigation water use, with output and input factors remaining unchanged, including non-market factors. For those irrigators able and willing to trade in water in any one year (given market and institutional conditions, and farm characteristics and plans), the market price of water (rather than just the charges levied by irrigation authorities) may be the key price in decisions about water use and trade.

Figure 3 **Participation in water trade by industry group, 2001-02 to 2003-04[a]**

Total number of farms (weighted totals)



[a] Estimates for 2001-02 and 2002-03 are for temporary trade only; estimates for 2003-04 include permanent transfers of water entitlements.

Source: ASURF 2006.

Farm performance

Against a background of lower irrigation water availability and low rainfall more generally, production of most crops declined substantially in the early 2000s (ABS-PC 2006). For many farms, input costs also increased, with higher water costs and higher grain and fodder prices, coupled with the increased supplementary feeding of livestock (Martin et al. 2003). Improved seasonal conditions over much of Australia during 2003-04 was associated with stronger performance for many farms at that time (Martin et al. 2005). Farms with rice or cotton as their main irrigated activity were the exception to this, with substantial declines in both irrigated water use and irrigated land on large farms with these activities in 2003-04 (ABS-PC 2006).

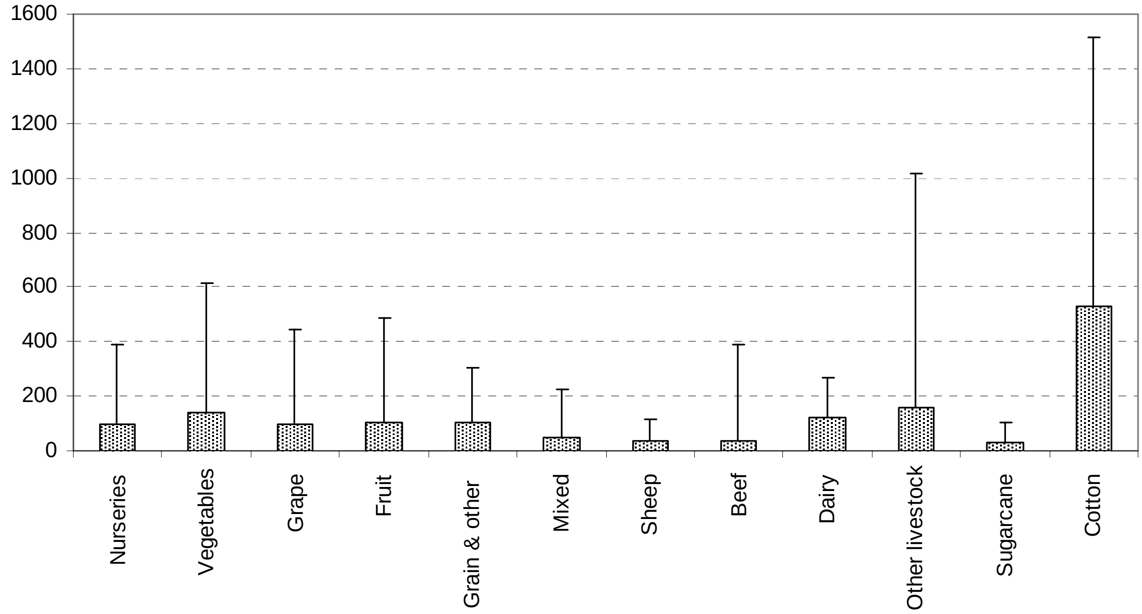
Over the four year sample period, all industry groups generated positive returns ('profits'), as measured by farm gross operating surplus (GOS) (figure 4).[2]

[2] GOS is measured as the difference between the local value of production and total variable costs (the costs of fertiliser, irrigation, paid labour and other materials and services). This measure reflects returns to farm management, capital and land and is closely related to the

However, farm profits have varied widely across and within each agricultural industry group, with the highest GOS levels evident for farms in the Cotton and the Other livestock industry groups. The greatest variability between farms in GOS, relative to industry group average levels, was for farms in the Beef and Other livestock groups.

Figure 4 **Farm gross operating surplus by industry group, average over 2000-01 to 2003-04**

$'000 weighted, and one-sided standard deviation



Source: ASURF 2006.

3. Analysis

Modelling framework

The model used in this study is based on the traditional assumption of profit maximisation and is represented by:

$$\max \Pi = P_y Y - P_x X \quad \text{subject to} \quad Y = f(X, Z) \qquad (1)$$

Australian National Accounts definition of GOS as value added less wages, salaries and supplements.

where Π is the model measure of profits, Y is a vector of outputs, X is a vector of inputs, P_y and P_x are vectors of output and input prices respectively, Z is a range of exogenous factors assumed to be fixed in the short run.

A similar framework to this has been used by Ahammed and Islam (1999), Gretton and Salma (1996), Fisher and Wall (1990) and Lawrence and Zeitsch (1990) to examine factors influencing profits in the Australian agricultural sector. In this study, the framework is applied across agricultural industries and exploits the new farm-level information on irrigation water use and trade. The framework allows variable returns to scale and simultaneous input and output decisions of farmers, which are common features in agricultural production relationships.

Given the representation of a profit function in (1), a general form of the output supply and input demand equations can be derived by differentiating with respect to prices (Hotelling's lemma). To implement this approach empirically, the normalised quadratic form of the indirect profit function was chosen. The normalised quadratic is a Taylor series approximation to the underlying production function that does not impose as many restrictions on production technology as other functional forms such as Cobb-Douglas or CES. Further, it allows global convexity to be imposed without loss of flexibility, and is self-dual, in that under certain conditions, the production function and the normalised quadratic profit function contain the same information about the underlying production technology. The estimated empirical model of profit used in this study is thus given by:

$$\Pi = \beta_0 + \sum_{j=1}^{m-1} \beta_j P_j + \sum_{r=1}^{v} \gamma_r Z_r + 0.5 \sum_{j=1}^{m-1} \sum_{k=1}^{m-1} \beta_{jk} P_j P_k + 0.5 \sum_{r=1}^{v} \sum_{s=1}^{v} \gamma_{rs} Z_r Z_s + \sum_{j=1}^{m-1} \sum_{r=1}^{v} \lambda_{jr} P_j Z_r \qquad (2)$$

where *m* represents the number of outputs and inputs ('netputs') in the model, in which netput quantities are defined as positive for an output and negative for an input, and *v* represents the number of 'fixed effect' environmental variables included in the estimation.

Output of crops Y_1 and livestock Y_2 (including livestock products) are included separately in the model for each industry group, and for the Grains industry group, output of rice Y_3 is also considered. The variable inputs in the model are fertiliser F, irrigation water W, paid labour L and other materials and services O. Profit and the prices of inputs and outputs were 'normalised' by dividing by the price of the model numeraire variable 'other materials and services'. For simplicity of presentation, the subscripts for time and farm have been dropped.

Farmers are assumed to make decisions about their output and input mix simultaneously based on the prices of inputs purchased and outputs sold in competitive markets. The farm's optimal level of output supply and input demand are given by the first derivative of the profit function with respect to the relevant price. Specifically, normalised output supply equations for crops and livestock for each farm in each year are given by:

$$Y_1 = \beta_1 + \sum_{k=1}^{m-1} \beta_{1k} P_1 + \sum_{r=1}^{v} \lambda_{1r} Z_r \tag{3}$$

$$Y_2 = \beta_2 + \sum_{k=1}^{m-1} \beta_{2k} P_2 + \sum_{r=1}^{v} \lambda_{2r} Z_r \tag{4}$$

Negative input demand equations for fertiliser, irrigation water and paid labour are similarly derived as:

$$-F = \beta_3 + \sum_{k=1}^{m-1} \beta_{3k} P_3 + \sum_{r=1}^{v} \lambda_{3r} Z_r \tag{5}$$

$$-W = \beta_4 + \sum_{k=1}^{m-1} \beta_{4k} P_4 + \sum_{r=1}^{v} \lambda_{4r} Z_r \tag{6}$$

$$-L = \beta_5 + \sum_{k=1}^{m-1} \beta_{5k} P_5 + \sum_{r=1}^{v} \lambda_{5r} Z_r \tag{7}$$

Model specification

Previous studies have canvassed a range of farm–specific characteristics as well as the physical, institutional and environmental characteristics that may influence farm performance. Table 2 outlines the nature and summary findings of a selection of studies that analyse potential influences on farm performance.

These background studies are indicative of the influences that are likely to be empirically significant in assessments of farm performance. Taking account of the findings of these studies, along with the availability of relevant farm-level and environmental data to this study, the empirical model used to examine profit performance relates farm profit and output and input decisions in each period (outlined in the modelling framework above) to the output and input prices and other factors outlined in table 3.

In the model, the area of land and other farm management, physical environment and institutional factors assumed fixed in any on year. In this setting, the estimated price elasticities are short run in character. Also, through the inclusion of variables that control for influences on farm decisions, including farm characteristics such as the likelihood of farmers trading water (Z_4), inter-jurisdictional differences ($Z_{12–16}$) and technological and regulatory progression

($Z_{17–19}$), it is intended that the estimated price elasticities abstract from non-price constraints on farm supply and purchasing decisions, over the sample period.

The possibility of non-linearities and complementarities was taken into account by including as additional variables in the profit equation, the square of each input price and exogenous variable and the cross product terms between each of these explanatory variables.

Model estimation and explanatory power

The responsiveness of farm performance to water use practices, involvement in water trading and other farm characteristics was determined by estimation of equations (2) to (7) for each of the twelve agricultural industry groups. The model was estimated for each industry as a system of seemingly unrelated regressions (SUR) using generalised least squares, as implemented in STATA 9 (STATA 2005). Correction for heteroskedasticity associated with the livestock supply and irrigation water demand equations in some industry groups was also undertaken using the robust White's correction in STATA.

While the regression models have a small number of 'focus' variables that are of primary interest (in particular, the irrigation and water trade variables) in this paper, there is a range of additional regressors which, while not of prime interest to this study, are included to control for other factors that may shape farm performance. A range of estimators presented in Heckman, Lalonde and Smith (1999) suggests that estimates derived from a broad model are no worse (and often better) in terms of bias, than estimators from more specific models. The main implication of a broad model is the potential for loss of efficiency in the estimators. This approach has been adopted in other (unrelated) empirical studies, such as Revesz and Lattimore (2001). That said, these other variables in the data panel may be of specific use to the analysis of other policy questions.

Regression sample sizes range from 1 285 farm observations over the four year period in the Cotton industry to almost 36 000 in the Beef industry (table 4). While the total number of coefficients estimated in the final model is also large — typically around 270 — degrees of freedom remain high.

Table 2 **Potential influences on farm profits**

Broad categories	*Influence*	*Rational for inclusion*	*Supporting studies*
Production factors	Land area Irrigation water use Labour input Fertiliser use Other materials and services	Key inputs of interest in farm production decisions.	Thirtle & Holding (2003); Ahammed & Islam (1999); Gretton & Salma (1996); Fisher & Wall (1990); Lawrence & Zeitsch (1990)
Pricing factors	Commodity (output) prices Input prices (eg: irrigation water charges, water trade prices, wage rates, fertiliser prices)	Allows for the cost of production inputs and the return on commodities to impact on farm production decisions.	Ahammed & Islam (1999); Gretton & Salma (1996); Fisher & Wall (1990)
Farm size factors	Area of holding EVAO	Allows for differences between farms in the scale of operation.	Apted et al. (2006); ABS-PC (2006); ABARE (2004); Hooper et al. (2002)
Irrigation practices	Irrigation application methods Irrigation scheduling tools usage Laser levelled land Sources of irrigation water On-farm water storage usage	Allows for farm choice of irrigation technology and irrigation management practices to influence farm performance outcomes.	McClintock et al. (2000) Topp and McClintock (1998)
Environmental factors	Rainfall level Rainfall percentile of long term average Soil erodibility Soil acidity Soil salinity Agro-ecological region	Allows for differences in the physical environment in which farms operate.	Davidson et al. (2006); Alexander & Kokic (2005); Chapman et al. (1999); Harrison & Chapman (1999); Gretton & Salma (1996); Fisher & Wall (1990)
Adaptive capacity	Farmer age Farmer education level Computer usage Participation in land/farm management programs Farm capital stock level/age	Signals the capacity of a farm to adapt to change and innovation.	Davidson et al. (2006)
Institutional and industry factors	State jurisdiction Irrigation region Industry grouping Water entitlement volume Seasonal allocation percentage Access to water markets	Allows for institutional-specific regulations or arrangements that are not captured by more descriptive characteristics – for example: differences between states in employment conditions; region-specific restrictions on water trade.	Davidson et al. (2006); Thirtle & Holding (2003); Ahammed & Islam (1999); Fisher & Wall (1990); Lawrence & Zeitsch (1990)
Temporal factors	Time index Technology index	Allows for temporal changes and/or technological progress.	Khatri & Thirtle (1996); Agbola & Harrison (2005); Ahammed & Islam (1999); Fisher & Wall (1990); Lawrence & Zeitsch (1990)

Table 3 **Factors modelled**

Category	*Characteristic*[a]	*Model variable*	
Outputs		*Quantity*	*Price*
	Crops	Y_1	P_{y1}
	Livestock	Y_2	P_{Y2}
	Rice (within the grains industry group)	Y_3	P_{y3}
Inputs			
	Fertiliser	F	P_F
	Irrigation water	W	P_W
	Paid labour	L	P_L
	Other materials and services (the model numeraire)	M	P_M
Exogenous factors (assumed fixed in the short run)			*Z Variables*
	Farm size: area of holding		Z_1
	Unpaid labour (discrete count variable)		Z_2
	Adoption or not of farm-level land management strategies (binary)		Z_3
	Estimated likelihood of engaging in temporary water trade to either buy or sell		Z_4
	The use of sprinkler irrigation technology instead of surface (dummy variable)		Z_5
	The use of drip irrigation technology instead of surface (dummy variable)		Z_6
	Annual level of rainfall for the SLA as an indicator of seasonal conditions[bc]		Z_7
	Dryland salinity (per cent of SLA affected)[c]		Z_8
	Soil acidity (median pH level in SLA)[c]		Z_9
	Soil erobability (median K-factor in SLA)[c]		Z_{10}
	Dust storm activity (median index in SLA)[c]		Z_{11}
	State jurisdiction (dummy variables for: Vic, Qld, SA, WA, Tas; NSW the control)		Z_{12}–Z_{16}
	Technological and regulatory progression effects (dummy variables for: 2001-02 to 2003-04 with 2000-01 as the control)		Z_{17}–Z_{19}
Past farm conditions[d] *(assumed independent and fixed)*			
	Change from previous year in farm profit per hectare		$\ln[\Delta(\pi / ha)]$
	Change from previous year in revenue per hectare		$\ln[\Delta(P_y Y / ha)]$
	Change from previous year in input cost		$\ln[\Delta(P_X)]$

a All variables are continuous unless otherwise specified. **b** For some industry groups, the use of annual rainfall may be a comparatively crude proxy for seasonal conditions as it does not capture within-season variability in the timing of rainfall or the varying importance of rainfall on different soil types. **c** Variables only observed at the Statistical Local Area (SLA) level, and hence, do not distinguish farm level differences within the SLA. **d** These factors are included in the modelling as ad-hoc additions to the appropriate equation in the SUR estimation, and so as to provide an adequate specification of profit, output supply and input demand equations. The empirical relation of each of these terms to the dependent variable is not well understood at this stage. Nevertheless, it is not necessary to interpret their coefficient for the purpose of this study.

Table 4 **Model estimation summary statistics for the SUR system**

Industry group	*Number of observations*	*Estimated parameters*	*Breusch-Pagan chi-square* [a]
Nurseries	5 695	270	937
Vegetables	10 029	274	19943
Grapes	8 343	270	1053
Fruit	12 979	274	14074
Grains & other crops	22 948	323	3925
Mixed crops & livestock	31 618	273	3050
Sheep	15 216	274	889
Dairy	13 483	274	12826
Sugar	5 444	247	12826
Cotton	1 285	217	11881

[a] The Breusch-Pagan statistic indicates the usefulness of model estimation as a system of equations. The null hypothesis of no correlation between the error terms of the regression equations is rejected at the 1 per cent level of significance for each industry group, suggesting that the residuals of regression equations are correlated and lending support to the use of SUR estimation. The Breusch-Pagan statistic has been shown to exhibit size distortions in panels for which the time series dimension is less than the cross-sectional dimension. An alternative test proposed very recently by Hoyos and Sarafidis (2006), that is applicable in this instance, will be considered in ongoing work in this study.

The estimated models were found to have considerable explanatory power in all industry groups. The estimated chi-square statistics indicated that the models were statistically significant at the 1 per cent level or above. Further, around 40 per cent or higher of the parameter estimates were found to be significant.

Further, the model estimates are generally consistent with economic principles associated with profit maximisation: the properties of *homogeneity* and *symmetry* are built into the model; and *monotonicity*[3] was tested for the Grains model and was satisfied for all but 100 of the near 23 000 observations in this industry group. It was somewhat more difficult to satisfy *convexity*[4] conditions, with violations of convexity found for other materials and services prices in all industries except Cotton.

The consistency of panel data used in the modelling was also empirically tested using a standard growth accounting framework. In particular, growth model estimates of input elasticities were found to broadly align with measures of the

[3] Monotonicity requires that the estimated values for output supply and input demand associated with the profit function must be positive at all data points, as negative values hold no economic interpretation. The satisfaction of monotonicity was checked simply by identifying any estimated data that violated this property.

[4] The property of convexity requires that the Hessian matrix of the model's second-order partial derivatives with respect to prices be positive semi-definite, which is often a property that is violated in empirical models. Convexity was tested in this study using a Cholesky decomposition (Lau 1978).

share of inputs in variable costs derived from basic data and robust to alternative model specifications.

Overall, the estimated model is considered to represent a useful starting point for the evaluation of the irrigation and water trade effects on farm performance for 11 of the industry groups and for the analysis of agricultural issues more generally. Results are not presented for the Other livestock industry group — a lack of homogeneity amongst farms reduced the explanatory power of the model and low irrigation water usage reduced its relevance to this study.

Elasticity estimates

The estimated own and cross-price elasticities are provided in table 5 for 11 industry groups. These elasticities measure the ease with which producers have been able to alter the combination of outputs produced and inputs used. As indicated above, with the area of land and other farm management, physical environment and institutional factors held fixed, the estimates are short run in character. Further, through the inclusion of variables controlling for a range of influences on farm decisions including farm characteristics, inter-jurisdictional differences and technological and regulatory progression, the estimated price elasticities abstract from non-price constraints on farm supply and purchasing decisions, over the sample period.

Own-price elasticities

Own-price elasticities indicate the percentage change in the volume of output (input) for a one percent change in the price of that output (input) with all other output and input prices held constant. With the area of farmland and other environmental factors held fixed, as noted, the estimated elasticities are short run in character and abstract from the influence of other factors included in the model. Most of the own-price elasticities on outputs and all of the own-price elasticities on irrigation water were found to be statistically significant at the 5 per cent level or above. Importantly, all of the own-price elasticities were of the expected sign — that is, an increase in an output price is estimated to lead to an increase in supply of that product and an increase in input prices is estimated to lead to a reduction in the use of that input.

Table 5 **Estimated short-run own- and cross-price elasticities**

	Elasticity with respect to the price of						
	Crops	*Livestock*	*Rice*	*Fertiliser*	*Irrigation water*	*Paid labour*	*Other materials*
Nurseries							
Crops	0.94*	0.01		0.19	0.03	-0.32	0.16
Livestock	0.71	0.10*		1.65	-0.05	-1.59	0.19
Fertiliser	0.15	0.02		-1.53*	0.03	-0.53	2.85
Irrigation water	0.05	0.00		0.07	-0.88*	0.09	1.68
Paid labour	-0.47	-0.04		-0.95	0.07	-2.21*	4.60
Other materials	-0.37	0.91		1.58	1.81	5.56	-8.48
Vegetables							
Crops	0.76	-0.01		0.18	0.04	0.28	-0.26
Livestock	-0.05	0.78*		0.09	-0.07	0.01	0.23
Fertiliser	0.07	0.01		-1.41*	-0.12	0.21	2.23
Irrigation water	0.02	-0.01		-0.13	-0.83*	-0.04	1.99
Paid labour	0.19	0.00		0.34	-0.06	-0.73	1.27
Other materials	0.00	0.22		1.93	2.04	1.27	-4.47
Grapes							
Crops	0.55*	0.00		0.24	0.10	0.28	-0.16
Livestock	0.06	0.90*		-0.36	0.06	0.12	0.22
Fertiliser	0.18	-0.01		-1.57*	-0.04	-0.69	3.12
Irrigation water	0.09	0.00		-0.05	-1.04*	0.00	2.00
Paid labour	0.94	0.01		-3.08	-0.01	-1.00	4.15
Other materials	-0.82	0.10		5.82	1.94	2.30	-8.34
Fruit							
Crops	0.45	0.00		0.45	-0.24	-0.45	0.78
Livestock	0.25	0.86*		0.59	-0.17	-0.60	0.07
Fertiliser	0.11	0.00		-0.57*	0.01	-0.16	1.62
Irrigation water	-0.06	0.00		0.01	-0.82*	0.06	1.81
Paid labour	-0.55	-0.01		-0.85	0.28	-0.49	2.62
Other materials	0.81	0.14		1.37	1.94	2.64	-5.91
Grains and other crops							
Crops	0.70*	0.10	0.01	1.21	-0.01	-0.76	-0.24
Livestock	0.06	0.07*	0.00	0.25	0.00	-0.05	0.67
Rice	0.29	0.00	0.18*	-0.06	-0.01	-0.12	0.72
Fertiliser	0.62	0.22	0.00	-0.24	0.01	-0.96	1.36
Irrigation water	-0.20	0.00	-0.01	0.54	-1.41*	-0.36	2.44
Paid labour	-1.28	-0.14	-0.01	-3.17	-0.02	-0.53	6.15
Other materials	0.82	0.75	0.83	2.46	2.44	3.79	-10.10
Mixed crops and livestock							
Crops	0.66*	0.16		-0.37	0.00	-0.03	0.58
Livestock	0.11	0.85*		-0.51	0.00	0.02	0.54
Fertiliser	-0.25	-0.50		-0.24*	0.00	-0.14	2.13
Irrigation water	-0.04	0.16		0.12	-0.96*	-0.56	2.28
Paid labour	-0.11	0.10		-0.85	-0.03	-0.04	1.94
Other materials	0.63	0.24		2.86	1.99	1.76	-6.47

Continued next page

	Crops	Livestock	Rice	Fertiliser	Irrigation water	Paid labour	Other materials
	Elasticity with respect to the price of						
Sheep							
Crops	0.80*	0.01		-0.04	0.00	-0.10	0.33
Livestock	0.00	0.78*		-0.15	0.00	0.04	0.33
Fertiliser	-0.01	-0.14		-0.59*	0.00	-1.25	2.99
Irrigation water	-0.03	0.28		1.66	-0.99*	-2.06	2.14
Paid labour	-0.15	0.33		-1.98	-0.02	-0.98*	3.81
Other materials	0.39	-0.25		2.10	2.01	5.36	-8.61
Beef							
Crops	0.45*	-0.19		1.19	0.00	0.03	-0.48
Livestock	-0.03	0.00		1.24	0.00	0.19	-0.39
Fertiliser	0.07	0.47		-0.50	0.00	-2.25	3.22
Irrigation water	0.02	-0.05		-0.76	-0.94*	-0.91	3.63
Paid labour	0.04	0.37		-11.75	-0.03	-2.23*	14.60
Other materials	0.62	0.41		11.58	1.97	6.17	-19.75
Dairy							
Crops	0.53*	0.04		0.07	0.05	0.10	0.20
Livestock	0.02	0.56*		-0.01	0.01	0.48	-0.06
Fertiliser	0.04	-0.01		-1.23*	-0.04	0.08	2.17
Irrigation water	0.07	0.04		-0.13	-1.40*	-0.25	2.67
Paid labour	0.14	1.25		0.20	-0.22	-5.10*	4.73
Other materials	0.19	-0.88		2.10	2.60	5.70	-8.71
Other livestock	*(not reported)*						
Sugar							
Crops	0.36*	-0.01		-0.17	-0.11	-0.10	1.03
Livestock	-0.24	0.95*		-0.28	-0.03	0.49	0.12
Fertiliser	-0.18	-0.01		-0.88*	0.05	0.30	1.72
Irrigation water	-0.48	0.00		0.20	-1.87*	0.09	3.06
Paid labour	-0.11	0.01		0.32	0.02	-0.54*	1.30
Other materials	1.66	0.05		1.82	2.94	0.77	-6.23
Cotton							
Crops	0.69*	0.04		0.41	-0.04	-0.14	0.05
Livestock	0.27	0.89*		-0.11	0.05	0.15	-0.25
Fertiliser	0.24	-0.01		-2.12*	0.06	0.90	1.93
Irrigation water	-0.05	0.01		0.12	-1.44*	0.02	2.34
Paid labour	-0.10	0.02		1.10	0.01	-0.86*	0.83
Other materials	-0.05	0.06		1.60	2.35	0.93	-3.90 *

* Indicates significance of own-price estimates at 5 per cent level or above. The significance of cross-price elasticities is available on request. The statistical significance of elasticity estimates for the model numeraire 'Other materials', could not be validated as these estimates are calculated as residuals rather than directly estimated. Own-price elasticities are highlighted to assist the reader.

Source: Model estimates.

The own-price elasticities of crop and livestock output are consistently less than one, indicating that production responds less than proportionately to a change in its own price in the short run. Further, the estimates generally lie within the range established by other studies (table 6). The estimated elasticities of crop production to a change in crop prices range from 0.2 to 0.4 for rice and sugar production to 0.9 for the Nurseries industry group. The relatively low estimate for rice production compared with other grains may reflect a combination of the low risk relative to returns perceived to be available from rice production and the vertical integration of the industry which provides additional incentives for farmers to retain some area under rice production (Jones 2004). The estimated own-price elasticities of livestock ranged from slightly above 0 to around 1. Livestock production in the Sugar, Grape and Cotton groups was the most responsive to price changes, suggesting that for these industry groups, resources used in livestock are readily transferable to other activities.

The estimated own-price elasticities for fertiliser and paid labour are typically in the range of -0.5 to -2.2, although few of the own-price elasticities on paid labour are significant. The own-price elasticity for labour in the Dairy industry, at -5.1, is an exception to this result and may reflect the influence of restructuring that occurred in the industry during the period of analysis. As a central focus of this study, the estimated own-price elasticities for irrigation water are discussed separately below.

The use of other materials and services was found to be relatively elastic to changes in its own price in all industry groups with elasticities ranging from -3.9 in the Cotton industry up to -20 in the Beef industry group. In general, these estimates were at the upper end of the range of estimates reported in other studies (table 6). As this item is the numeraire variable in the model, its own and cross-price elasticity values are computed as residuals rather than directly estimated. Consequently, the statistical significance of the coefficients that would otherwise underlie estimates of material and services elasticities could not be validated after controlling for other factors and the estimates should be viewed with additional caution.

Cross-price elasticities

The cross-price elasticities appear in the off-diagonal entries of table 5 and capture the impact of price of an output (input) on the supply (demand) of another output (input). It should be noted that many of the cross-price elasticities are not significantly different from zero — particularly in the Cotton and Vegetable industry groups.

Table 6 **Selected econometric estimates of own-price elasticities for Australian agriculture[a]**

	Lawrence & Zeitsch (1990)	Fisher & Wall [b] (1990)	Gretton & Salma [c] (1996)	Pagan et al.[d] (1997)	Ahammad & Islam[e] (1999)	Jayasuriya et al.[d] (2001)	Hall (2003)	Agbola & Harrison[f] (2005)
Outputs								
Grains	0.15	(0.28 to 2.67)	0.79		1.23			0.2
Other crops		(0.14) to 0.76						
Animal products			1.12					
Wool		(0.04 to 0.10)			0.53			0.21
Sheep		(0.28 to 0.39)			1.11			
Cattle /Other livestock	0.23	(0.11 to 0.43)			0.02			
Inputs								
Fertiliser			-3.27					
Water			-2.34	-2.81		(-0.82 to -3.52)	-0.14	
Labour	-0.52		-2.46		-4.38			0.4
Other materials & services	-0.37		-14.59		-1.62			0.06

a Items from source studies are selected to coincide as closely as possible with the items listed in the table row headings. **b** Covers the sheep industry in the pastoral, wheat-sheep and high rainfall zones. **c** NSW agriculture. **d** Estimates for short run elasticities at water prices over $50/ML (as quoted in Appels et al. 2004). **e** WA agriculture. **f** Estimates reported are short run elasticities for the pastoral industry.

Sources: As listed in table.

On the output side, a complementary relationship between crop and livestock production was found in the Nurseries, Grains, Fruit, Grapes, Mixed crops and livestock, Sheep, Dairy and Cotton industry groups. This suggests that the total on-farm production response is larger than the individual commodity response — for example, a 1 per cent increase in nursery product prices is estimated to increase the nursery crop production by 1 per cent and livestock production of predominantly nursery enterprises by a further 0.7 per cent. In contrast, for farms in the Vegetables, Beef and Sugar industry groups, the estimates suggest that crop production is a substitute for livestock production. For example, an increase in the price of sugar product prices is estimated to draw resources away from livestock production of predominantly sugar producing enterprises to enable an increase in sugar production.

On the input side, the empirical evidence indicates that the nature of the relationship — whether inputs are substitutes or compliments in production — between the variable inputs differs between items and industry groups, after controlling for other factors. For example, the use of fertilizers and paid labour was found to be complementary to the use of irrigation water in the Vegetables, Grapes, Grains and other crops, Beef and Dairy industries, but substitutes in the Nurseries, Fruit, Sugar and Cotton industries. In addition, for the Mixed crops and livestock and Sheep industries, fertilizers and irrigation water were estimated to be substitutes, while paid labour and water were estimated to be complements.

The estimated empirical relationships between variable inputs reflect many factors relating to farmer decisions, the application of farm production technologies over the sample period and biophysical factors. For example, some inputs (including water and some fertilizers) can have residual effects spanning several growing seasons or years and their usage (effectiveness) can be limited by the availability of other inputs. Accordingly, the estimates reported here are intended to reflect overall relationships between the variable input items in production after controlling for other factors, over the sample period.

Irrigation water demand elasticities

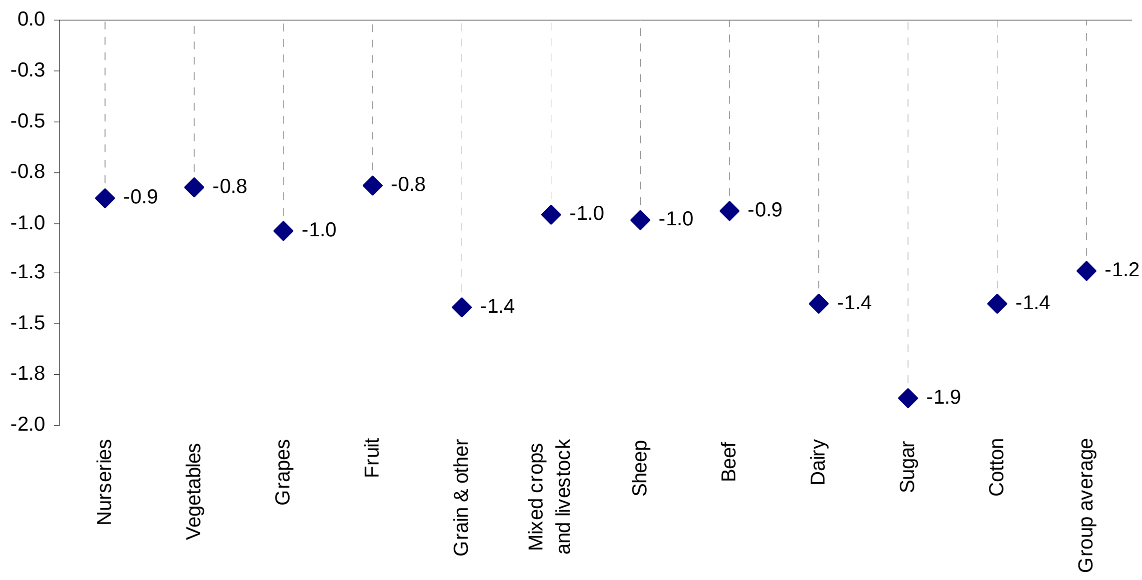
The responsiveness of farm irrigation water demand to changes in irrigation costs is often the focus of studies that examine the implications of possible reductions in the availability of irrigation water to Australian agriculture and market based reforms for the allocation of available supplies. Estimates of irrigation water demand elasticities can be readily calculated in the current analysis and provide an important basis for a comparison of the model results with those of other studies in Australian agriculture. Elasticity estimates from the current study are short run estimates in the sense that land area, farm capital (including irrigation infrastructure) and farm unpaid labour are assumed to be fixed.

The irrigation water demand elasticities, calculated as the industry average water use over the sample regression, were found to range from –0.8 for the Fruit and Vegetable industry groups to –1.9 for Sugar (figure 6). In general, irrigation water demand was found to be less responsive to water prices in the horticultural industries (such as Nurseries, Vegetables and Fruit) than in the broadacre cropping industries such as Grains, Sugar and Cotton. For the Fruit and Grapes industry groups at least, this is likely to reflect the often substantial longer-term investment by farm enterprises in fruit trees and grape vines that take some years to mature and which require regular watering. Elasticities for the animal-based industry groups were typically around –1.0 to -1.4.

Nevertheless, the water demand elasticity estimates in this study are somewhat less elastic (lower in absolute terms) than those reported in some earlier (mid-1990s) econometric studies for Australian agriculture (table 6). One possible reason for the less elastic values could be a move towards more economical use of water as a farm input with the passage of time and an associated shift in usage closer to technological constraints. On the other hand, an increase in the unit cost of water over time would tend to be associated with higher absolute elasticity estimates. A prior expectation given the range of elasticity estimates in other studies was that there is substantial variation in price-responsiveness between industry groups and/or that the industry-scope and methodology used to derive estimates may explain some of the variability. As a consistent methodology is used for each industry group in the current study, the results presented are supportive of the view that the price-responsiveness of farms varies substantially between industry groups.[5]

Figure 5 **Irrigation water demand elasticities[a]**

Percentage change in irrigation water demand for a one per cent change in the price of irrigation water



[a] Estimated elasticities are computed at sample means from the restricted form of the model and represent an industry average elasticity.

Source: Model estimates.

Responsiveness of farm performance to water trade

While the model developed in this study captures the potential influence of a broad range of production, institutional, seasonal and environmental factors on

[5] As outlined in box 1, the benchmark unit water cost (price) data used in this study is a comprehensive measure of the variable costs of water use. It includes license and application charges, volumetric and usage charges (on allocated water and extra water purchased), other fees and charges (eg environmental charges) and irrigation operating expenses (eg pumping expenses).

farm performance, of particular interest is the potential influence on profit performance of irrigation-related factors and water trade (either to buy or sell). The agricultural and natural resource surveys provide new information that can be used to empirically assess the potential influence of irrigation related factors and water trading on farm profits, after controlling for other factors.

Prima facie, it would be expected that for sellers, water sales provide additional net receipts that are in excess of any reduction in income associated with lower irrigated production; and for buyers, water purchases enable the generation of additional irrigated production income above the total cost of the additional water. In both cases it would be expected water trade would contribute to higher farm profits, although lags could occur between a water trade event and the full impact on profits, particularly in the case of permanent water trades.

A limitation of the survey data is that it records only whether a farm bought or sold water (a binary event) rather than the farm's propensity to trade. To overcome this limitation, the likelihood of (or propensity to) trade on a temporary basis (to either buy or sell), was estimated for each farm using farm and regional characteristics (appendix A). In the likelihood estimation, farms that held water entitlements were assumed able to trade and were distinguished from those that did not hold entitlements.

Consistent with expectations, the impact of temporary water trade on farm profits was found to be positive for the assessed industry groups (table 7). That is, farms that were more likely to engage in water trade (either to buy or sell), tended to have higher profits than other farms in the same industry. Across all industry groups and holding other factors unchanged, a 1 per cent increase in the likelihood of water trade was associated with a 2 per cent higher level of farm GOS than would otherwise be the case.

Table 7 **Estimated impact of trading water on farm profits**[a]

Percentage change in average farm GOS associated with a one per cent change in the likelihood of water trade.

Industry group	*GOS*	*Change in GOS*
	$000 per farm	%
Nurseries	99	0.7
Vegetables	138	0.8
Grapes	95	0.7
Fruit	106	7.8
Grains & other crops	106	1.1
Mixed crops & livestock	46	2.7
Sheep	36	2.1
Beef	38	1.7
Dairy	119	1.5
Sugar	29	6.2
Cotton	530	1.0

a Based on normalised quadratic restricted profit function, evaluated at sample means. The dollar increase in GOS can be calculated as total effect of variable (direct plus cross product terms) multiplied by the weighted GOS for each industry group, averaged over the four years 2000-01 to 2003-04.

Source: Model estimates.

The impact of the likelihood of water trade on farm profits was estimated to be largest for farms in the Cotton, Sugar and Dairy industries (figure 7). For example, for farms which grew Cotton and participated in water trade during the study period, a 1 per cent increase in the likelihood of water trade was associated with GOS that was about 1 per cent, or just over $5 000 per farm, higher than would be the case if they had not participated in water trade. However, this estimated effect of water trade is modest when compared to the relatively large average farm GOS in Cotton growing. The apparent relatively large impact of water trade on farm performance in the Sugar industry may partially reflect the effects of not just temporary, but also permanent trade (which was particularly high in 2002-03 and which cannot be separated from temporary trade in 2003-04).

For farms in the Nurseries, Grapes, Grains, Dairy and Sugar industry groups, the positive relationship between the likelihood of trade and farm profits holds generally. In the remaining industry groups, the relationship is less clear as there is evidence of non-linearities between the trade likelihoods and farm profits. The evidence of non-linearities is suggestive that the relationship between trade and profits is complex and warrants further investigation.

4. Conclusions

This study provides a broad analysis of factors influencing farm performance using an established analytical framework. It uses a new farm-level data set prepared as part of a joint project between the ABS and the Productivity Commission. While at this stage, the empirical results should be viewed as experimental, the detailed estimates are plausible, in absolute terms and relative to other studies.

In particular, this study provides evidence of the relationship between farm profits and water use practices. The main findings from the study are that:

- the use of irrigation water by farms is more responsive to a change in water prices, after controlling for all other factors, in the broadacre cropping industry groups (Grains, Sugar and Cotton) than in the Fruit, Vegetables or Nurseries industry groups. The more elastic estimates indicate the ability of some irrigated production activities to flexibly adjust their input use with a change in the price of water. Therefore, despite the significance of irrigation water use in many industries and regions, increases in water prices would lead to lower on-farm irrigation water use in some irrigated activities, all other things being equal.
- a greater likelihood of temporary water trade is, on average, associated with higher farm profits in each industry group.

The study suggests that further data developments and empirical analysis would be worthwhile. In particular,

- the completion of the experimental panel data set involved use of information from different sources and some data imputation. To support broad analyses of the type undertaken in this study, it would be worthwhile, in the longer term, to improve the comprehensiveness and integration of available data.
- because of the importance of the regional dimension in agriculture, it would be of relevance to assessments of policy and other changes affecting agriculture to further disaggregate the model to regional industries and undertake sensitivity testing of empirical estimates across regions.
- the availability of farm-level panel data offers the opportunity to include dynamics in the empirical modelling. This has been implemented in the current study through the addition of selected lagged control variables. It would be worthwhile to further develop the theoretical specification of the model and to test the sensitivity of results to alternative specifications.

Appendix A. Likelihood of water trade

The likelihood that a farm engages in temporary water trade (ie farm propensity to trade) is used as an explanatory variable in the farm profit system estimation. This likelihood is determined as the predicted probability of a farm engaging in water trade (either to buy or sell on a temporary basis) using a logit form of discrete choice regression. That is, the likelihood of a farm engaging in water trade is given as:

$$\begin{matrix} \textit{Likelihood of farm i} \\ \textit{participating in water trade} \end{matrix} = \mathrm{Fn}\left[\alpha + \sum_{j=1}^{K} \beta_j X_{ij}\right]$$

where Fn is the logistic cumulative distribution function and *Xij* is a list of explanatory variables. To support meaningful modelling of the likelihood of farms engaging in water trade, as far as practicable, farms for which trade was not relevant have been excluded from the regression analysis. Farms excluded from the analysis were those which did not irrigate and for which water trade was judged to be not a relevant consideration during the sample period.[6]

The factors that determine the extent of trade in water, for eligible farms, are largely those which underpin demand for irrigation water. However, there are also a number of physical and institutional factors, such as the need to hold an entitlement that is tradeable, which constrain the extent and type of water trade The explanatory variables *Xij* in the above model include: farm financial size (measured by EVAO and EVAO squared); area irrigated; possession of an ongoing water entitlement; unit water charges; commodity output prices; irrigated application method used; binary indicator of laser levelled land; binary indicator of the adoption of land management practices; binary indicator of availability of on-farm water storage facilities; binary indicator of irrigation water source (eg: surface or groundwater); age and age square of the farmers; count indicator of intensity of computer use for farm management; binary indicator for State jurisdiction; binary indicator for agro-ecological regions; seasonal rainfall in the farm's SLA; and the dust storm index for the farm's SLA.

This approach to examining the impact of water trade on farm performance overcomes the lack of a consistent data series for the volume of water traded, across farms and sample years, and relaxes the homogeneity assumption of using a binary (yes or no) variable approach (Gretton and Gali 2003) — for example, whether a farm participated in water trade or not. The estimated logit equations

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[6] It should be noted that some 'dryland' farms reported trade in water during the sample period and were included in the analysis. The likelihood of water trade for farms excluded from the regression analysis was assumed to be zero in the farm profit system estimation.

provided a good fit to the available water trade data, with the percentage of correct predictions (trade or not trade) being over 90 per cent for each of the industry groups.

The results from the logit analysis indicate broadly that the likelihood of water trade increases with the farm size, ongoing water entitlements, the multi-purpose use of computers, the availability of on-farm storage facilities, adoption of land management practices, laser levelling and the time period. For farms which have rainfall levels consistent with long-term average levels, or which have older age farmers, the likelihood of water trade participation is lower.

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