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Estimating irrigation farm production functions with ABARES survey data

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Abstract

The ABARE (now ABARES) survey of irrigation farms in the Murray–Darling Basin began in 2006–07 and provides a comprehensive farm-level panel dataset, which, to date, has seen limited econometric analysis (Ashton et al. 2009). At present, three complete years of irrigation survey data are available: 2006–07, 2007–08 and 2008–09. In each year, approximately 850 farms are sampled. As with the ABARES broadacre surveys, the irrigation survey is a rotating (unbalanced) panel dataset.

This study makes use of the irrigation survey data to estimate production functions at both the farm and enterprise (crop/livestock activity) level. In addition to the traditional categories of input use (land, labour, capital and materials), the study incorporates measures of water use, tree and vine capital and local seasonal rainfall. The analysis incorporates fixed effects models to take advantage of the survey's panel structure, as well as consideration of potentially endogenous inputs via instrumental variable methods. The study focuses on the short-run marginal revenue product of water implied by the estimated production functions.

The results provide an encouraging demonstration of the kind of analysis that can be undertaken with the irrigation survey dataset. The estimated marginal product curves showed horticulture farms to have the steepest marginal product curve and broadacre farms to have the most elastic. There remain a number of promising areas for potential future research using the dataset, particularly if the survey were to continue for a longer and more representative sample of years.

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This report draws heavily on data collected in the ABARES survey of irrigation farms in the Murray–Darling Basin. The survey has been funded by the Department of Sustainability, Environment, Water, Population and Communities. The success of these surveys depends on the voluntary cooperation of farmers, their accountants and marketing organisations in providing data. The dedication of ABARES survey staff in collecting these data is also gratefully acknowledged. Without this assistance, the analysis presented in this report would not have been possible.

1 Introduction

The establishment of the Water Act in 2008 reflected a significant shift in the evolution of Australian water policy. The Act represented official recognition of the overuse of water resources in the Murray–Darling Basin and a commitment to address the balance in favour of the environment via the establishment of Sustainable Diversion Limits (SDLs).

The Murray–Darling Basin Authority (MDBA) has been tasked with the difficult problem of setting the SDLs and, in effect, determining the optimal long-run balance between consumptive and environmental water use for each catchment within the Basin. The MDBA must make this decision subject to limited information on both the expected benefits of additional environmental water and the expected costs of withdrawing water from consumptive use. While the valuation of environmental benefits remains a particularly difficult task, significant uncertainties and information gaps also remain on the costs side.

Irrigated agriculture is the primary consumptive water user in the Basin, accounting for 80 per cent of use in 2004–05. Until recently, econometric analysis of irrigation water demand in Australia was limited by a lack of suitable datasets, with the majority of irrigation water demand estimates being derived from mathematical programming models. In recent times there have been a number of econometric studies making use of the growing time series of water market price data to directly estimate water demand curves (Wheeler et al. 2008, Brennan 2006), and one significant study making use of farm-level production data (Bell et al. 2007).

This study makes use of data from the ABARE (now ABARES) survey of irrigation farms in the Murray–Darling Basin (Ashton et al. 2008) to estimate irrigation farm production functions. The ABARE survey of irrigation farms in the Murray–Darling Basin began in 2006–07 and provides a comprehensive farm-level panel dataset, which, to date, has been the subject of limited econometric analysis. A key focus of the study is the short-run marginal revenue product of water curves implied by the estimated production functions.

The analysis represents an initial step toward the aim of deriving robust estimates of water input demand curves. Such estimates would form useful inputs into quantitative economic models of irrigation in the Murray–Darling Basin, such as the ABARES Water Trade Model. While, at present, only three (drought-affected) years of survey data are available, it is hoped this study will inform future efforts aided by longer and more representative samples.

2 Background

This section briefly considers some of the key determinants of water input demand in the context of irrigated agricultural production, before providing a literature review of Australian empirical studies estimating water input demand curves. A more detailed consideration of irrigation water demand is contained in Apples, Douglas and Dwyer (2004).

Determinants of water demand

Key inputs into the irrigation farm production function include land, labour, capital, materials and services, water and rainfall. Crops' moisture requirements are satisfied by a combination of water obtained via irrigation schemes and naturally available moisture, dependent on rainfall. Capital can be interpreted generally to include both traditional capital items, such as farm vehicles, machinery, vehicles and equipment, and tree and vine capital and livestock capital. The nature of water input demand varies significantly over the short, medium and long run.

- **Short run (intra-season)—water application decision:** the water yield function defines the relationship between water applied per unit of crop area (the water application rate) and yield (volume of output per unit of land) for a given level of natural moisture availability. This relationship is typically characterised by decreasing returns to additional water use.
- **Medium run (inter-season)—crop planting decision:** in the medium term, irrigation farms have the ability to alter the area planted (as a proportion of available land) and type of annual crops planted. This decision will be made subject to an expectation of seasonal water availability. The annual crop planting decision provides additional flexibility to farms primarily engaged in annual cropping (for example, broadacre farms).
- **Long run—capital investment decision:** in the long run, all inputs may be altered. For example, investments in tree (and vine) capital (such as fruit trees and grape vines) will be made with an expectation about future irrigation water supply—both the expected mean and the expected variation (see, for example, Brennan 2006). More generally, farms may alter other aspects of the capital stock, particularly those related to irrigation infrastructure.

Farm water input demand will also be influenced by exogenous movements in output prices and in the prices of complement and substitute inputs. A notable example is that of the dairy industry where farms may substitute between using irrigation water to grow pastures/silage or hay on farm and purchasing fodder from external suppliers, depending on relative prices.

Estimating water demand curves

A wide variety of methodological approaches have been employed to derive estimates of water input demand curves (and associated elasticities) in Australian irrigated agriculture, including the application of mathematical programming models and econometric studies using either time series market price data or farm-level production data.

Mathematical programming

Given limited data availability, most early studies employed mathematical programming (optimisation) models to estimate regional water demand schedules—for example, Hall (2003), Pagan et al. (1997) or Hall, Poulter and Curtotti (1994). A summary of this literature is presented in Apples, Douglas and Dwyer (2004) and, more recently, Qureshi, Ranjan and Qureshi (2010).

Mathematical programming models combine a range of assumptions about irrigated production, including crop yields and water application rates for different crop types, with standard profit maximisation assumptions. These models employ traditional optimisation techniques, commonly linear programming, to derive regional-level water price schedules. A common assumption among earlier optimisation models is a relatively inflexible Leontief-type production structure with fixed water application rates. These models typically produce very inelastic water demand responses at low water prices, which become increasingly elastic at higher prices (Apples, Douglas and Dwyer 2004).

Scheierling et al. (2006) conducted a meta analysis on the elasticity of demand for irrigation water, comparing the results of 24 US studies, and found that mathematical programming studies tended to derive lower elasticity estimates (an average of -0.45) relative to econometric studies (an average of -0.62).

Econometric studies: market price data

With the establishment of water markets in the Murray–Darling Basin, there has been an increased focus on applying econometric methods to market price time series data (Brennan 2006, Bjornlund and Rossini 2005 and Wheeler et al. 2008). To date, much of this analysis has focused on the southern Murray–Darling Basin, particularly in Victoria where a significant time series of market price data is available. The availability and quality of market price data varies significantly across the Basin's individual catchments.

Wheeler et al. (2008) analysed a monthly time series of water allocation market price data over the period 1997 to 2007 for the Goulburn and Murray regions in Victoria. Wheeler et al. (2008) regressed water allocation market prices against water availability (allocation volumes) and other explanatory variables, including lagged allocations, and month and drought year dummies. They estimated a short-run water price elasticity of demand of -0.52 and a long-run price elasticity of -0.81 .

Econometric studies: farm production data

Bell et al. (2007) made use of a farm-level panel dataset, drawing on the Australian Bureau of Statistics Agricultural Census 2000–01 and subsequent agricultural surveys up until 2003–04. Bell et al. (2007) employed a dual approach, distinct from the primal approach: direct estimation of production functions given data on input and output quantities. The dual method employed by Bell et al. (2007) involves estimation of a profit function, specifying profit as a function of input and output prices as well as a range of exogenous factors.

Bell et al. (2007) estimated the elasticity of demand for irrigation water for 10 defined industries. The results confirm prior expectations that demand for water in perennial

horticulture activities such as fruit and vegetables is generally more inelastic (-0.8) relative to broadacre activities such as grains (-1.4) and dairy (-1.4). Bell et al. (2007) suggested the results should be considered experimental and highlight limitations of the study, including the various data sources and data imputation required and the lack of regional disaggregation.

Hone et al. (2009) made use of the first year of the ABARE irrigation survey (2006–07) to estimate farm production functions, as part of their broader analysis of the Australian Government's water entitlement purchase program. Hone et al. (2009) estimated production functions for grapes, wheat and dairy enterprises and derived water input demand functions by placing these production functions within a profit maximisation framework. Their estimated elasticities varied widely across the different models.

Comparing the alternative approaches

A key advantage of the market price approach is that the market price encapsulates all aspects of farms' willingness to pay for water, while studies that employ farm-level data (and a primal approach) typically only consider the short-run marginal benefits (revenue/profit) associated with irrigation water use. In the case of perennial horticulture, water use decisions may have long-run consequences (that is, dynamic yield effects). Farm-level data studies can attempt to estimate dynamic yield effects only where panel data for a significant number of years are available.

A limitation of market price methods is that they require a significant time series to generate efficient estimates. A further limitation is that once an adequate time series is established, it may be difficult to control for changes in relevant exogenous variables, such as changes in industry structure or technology that occur over time.

One of the central criticisms of the primal method of estimating production functions is the potential for input variables to be endogenous, leading to biased estimates. The dual method circumvents this issue by regressing profit against input prices, which are taken to be exogenous. However, dual methods are subject to their own limitations: they require reliable price data; they exclude information contained in input use variables (Mundlak 1996); and they rely on an assumption of profit maximisation.

3 ABARES survey of irrigation farms in the Murray–Darling Basin

Survey method

The ABARE (now ABARES) survey of irrigation farms began in 2006–07, and at present three years of data—2006–07, 2007–08 and 2008–09—are available. The irrigation survey follows the same methodology employed in the long-running Australian agricultural and grazing industries survey (AAGIS) and the Australian dairy industry survey (ADIS) (see Ashton et al. 2009).

The ABARES survey of irrigation farms has been designed to provide coverage of three industry categories (broadacre, horticulture and dairy) across 10 regions within the Murray–Darling Basin, as highlighted in map 1. Within each region, the survey provides coverage of around 10 per cent of the irrigation farm population (Ashton et al. 2009).

A key advantage of the ABARES surveys over other data sources is the substantial amount of detail collected from each survey participant. Surveys are conducted via face-to-face interviews by ABARES officers to obtain a range of detailed farm physical and financial information, including supplementary irrigation detail such as engagement in water entitlement and allocation trading and types of irrigation infrastructure.

Sample size by farm and enterprise

Table 1 summarises the sample size of the irrigation survey dataset; a total of 2557 farms were sampled across the three-year period. The southern Basin is defined as the Murrumbidgee, Murray, Goulburn–Broken, Eastern Mount Lofty Ranges and Loddon regions. The southern Basin accounts for a majority of irrigation activity and irrigation farms, and dominates horticultural and dairy production within the Basin.

1 Irrigation survey sample size, by industry and northern/southern Basin

	horticulture	broadacre	dairy	total
2006–07	427	259	142	828
2007–08	436	303	143	882
2008–09	367	306	174	849
Total	1 230	868	459	2 557
Southern MDB	1 000	460	416	1 876
Northern MDB	230	408	43	681
Total	1 230	868	459	2 557

map **1** Regional coverage of the ABARES survey of irrigation farms in the Murray–Darling Basin



The irrigation survey is a rotating (unbalanced) panel. Table 2 outlines the panel structure of the sample over the three-year period; more than half of the farms in the sample appear for only one year.

2 Sample size by duration (number of years farms were present in the sample)

	1 year	2 years	3 years	total
Farms	912	440	255	1 607
Observations	912	880	765	2 557

For the purposes of this study 15 agricultural enterprises are defined, consistent with Hughes et al. (2009) (see table 3). These enterprises refer to the specific crop and livestock activities undertaken by irrigation farms. Most irrigation farms, particularly those classified as horticulture or broadacre farms, undertake multiple crop and livestock enterprises.

3 Defined enterprise categories

industry	enterprise	commodities produced
Horticulture	1. Pome fruit	Apples, pears etc.
	2. Stone fruit	Peaches, apricots, cherries etc.
	3. Citrus fruit	Oranges, lemons, mandarins, grapefruit
	4. Table grapes	Table grapes, sultanas, currants etc.
	5. Wine grapes	Wine grapes
	6. Vegetables	Potatoes, tomatoes, onions, pumpkins etc.
	7. Other horticulture	Almonds, olives, berries
Broadacre	8. Cotton	Cotton
	9. Rice	Rice
	10. Wheat (irrigated)	Wheat
	11. Wheat (dryland)	Wheat
	12. Other broadacre	Other grains, oilseeds, pulses, hay
	13. Beef	Beef
	14. Sheep	Lamb, wool
Dairy	15. Dairy	Milk

A picture of the enterprise mix observed in the survey data is provided in table 15 (Appendix A). Broadacre farms tend to be relatively diversified, generally undertaking a variety of annual crop and livestock activities. Although horticultural farms tend to be more specialised, they commonly undertake multiple horticultural activities. In contrast, dairy farms are almost exclusively engaged in dairying. Dairy farm involvement in the other broadacre enterprise is primarily the generation of hay/fodder for dairy cattle.

4 Irrigation survey sample size by enterprise

enterprise	2006–07	2007–08	2008–09	total	primary a
Pome fruit	51	62	59	172	109
Stone fruit	85	91	82	258	135
Citrus fruit	100	86	70	256	145
Table grapes	71	38	20	129	67
Wine grapes	214	219	144	577	425
Vegetables	94	104	103	301	228
Other horticulture	52	59	59	170	75
Cotton	38	27	54	119	81
Rice	23	6	9	38	23
Wheat (irrigated)	87	67	99	253	32
Wheat (dryland)	143	210	268	621	72
Other broadacre	446	504	514	1 464	271
Beef	227	245	267	739	180
Sheep	166	204	197	567	252
Dairy	138	141	155	434	414

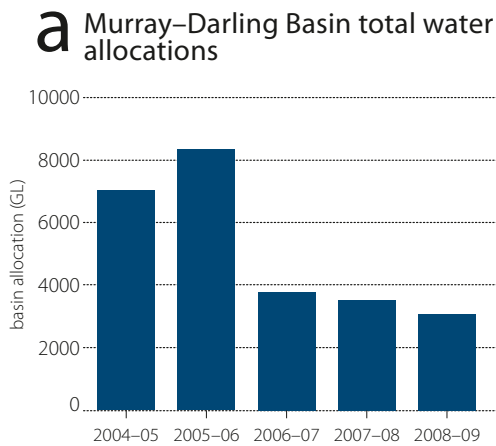
a Farms for which the enterprise is the main contributor to total cash receipts.

Table 4 shows the survey sample coverage at the enterprise level. The sample coverage is relatively limited for the cotton and rice enterprises because of the prevailing drought conditions. Table 4 also shows the number of farms by primary enterprise, defined as the enterprise making the greatest contribution to total farm receipts.

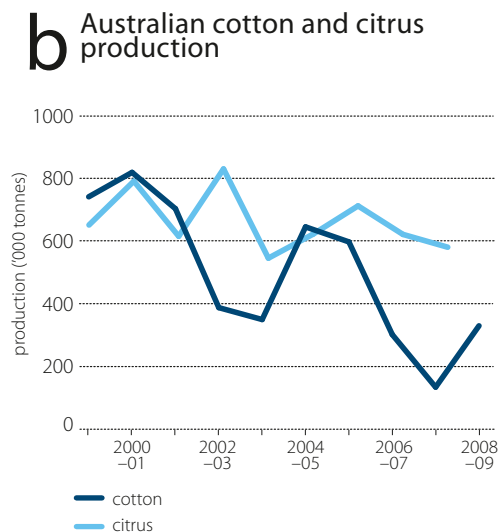
Seasonal conditions

The three years 2006–07, 2007–08 and 2008–09 represent the height of the recent drought. In each of these years water allocations in the Basin were historically low (figure a). The 2004–05 and 2005–06 years were also significantly below the long-run average.

While each of the three survey years were significantly drought-affected, peak water scarcity (particularly in the southern Basin) occurred during the 2007–08 season, as illustrated by observed annual average market prices shown in table 5. In the Murray and Goulburn regions, average annual prices peaked at between \$550 and \$600 per megalitre (ML) in 2007–08 (in both regions weekly prices peaked at more than \$1000 within the year).



Source: Murray–Darling Basin Authority (MDBA) 2010.



Sources: ABARE 2009, Citrus Australia 2010.

Despite the drought conditions, significant irrigation production still occurred during the sample period; the gross value of irrigated agricultural production in the Basin was an estimated \$5 billion in 2007–08 (ABS 2010). Production of key broadacre irrigated crops, such as cotton and rice, declined dramatically during the period, while production of major perennial horticultural crops remained relatively steady (figure b).

While all survey years are characterised by relatively low water use and areas irrigated, the survey data display substantial cross-sectional variation across regions and industries within

the Basin, as well as across individual farms within given regions and industries. Given the short time series, this cross-sectional variation is necessary to facilitate efficient econometric analysis.

5 Annual average market water allocation prices (\$/megalitre), selected regions 2004–05 to 2008–09

	Macquarie \$/ML	Murrumbidgee \$/ML	Murray a \$/ML	Goulburn b \$/ML
2004–05	175	72	70	55
2005–06	125	37	53	47
2006–07	153	213	330	457
2007–08	381	486	556	572
2008–09	171	358	392	403

a Hume to Barmah trading zone. **b** Greater Goulburn trading zone.

Source: www.waterexchange.com.au, accessed on 1 September 2010, average of weekly prices.

4 Variable construction

This section details the steps involved in constructing the final set of output and input variables. For this study, an attempt was made to exclude all observations containing incomplete or unreliable data (including outliers). A total of 53 observations were omitted from the dataset, leaving a final sample of 2504.

Output

Defined output variables include $REC_{i,e,t}$, $QTY_{i,e,t}$ and $SOLD_{i,e,t}$, where the i denotes farms, e denotes enterprise category (1 to 15) and t denotes the year (2007, 2008, 2009). $REC_{i,e,t}$ is gross cash receipts in 2008–09 prices, $QTY_{i,e,t}$ is the quantity of output harvested (in tonnes for cropping enterprises) and $SOLD_{i,e,t}$ is the quantity of output sold. Differences between quantities harvested and sold can occur for two reasons: volumes harvested but not sold (for example, wastage or crops used for fodder); and volumes harvested in one period and then sold in the next.¹ Summary data for $REC_{i,e,t}$, $QTY_{i,e,t}$ and $SOLD_{i,e,t}$ are presented in table 6. Summary data presented throughout this report are unweighted sample mean estimates.²

6 Output variable summary data by enterprise

	REC (\$'000)		QTY (tonnes) a		SOLD / QTY	
	mean	SD	mean	SD	mean	SD
Pome fruit	362	(173)	678	(1 092)	1.04 b	(0.81)
Stone fruit	244	(233)	214	(576)	0.96	(0.21)
Citrus fruit	243	(581)	627	(1 528)	0.99	(0.06)
Table grapes	296	(606)	244	(516)	0.98	(0.12)
Wine grapes	365	(581)	695	(1 404)	0.97	(0.15)
Vegetables	699	(595)	1 387	(2 706)	0.97	(0.20)
Other horticulture	545	(1 149)	249	(815)	1.10a	(1.19)
Cotton	947	(787)	467	(515)	0.97	(0.15)
Rice	470	(1 282)	857	(1 052)	1.00	(0.00)
Wheat (irrigated)	170	(1 571)	623	(951)	0.94	(0.39)
Wheat (dryland)	129	(1 052)	575	(1 619)	0.85	(0.95)
Other broadacre	130	(566)	639	(1 288)	0.63	(2.43)
Beef a	92	(283)	126	(197)	1.00	(0.00)
Sheep a	145	(330)	1 259	(1 695)	1.00	(0.00)
Dairy a	708	(343)	1 532	(1 258)	1.00	(0.00)

a Beef and sheep $QTY_{i,e,t}$ and $SOLD_{i,e,t}$ are number of livestock sold; dairy $QTY_{i,e,t}$ and $SOLD_{i,e,t}$ are kilolitres of milk sold.

b Number of farms with $SOLD$ greater than QTY in 2006–07 for pome fruit and other horticulture enterprises. Likely due to selling of crops harvested late in 2005–06.

Note: Standard deviation (SD) in parentheses.

¹ Over an annual time scale, inventory effects are expected to be minimal given limited on-farm storage of most commodities. Explicit consideration of farm output inventories remains a subject for future research. Summary data show minimal differences for horticultural enterprises, while for broadacre crops the quantities sold are commonly less than harvested (as expected given broadacre crops may be used as fodder).

² Survey statistics reported in ABARES publications are typically, presented as weighted averages at a farm or industry level. Sample weights are designed to take into account the non-random stratified sampling procedures employed in the survey.

7 Price indexes by enterprise

	2006–07	2007–08	2008–09
Pome fruit	1.07	1.36	1.00
Stone fruit	0.87	0.95	1.00
Citrus fruit	0.82	1.11	1.00
Table grapes a	0.96	1.31	1.00
Wine grapes	0.96	1.31	1.00
Vegetables b	0.92	1.01	1.00
Other horticulture b	0.93	1.18	1.00
Cotton	0.85	0.92	1.00
Rice	0.58	0.77	1.00
Wheat (irrigated)	1.04	1.29	1.00
Wheat (dryland)	1.09	1.35	1.00
Other broadacre	0.99	1.12	1.00
Beef	0.96	0.95	1.00
Sheep c	0.84	0.93	1.00
Dairy	0.81	1.16	1.00

a Price index set to wine grapes. **b** External price index, ABARE (2009). **c** Price index based on quantity weighted combination of wool and sheep prices.

Note: Price indexes represent average enterprise-level price changes, which differ from the price changes of individual commodities. In the pome, stone and citrus fruit enterprises, substantial, cross-sectional variation in prices is observed.

Nominal cash receipts figures are adjusted using a set of price indexes derived from the survey data, based on median prices ($REC_{i,e,t} / SOLD_{i,e,t}$) for each enterprise and time period. Prices for the vegetables, other horticulture and table grapes enterprises proved unreliable so indexes were based on alternative sources. For a number of enterprises, prices peak in 2007–08 (table 7).

Land and water

Land area planted $AREA_{i,e,t}$ (hectares) and irrigation water applied $WATER_{i,e,t}$ (megalitres) are available for each cropping enterprise. Summary data are presented in table 8. At the farm level, $LAND_{i,t}$ is defined as total area operated less unproductive land area. Summary data for farm-level variables are presented in table 13. Total farm water use is defined as the sum of water use across each enterprise $\sum_e WATER_{i,e,t}$ (referred to as $WATER_{i,t}$).

Grazing land and irrigation water use are not available separately for the beef, sheep and dairy enterprises (they are included within the other broadacre enterprise). Given the homogeneity of dairy farms, land and water inputs in the dairy enterprise can be adequately approximated by $LAND_{i,t}$ and $WATER_{i,t}$.

Summary data for yields ($REC_{i,e,t} / AREA_{i,e,t}$, $QTY_{i,e,t} / AREA_{i,e,t}$) are shown in tables 9 and 10. Substantial variation in yields is observed across farms in each enterprise. An increase in sample mean yields is observed in 2008–09 relative to 2007–08 for most enterprises. Summary data for water application rates ($WATER_{i,e,t} / AREA_{i,e,t}$) are presented in table 11.

8 Land and water variable summary data, by cropping enterprise

	AREA (Ha)		WATER (ML)	
	mean	SD	mean	SD
Pome fruit	23.0	(36.3)	86	(186)
Stone fruit	16.3	(37.0)	86	(280)
Citrus fruit	25.0	(48.7)	181	(388)
Table grapes	18.6	(44.2)	108	(292)
Wine grapes	51.2	(89.6)	209	(418)
Vegetables	39.7	(53.6)	178	(299)
Other horticulture	59.5	(126.5)	469	(1 236)
Cotton	223.5	(219.2)	1 195	(1 426)
Rice	97.1	(110.1)	1 308	(1 982)
Wheat (irrigated)	221.6	(380.5)	353	(606)
Wheat (dryland)	468.2	(813.1)	0	(0)
Other broadacre	296.9	(442.4)	223	(471)

Note: Standard deviation (SD) in parentheses.

9 Sample mean receipts yield by enterprise and year

	REC / AREA (\$/Ha)			
	2006–07	2007–08	2008–09	all years
Pome fruit	15 153	12 651	18 412	15 370 (12 085)
Stone fruit	12 368	14 695	17 108	14 695 (13 395)
Citrus fruit	10 196	7 981	9 309	9 209 (7 556)
Table grapes	10 817	8 516	17 493	11 077 (11 305)
Wine grapes	5 746	6 362	6 597	6 191 (3 197)
Vegetables	18 071	18 418	24 276	20 322 (23 758)
Other horticulture	10 027	9 603	10 303	9 975 (14 640)
Cotton	4 363	4 052	4 231	4 233 (1 565)
Rice	4 477	4 113	4 445	4 412 (1 980)
Wheat (irrigated)	787	960	864	863 (661)
Wheat (dryland)	156	253	345	270 (334)
Other broadacre	557	364	584	500 (3 235)
Broadacre farms a	603	421	552	521 (763)
Dairy farms a	2 895	2 638	2 630	2 717 (2 022)

a Calculated at the farm level: $\sum REC_{i,e,t} / LAND_{it}$.

Note: Standard deviation in parentheses.

10 Sample mean quantity yield by enterprise and year

	QTY / AREA (\$/Ha)			
	2006–07	2007–08	2008–09	all years
Pome fruit	25.6	22.1	29.2	25.5 (15.9)
Stone fruit	10.2	10.8	11.8	10.9 (10.6)
Citrus fruit	24.9	21.6	22.4	23.1 (13.4)
Table grapes	14.4	11.8	20.6	14.5 (12.8)
Wine grapes	11.7	13.8	13.6	13.0 (7.2)
Vegetables	24.7	23.9	33.1	27.3 (26.8)
Other horticulture	4.4	4.6	5.8	5.0 (7.3)
Cotton	2.0	2.2	2.1	2.1 (0.7)
Rice	8.0	7.8	8.0	8.0 (3.3)
Wheat (irrigated)	3.4	3.4	3.3	3.3 (1.8)
Wheat (dryland)	0.8	1.1	1.5	1.2 (1.2)
Other broadacre	2.4	2.5	2.4	2.4 (3.7)
Dairy farms a	6.2	5.8	5.5	5.8 (4.7)

a Milk production (kilolitres per hectare) at the farm level ($QTY_{i,t} / LAND_{i,t}$).
 Note: Standard deviation in parentheses.

11 Sample mean water application rate by enterprise and year

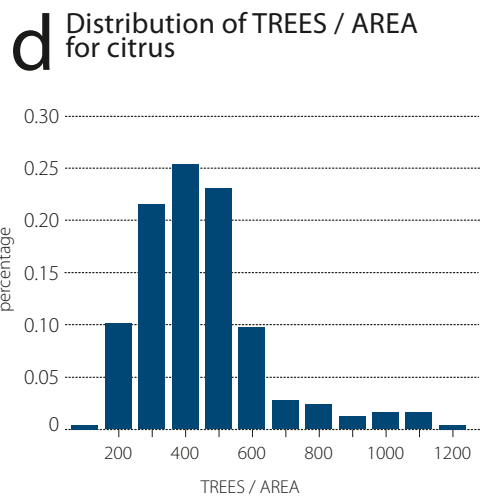
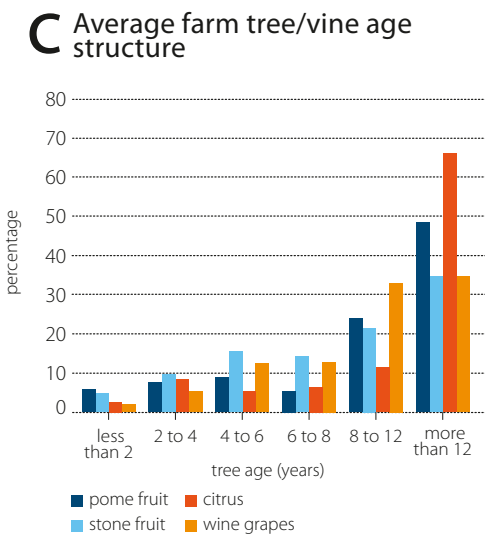
	WATER / AREA (\$/Ha)			
	2006–07	2007–08	2008–09	all years
Pome fruit	5.1	4.3	3.7	4.3 (4.6)
Stone fruit	5.5	5.1	4.6	5.1 (3.7)
Citrus fruit	8.2	6.6	7.7	7.5 (3.8)
Table grapes	6.3	4.5	5.9	5.7 (2.8)
Wine grapes	4.7	4.4	4.2	4.5 (2.7)
Vegetables	4.7	3.6	4.4	4.2 (3.0)
Other horticulture	6.8	5.7	6.0	6.1 (5.6)
Cotton	6.0	4.5	5.2	5.3 (2.5)
Rice	12.3	5.9	12.7	11.4 (5.0)
Wheat (irrigated)	2.4	1.8	1.8	2.0 (1.5)
Wheat (dryland)	0.0	0.0	0.0	0.0 (0.0)
Other broadacre	2.0	1.2	1.0	1.4 (2.1)
Broadacre farms a	0.8	0.3	0.4	0.5 (0.9)
Dairy farms a	2.2	1.2	1.1	1.5 (1.8)

a Estimated at the farm level as $\sum WATER_{i,t} / LAND_{i,t}$.
 Note: Standard deviation in parentheses.

Tree capital

The irrigation survey included questions related to fruit and nut trees and grape vines. These data have not previously been analysed. The number of trees/vines $TREES_{i,e,t}$ is available at the enterprise level for pome fruit, stone fruit, citrus fruit, table grapes, wine grapes and other horticulture. The survey also collected information on tree/vine age structure. Tree/vine age structure is relevant since tree yields vary significantly with age.

The age structure data collected in the survey specifies the proportion of trees less than two years of age, two to four years, four to six years, eight to 12 years, and greater than 12 years of age. Given that tree productive life spans can extend to around 30 years, the tree age structure data provide a picture of only one side of the age distribution (figure c). Tree data demonstrate significant variation across farms in the number of trees per hectare of planted area (figure d) and in the relative tree age structures.



For this study, available tree data were combined to construct enterprise and farm-level measures of tree capital ($TREE_CAP_{i,e,t}$, $TREE_CAP_F_{i,t}$). This procedure is summarised in figure e. Tree age structure variables were multiplied by assumed tree age yield factors (derived from Qureshi, Ranjan and Qureshi 2010) to estimate mean tree yield $TY_{i,e,t}$ (a value between 0 and 1). An enterprise-level tree capital measure $TREE_CAP_{i,e,t}$ was constructed by multiplying $TREES_{i,e,t}$ by $TY_{i,e,t}$. The enterprise tree capital variables were aggregated using constructed enterprise weights to form a farm-level tree capital variable $TREE_CAP_F_{i,t}$. Enterprise weights were calculated as median tree yields ($QTY_{i,e,t} / TREE_{i,e,t}$) multiplied by median prices ($REC_{i,e,t} / SOLD_{i,e,t}$).

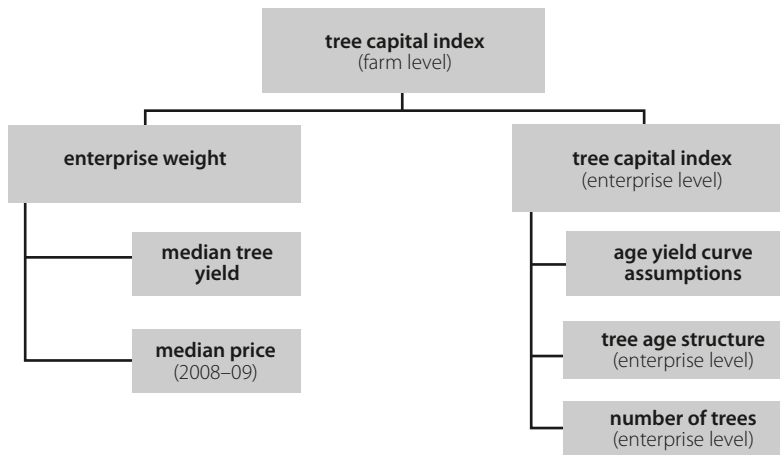
Given the reliability of underlying data, resulting measures of tree capital should be considered relatively reliable for the pome, stone and citrus fruit and wine grape enterprises and less reliable for the other horticulture and table grapes enterprises. Tree capital summary data are presented in table 12.

12 Tree capital summary data by enterprise

	TREES (no.)		TREES / AREA (no. / ha)		TREE_CAP (no. × TY)	
	mean	SD	mean	SD	mean	SD
Pome fruit	16 066	(40 074)	634	(387)	12 235	(33 247)
Stone fruit	8 774	(15 549)	577	(324)	5 843	(9 749)
Citrus fruit	12 246	(29 135)	392	(186)	9 307	(22 663)
Table grapes	20 032	(46 342)	714	(685)	17 377	(40 201)
Wine grapes	90 791	(220 213)	1 570	(1 586)	75 235	(174 976)
Other horticulture	18 763	(42 621)	270	(300)	16 277	(36 974)

Note: Standard deviation (SD) in parentheses.

e Construction of a tree capital variable



Farm capital, labour and materials

Information on remaining inputs is available only at the whole-of-farm level. $FARM_CAP_{i,t}$ is defined as the market value of all farm capital excluding land and water (entitlement) assets (indexed to 2008–09 prices). Farm capital includes the value of vehicles, plant equipment, fixed structures and on-farm irrigation equipment, as well as the market value of livestock.

$LABOUR_{i,t}$ includes expenditure on hired labour and contract labour, as well as the imputed market value of farm family labour (which is available as a standard variable in the survey dataset). A labour wage index is constructed from the survey data using data on hired labour and family labour weeks worked.

$MAT_{i,t}$ is defined as total farm cash costs less interest expenses, less labour expenses (hired labour and contract labour) and less water costs, (water utility charges and water entitlement and allocation trades expenses). $MAT_{i,t}$ is indexed to 2008–09 prices. Summary data are contained in table 13.

Rainfall

Rainfall data were obtained from the Australian Water Availability Project (AWAP). This project has produced long time series of interpolated grids of key meteorological variables, covering Australia at daily, weekly and monthly intervals at a 0.05 degree, or about 5 km, resolution.

Geographic location data (latitude and longitude coordinates) are recorded for each farm in the irrigation survey. Given these coordinates, and information on farm size (total land operated), the survey farms can be matched to the geographically coded rainfall data using Geographic Information System (GIS) software. This process yields farm-specific monthly rainfall observations covering the sample time period. Two separate rainfall variables are defined: winter rainfall ($W_RAIN_{i,t}$) and summer rainfall ($S_RAIN_{i,t}$). The winter rain season is defined as the period April to October, while the summer rain season is defined as the period November to March.

Other explanatory variables

Other potential explanatory variables defined for this study include expenditure on fodder $FODDER_{i,t}$, expenditure on fertiliser $FERT_{i,t}$, the market value of on-farm irrigation equipment $IRRIG_CAP_{i,t}$, the age of the farm operator $AGE_{i,t}$, and the highest level of educational attainment reached by the farm operator $EDU_{i,t}$. $FODDER_{i,t}$ and $FERT_{i,t}$ are both components of materials, while $IRRIG_CAP_{i,t}$ is one component of farm capital. These variables are all indexed to 2008–09 prices. Average livestock numbers $CATTLE_{i,t}$, $SHEEP_{i,t}$ and $DCATTLE_{i,t}$ are defined as beef cattle, sheep and dairy cattle numbers, respectively. State indicator variables for South Australia (SA_i) and Victoria (VIC_i) are also defined. See table 13 for summary data.

13 Farm-level input variables summary data (mean and standard deviation), by farm type

	units	horticulture	broadacre	dairy	all farms	
LAND	Ha	210	2 141	337	893	(2 828)
FARM_CAP	\$'000	361	831	722	586	(659)
LABOUR	\$'000	250	152	114	193	(352)
MAT	\$'000	309	472	537	405	(592)
TREE_CAP_F	\$'000	290	12	0	143	(503)
W_RAIN	mm	175	174	194	178	(89)
S_RAIN	mm	161	219	166	182	(113)
FERT	\$'000	34	66	26	44	(90)
FODDER	\$'000	2	14	273	54	(163)
IRRIG_CAP	\$'000	34	29	21	30	(105)
AGE	years	52	54	53	53	(13.1)
EDU	0 to 6	4.0	4.2	4.0	4.0	(1.4)
SA	1 or 0	0.31	0.02	0.15	0.18	(0.39)
VIC	1 or 0	0.31	0.19	0.70	0.33	(0.47)
CATTLE	no.	18	150	23	64	(209)
SHEEP	no.	88	1122	12	428	(1 583)
DCATTLE	no.	1	2	372	67	(190)

Note: Standard deviation in parentheses.

5 Enterprise yield functions

For each crop enterprise, quantity and receipts yield functions are estimated, specifying yield ($QTY_{i,e,t}/AREA_{i,e,t}$ or $REC_{i,e,t}/AREA_{i,e,t}$) as a function of the water application rate ($WATER_{i,e,t}/AREA_{i,e,t}$) and per hectare tree capital ($TREE_CAP_{i,e,t}/AREA_{i,e,t}$). Other explanatory variables include $W_RAIN_{i,t}$ and $S_RAIN_{i,t}$ and state and year indicator variables. A quadratic functional form was chosen. All models were estimated via Ordinary Least Squares (OLS) regression.

Given the omission of farm-level inputs such as materials and farm capital, a key limitation of the crop enterprise yield functions is the potential for omitted variable bias. Reliable estimates of yield functions are more likely where the defined enterprise categories are relatively homogenous in terms of their use of other inputs. An advantage of the enterprise yield functions is that included explanatory variables can safely be considered exogenous.

Quantity yield functions

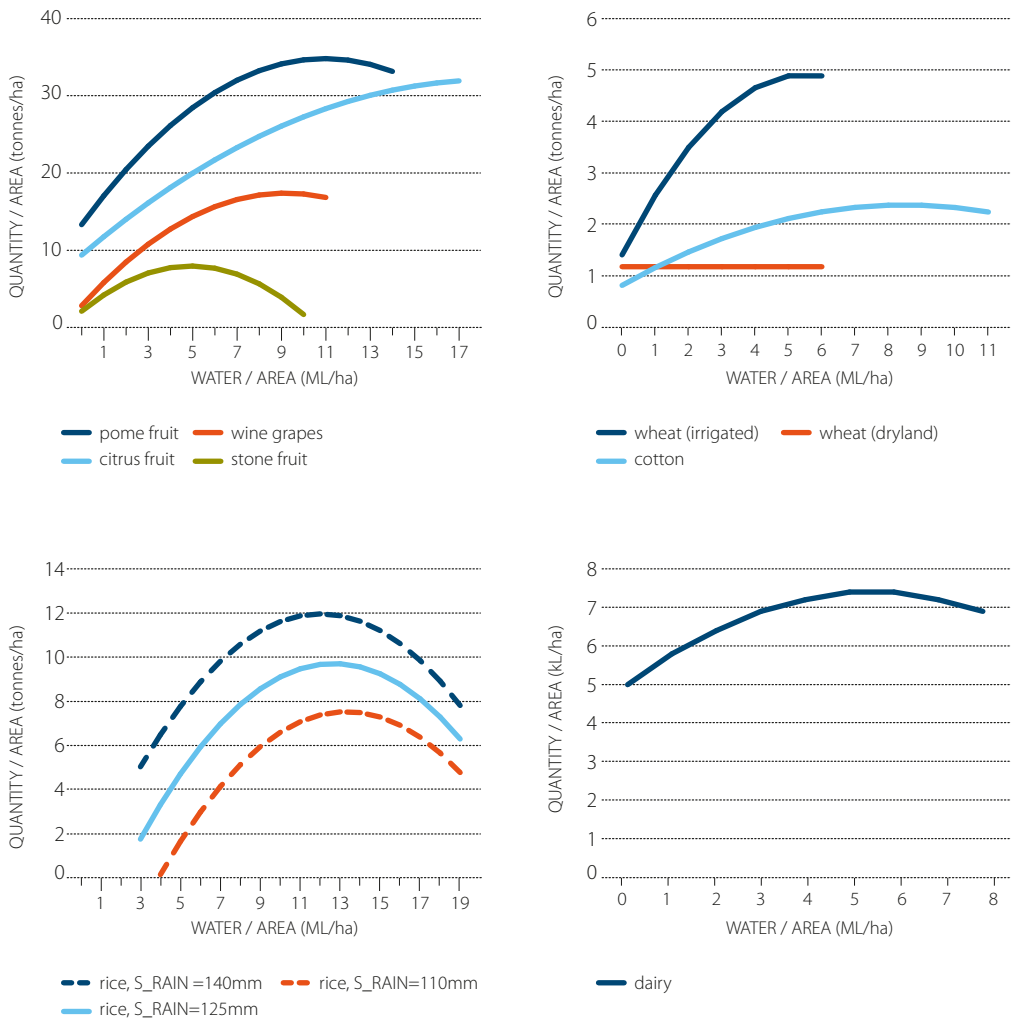
Estimated quantity yield function parameters are contained in Appendix B. The degree of explanatory power varies significantly across enterprises. In each of the pome fruit, stone fruit, citrus fruit, wine, dairy, cotton, wheat and rice enterprises, water coefficients proved statistically significant with anticipated signs. Explanatory power was low in the more heterogeneous enterprise categories such as other broadacre, other horticulture and vegetables.

Estimated quantity yield functions are displayed in figure f. Yield functions are shown over the 2nd to 98th percentile range of water application rates observed in the sample. For example, pome fruit application rates are observed to vary over the range 0 to 14 ML/ha, with a sample mean of 4.3 ML/ha. Given the drought conditions, median water use rates tended toward the lower end of the observed range, in all cases well below the estimated point of maximum yield. Estimated yield functions should be considered more reliable over the lower range of water use rates.

Quantity and receipts yield functions are also estimated for the dairy enterprise (table 17). Given that dairy farms rely almost exclusively on dairying, key farm-level inputs ($FARM_CAP_{i,t}$ and $FODDER_{i,t}$) can be included. The dairy yield function displays a superior degree of explanatory power; key parameter estimates are significant and adhere to expected signs. Fodder, winter rainfall and summer rainfall are all observed to act as substitutes for irrigation water.

Rainfall is found to be a significant input for wine grapes, with both winter and summer rainfall observed as substitutes for irrigation water (significant negative coefficients are observed on water–rainfall interaction terms). As can be expected, summer rainfall is observed to be a substitute for irrigation water for rice, while winter rain is observed as a substitute in the case of wheat. The estimated effect of summer rainfall on the rice yields is particularly strong, as demonstrated in figure f. A quadratic relationship between tree capital and yield is estimated for the perennial horticulture enterprises, although coefficients are only significant in the citrus fruit, wine grape and other horticulture enterprises.

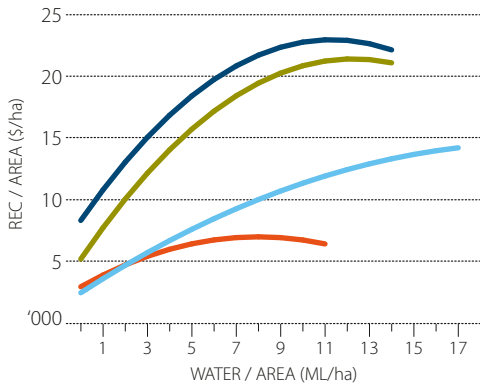
f Estimated quantity – water yield functions



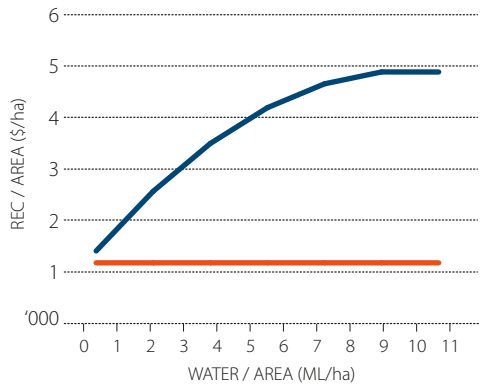
Receipts yield functions

Figure g displays the estimated receipts—water yield functions; parameter estimates are contained in Appendix C. Employing $REC_{i,e,t} / AREA_{i,e,t}$ as the dependent variable is useful, because of the significant differences in the prices per tonne both between enterprises and between individual commodities within enterprise categories. $REC_{i,e,t} / AREA_{i,e,t}$ then allows for a more effective comparison across enterprises. There is also the possibility that the receipts–yield relationship may capture the effect of water use on prices received, where, for example, water use has an effect on the quality of commodities produced.

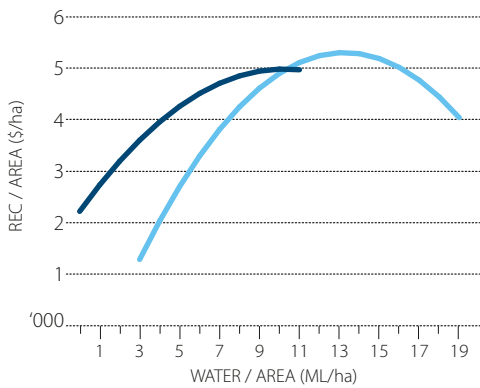
g Estimated receipts – water yield functions



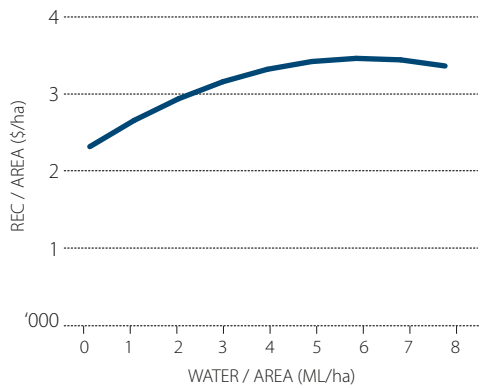
— pome fruit — wine grapes
 — stone fruit — citrus fruit



— wheat (irrigated)
 — wheat (dryland)



— cotton
 — rice



— dairy

6 Farm production functions

Estimating production functions at the farm level allows for the inclusion of the full range of input variables. There are also important theoretical motivations for estimating farm-level production functions. First, a farm-level approach accounts for potential interactions between different enterprises on a farm; for example, interactions between annual cropping activities and livestock production. A farm-level approach also implicitly takes into consideration farm-level adjustment to changes in water availability, in particular the ability of farms to vary the size, type and mix of annual crop areas planted.

Total revenue is used as a measure of aggregate farm output, (effectively weighting individual farm products by their relative market prices). Farm production function estimation then involves regression of total farm revenue ($\sum_e REC_{i,e,t}$) against the full range of farm inputs: $LAND_{i,t}$, $WATER_{i,t}$, $TREE_CAP_F_{i,t}$, $FARM_CAP_{i,t}$, $MAT_{i,t}$, $LABOUR_{i,t}$, $W_RAIN_{i,t}$ and $S_RAIN_{i,t}$.

One of the key limitations of this primal approach is the possibility of endogenous input variables. In this study, a particular emphasis is placed on the potential endogeneity of the $MAT_{i,t}$ and $LABOUR_{i,t}$ inputs. Both of these inputs are likely to contain a component of harvesting, processing and/or freight costs, which are expected to be, at least partially, dependent on output/yield levels. As such, both inputs could be correlated with any omitted, yield-relevant variables contained in the error term, leading to biased coefficient estimates.

Models estimated

Farm-level production functions were estimated for four farm categories: horticulture, dairy and broadacre farms in the southern Basin; and broadacre farms in the northern Basin. For each farm category, four models were estimated. Model 1 is the OLS estimate of the farm production function with the $MAT_{i,t}$ and $LABOUR_{i,t}$ inputs omitted, while Model 2 is the OLS estimate with $MAT_{i,t}$ and $LABOUR_{i,t}$ variables included.

Model 3 is a two-stage least squares instrumental variables estimate. Model 3 involves estimating separate instrumental variable equations for $MAT_{i,t}$ and $LABOUR_{i,t}$ and including fitted values as explanatory variables in the farm production function. A range of candidate instruments for $MAT_{i,t}$ and $LABOUR_{i,t}$ were identified, including enterprise-level land areas $AREA_{i,e,t}$ and farm operator characteristics $AGE_{i,t}$ and $EDU_{i,t}$, as well as expenditure on fertiliser $FERT_{i,t}$ and the value of irrigation capital $IRRIG_CAP_{i,t}$. Enterprise land areas, in particular, demonstrate a high degree of correlation with both $MAT_{i,t}$ and $LABOUR_{i,t}$ inputs, while having a much clearer direction of causality with respect to output.

Model 4 is the fixed effects estimate of the production function, taking advantage of the panel structure of the dataset to control for unobserved cross-sectional heterogeneity. There are a range of potential sources for unobserved heterogeneity, including spatial variation in land quality and climate conditions, omitted or poorly measured inputs or variation in levels of farm technical efficiency. A disadvantage of the fixed effects model is that, because of the

unbalanced nature of the dataset, a significant proportion of the sample is not usable (farms that are in the sample for only one period).

A quadratic functional form is employed in all models. Given the number of inputs relative to the available sample size, a subset of the potential interaction terms are included, with a particular emphasis on water interaction terms. Parameter estimates for all farm production models are contained in Appendix D.

The short-run marginal revenue product of water

In the discussion of the results, the focus is primarily on the short-run marginal revenue product of water. Given the inclusion of a range of water interaction terms in the model, marginal product curves vary across farms depending on input mix. The marginal product curves presented below are calculated for the representative median farm (with all other explanatory variables fixed at median values)

These estimated marginal product curves are distinct from water input demand curves. In practice, there are other inputs that remain variable over the short run, specifically materials and labour. Generating short-run input demand curves then involves determining the optimal (profit maximising) combination of all variable inputs. Estimating input water demand curves remains a subject for future research. Given that increases in water use may increase other

variable costs, the estimated marginal revenue product may be higher than water demand / willingness to pay (in the absence of long-run yield effects).

14 Farm water use rates by industry

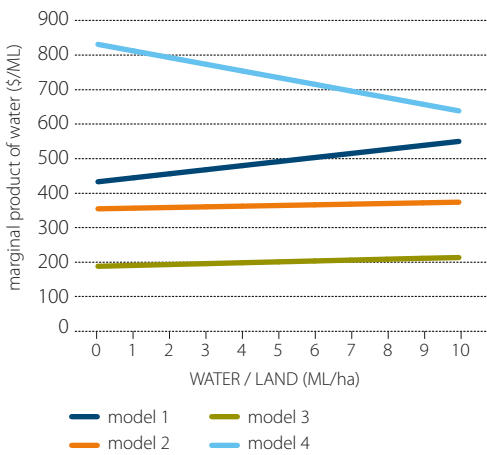
	WATER / LAND (ML/ha)	
	mean	median
Southern horticulture	3.9	3.7
Southern broadacre	0.4	0.1
Northern broadacre	0.5	0.2
Southern dairy	1.6	1.1

Marginal product curves are displayed on a farm water use rate (*WATER/LAND*) basis. There are significant differences in farm water use rates across the defined industry categories (table 14).

Horticulture farms (southern Murray–Darling Basin)

Coefficient estimates for the southern horticulture farm model are presented in table 19 (Appendix D). Estimated short-run marginal product curves are displayed in figure h. Across models 1, 2 and 3, estimated water coefficients lack significance; in Model 3, both water coefficients are insignificant at the 5 per cent level. The land, farm capital and tree capital coefficients in models 1, 2 and 3 suggest increasing returns (positive quadratic terms). Controlling for unobserved heterogeneity via a fixed effects model (Model 4) results in coefficient estimates and marginal product curves that more closely align with prior expectations. Model 4 also results in improved statistical significance for both water coefficients.

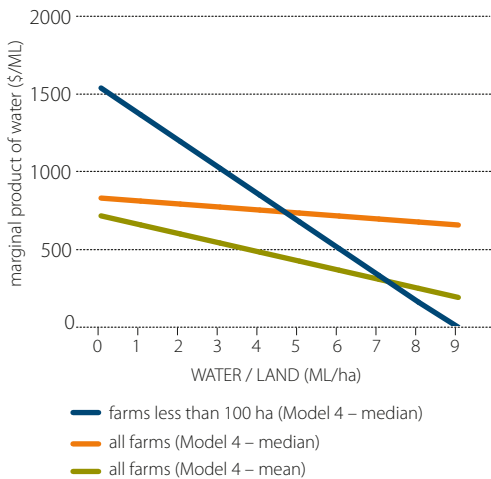
h Estimated marginal revenue product of water (horticulture, southern Murray–Darling Basin)



The inclusion of materials and labour inputs (Model 2) tends to significantly reduce the estimated marginal product of water (relative to Model 1); this effect is consistently observed across all of the industry categories. Models 1, 2 and 3 all generate relatively constant or increasing marginal product of water curves, inconsistent with prior expectations and estimated water yield functions.

One potential problem with the horticulture farm model is the extreme positive skewness of farm size, with a mean $LAND_{i,t}$ of 166.6 Ha and a median of 34.4 Ha among southern horticulture farms. This skewness is due to the inclusion of a minority of farms with a large proportion of non-horticulture land—typically farms with larger dryland broadacre areas. As such, there is a significant difference between the estimated marginal product curve of the mean and median farms (figure i).

i Farms less than 100 ha, estimated marginal revenue product of water (horticulture, southern Murray–Darling Basin)

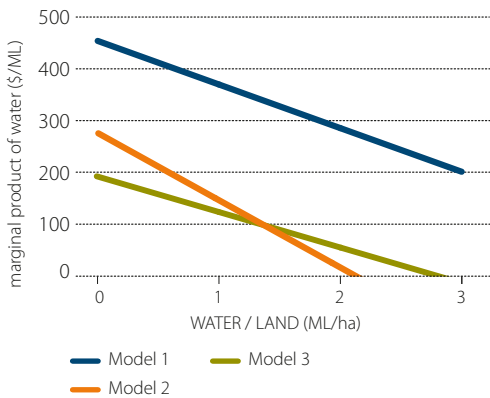


One solution to this problem would be to control for variation in proportion of horticultural/irrigated land, although tree and farm capital variables should, to some extent, control for variation in land use intensity. An alternative approach is to exclude from the sample outlying farms with small proportions of horticultural land. A separate model was estimated, restricting the sample to southern horticulture farms with $LAND_{i,t}$ less than 100 Ha (702 of 971 observations). Coefficient estimates for this model are contained in table 19 (Appendix B). Estimated marginal product curves are shown in figure i. This model generates marginal product curves that adhere more closely to prior expectations and to the range of observed market prices.

Broadacre farms (southern Murray–Darling Basin)

Estimated coefficients for southern Basin broadacre farms are presented in table 19 (Appendix D). Estimated marginal product curves are displayed in figure j.

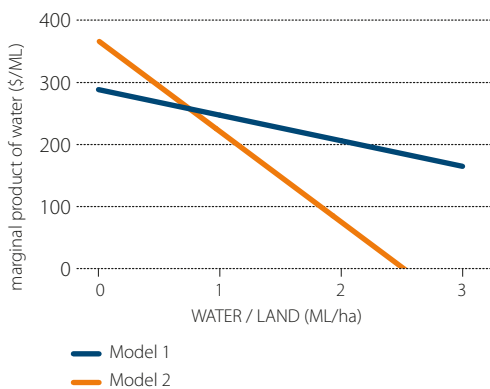
j Median farm, estimated marginal revenue product of water (broadacre, southern Murray–Darling Basin)



Across these farms, a median water use rate of just 0.1 ML/ha is observed; 172 of the 451 observations reported zero irrigation water use. Farm-level water use rates are expected to be lower than enterprise level rates, given a significant proportion of non-irrigated cropping and grazing land. However, since the observed sample water use rates on broadacre farms are clearly affected by the drought conditions, the estimated marginal product curves have to be treated with caution.

Again, Model 1 generates significantly higher estimates of marginal product than Model 2 (with *MAT* and *LABOUR* variables included). The estimates generated by Model 3 (instrumental variables) are comparable with those of Model 2. The results confirm expectations of a relatively lower short-run marginal product of water among broadacre farms relative to horticulture farms.

k Median farm, estimated marginal revenue product of water (broadacre, northern Murray–Darling Basin)



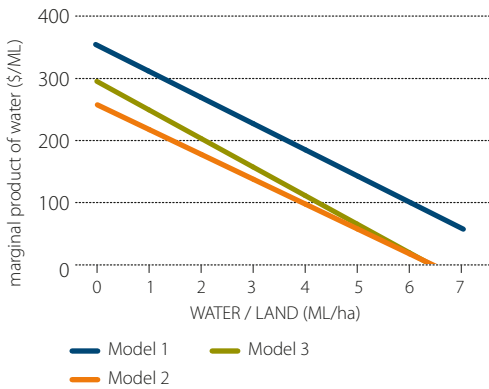
The marginal product curve from Model 4 is not shown, since coefficient estimates are mostly insignificant. The fixed effects estimator (Model 4) is also inefficient in the northern broadacre and dairy categories, possibly because of the smaller sample sizes relative to horticulture.

Broadacre farms (northern Murray–Darling Basin)

Estimated coefficients for northern Basin broadacre farms are presented in table 20 (Appendix D). Estimated marginal product curves are displayed in figure k.

Water use on northern broadacre farms was also particularly low, with a median water use rate of 0.2 ML/ha and 98 out of the 401 observations reporting zero irrigation water use. The marginal product curve from models 1 and 4 are not shown, since the water coefficient

Median farm, estimated marginal revenue product of water (dairy, southern Murray–Darling Basin)



estimates were insignificant. The marginal product of water among northern broadacre farms appears relatively consistent with the range of water prices observed in the northern Basin during the sample period.

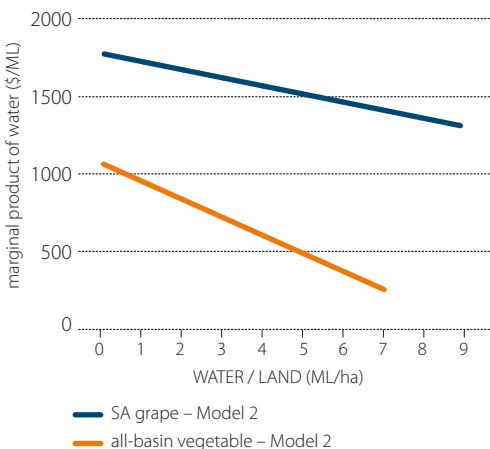
Dairy farms (southern Murray–Darling Basin)

Estimated coefficients for southern Basin dairy farms are presented in table 19 (Appendix D). Estimated marginal product curves are displayed in figure l.

Compared with the horticulture and broadacre farm categories, more consistency in the estimated marginal product curves is observed across models 1 through 3. This result is not

surprising given the relative homogeneity of dairy farms in comparison with horticulture and broadacre farms. Again, Model 1 generates a higher estimate of marginal product than Model 2, while the inclusion of instruments for $MAT_{i,t}$ and $LABOUR_{i,t}$ (Model 3) results in an increase in the size of both water coefficients. Model 4 results were generally insignificant and are not shown.

Estimated marginal revenue product of water (South Australian Murray–Darling Basin grape specialists and all-basin vegetable specialists)



Note: Marginal product curves based on Model 2 coefficient estimates.

Grape and vegetable specialists

An alternative approach is to estimate production functions for smaller, more homogenous groups of farms, subject to the constraint of sample size. Farms can be classified according to their primary enterprise; two enterprises for which there are a significant number of specialists are wine grapes and vegetables.

To demonstrate the feasibility of this approach, farm production models were estimated separately for a sample of 209 vegetable specialist farms and a sample of 200 South Australian grape specialist farms. Coefficient estimates are presented in table 23 (Appendix D) and marginal product curves are displayed in figure m.

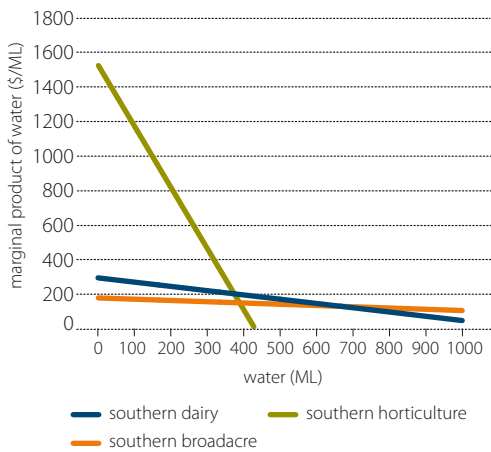
For both categories, high degrees of explanatory power and coefficient significance are observed. Relatively high estimates of

marginal revenue product of water are obtained despite the inclusion of labour and materials inputs without instrumentation.

Comparing horticulture, dairy and broadacre farms

The above marginal product curves are shown on a per hectare water use basis, which makes comparisons between industry categories problematic because of the substantial differences in farm size between the categories. Figure n provides a comparison of the marginal product of water curves in nominal water use terms, based on the median farm marginal product curve and a preferred estimator for each industry (horticulture: Model 4 farms less than 100 Ha; southern broadacre: Model 3; dairy: Model 3).

n Median farm short-run marginal revenue product of water, dairy, broadacre and horticulture



Note that these estimates represent just one of a number of estimated marginal product curves, and results are shown to vary significantly across models. Further, these marginal product curves cannot be interpreted directly as market water demand curves. Nevertheless, these results are encouraging as they represent the basic expected differences between horticulture, broadacre and dairy farms in terms of responsiveness to changes in water availability.

Note: : Weighted by the number of sample farms relative to southern broadacre (southern horticulture: 2.17, southern broadacre 1, southern dairy 0.90).

7 Conclusions

In this study, ABARES irrigation survey data have been used to derive estimates of water yield curves at an enterprise level and production functions at a farm level. This analysis required the construction of a comprehensive set of output and input variables, including measures of land, labour, materials, water and farm capital. A measure of tree/vine capital was also derived, drawing on data collected in the survey detailing the number of trees held and the tree age structure. In addition, summer and winter rainfall data was matched to each of the survey farms via GIS methods.

Estimated yield functions demonstrated the expected quadratic relationship between per hectare water use and yield across a range of different farm enterprises. Estimated yield functions performed better for more homogenous enterprise categories such as pome fruit, wine grapes and rice. Yield functions also demonstrated significant relationships between rainfall and crop yield, and between tree capital and crop yield.

Farm-level production functions were estimated separately for horticulture farms, broadacre farms, and dairy Farms in the southern Basin and for broadacre farms in the northern Basin. For each farm category, four alternative models were estimated, including instrumental variable techniques to account for the potential endogeneity of the materials and labour input variables, as well as the use of a fixed effects estimator to control for unobserved cross-sectional heterogeneity. The results provided some evidence of the success of both the instrumental variable estimator and fixed effects estimator in achieving their respective objectives.

A key focus of this study is the short-run marginal revenue product of water implied by the estimated farm production functions. The results in this regard were encouraging, with estimated marginal product curves generally consistent with prior expectations and the observed range of water prices during the sample period. In particular, the estimated marginal product curves showed horticulture farms to have the steepest (most inelastic) marginal product curve and broadacre farms to have the most elastic. However, at this stage the results display a lack of robustness, with estimated marginal product curves highly sensitive to changes in model specification and estimation techniques.

A key limitation of the dataset is that only three years of survey data are available and each of these years (2006–07, 2007–08 and 2008–09) were significantly drought-affected. Despite the drought conditions, a number of useful and statistically significant relationships were generated. Undoubtedly, the precision and generality of the results will improve significantly in the event that a longer and more representative time series of survey data becomes available.

There remain a number of important areas for potential future research using the irrigation survey dataset, particularly if a longer time series becomes available. Future research could involve the estimation of farm-level and market-level water input demand curves. Such estimates would form useful inputs into economic models of irrigation in the Basin, such as the ABARES Water Trade Model. Alternatively, econometrically derived production functions could form the basis of a new generation of farm-level micro simulation models of irrigation production in the Basin.

Appendix A: Enterprise mix

15 Enterprise mix: percentage of farms reporting enterprise 1 also reporting enterprise 2 (average of all years)

enterprise 2	enterprise 1														
	pome fruit	stone fruit	citrus fruit	table grapes	wine grapes	vege.	horticulture	cotton	rice	wheat (irrig)	wheat (dry)	other broad.	beef	sheep	dairy
Pome fruit	100	65	9	2	9	4	6	0	0	0	0	15	19	7	1
Stone fruit	43	100	16	5	20	8	11	0	0	1	2	14	13	9	1
Citrus fruit	6	16	100	14	47	5	20	0	0	2	4	6	3	3	0
Table grapes	3	9	27	100	59	7	10	0	0	1	5	9	5	5	0
Wine grapes	3	9	21	13	100	6	9	0	0	2	7	14	7	8	0
Vegetables	2	7	4	3	12	100	6	1	0	9	15	53	37	20	2
Other horticulture	6	16	31	8	32	10	100	1	0	2	8	16	11	7	0
Cotton	0	0	0	0	1	2	1	100	1	38	57	98	45	11	0
Rice	0	0	0	0	3	3	0	3	100	66	26	87	34	66	0
Wheat (irrigated)	0	1	2	0	4	11	2	18	10	100	47	93	45	49	2
Wheat (dryland)	0	1	2	1	7	7	2	11	2	19	100	91	52	52	5
Other broadacre	2	2	1	1	5	11	2	8	2	16	39	100	43	33	28
Beef	4	4	1	1	6	15	3	7	2	15	44	86	100	37	10
Sheep	2	4	1	1	8	10	2	2	4	22	57	85	48	100	2
Dairy	0	0	0	0	0	1	0	0	0	1	7	95	16	3	100

Appendix B: Quantity yield functions

16 Quantity yield function estimates

horticulture	coefficient estimate					
	pome fruit	stone fruit	citrus fruit	table grapes	wine grapes	other
Explanatory variable						
Constant	21.886	-7.123	-28.057	35.848	0.790	-2.022
WATER / AREA	5.564**	1.730**	5.935**	2.975	3.741**	0.142
(WATER / AREA) ²	-0.179**	-0.053	-0.229**	-0.297**	-0.173**	-0.010
TREE_CAP / AREA	0.018	0.006	0.145**	-0.027	-0.001*	0.015**
(TREE_CAP / AREA) ²	-8.7E-6	-6.8E-6	-1.1E-4**	6.2E-6	-1.2E-8	-1.4E-5**
W_RAIN	-0.107	0.009	0.046	-0.116	-0.022	0.047
W_RAIN ²	1.7E-4	-1.4E-5	-2.3E-4	3.3E-4	3.6E-5	-7.0E-5
S_RAIN	0.056	0.029	0.058	-0.088	0.039**	-0.044
S_RAIN ²	-8.0E-5	-2.1E-5	-2.3E-4	1.5E-4	-5.4E-5**	8.2E-5
(TREE_CAP / AREA) × (WATER / AREA)	-1.9E-4	0.001	-0.012**	0.003	3.8E-4**	0.002*
WATER / AREA × W_RAIN	-0.002	-0.001	-0.003	-0.004	-0.005**	-0.002
WATER / AREA × S_RAIN	-0.005	-0.002	0.006	-0.005	-0.003*	7.1E-4
2008	-2.582	1.232	-0.224	3.976	2.572**	0.329
2009	1.629	1.561	-0.970	9.609**	3.819**	1.963
SA	-29.369**	0.429	3.031	-4.205	1.800**	0.798
VIC	-6.752	8.652**	-1.513	-5.541*	-0.067	0.678
(TREE_CAP / AREA) × (WATER / AREA) ²			5.3E-4**			
R ²	0.36	0.33	0.26	0.26	0.16	0.14
Observations	169	257	252	126	573	165

continued...

16 Quantity yield function estimates continued

explanatory variable	coefficient estimate					
	vegetables	cotton	rice	wheat (irrig.)	wheat (dry)	other broadacre
Constant	3.607	-1.190	3.755	-1.564	-1.088**	-1.278*
WATER / AREA	4.726**	0.587**	2.652**	1.979**		0.996**
(WATER / AREA) ²	-0.142	-0.022**	-0.085**	-0.116**		-0.020**
W_RAIN	0.070	0.006	-0.338	0.023	0.011**	0.005
W_RAIN ²	-6.1E-5	-1.5E-5	8.4E-4	-2.2E-5	-2.6E-6	9.7E-6
S_RAIN	0.008	0.005	0.241*	-0.002	0.002	0.012**
S_RAIN ²	-4.0E-5	8.0E-7	-5.5E-4	4.1E-6	-4.0E-7	-1.4E-5
WATER / AREA × W_RAIN	-0.008	-3.0E-4	0.003	-0.004**		-0.004**
WATER / AREA × S_RAIN	0.011*	-5.5E-4	-0.007**	-2.8E-4		0.002**
2008	-7.253*	0.067	1.503	-0.182	-0.100	0.451*
2009	-6.628*	0.156	6.914**	-0.081	-0.594**	-0.367
SA					0.047	
VIC					0.116	
R ²	0.17	0.27	0.53	0.36	0.42	0.12
Observations	283	116	38	251	612	1 451

Note: * Indicates statistical significance at the 10% level. ** Indicates statistical significance at the 5% level.

17 Yield function estimates (dairy)

explanatory variable	quantity yield coefficient estimate	receipts yield coefficient estimate
C	-2 079.041**	-295.079
WATER / LAND	1 247.586**	322.601*
(WATER / LAND) ²	-122.523**	-35.042*
W_RAIN	13.798**	7.841**
W_RAIN ²	-0.014*	-0.009**
S_RAIN	0.333	-3.330
S_RAIN ²	0.003	0.006
(WATER / LAND) × WINTER_RAIN	-2.546*	-0.423
(WATER / LAND) × SUMMER_RAIN	-0.870**	-0.455
FARM_CAP / LAND	1.228**	0.504**
(FARM_CAP / LAND) ²	-1.6E-4**	-4.5E-5**
FODDER / LAND	2.166**	0.914**
(FODDER / LAND) ²	3.5E-5	4.4E-5
(FODDER / LAND) × (WATER / LAND)	-0.365**	-0.046
(FODDER / LAND) × (WATER / LAND) ²	0.034*	0.004
(FARM_CAP / LAND) × (WATER / LAND)	0.229**	0.083**
(FARM_CAP / LAND) × (FODDER / LAND)	1.2E-4	-6.0E-06
2008	-1 364.628**	-542.470**
2009	-420.412	-76.298
SA	-283.338	-528.539*
VIC	412.360	-135.725
R ²	0.85	0.84
Observations	419	419

Note: * Indicates statistical significance at the 10% level. ** Indicates statistical significance at the 5% level.

Appendix C: Receipts yield functions

18 Receipts yield function estimates

horticulture	coefficient estimate					
	pome fruit	stone fruit	citrus fruit	table grapes	wine grapes	other
explanatory variable						
Constant	3 692.02	-11 962.48	2 452.51	-20 174.07	-3 314.17**	-1 312.24
WATER / AREA	1 569.14	56.88	2 212.64*	5 900.27	1 520.64**	85.60
(WATER / AREA) ²	-114.35*	113.91	-73.69	-16.16	-63.31**	-29.11
TREE_CAP / AREA	12.78	19.75*	57.30**	-1.46	0.55	17.56
(TREE_CAP / AREA) ²	-4.7E-3	-0.02**	-0.05**	3.0E-3	-5.3E-5*	-0.02
W_RAIN	-30.31	92.31**	-207.20	84.85	20.04**	52.59
W_RAIN ²	0.03	-0.07	0.83*	-0.08	-0.01	-0.09
S_RAIN	30.51	-6.89	0.14	125.32	24.28**	-56.48
S_RAIN ²	4.2E-3	-9.6E-3	-0.08	-0.30	-0.04**	0.18*
(TREE_CAP / AREA) ×						
(WATER / AREA)	1.44*	7.26**	-3.20	-1.27	0.06	0.28
WATER / AREA × W_RAIN	6.83*	-5.71**	-5.73	-28.56	-2.38*	9.78**
WATER / AREA × S_RAIN	-5.91	4.23	5.73	6.75	-1.86*	-2.91
2008	-4 639.18	1 018.33	-226.29	3 775.42	457.28	-3 320.35
2009	872.22	2 790.28	254.01	8 718.00**	654.47*	-1 572.37
SA	-3 937.68	3 459.63	1 523.14	-4 302.90	1 327.02**	1 185.33
VIC	-273.34	-235.48	4 405.98**	-2 847.08	594.61	4 481.91
(TREE_CAP / AREA) ×						
(WATER / AREA) ²		-0.56**	0.15			
R ²	0.29	0.25	0.32	0.30	0.51	0.17
Observations	169	257	253	126	573	165

continued...

18 Receipts yield function estimates continued

explanatory variable	coefficient estimate					
	vegetables	cotton	rice	wheat (irrig.)	wheat (dry)	other broadacre
Constant	27 084.42**	-1 506.31	-972.19	25.28	-324.44**	897.69
WATER / AREA	-3 395.81*	983.55**	1 022.85	444.86**		-67.46
(WATER / AREA) ²	-37.13	-26.34	-38.28**	-18.06		-3.01
W_RAIN	49.34	10.54	-105.05	0.94	2.77**	-2.42
W_RAIN ²	-0.05	-0.01	0.13	0.007	-3.6E-4	0.006
S_RAIN	-152.66**	11.82	133.35	-1.14	0.70	-3.94
S_RAIN ²	0.18**	-0.01	-0.31	0.003	-3.1E-4	0.01
WATER / AREA × W_RAIN	0.02	-2.13*	2.88	-0.93		-1.01*
WATER / AREA × S_RAIN	30.65**	-0.10	-3.19*	-0.12		2.77**
2008	-3 706.80	-338.39	2 131.77	144.75	-99.91**	-492.33**
2009	1 594.95	-282.90	-873.09	134.33	32.89	-89.55
SA					-33.08	
VIC					19.27	
R ²	0.17	0.27	0.53	0.36	0.42	0.12
Observations	283	116	38	251	612	1 451

Note: * Indicates statistical significance at the 10% level. ** Indicates statistical significance at the 5% level.

Appendix D: Farm production functions

19 Horticulture farms (southern Murray–Darling Basin), production function estimates

explanatory variable	all farms			less than 100 ha	
	Model 1 estimate	Model 2 estimate	Model 3 estimate	Model 4 estimate	Model 4 estimate
Constant	122 004.74	35 555.19	98 195.74	-378 994.83**	198 627.0
LAND	-273.63	-243.24*	-284.81	1 625.49	-2 941.05
LAND ²	0.05	0.04	0.11**	-0.53	13.08
WATER	-371.99*	506.34**	125.84	1 421.03**	2 042.79**
WATER ²	0.16**	0.04	-0.07	-0.55**	-7.24**
TREE_CAP_F	0.25**	-0.05	-0.15	0.36*	0.32
TREE_CAP_F ²	-6.73E-09	5.0E-8**	5.3E-8**	-1.44E-08	-3.26E-09
FARM_CAP	0.85**	0.27**	0.46**	0.23	-0.45
FARM_CAP ²	2.0E-7**	3.08E-08	1.4E-7**	-1.08E-07	5.99E-08
MAT		0.98**	0.07	0.53	-0.05
MAT ²		2.78E-08	2.2E-7**	-6.2E-7**	-9.7E-7**
LABOUR		0.37**	1.67**	0.87	-0.25
LABOUR ²		1.3E-7**	-3.5E-7**	3.89E-07	5.31E-07
W_RAIN	-1 269.32	-855.15	-1 500.96**	537.41	-925.25
W_RAIN ²	1.70	1.14	1.90*	0.32	1.25
S_RAIN	-90.10	394.88	-7.06	-19.93	1 028.29**
S_RAIN ²	0.68	-0.19	0.82	-0.20	-1.54**
2008	-44 376.53	-13 619.0	-36 396.87	-15 686.39	18 919.02
2009	98 987.36**	42 681.23	67 244.88*	36 923.74	43 693.26**
WATER*LAND	0.75**	0.28**	0.65**	0.67**	7.12
WATER*TREE_CAP_F	7.60E-05	-1.3E-4*	-1.25E-04	-8.1E-4**	-1.83E-03
WATER*FARM_CAP	-4.6E-4**	7.5E-6*	-3.8E-4**	1.1E-4*	-1.5E-3*
WATER*S_RAIN	-0.65	-3.65**	-3.79**	-3.59**	-10.28**
WATER*W_RAIN	7.45**	1.54**	3.67**	-2.46	3.03
WATER*MAT		-4.3E-5*	1.6E-4**	7.2E-4**	4.0E-3**
LAND*FARM_CAP	-4.1E-4**	-3.8E-4**	-5.9E-4**	-4.4E-4*	0.01**
LAND*S_RAIN	2.46*	1.42	1.59	5.92**	3.59
LAND*W_RAIN	-0.85	0.97	0.62	-4.18**	-6.92
LAND*TREE_CAP_F	-1.75E-04	-3.64E-05	-2.0E-4**	1.54E-04	-3.20E-03
TREE_CAP_F*WATER ²	1.37E-08	1.76E-08	6.1E-8**	3.1E-7**	3.94E-06
LAND*WATER ²	-1.1E-4**	-2.31E-05	-7.1E-5**	-2.3E-4**	0.01
LAND*S_RAIN ²	1.17E-04	-1.4E-4*	1.1E-3**	2.7E-3**	0.03**
R ²	0.82	0.92	0.86	0.98	0.98
Observations	971	971	971	638	466

Note: * Indicates statistical significance at the 10% level. ** Indicates statistical significance at the 5% level.

20 Broadacre farms (southern Murray–Darling Basin), production function estimates

explanatory variable	Model 1 estimate	Model 2 estimate	Model 3 estimate	Model 4 estimate
Constant	55 721.24	4 352.4	-21 385.74	1 783 353.27
LAND	-78.09**	-60.86**	-43.69*	37.00
LAND ²	2.46E-04	5.36E-04	-7.00E-05	-1.90E-03
WATER	410.52**	284.64**	385.63**	232.22
WATER ²	-0.07**	-0.09**	-0.05**	-0.31
TREE_CAP	0.70**	-0.53*	0.06	17.38
TREE_CAP ²	-2.8E-7**	1.39E-07	-6.31E-08	-2.96E-05
FARM_CAP	0.33**	-0.13**	-6.95E-03	-0.57
FARM_CAP ²	1.62E-08	3.34E-08	-1.9E-7**	2.08E-07
MAT		1.10**	0.91**	-0.62
MAT ²		-5.2E-7**	-8.5E-7**	1.91E-07
LABOUR		1.64**	1.26*	3.77
LABOUR ²		-4.32E-07	-2.42E-07	-1.15E-05
W_RAIN	-36.26	-325.11	922.69	2 685.93
W_RAIN ²	0.67	1.48	-0.49	-3.63
S_RAIN	-1 077.24	-633.84	-1 870.46	-2 032.42
S_RAIN ²	1.57	0.72	4.13	2.92
2008	22 822.52	2 008.06	-16 933.29	380.35
2009	36 738.15	-3 057.73	17 995.30	840.67
WATER*LAND	7.06E-04	1.09E-03	1.50E-03	-0.03**
WATER*TREE_CAP	7.8E-4**	1.2E-3**	1.0E-3**	-0.03
WATER*FARM_CAP	-1.5E-4**	-1.6E-4**	-1.4E-4**	3.9E-4**
WATER*S_RAIN	0.41	-0.14	0.52	1.85
WATER*W_RAIN	0.40	0.32	-1.70*	-0.66
WATER*MAT		1.2E-4*	2.5E-4**	-4.56E-04
LAND*FARM_CAP	-5.45E-06	3.5E-6*	6.5E-6**	-6.96E-05
LAND*S_RAIN	0.17	0.15*	0.24**	0.55**
LAND*W_RAIN	0.73**	0.35*	0.21	-0.93
LAND*MAT		-2.45E-06	-4.62E-06	3.7E-4**
FARM_CAP*MAT		1.51E-07	7.4E-7**	8.44E-08
FARM_CAP*WATER ²	3.0E-8**	3.4E-8**	1.05E-08	1.20E-07
R ²	0.86	0.92	0.91	0.98
Observations	451	451	451	287

Note: * Indicates statistical significance at the 10% level. ** Indicates statistical significance at the 5% level.

21 Broadacre farms (northern Murray–Darling Basin), production function estimates

explanatory variable	Model 1 estimate	Model 2 estimate	Model 3 estimate	Model 4 estimate
Constant	-543 159.71	-455 673.08	-329 969.05	-656 052.6
LAND	-142.03**	-12.39	-28.21	229.70
LAND ²	3.34E-04	1.48E-03	3.1E-3**	-0.04**
WATER	243.49	373.43**	471.94**	359.93
WATER ²	0.02	-0.01	-0.04**	0.05
FARM_CAP	0.62**	0.35**	0.27**	0.84**
FARM_CAP ²	-6.0E-8*	-2.60E-09	-4.7E-8**	-3.1E-7**
MAT		0.55**	0.43**	0.39
MAT ²		-7.57E-08	2.7E-7**	-5.1E-7**
LABOUR		0.43	1.13**	-0.99
LABOUR ²		8.0E-7**	5.5E-7*	1.1E-5**
W_RAIN	818.97	777.30	-543.26	6 585.34**
W_RAIN ²	-2.14	1.35	3.05	-16.27**
S_RAIN	2 240.58	972.04	1 282.37	-2 915.76*
S_RAIN ²	-2.47	-1.58	-1.33	4.53*
2008	-236 063.0**	-94 098.99	-118 420.61	178 729.0
2009	21 355.08	51 630.27	12 629.28	236 206.8**
WATER*FARM_CAP	-2.43E-05	-1.2E-4**	-4.29E-05	-2.6E-4**
WATER*LAND	0.02	-0.03**	-0.02**	-0.09**
WATER*S_RAIN	1.62E-03	0.57**	-0.24	0.50
WATER*W_RAIN	1.05	-0.94*	-0.22	-0.39
WATER*MAT		1.5E-4**	5.32E-05	-6.30E-05
LAND*FARM_CAP	2.41E-06	-3.3E-5**	-1.41E-05	9.13E-05
LAND*S_RAIN	0.10	0.02	-0.01	-0.08
LAND*W_RAIN	1.00**	0.21	0.16	-0.32
LAND*MAT		3.8E-5**	-2.01E-05	2.4E-4**
R ²	0.79	0.89	0.92	0.98
Observations	401	401	401	231

Note: * Indicates statistical significance at the 10% level. ** Indicates statistical significance at the 5% level.

22 Dairy farms (southern Murray–Darling Basin), production function estimates

explanatory variable	Model 1 estimate	Model 2 estimate	Model 3 estimate	Model 4 estimate
Constant	-242 214.6**	-150 881.1*	-61 940.85	-31 422.62
LAND	28.12	26.09	-55.24	681.49
LAND ²	-0.30**	-0.07	-0.08	0.28
WATER	878.02**	422.78**	524.35**	-154.13
WATER ²	-0.29**	-0.18**	-0.20**	-0.10
FARM_CAP	0.49**	0.31**	-0.28	0.38
FARM_CAP ²	6.6E-08	-2.0E-08	1.3E-07	2.6E-07
FODDER	0.87**	0.61**	-1.62**	-1.06
FODDER ²	4.0E-7**	3.6E-7**	1.4E-6**	2.9E-6**
(MAT -FODDER)		0.85**	2.57**	1.24
(MAT-FODDER) ²		-2.0E-08	-8.2E-7**	-1.4E-6**
LABOUR		1.03**	0.54	-1.38
LABOUR ²		1.9E-6**	5.2E-6**	1.5E-5**
W_RAIN	1 219.99*	903.60*	606.22	1 130.97
W_RAIN ²	-1.81*	-1.22*	-0.87	-0.69
S_RAIN	513.48	-268.94	-1 632.02**	-209.33
S_RAIN ²	-0.13	1.26	4.14**	1.58
2008	-139 188.2**	-115 127.9**	-52 430.47	-125 906.4*
2009	-39 643.3	-37 183.0	11 928.30	-33 901.31
WATER*FARM_CAP	-7.3E-4**	-2.6E-4**	-3.1E-4**	-2.7E-04
WATER*LAND	0.20*	0.20**	0.19*	-0.40*
WATER*S_RAIN	0.16	0.10	-0.15	-0.60
WATER*W_RAIN	-0.71*	-0.47*	-0.32	2.64*
WATER*FODDER	9.7E-05	-3.0E-05	6.9E-05	5.6E-4**
LAND*FARM_CAP	2.3E-04	1.4E-04	3.4E-4**	-1.5E-3*
LAND*S_RAIN	-0.44	-0.40	-0.05	-0.50
LAND*W_RAIN	0.82**	0.31	0.16	-0.99
FODDER*FARM_CAP	-2.7E-07	-2.3E-07	-2.1E-07	-5.8E-7*
LAND*FODDER	2.9E-05	2.6E-04	1.4E-03	-5.5E-03
LAND*(MAT-FODDER)		2.4E-05	-1.2E-03	6.2E-3*
LAND*LABOUR		-2.1E-3**	5.1E-04	-0.01
FARM_CAP*WATER ²	2.9E-7**	1.5E-7**	1.3E-7**	1.4E-07
R ²	0.82	0.95	0.89	0.98
Observations	374	374	374	287

Note: * Indicates statistical significance at the 10% level. ** Indicates statistical significance at the 5% level.

23 Vegetable specialist farms (all Murray–Darling Basin) and grape specialist farms (SA Murray–Darling Basin) production function estimates

explanatory variable	grapes specialists (SA MDB)		vegetable specialists (all MDB)	
	Model 1 estimate	Model 2 estimate	Model 3 estimate	Model 4 estimate
Constant	-617 462.71**	-533 013.1	-326 992.7**	158 014.64
LAND	339.88	463.64	-227.60	571.70
LAND ²	-0.46	-0.73	0.01	-0.03
WATER	2 278.60**	1 548.30**	1 071.02**	-1 757.08**
WATER ²	-0.66**	-0.23	-0.36**	1.14**
TREE_CAP_F	0.02	-0.13	-1.54**	-1.27
TREE_CAP_F ²	-5.51E-09	-3.6E-8**	1.8E-6**	3.5E-6**
FARM_CAP	-0.54**	-0.43**	-0.07	0.48*
FARM_CAP ²	2.5E-7**	7.5E-7**	-6.65E-08	3.4E-7**
MAT	0.98**		1.16**	
MAT ²	-4.7E-8*		4.95E-08	
LABOUR	-0.48**		0.69**	
LABOUR ²	6.1E-7**		2.0E-7**	
W_RAIN	2 439.87**	2 807.18**	1 837.15	-1 508.89
W_RAIN ²	-3.02**	-3.31*	-2.86	2.80
S_RAIN	5 995.47	5 058.14	126.17	-626.69
S_RAIN ²	-25.05	-29.22	0.04	1.23
2008	82 083.76**	78 814.73	-14 468.91	136 428.26
2009	43 419.89	-14 628.62	73 436.75	336 314.3**
WATER*LAND	0.46	-0.67	-0.39**	-0.06
WATER*TREE_CAP_F	7.84E-05	1.8E-3**	-8.67E-04	-7.79E-04
WATER*FARM_CAP	-4.2E-4*	-2.1E-3*	2.34E-04	-1.4E-3*
WATER*S_RAIN	-6.00**	0.59**	-0.70	6.37**
WATER*W_RAIN	0.22	2.58	0.28	8.73**
LAND*FARM_CAP	3.05E-04	1.3E-3**	5.86E-05	1.38E-04
LAND*S_RAIN	3.11	3.51	0.28	2.18
LAND*W_RAIN	-0.55	-0.15	1.05	-5.62**
LAND*TREE_CAP_F	-1.59E-04	-9.4E-4**	1.3E-3**	3.56E-04
TREE_CAP_F*WATER ²	7.84E-08	-4.3E-7**		
LAND*WATER ²	2.22E-05	6.7E-4**		
FERT			1.16**	0.35
FERT ²			5.2E-7*	-6.60E-07
FERT*WATER			-4.9E-4**	-1.7E-3**
FERT*LAND			-3.6E-4**	3.78E-05
FERT*FARM_CAP			2.27E-07	3.0E-6**
R ²	0.97	0.92	0.98	0.86
Observations	200	200	209	209

Note: * Indicates statistical significance at the 10% level. ** Indicates statistical significance at the 5% level.

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