An economic analysis of the

Impact of the National Water Initiative on the efficiency and productivity of water use

2011

Report to Client

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Summary

This report to the National Water Commission (the Commission) is intended to be input to the third biennial assessment in 2011 to inform the Council of Australian Governments (COAG) of the outcomes of the National Water Initiative (NWI) agreement implementation.

Alongside other water reform initiatives led originally by the 1994 COAG agreement, Australian Governments agreed to implement the NWI on the basis of a clear imperative to increase the productivity and efficiency of Australia's water use. The modelling and analysis presented in this study attempts to identify the extent to which this imperative has been met by the NWI implementation process that has occurred between 2004 and 2010. The assessment acknowledges the ongoing nature of water reform and identifies the extent to which the original NWI aspirations can be met in the future through continued implementation of the NWI (Figure 1).

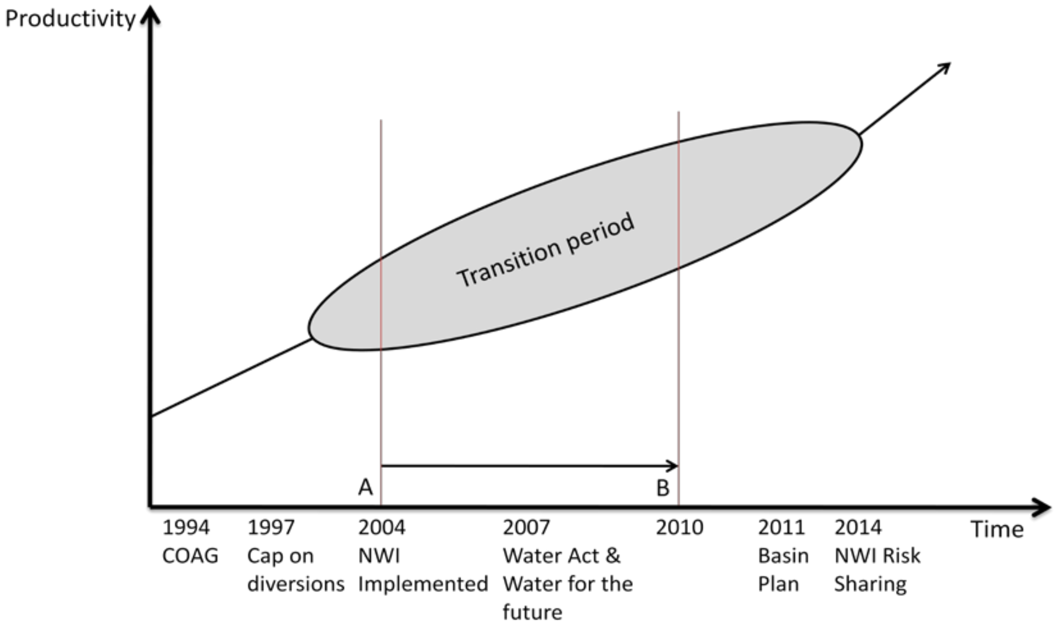

Figure 1. Conceptual relationship for policy induced productivity change in the water sector

The analysis includes three components:

a) An allocative efficiency analysis underpinned by RSMG model;
b) A desktop analysis of irrigation in the Murray-Darling Basin (Basin) over the past decade; and
c) Econometric analysis of productivity trends including:
    - Analysis of Total Factor Productivity (TFP) of irrigated farm enterprises by ABARES using farm survey data for 2006-07, 2007-08 and 2008-09; and
    - Productivity decomposition analysis by CEPA based on TFP analysis of ABARES.

As foreshadowed in Figure 1, and the NWC project brief, the implementation of the NWI policies are still in train. Moreover, the drought that commenced in 2000 in Victoria and extended across the basin over the past decade was both a precursor to NWI implementation as well as a significant factor that influenced its policy impact. Along with the 2008 Global Financial Crisis, and the associated global economic downturn, the period under review can be considered a period of significant volatility. This volatility may mean that the changes in economic performance of irrigated industries over the NWI implementation period cannot be confidently attributed to a particular policy. Rather, business performance was subjected to numerous pressures and the ability of businesses to respond to those pressures was the key attribute that defined their performance. There are no credible economic assessment approaches that can isolate these 'simultaneity' effects, particularly over the relatively short implementation period.

The economic analysis was therefore used to gather evidence about the potential impact of water policy reform in providing flexibility for farm businesses to adapt to change in conditions in the operating environment. The focus of the aforementioned three-part assessment was on water trading in the Basin. As a key element, NWI sought to promote water trading through deregulation of water property rights and water service delivery to develop a nationally consistent Cap and Trade system for water allocation. The MDB Cap was defined as *"The volume of water that would have been diverted under 1993/94 levels of development".* The NWI sought to harmonise the property rights structure for water access by having all jurisdictions define rights as a share of a variable consumptive pool.

Together with the broader assessment of progress in institutional change, the economic analysis provides a robust best bet approach to illustrate the NWI policy influence in improving the productivity and efficiency of irrigated industries in the Basin.

a). Simulation of NWI policy impacts

Economic modelling for the productivity and efficiency assessment was designed to estimate how NWI policies have influenced the allocative efficiency of water. This was achieved by simulating model scenarios with and without water trade in the Basin.

Because water requirements are closely correlated with seasonal conditions, two sets of model simulations were conducted for the range of water availability across the three states of nature, namely normal, dry and wet seasons. This approach provides greater detail about performance by modelling irrigators respond to risks associated with seasonal conditions, including water trading. The analysis was repeated for two scenarios, to reflect the Baseline and NWI policy context.

- The first set, the Baseline, models irrigated land use where water is utilised within the diversion pattern that existed in 2000-01 (this is the most relevant year for the baseline as it is an ABS Census year).
- The second set, the NWI scenario, represents an alternative irrigated land use where water is utilised within the diversion Cap administered by the state Governments as part of the Murray-Darling Basin Agreement. The NWI policy simulation period covers 2001-02 to 2008-09.

In these simulations, the modelled variables were estimated for each of the normal, dry and wet seasonal conditions as well as the 'state-contingent' average. The state-contingent estimate represents the medium term average including a mix of the three different states of nature following the probabilities based on observed historical pattern (Normal-50%; Dry- 20%; Wet-30%).

Key observations, under the irrigation technology, land availability and production system assumptions employed:

- Water trading has provided flexibility for reallocating irrigation water during seasons of low availability (dry years);
- In catchments where there is greater flexibility (relevant technological options) to respond to changes in seasonal conditions, such as in the Murrumbidgee, the return for irrigation are greater in the medium term;
- The net productivity benefit from water trading in the Basin would be around $300 million per year assuming no changes in commodity prices and unimpeded trade across the Basin. ABARE econometric analysis estimated that in 2007-08, where there were some restrictions for trade, the benefits of water trade to South Australia were around $31 million (Mallawaarachchi & Foster 2009); and

- Over the medium term, water use may increase in New South Wales (NSW) and Queensland (Qld)broadacre industries to take advantage of more flexible farming systems. Farming systems such as rice and cotton, for example, can provide productivity benefits in particular over Wet and Normal seasons.

It must be noted that original water licences were issued progressively by each jurisdiction as development was occurring and that there were restrictions for movement of resources across borders. Although some of these restrictions have been lifted recently, further relaxation of trade restrictions allowing water to be matched to economically superior water uses, could expect to lead to a contraction in the irrigation area (Table 7). These changes are expected to occur in all Australian States & Territories within the Basin excluding Qld where there is opportunity for expansion in irrigation following more efficient water use within the Cap.

These results illustrate the need to further reduce restrictions on water trade to allow for a medium term equilibrium in land use to reflect economic rather than political realities.

b). Irrigation in the Murray-Darling Basin over the past decade

The purpose of this analysis was to highlight the performance of irrigated industries at an aggregate level over the past ten years (2000-2010). This period includes the inception of NWI and a number of policy changes, increased volatility due to extended droughts and the international economic downturn in 2008. These events acted as both a trigger for innovation and a deterrent for investment.

An examination of available data illustrates how water use for irrigation in the MDB has changed over the past decade.

- Following the drought, irrigation allocations fell to record lows in many regions including a zero allocation in a number of irrigation regions (Table 8).
- Both the area of land irrigated (Table 9) and the volume of water applied (Table 10) have continued to decline, reaching record low area irrigated of 929,000 ha in 2008-09. In 2007-08, Basin irrigators used 30 per cent less irrigation water than in 2006-07, with the estimated volume of water applied falling to 3,142 gigalitres, the lowest recorded for the Basin in the recent decade. This is equivalent to 30 per cent of the pre-drought level of water use, which was 10,516 gigalitres in 2000-01 (Table 10).

Water trading has been the single biggest policy influence on irrigation since water policy reform began. This is because it provides the flexibility for irrigators to manage water shortages in an efficient manner. An analysis based on the time series of water trading statistics since 1996-97 illustrates the following points.

- While the permanent sale of water entitlements (Figure 1), has been an instrument for reallocating water between irrigators, including new developers pursuing greenfield developments to assist restructuring of activities, the temporary water trade (Figure 2) has largely been an instrument of choice to meet seasonal water shortages. This is clearly evident in recent statistics where in 2008-09, 41 per cent of water used for agriculture in the Basin has been recorded as traded. Temporary trade has been a key source of resilience in managing the supply-demand imbalance.
- These observations are consistent with other analyses of the impact of water trade (Frontier Economics 2007; Mallawaarachchi & Foster 2009; National Water Commission 2010; Qureshi et al. 2009).
- The nominal gross value of irrigated production in the Basin has barely changed despite massive decreases in the area irrigated and water use. The decline in the in the gross value of irrigated production (GVIAP) in the MDB between 2000-01 and 2007-08 from $5,079 million to $5,085 million in nominal terms was limited to 1 per cent in nominal terms (or 18 per cent in real value). While increases in in commodity prices have played a role the flexibility in reallocation of water to permanent crops via trade, improved management practices, and substitution of other inputs for water in the production processes, have played a significant role in supporting agricultural output and maintaining the GVIAP over the drought period.

- Producers have altered the mix of agricultural production to maximise returns. The commodities that contributed most to the value of irrigated production during 2006-07 in the Basin were fruit and nuts ($1,207 million or 24%), dairy production ($763 million or 15%) and grapes ($651 million or 13%). These were also the crops that received most of the irrigation water (Table 11). In comparison, during 2000-01, cotton, an annual crop, contributed most to the total value of irrigated production ($1,111) with a share of 22 per cent of total Basin GVIAP. In 2006-07 cotton only accounted for $457 million or 9 per cent of total Basin GVIAP. This is largely reflected in the decrease in the volume of water applied to cotton.
- As a consequence, the ratio of real GVIAP to volume of water applied in the Basin increased from $585/ML in 2000-01 to $1,107/ML in 2006-07.
    - However, these GVIAP estimates do not in themselves suggest that horticultural crops provide the best use for water. Rather, it is a reflection that these perennial crops require continued supply of water, even at a high cost, to maintain productive life. A more informative indicator of productivity of irrigated crops would be the rates of return, TFP and profitability, which are examined later.
- ABARE data indicates that in 2007-08, the average area operated increased across all irrigated industries, while the actual area irrigated decreased consistent with water availability. Consequently, farm business profits were negative for all industries except horticulture. Horticulture farmers also recorded a higher rate of return compared to broadacre and dairy, although the rates of return were relatively low across the irrigation sector, reflecting higher costs of production.
- ABARE farm survey data indicates that farm returns measured in terms of farm cash receipts per hectare varied significantly across farms for each class of enterprises. While all farms reported a decrease in the area irrigated in 2007-08 compared to the previous year, the proportion of the area irrigated fell sharply for dairy farms (Hughes, Mackinnon and Ashton 2009). These patterns are consistent with that observed with ABS data, and indicates that where possible irrigators are substituting other inputs for water in responding to the water shortage.

Thus trade provided an efficient means to reallocating existing water between users, reflecting demand and supply conditions.

c). Econometric analysis of productivity trends

Total Factor Productivity (TFP) represents the ratio of the total quantity of outputs to the total quantity of inputs. In the agricultural context, the primary inputs of production include land, labour, capital and material inputs, while outputs include crop and livestock products.

TFP is a more robust approach to productivity analysis as it considers the contribution of the full complement of inputs in the production of desired outputs.

Analysis of Total Factor Productivity (TFP)

In this analysis ABARES irrigation farm survey data is used to identify any discernible trends in TFP. RSMG model simulations indicates the extent of potential productivity gains achievable at the Basin and sub catchment scale when irrigators adopt technologies consistent with agronomic recommendations within the available water supplies, with and without water trade. The productivity analysis provides a basis to develop benchmarks to compare observed performance over time.

The key observations from the TFP analysis include:

- Between 2006-07 and 2008-09, farm-level productivity in the irrigation agriculture has on average been increasing. Over this period, the average farm-level TFP index has increased from 0.6 in 2006-07 to 0.8 in 2008-09 (Figure 3).

  - ➢ This result suggests that irrigated farms' productivity has been increasing, and this increase can be partly attributed to technological progress and efficiency improvement. Moreover, the standard deviation of TFP index has also increased from 0.7 in 2006-07 to 0.9 in 2008-09. This implies that disparity in productivity across irrigated farms has been growing over time along with the general growing trend.
  - ➢ In other words, the irrigated farms are becoming more diverse, in terms of productivity (Table 13 & Figure 6).
- The annual growth rate of productivity for all irrigated farms is on average 1.1 per cent a year, which is mainly driven by a decrease in input usage. While this decrease in input usage may be attributable to efficiency gains in water use, the driver of reduced water use is primarily the drought, rather than any policy changes. Policy changes, however, enabled the irrigators to better manage the water scarcity.
- Over the three financial years, the average TFP index for horticultural farms as a group has increased from 0.3 in 2006-07 to 0.6 in 2008-09 (almost doubled). For broadacre farms, the average TFP index increased from 1.2 in 2006-07 to 1.4 in 2008-09. Diary farms' productivity fluctuated around 0.4 between 2006-07 and 2008-09 (Fig 7).
- Decline in productivity in the dairy industry can be attributed to high cost of dairy operations during the drought where dairy operators increased the level of purchased feed as on-farm pasture production declined.
  - ➢ Clearly, in the absence of water trading, the levels of productivity observed for these farms would have been much lower, because during these drought years temporary trading in particular provided the flexibility for dairy farms to sell some of their water to orchards, and use the proceeds to buy feed.
- Large diversity in productivity of irrigated farms has been observed across regions over the period of 2006-07 and 2008-09. These disparities in productivity growth across regions demonstrate the variable capacity of different industries and firms in different regions to cope with changes in operating environment. More detailed analysis is required to isolate specific reasons for this variability.
- By industries, horticulture industry has achieved TFP growth by 4.0 per cent a year, followed by dairy industry. However, broadacre industry has a decline in TFP growth by 3.4 per cent a year (Table 17). The horticulture industry has been the leading water purchaser during this period, to offset large reductions in water allocations, which enabled them to maintain a positive output growth.
- By regions, productivity growth increased in some regions while decreasing in others. Irrigated farms in Macquarie in NSW achieved the highest productivity growth with the annual growth rate of 11.0 per cent a year, followed by Murrumbidgee, also in NSW (of 10.7 per cent a year). In contrast, productivity of irrigated farms in Border Rivers declined by 19.5 per cent a year, followed by Namoi (of 13.2 per cent a year) and Condamine-Balonne (by 11.1 per cent a year).
- These differences in regional TFP arise from the diversity of production mix, technology and water availability in these regions which variously influenced the adaptation of different industries to the continuing drought.
- Despite these regional and inter-firm differences, the average water productivity (that is, the amount of output relative to irrigation water used) appears to have improved across the survey sample during the review period. Although there are likely to be multiple factors at work, including water markets operating more efficiently, the dry conditions which have persisted in recent years are expected to have led some farmers to substitute various water saving technologies for purchased irrigation water.
- The increases in water productivity appear greater on broadacre (1.1 per cent a year) and dairy (0.6 per cent a year) farms compared to horticulture farms (which showed no significant improvement). Across all irrigated farms, water productivity increased, on average, by 0.3 per cent a year between 2006-07 and 2008-09 (Table 20).

Productivity Decomposition Analysis by CEPA

The focus of the analysis was to use the TFP indexes evaluated by ABARE in the previous section to analyse profitability change, technical change and efficiency change that underpin the observed changes in TFP. This analysis was conducted for each farm survey sample (2502 observations) where consistent data were available.

Given the nature of NWI coordinated policies, the main potential influence of NWI on productivity is through scale and mix efficiency changes. These improvements in efficiency are gained respectively from increases in the scale of operations and the scope of operations representing the mix of activities allowing more efficient use of resources.

The key observations from the productivity decomposition analysis include:

1) <u>the average profitability and productivity</u> levels were
    a) highest in the Namoi region and lowest in the Border Rivers region; and
    b) highest in broadacre agriculture and lowest in the horticulture industry.
2) <u>the terms-of-trade</u> (ratio of output to input prices) was
    a) most favourable in the Lachlan region and least favourable in the Mount Lofty Range region; and
    b) most favourable in broadacre agriculture and least favourable in the horticulture industry.
3) <u>output-oriented measures of technical efficiency</u> (a measure of distance to the production frontier) were
    a) increasing over time;
    b) highest in the Namoi region (median 0.98) and lowest in the Murray region (median 0.52); and
    c) highest in broadacre agriculture (median 0.94) and lowest in the horticulture industry (median 0.39).
4) <u>output-oriented measures of pure scale efficiency</u> (a measure of returns to scale) were
    a) highest in 2008 (median 0.94);
    b) highest in the Murrumbidgee region (median 0.94) and lowest in the Namoi region (median 0.77); and
    c) equally high in broadacre agriculture and horticulture (median 0.91) and relatively low in dairy (median 0.87).
5) <u>output-oriented measures of pure mix efficiency</u> (a measure of returns to scope) were
    a) generally extremely low throughout the sample period (median OME scores less than 0.14);
    b) highest in the Murrumbidgee region (median 0.18) and lowest in the Loddon-Avoca region (median 0.10); and
    c) highest in the horticulture industry (median 0.14) and lowest in dairy (median 0.10).
6) <u>output-oriented measures of scale-mix efficiency</u> (a combined measure of returns to scale and scope) were
    a) lowest in 2008 (on average 80% below a reference firm);
    b) highest in the Murrumbidgee region (on average 49% lower than the reference firm) and lowest in the Border Rivers region (on average 79% lower than the reference firm); and
    c) similar across all industries (on average 70% lower than the reference firm).

- An analysis of profitability indexes across years, regions and industries indicates that the average firm profitability across all 2502 firms in the sample was 22% lower than the profitability of the reference firm (Table 21). The firm profitability was on average:
    - ➢ decreasing over time;
    - ➢ highest in the Namoi region and lowest in the Border Rivers region; and
    - ➢ highest in broadacre agriculture and lowest in the horticulture industry.

Conclusions

It is difficult to relate the changes in efficiency and productivity between these industries and identify their link to changes in water policy in this period from this analysis alone. However, taken together with the analysis of ABS water use and farm production and ABARES farm survey data, a broad indication is that the broadacre farms that irrigated during this period included more efficient operators. They produced high value outputs such as hay and silage, sold mainly to the dairy industry that was substituting purchased feed for lost pasture production. For the horticulture industry in particular, availability of water trading helped maintain outputs, which enjoyed relatively favourable terms of trade during the period.

Regional variability in observed productivity relates primarily to the production mix and technologies adopted as well as the level of water policy reform implemented in that region.

- Generally high profitability in the Namoi region is clearly related to the cotton industry in that region, where adaptation to water scarcity has been facilitated by the adoption of a water management plan, a range of agronomic management options and the availability of groundwater. Recent R&D in the cotton industry has led to improved water management in the cotton-based farming systems across the Basin.
- Low levels of mix efficiency such as in the horticulture industry reflect that farmers often specialise in the production of a small number of outputs in order to maximise profits, not productivity.
- These observations are consistent with the changes in water availability which prompted changes in input use during this period, and the specialised nature of dairy and horticulture enterprises. Moreover, the regional enterprise mix and the level of water allocations and the water entitlement mix, including access to groundwater are important determinants of TFP and profitability change.

The general conclusion from this analysis is that there is significant variability in productivity performance across the three industries and within them. The relatively short period in which the NWI has been in operation, combined with the fact that drought conditions also prevailed across the Basin within the same period, means that any general trends in productivity performance are masked by a variable response to drought adaptation by different firms.

While the observations based on ABS data and RSMG model simulations indicates that water trading has been a clear source of allocative efficiency improvements, a clearer picture on the effectiveness of NWI could only be developed using a longer time series.

Introduction

The standard economic approach to the analysis of efficiency distinguishes between static and dynamic efficiency concepts (efficiency at a point in time and efficiency over time). Concepts of static efficiency may be further refined by considering allocative efficiency, scale efficiency and technical efficiency. The main focus of the NWI is on measures that increase allocative efficiency by allowing water to be allocated to its most productive use. To some extent, there may also be increases in scale efficiency (by making it easier to assemble the water rights required for large-scale operations) and technical efficiency (to the extent that efficient farmers find it easier to expand, and less efficient farmers have more attractive exit options). However, there is little reason to expect, as a result of NWI measures, any significant change in the efficiency of existing farms that continue in business.

Given farm-level data, it would be possible to apply standard efficiency estimation techniques (data envelopment analysis and stochastic frontier analysis) to the assessment of efficiency. The ABARES irrigation farm survey dataset, has limited coverage of three consecutive financial years 2006-07 to 2008-09, all of which also coincide with the widespread drought in the Basin.

In this study a three-part approach to analysis of efficiency and productivity impacts of NWI led water policy is attempted. It involves:

a. estimating allocative efficiency gains from removal of restrictions on water trade and express these in terms of the social productivity of water use. As far as technical efficiency is concerned, main issues would be to consider incentives for more water efficient technology. Both these aspects are handled using RSMG Water allocation model;
b. a desktop analysis of irrigation in the Basin over the past decade; and
c. Econometric analysis of productivity trends using ABARES farm survey data, including
    - an analysis of Total Factor Productivity (TFP) at an industry level for the irrigated broadacre, horticulture and dairy industries ; and
    - using the ABARES unit record data used in step b above to decompose TFP estimates at a firm level to investigate the nature of productivity performance.

Allocative Efficiency Analysis

Economic modelling for the productivity and efficiency assessment was designed to estimate the allocative efficiency benefits of NWI by simulating RSMG model scenarios with and without NWI policy changes that influence the scope and nature of trade in the Basin.

Simulation of NWI policy impacts

The RSMG model has two principal ways of modelling changes to water policy, such as a diversion limit (Cap) or trade. The RSMG model incorporates a medium-term analysis timeframe (approximately 5-10 years), key factors of production are assumed to be mobile. A wide set of technology choices provide greater flexibility in land use as water availability declines. However, in this analysis, we have used the model to conduct simulations also involving changes between years to draw insights on the adaptability of enterprises to changes in water availability with and without water trading.

> Option 1: Determine the regional impact of Cap. Here the water allocation under the Cap is used within the specified catchment. This equates to intraregional water trade (there is no water trade across catchments). The model is simulated to represent water flows down the Basin flow network (sequential runs).
>
> Option 2: Optimise the Basin water allocations for the national benefit of the available water for irrigation, allowing full trade within and across regions where trade is physically feasible (global run).

Under option 2, the water is used within the specified trading region incorporating a set of catchments (southern Basin including state borders) but the solution is globally optimised so that impacts of inter-regional trade can be estimated.

Overview of the Model and Core Assumptions

The RSMG water allocation model is a regional programming model developed by The University of Queensland to simulate water allocation for irrigated agriculture within the Basin. For 19 regions within the Basin, the model optimally allocates an amount of water among enterprises according to relative profitability. The impacts of water availability on production are quantified as changes in the gross value of irrigated agricultural production (GVIAP) for a set of commodities. The GVIAP reflect changes in areas and yields resulting from water reallocations, as prices are assumed fixed. Other outputs from the model are farm profit, land use and water use.

The RSMG model, considers the firm level as the primary point of analysis. The model includes all catchments of the Murray-Darling Basin and the economic impacts of water using activities are progressively aggregated from the firm level to the Basin level. In this way the RSMG model allows the key elements of the NWI to be examined by an assessment of micro-economic reform outcomes at the firm level, aggregated progressively to state and the national level, taking the Basin as an example.

The RSMG model broadly reflects existing biophysical conditions in each of the regions. The RSMG model’s 19 regions are broadly consistent with the CSIRO sustainable yield regions. The two additional entities account for urban water use in Adelaide and residual flows to the sea. These regions and entities are sequentially linked in the model to mimic the natural flow patterns of the Basin river system. Moreover:

- Water availability in the model comprises both surface and groundwater. However, assumed reductions in water availability in the simulations reflect only the reductions in surface runoff. Groundwater availability over the medium term is incorporated in the specified diversion limits for each state of nature, i.e., dry, normal and wet with regard to water availability. For these simulations, flow variability will be accounted by region and state of nature.
- The regions are linked by endogenously determined flows of salt and water. For the current simulations the salt module will be switched off. Water flows into and out of a region are modelled as being equal to inflows (net of evaporation and seepage), less extractions, net of return flows. Maximum extraction rates for each region are specified via the Basin Cap (the Cap).
- The irrigated agricultural enterprises modelled are horticulture (citrus, stone fruit, grapes, pome fruit and vegetables), a number of broadacre systems including dairy, beef, sheep, wheat, rice–wheat (on a rotational system), cotton, grain legumes, sorghum and a generic dryland enterprise. The dryland option accounts for any shifts from irrigation to dryland production. That is, if returns to irrigated agriculture decline, or irrigation is constrained by reductions in water availability, say due to water trade, land may be transferred from irrigated to dryland agriculture.
- While the model accounts for all irrigable land within each region it does not specifically identify individual irrigation schemes within regions. Within each region, water and land are allocated so as to maximise net returns subject to the Cap and other constraints such as available land in a catchment.
- The RSMG model assumes uniform water charges across the Basin. This is in contrast with the existing situation where a range of water charging arrangements exists, even within regions. This will allow the benefits of water trade to be better reflected, as the price of water will be the key driver of use.
- In general, if agricultural commodity output falls, then any resultant price increases may offset the reductions in farm income. Such changes will not be considered in the current assessment. A key assumption made in this analysis is constant commodity prices. This assumption means that production impacts in response to reduced surface water availability are considered in isolation from any price changes for agricultural commodities.

The modelling assumes annual allocations of water under the Cap and therefore water management policies within a season (such as storage releases) are not explicitly considered. Although the model parameters represent all available seasonal conditions for most regions, modelling estimates for some regions may not fully correspond to available estimates from other sources. However, disparities have been minimised through model calibrations.

Two sets of model simulations were conducted for the range of water availability across the three states of nature, namely normal, dry and wet seasons. This approach provides greater detail about performance by modelling irrigators respond to risks associated with seasonal conditions.

- The first set, the Baseline, develops a modelled irrigated land use that utilised water within the diversion pattern existed in 2000-01 (this is the most relevant year for the baseline as it is an ABS Census year).
- The second set, the NWI scenario, represents an alternative irrigated land use that utilised water within the diversion Cap based on the historical experience over the period 2001-02 to 2008-09, based on ABS data availability.

Further details on the RSMG model can be accessed from:
http://www.uq.edu.au/rsmg/docs/RSMG_MDB_Model_Documentation_010610.docx .

All model runs were produced under both the sequential (SEQ) and global or common property (CP) modes of the RSMG model to estimate the impacts with and without NWI policy.

The Baseline solution

In these simulations the estimated variables were assessed for each of the normal, dry and wet seasonal conditions as well as the 'state-contingent' average that represent the medium term average including a mix of the three different states of nature following the probabilities based on observed historical pattern (Normal-50%; Dry- 20%; Wet-30%). The summary results from the Baseline run are presented in Table1.

Table 1: Summary — Baseline scenario representing pre NWI basin land and water use, sequential solution

State	Description	Normal	Dry	Wet	State-Contingent
Queensland	Area irrigated ('000 ha)	177.4	10.2	177.4	74.5
	Water use (GL)	905.3	69.2	919.2	742.3
	Surplus ($m)	198.2	55.9	281.0	194.6
	Gross value ($m)	1,801.6	792.7	1,854.5	1,615.7
New South Wales	Area irrigated ('000 ha)	961.0	626.2	1,463.7	0.0
	Water use (GL)	6,672.4	4,489.2	10,002.3	7,234.7
	Surplus ($m)	1,416.7	519.4	1,850.6	1,367.4
	Gross value ($m)	4,828.4	2,424.3	5,065.4	4,418.6
Victoria	Area irrigated ('000 ha)	438.6	438.6	438.6	0.0
	Water use (GL)	3,530.8	3,530.8	4,237.0	3,742.7
	Surplus ($m)	350.5	-31.3	1,109.7	501.9
	Gross value ($m)	525.3	471.0	630.6	546.0
South Australia	Area irrigated ('000 ha)	73.6	73.6	73.6	0.0
	Water use (GL)	522.6	522.6	627.2	554.0
	Surplus ($m)	334.2	243.4	510.0	368.8
	Gross value ($m)	99.5	89.1	119.4	103.4
Total MDB	Area irrigated ('000 ha)	1,650.7	1,148.6	2,153.4	74.5
	Water use (GL)	11,631.1	8,611.9	15,785.6	12,273.6
	Surplus ($m)	2,299.6	787.4	3,751.3	2,432.7
	Gross value ($m)	7,254.7	3,777.0	7,669.9	6,683.7

Source: RSMG Model simulations

The irrigated area, water use and gross value of irrigated agriculture for the Baseline are presented by catchment in Tables 2, 3, 4 & 5 below. These results for the sequential solution runs assume that water available in each catchment is used with the specified Cap consistent with the economic returns available from using that water. Hence the runs represent a situation of unimpeded water trade within a catchment but no trade between catchments. In these results, indicate that in catchments where there is greater flexibility to respond to changes in seasonal conditions (state-allocable technological options), the return for irrigation are greater under the state-contingent specification.

Table 2: Baseline irrigated area, by catchment and State

Baseline ('000 ha)	Normal	Dry	Wet	State-Contingent
Condamine	74.5	3.6	74.5	74.5
Border Rivers Qld	46.6	6.6	46.6	46.6
Warrego Paroo	11.8	0.0	11.8	11.8
Namoi	126.5	0.6	126.5	126.5
Central West	126.4	7.7	129.5	129.5
Maranoa Balonne	44.6	0.0	44.6	44.6
Border Rivers Gwydir	91.0	0.7	212.3	212.3
Western	52.4	52.4	52.4	52.4
Lachlan	67.6	67.6	67.6	67.6
Murrumbidgee	282.6	282.6	457.8	457.8
North East	21.2	21.2	21.2	21.2
Murray 1	8.0	8.0	8.0	8.0
Goulburn Broken	211.3	211.3	211.3	211.3
Murray 2	108.6	108.6	228.4	228.4
North Central	179.3	179.3	179.3	179.3
Murray 3	84.4	84.4	167.6	167.6
Mallee	26.8	26.8	26.8	26.8
Lower Murray Darling	13.5	13.5	13.5	13.5
SA MDB	73.6	73.6	73.6	73.6
Total	**1,650.7**	**1,148.5**	**2,153.3**	**2,153.3**

Source: RSMG Model simulations

Table 3: Baseline water use, by catchment

Baseline (GL)	Normal	Dry	Wet	State-Contingent
Condamine	377.5	23.1	382.1	308.0
Border Rivers Qld	246.3	46.1	255.5	209.0
Warrego Paroo	58.8	0.0	58.8	47.0
Namoi	708.7	3.9	709.5	568.0
Central West	807.9	59.8	843.5	669.0
Maranoa Balonne	222.8	0.0	222.8	178.3
Border Rivers Gwydir	636.3	4.4	1,656.6	816.0
Western	191.8	200.3	205.8	197.7
Lachlan	564.2	498.9	677.0	585.0
Murrumbidgee	2,206.0	2,164.5	3,330.4	2,535.0
North East	155.3	155.3	186.4	164.7
Murray 1	66.0	66.0	79.2	70.0
Goulburn Broken	1,744.3	1,744.3	2,093.2	1,849.0
Murray 2	768.1	768.1	1,341.0	940.0
North Central	1,430.2	1,430.2	1,716.2	1,516.0
Murray 3	595.8	595.8	1,006.4	719.0
Mallee	200.9	200.9	241.1	213.0
Lower Murray Darling	127.4	127.4	152.8	135.0
SA MDB	522.6	522.6	627.2	554.0
Total	**11,631.1**	**8,611.9**	**15,785.6**	**12,273.6**

Source: RSMG Model simulations

Table 4: Baseline gross value of irrigated production, by catchment

Baseline ($m)	Normal	Dry	Wet	State-Contingent
Condamine	515.8	257.1	542.1	472.0
Border Rivers Qld	590.1	412.5	664.9	577.1
Warrego Paroo	64.6	23.1	64.9	56.4
Namoi	916.6	280.2	919.2	790.1
Central West	838.3	392.2	877.3	760.8
Maranoa Balonne	241.8	87.6	241.8	210.9
Border Rivers Gwydir	793.8	413.1	1,166.8	829.6
Western	79.7	91.6	83.6	83.2
Lachlan	393.8	280.5	482.4	397.7
Murrumbidgee	1,589.0	1,108.4	2,032.2	1,625.8
North East	154.0	138.6	203.7	165.8
Murray 1	48.4	40.1	58.1	49.7
Goulburn Broken	939.5	840.0	1,305.0	1,029.2
Murray 2	423.8	248.6	578.9	435.3
North Central	638.9	566.7	912.5	706.5
Murray 3	309.5	176.1	422.5	316.7
Mallee	477.5	380.0	573.2	486.7
Lower Murray Darling	260.8	233.9	312.9	271.1
SA MDB	845.2	759.7	1,025.1	882.1
Total	**10,120.9**	**6,729.9**	**12,467.2**	**10,146.6**

Source: RSMG Model simulations

Table 5: Baseline net value of irrigated production, by catchment and State

Baseline ($ m)	Normal	**Dry**	**Wet**	State-Contingent
Condamine	89.7	29.4	108.3	83.2
Border Rivers Qld	53.6	-1.7	123.4	63.5
Warrego Paroo	12.4	5.9	11.3	10.8
Maranoa Balonne	319.5	92.9	309.3	271.2
Namoi	171.3	111.8	186.8	164.1
Central West	42.4	22.3	38.0	37.1
Border Rivers Gwydir	189.8	103.5	141.6	158.1
Western	19.8	28.4	22.3	22.2
Lachlan	107.0	44.6	167.0	112.5
Murrumbidgee	380.9	96.8	640.9	402.1
Murray 1	31.1	10.7	80.0	41.7
North East	16.3	6.4	25.6	17.1
Goulburn Broken	131.7	-19.8	484.9	207.3
Murray 2	92.5	6.1	148.0	91.9
North Central	60.0	-54.3	323.6	116.2
Murray 3	60.4	-4.0	100.1	59.4
Mallee	127.7	32.1	221.1	136.6
Lower Murray Darling	59.1	32.9	109.0	68.8
SA MDB	334.2	243.4	510.0	368.8
Total MDB	**2,299.6**	**787.4**	**3,751.3**	**2,432.7**

Source: RSMG Model simulations

The global solution

In Table 6 the key model parameters are reported for the global solution where the model simulates the optimal allocation of water in each catchment to allow for best use of available water to attain the maximum economic output consistent with available resources and economic conditions. The comparison in Table 7 indicates the level of economic gains that may be achievable under fully unimpeded water trade between catchments across the Basin. This represents the upper level of possible gains under the full implementation of NWI objectives regarding water trade.

Table 6: Summary — Baseline scenario representing pre NWI basin land and water use, global solution

State	Description				State-Contingent
		Normal	Dry	Wet	
Queensland	Area irrigated (‘000 ha)	245.8	10.2	245.8	84.3
	Water use (GL)	1,247.5	69.2	1,261.3	1,016.0
	Surplus ($m)	267.4	90.1	343.3	254.7
	Gross value ($m)	2,012.7	869.9	2,065.0	1,799.8
New South Wales	Area irrigated (‘000 ha)	1,038.1	626.3	1,209.4	1,209.4
	Water use (GL)	7,890.8	5,238.8	9,872.3	7,954.9
	Surplus ($m)	1,547.8	519.7	2,055.7	1,494.5
	Gross value ($m)	5,328.49	2,613.25	5,564.02	4,856.10
Victoria	Area irrigated (‘000 ha)	439.3	439.3	439.3	439.3
	Water use (GL)	3,494.6	3,494.6	4,193.5	3,704.2
	Surplus ($m)	476.1	121.0	1,253.1	638.2
	Gross value ($m)	523.34	471.00	628.00	544.27
South Australia	Area irrigated (‘000 ha)	58.6	58.6	58.6	58.6
	Water use (GL)	387.6	387.6	465.2	410.9
	Surplus ($m)	326.4	243.2	487.6	358.2
	Gross value ($m)	98.97	89.07	118.76	102.93
Total MDB	Area irrigated (‘000 ha)	1,781.8	1,134.4	1,953.2	1,791.6
	Water use (GL)	13,020.5	9,190.3	15,792.3	13,086.0
	Surplus ($m)	2,617.7	974.1	4,139.8	2,745.6
	Gross value ($m)	7,963.49	4,043.22	8,375.82	7,303.13

Source: RSMG Model simulations

The key observations from the above analysis is that a clear benefit in water trading is in allowing flexibility for reallocating irrigation water during seasons of low availability denoted 'dry' in the simulations.

Under the current arrangements, the distribution of water licences predominantly reflects licences issued progressively as development was occurring at a time when there were restrictions for movement of resources across borders. A freer trade allowing water to be matched to economically superior water uses, could expect to lead to a reallocation of land uses, including a possible reduction in irrigation area (Table 7). These changes are expected to occur in all states excluding Queensland where there is opportunity for the expansion in irrigation area following more efficient water use within the Cap.

Table 7: difference in key model attributes between the sequential and global runs — potential gains under fully unimpeded water trade

State	Description	Normal	Dry	Wet	State-Contingent
Queensland	Area irrigated ('000 ha)	68.4	0.0	68.4	9.8
	Water use (GL)	342.2	0.0	342.2	273.7
	Surplus ($m)	69.2	34.2	62.3	60.1
	Gross value ($m)	211.1	77.2	210.5	184.1
New South Wales	Area irrigated ('000 ha)	77.0	0.2	-254.3	-254.3
	Water use (GL)	1,218.5	749.6	-130.0	720.2
	Surplus ($m)	131.1	0.3	205.1	127.1
	Gross value ($m)	500.1	189.0	498.7	437.5
Victoria	Area irrigated ('000 ha)	0.7	0.7	0.7	0.7
	Water use (GL)	-36.2	-36.2	-43.5	-38.4
	Surplus ($m)	125.6	152.3	143.4	136.3
	Gross value ($m)	-1.96	0.00	-2.55	-1.75
South Australia	Area irrigated ('000 ha)	-15.0	-15.0	-15.0	-15.0
	Water use (GL)	-135.0	-135.0	-162.0	-143.1
	Surplus ($m)	-7.7	-0.2	-22.4	-10.6
	Gross value ($m)	-0.49	0.00	-0.64	-0.44
Total MDB	Area irrigated ('000 ha)	131.1	-14.2	-200.2	-258.8
	Water use (GL)	1,389.4	578.4	6.7	812.4
	Surplus ($m)	318.1	186.7	388.4	312.9
	Gross value ($m)	708.8	266.2	706.0	619.4

Source: RSMG Model simulations

Such reductions are already occurring in a number of catchments where water licence holders are taking advantage in water trading to realise the value of their assets, for example, areas such as North Central (Loddon-Campaspe) Murrumbidgee (Lowbidgee and Coleambally) and in the Goulbourn-Broken Catchments.

Under the assumption of no changes in commodity prices, the net economic benefit from water trading in the basin would be around $300 million per year. These estimates are likely to be overstated as the RSMG analysis assumes optimal allocations under best available technological options. ABARE analysis, following an econometric analysis, estimated that in 2007-08under the partial restrictions on trade applicable at that time, benefits of water trade to South Australia was around $31 million (Mallawaarachchi & Foster 2009).

Moreover, the model simulations, under the assumptions of technology and land availability reflected in available data, over the medium term, water use may increase in NSW and Queensland broadacre industries to take advantage of more flexible farming systems that can provide productivity benefits in particular over Wet and Normal seasons. This also illustrates the need to further reduce restrictions on trade to allow for medium term equilibrium in land use reflecting economic rather than political realities.

The general insight gain from this analysis is that water trading across catchments allows for an efficient way to allocate existing limited water allocations in times of low water availability. Under the conditions assumed in RSMG model simulations, the benefits of trade could be around $300 million across the Murray-Darling Basin.

Irrigation in the MDB over the past decade

The purpose of this section is to highlight that the past ten years, which include the period when the NWC was established has been a time of immense volatility brought about by the extended droughts and international economic downturn related to the 2008 Global Financial crisis. It is widely believed that these two events acted both as a trigger for innovation and a deterrent for investment.

The feature of the past decade, with regard to Australian water policy, has been the 2002-2009 extended droughts. While the droughts created severe hardship across urban and rural communities through widespread water shortages, it also signalled the need to manage water resources more wisely, and acknowledge its value as a scarce resource. The past decade, thus represents an era of policy consolidation with the 2004 NWI built on the previous CoAG water reform framework initiated in 1994 as a highlight. The NWI drew on lessons learnt during a rapid expansion phase, characterised by advancements in irrigation technology, a high level of investment in irrigated land uses and a growing awareness of the environmental impacts of irrigation in the Basin (Quiggin 2001).

Moreover, the NWI demonstrated an appreciation by policymakers of two forms of market failure that determine the social value of water — uncertainty relating to water availability and a growing level of water use externalities leading to conflict among multiple users of water. In particular, the NWI acknowledged that water shortages due to drought and climate change, as well as the adverse consequences for the environment of overallocation of water to consumptive uses, justified the need for a coordinated approach to national water reform and improved water productivity. More specifically, the NWI sought to harmonise the property rights structure for water access by having all jurisdictions define rights as a share of a variable consumptive pool (National Water Commission 2008).

With the governments acknowledging the impacts of the prolonged drought, including the acceptance of the extent of over allocation of the Basin's water resources (Quiggin 2006), the emerging risks to Basin water resources (Dijk et al. 2006), and their impact on the Basin economy (Mallawaarachchi et al 2007), the Australian Federal Government saw the need for ceding state powers over water resources in the Murray-Darling Basin in view of national interest. These were part of the package of measures announced under the *National Plan for Water Security* (Howard 2007).

The Water Act 2007, which commenced on 3 March 2008, gave authority for a 'Federal takeover' of the management of water resources in the Murray-Darling Basin in the national interest, to optimise environmental, economic and social outcomes of water allocation and use (DEWHA 2009). On 25 September 2008, the Water Act 2007 was amended to give effect to the Intergovernmental Agreement on Murray-Darling Basin Reform. This agreement between the Commonwealth and Basin State Governments enabled:

- the creation of the Murray-Darling Basin Authority (MDBA) to supersede the Murray-Darling Basin Commission;
- strengthening the role of the Australian Competition and Consumer Commission in the formulation of water market and water charging rules; and
- the development of a Basin Plan to provide arrangements for meeting critical human water needs.

Under the Water Act the MDBA was given the responsibility for developing a new Basin Plan. This Plan is to include new Sustainable Diversion Limits (SDL) and an environmental watering plan. Taken together, NWI reforms and the reforms under the Water Act are expected to lead to more efficient and sustainable water use across the Basin.

In an attempt to ease the transfer to new SDLs, the Australian Government introduced the $12.9 billion *Water for the Future* Program. This comprised the $3.1 billion *Restoring the Balance in the Murray-Darling Basin Program*, to purchase water over 10 years for the environment and the $5.8 billion sustainable irrigation infrastructure fund. Other initiatives aimed at helping irrigators adjust include, for example, a special exit grant for small block irrigators, on 15 hectares or less, in the Murray-Darling Basin to receive up to $150,000 if they agreed to sell all their water entitlements to the Commonwealth before 30 June 2009. The position of Commonwealth Environmental Water Holder was also established under the *Water for the Future* Program to manage the water acquired through these measures, and to protect or restore environmental assets in the Murray-Darling Basin and in other areas where environmental water is held (DEWHA 2009).

The impacts of the NWI thus need to be viewed along with the above developments.

Irrigation Impact

During the drought, irrigation allocations fell to record lows in many regions including a zero allocation in a number of irrigation regions (Table 8). The current 2010-11 season will provide full water allocations for most regions in the Southern connected system and reverts the system to a more normal form of allocations consistent with the regional water sharing plans. However, a level of uncertainty will prevail as the irrigation areas recover from the floods and the MDB Basin Plan is formulated and agreed along with a clear role defined for the Environmental Water Holder.

Table 8: Irrigation water allocations in major areas of the Southern Murray Darling Basin 2000-01 – 2009-10.

	Allocation (%)					
System	2000-01	2005-06	2006-07	2007-08	2008-09	2009-10
South Australian Murray	100 (or more)	100(or more)	60	32	18	62
Victorian Murray (high security)	200	144	95	43	35	100
Victorian Goulburn (high security)	100	100	29	57	33	71
NSW Murray (high security)	100	97	69	25	95	97
NSW Murray (general security)	95	63	0	0	9	10
Murrumbidgee (high security)	100	95	90	90	95	95
Murrumbidgee (general security)	90	54	10	13	21	14

Source: State water authorities (NSW, Victoria, SA)

The important point to note in this table is that all regions suffered severe cut backs to irrigation since 2000-01. The general security entitlements were the worst hit, but regions such as Murrumbidgee where the bulk of the allocations are general security those allocations provided a valuable pool of water for trading into higher value uses. As a consequence areas of permanent crops such as grapes and horticulture were able to be maintained despite record low water allocation in the Basin (Table 9)

Table 9: Area irrigated in Murray–Darling Basin, by agricultural commodity

Area Irrigated ('000 ha)	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09
Pasture for dairy and other livestock farming	760	707	551	669	703	717	446	365	267
Rice	178	145	44	65	51	102	20	2	7
Cereals (excl. rice)	260	354	416	340	324	329	266	291	291
Cotton	405	394	218	174	258	247	126	53	128
Grapes	84	86	89	87	92	106	112	106	102
Horticulture (excl. grapes)	96	97	105	99	98	107	104	99	94
Other agricultural commodities	41	34	43	67	62	46	26	35	35
Total	**1,824**	**1,817**	**1,466**	**1,501**	**1,588**	**1,654**	**1,101**	**958**	**929**

Source: ABS 2010, ABS 2009a, ABS 2009b, ABS 2008

Recent statistics on irrigation water use indicate that both the total area of land irrigated (Table 9) and the total volume of water applied (Table 10) have declined further since 2005-06, reaching record low area irrigated of 929,000 ha in 2008-09. In 2007-08, Basin irrigators used 30 per cent less irrigation water than in 2006-07, with the estimated volume of water applied falling to 3,142 gigalitres, the lowest recorded for the Basin in the recent decade. This is equivalent to 30 per cent of the pre-drought level of water use, which was 10,516 gigalitres in 2000-01 (Table 10).

Table 10: Water consumption, by agricultural commodity

Water consumption (GL)	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09
Pasture for dairy and other livestock farming	3,227	2,971	2,343	2,549	2,371	2,571	1,143	997	760
Rice	2,418	1,978	615	814	619	1,252	239	27	101
Cereals (excl. rice)	751	1,015	1,230	876	844	782	572	805	789
Cotton	2,599	2,581	1,428	1,186	1,743	1,574	819	283	793
Grapes	469	479	492	489	510	515	534	434	439
Horticulture (excl. grapes)	538	541	567	576	551	565	542	480	494
Other agriculture	514	504	475	596	564	460	607	95	100
Total	**10,516**	**10,069**	**7,150**	**7,087**	**7,204**	**7,720**	**4,458**	**3,142**	**3,492**

Source: ABS 2009a, ABS 2009b, ABS 2009c, ABS 2009d;

The role of water trading

Water trading has been the single biggest policy influence since water policy reform began that provided the flexibility for irrigators to manage water shortages in an efficient manner. Numerous studies have analysed the impact of water trade (Frontier Economics 2007; Mallawaarachchi & Foster 2009; National Water Commission 2010; Qureshi et al. 2009).

An analysis based on the time series of water trading statistics since 1996-97 is presented below.

Since the establishment of a permanent Cap on water extractions NSW, Vic and South SA was implemented from 1 July 1997, water trading within the Basin started to take shape as a mechanism for reallocating a available water between willing sellers and willing buyers. The Cap is defined as "*The volume of water that would have been diverted under 1993/94 levels of development.*" For Qld , where a moratorium on further development was in place since September 2000, and for the Australian Capital Territory Cap arrangements were only finalised more recently. Together Qld and the ACT account for around 7% of total Basin diversions.

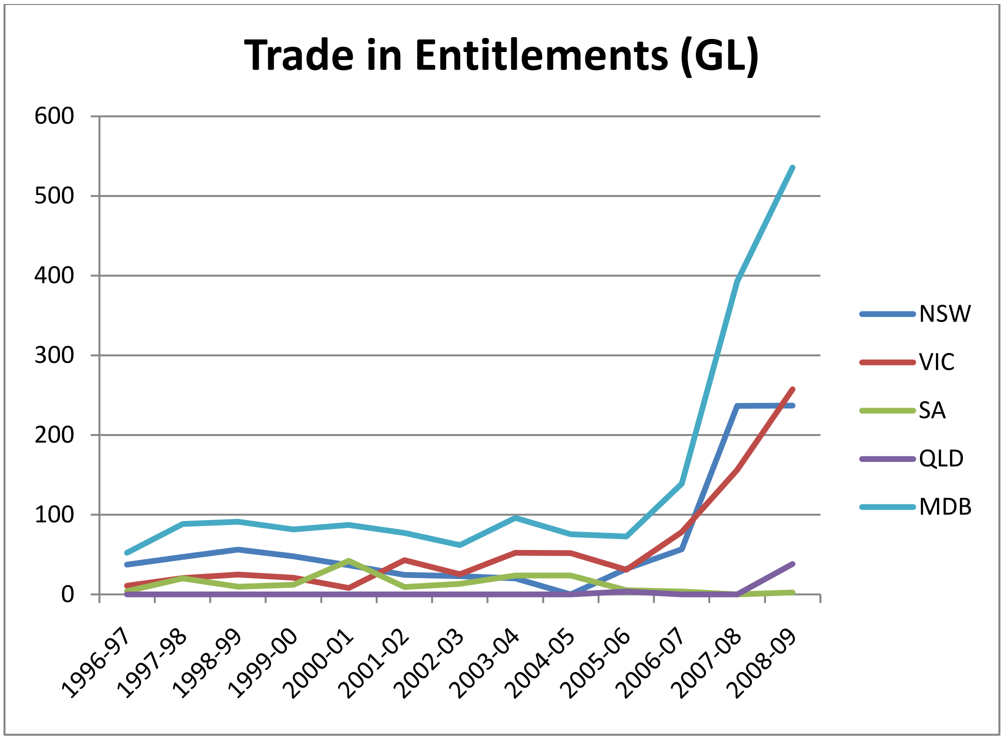

Figure 2a: Sale of water entitlements, by state in the Murray-Darling Basin, 1996-97 to 2008-09

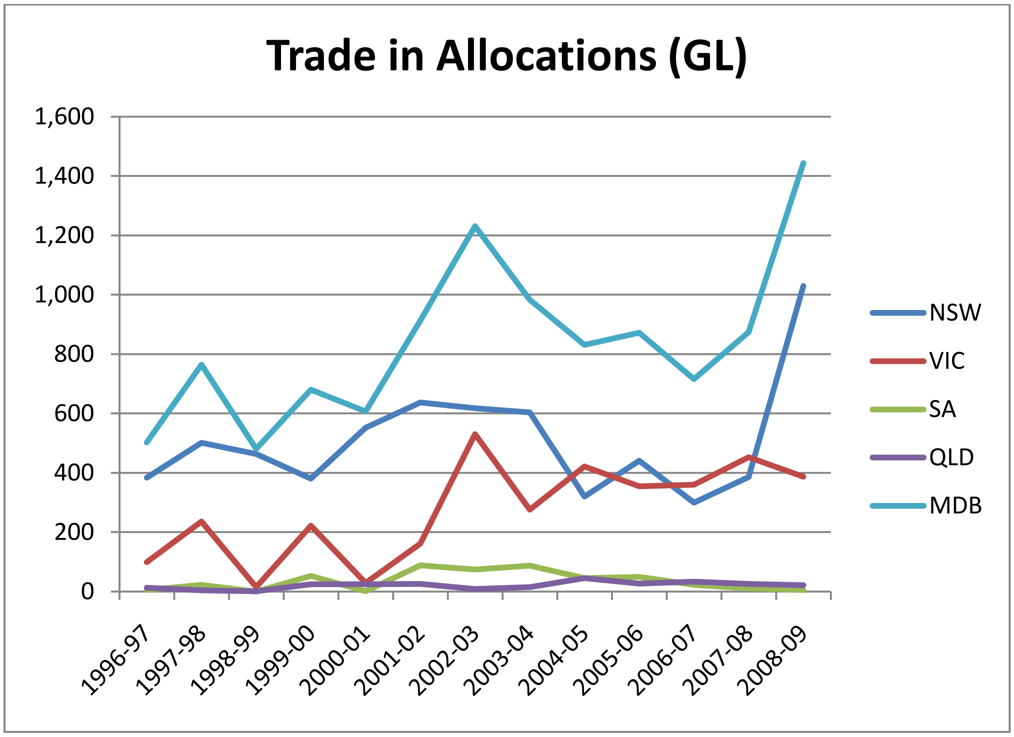

Figure 2b: Sale of water allocations, by state in the Murray-Darling Basin, 1996-97 to 2008-09

While the Cap restrains further increases in water diversions, it does not constrain new developments provided the water is obtained by reallocating uses within the Cap through efficient use or market exchanges. Thus trade thus provided an innovative means to reallocate existing water entitlements between users, reflecting demand and supply.

While the permanent sale of water entitlements (Figure 2a), has been an instrument of reallocating water between irrigators, including new developers pursuing greenfield developments to assist restructuring of activities, the temporary water trade (Figure 2b) has largely been an instrument of choice to meet seasonal water shortages. This is clearly evident in recent statistics where in 2008-09, 41 per cent of water used agriculture in the Basin has been recorded as traded. Although these would include transfers between owners of multiple licences, and the sale of a single parcel more than one time, temporary trade has been a key source of coping with supply-demand imbalance (Mallawaarachchi and Foster 2009).

Irrigated production in the MDB in 2007-08 was $5,079 million, whereas in 2000-01, this value was $5,085 million in nominal terms. It is noteworthy that between 2000-01 and 2007-08 irrigated water use in the Basin declined by 70 per cent to 3,142 gigalitres, while the area irrigated fell by 53 per cent. The associated decline in the gross value of irrigated production was limited to 1 per cent in nominal terms (or 18 per cent in real value). While there has been increases in price levels, this significantly lower impact at a Basin level is largely attributed to the flexibility in reallocation of water to permanent crops via trade, improved management practices, and substituting other inputs for water in the production processes. A further decline in GVIAP in 2008-09 is largely a result of poor prices for grapes and fruits and a small contraction in irrigated area, particularly of horticulture and pastures.

Commodity mix

As indicated in Table 11, the commodities that contributed most to the value of irrigated production during 2006-07 in the Basin were fruit and nuts ($1,207 million or 24%), dairy production ($763 million or 15%) and grapes ($651 million or 13%).

Table 11: Gross value of irrigated agricultural production — ABS estimates

Gross Value of Irrigated Agricultural Production	2000–01 ($m)	2005–06 ($m)	2006-07 ($m)	2007-08 ($m)	2008-09 ($m)
Hay production	79.9	160.5	175.7	138.7	80.1
Rice	349.2	273.6	55.0	7.3	34.5
Cereals (excl. rice)	148.7	180.3	190.8	269.2	278.7
Dairy production	803.6	901.4	762.8	961.5	790.7
Cotton	1,110.6	797.9	456.9	193.5	561.9
Grapes	785.2	720.8	650.5	1,103.8	598.4
Horticulture (fruit & nut excl. grapes)	701.2	1,011.0	1,207.1	1,182.0	1,032.5
Vegetables for human consumption and seed	467.7	554.6	556.3	718.3	564.2
Meat cattle	382.8	592.5	559.1	164.6	129.3
Sheep production	125.3	143.3	163.9	93.3	105.1
Nurseries, cut flowers and cultivated turf	90.3	149.8	128.7	225.5	119.4
Other agricultural commodities	40.9	36.3	15.0	21.3	54.2
Total Agriculture	**5,085.4**	**5,522.0**	**4,921.9**	**5,078.9**	**4,349.1**
Total 2000-01 real $m	**5085.4**	**4812.8**	**4168.2**	**4159.9**	**3454.1**

Source: ABS, cat No.4610.0.55.008 - Experimental Estimates of the Gross Value of Irrigated Agricultural Production, 2000-01 - 2008-09

During 2000-01, cotton, an annual crop, contributed most to the total value of irrigated production ($1,111) with a share of 22 per cent of total Basin GVIAP. In 2006-07 cotton only accounted for $457 million or 9 per cent of total Basin GVIAP. This is largely reflected in the decrease in the volume of water applied to cotton, with the volume decreasing from 1,574 GL in 2005-06 to 819 GL in 2006-07. As a result, the ratio of real GVIAP to volume of water applied in the Basin increased from $585/ML in 2000-01 to $1,107/ML in 2006-07. However, this does not in any way reflect that horticultural crops provide the best use for water. Rather it is a reflection that perennial crops require continued supply of water, even at a high cost, to maintain productive life. A more informative indicator of productivity of irrigated crops would be the rates of return, total factor productivity and profitability, which are examined later in this report.

Farm level performance

ABARE farm survey estimates provide additional insights on farm level performance of Basin irrigators during this drought. Detailed estimates of farm performance for irrigators in the Basin are available for 2006–07 and 2007–08 (Table 12).

Table 12: Farm performance estimates by industry, Murray–Darling Basin, 2006–07 and 2007–08

		Dairy farms irrigated		Broadacre farms irrigated		Horticulture farms irrigated	
		2006–07	2007–08	2006–07	2007–08	2006–07	2007–08
Average per farm							
Area operated	ha	229	260	1,106	1,962	90	125
Dairy cattle	no.	257	254	1	0	14	1
Area set up for irrigation	ha	109	125	201	371	29	46
Area actually irrigated	%	82	50	55	27	93	65
Irrigation water used	ML	336	177	275	232	126	125
Farm cash income	$	58,330	91,380	73,480	92,470	51,080	69,050
Farm business profit	$	–26,710	–8,180	–17,850	–20,200	950	8,160
Rate of return	%	0.3	1.5	0.6	1.2	1.5	2.0
Equity ratio	%	83	81	87	83	85	83

Source: ABARES, Surveys of irrigated farms in the Murray–Darling Basin, 2006–07 and 2007-08, (Ashton and Oliver 2008; Ashton, Hooper and Oliver 2009)

ABARE data indicates that in 2007-08, the average area operated has increased across all irrigated industries, while the actual area irrigated declined consistent with water availability. Consequently farm business profits were negative for all industries except for horticulture. Horticulture farmers also recorded a higher rate of return compared to broadacre and dairy, although the rates of return were relatively low across the irrigation sector, reflecting higher costs of production.

ABARE farm survey data indicates that farm returns measured in terms of farm cash receipts per hectare varied significantly across farms for each class of enterprises. This variability was greater amongst broadacre farms, where the area irrigated as a proportion of the area setup for irrigation was much lower. Horticulture farms, which are generally small in comparison to broadacre farms, had a higher proportion of the area under irrigation. Associated with this the horticulture farm returns displayed less variability. While all farms reported a decrease in the area irrigated in 2007-08 compared to the previous year, the proportion of the area irrigated fell sharply for dairy farms

(Hughes, Mackinnon and Ashton 2009). These patterns are consistent with that observed with ABS data, and indicates that where possible irrigators are substituting other inputs for water in responding to the water shortage.

Annual irrigated enterprises, which characterise irrigated activities on broadacre farms, can be more easily changed as water availability declines. Whereas, perennial activities such as horticulture are more difficult to change and the primary option available to irrigators is to supplement water allocations through trade or ground water where available, and to follow a more conservative irrigation regime. However, as discussed below, the high costs of producing this output meant that farm profits were affected severely (Table-12).

Moreover, although horticulture specialists have performed relatively better as a group, a further analysis of data at a regional level reported in a recent ABARE report (Ashton, Hooper & Oliver 2010) indicates that a significant share of horticulture farmer's income has been derived from non-horticulture activities, denoted as other crops in Figure 3 & 4, for example. This is consistent with observations from modelling that as the total cost of water increases during droughts, horticulture enterprises may become unviable and diversification into other activities allow these farms to make better use of their resources.

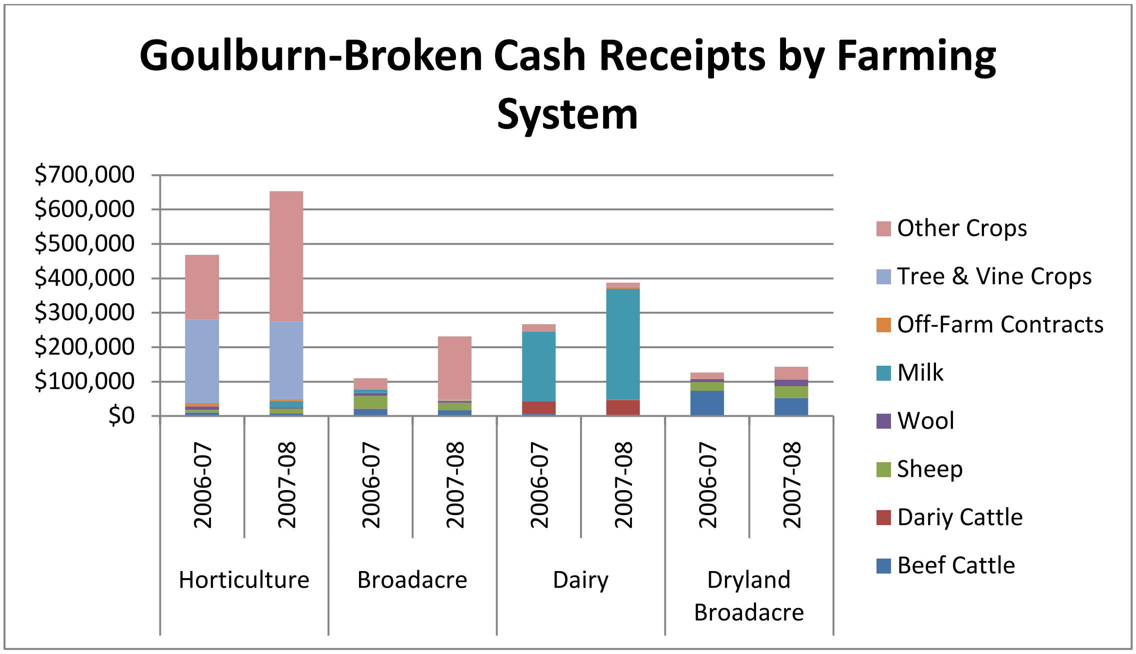

Figure 3. Cash receipts by farming system, Goulburn-Broken region, 2006-07 & 2007-08

Source: ABARES (Ashton, Hooper & Oliver 2010)

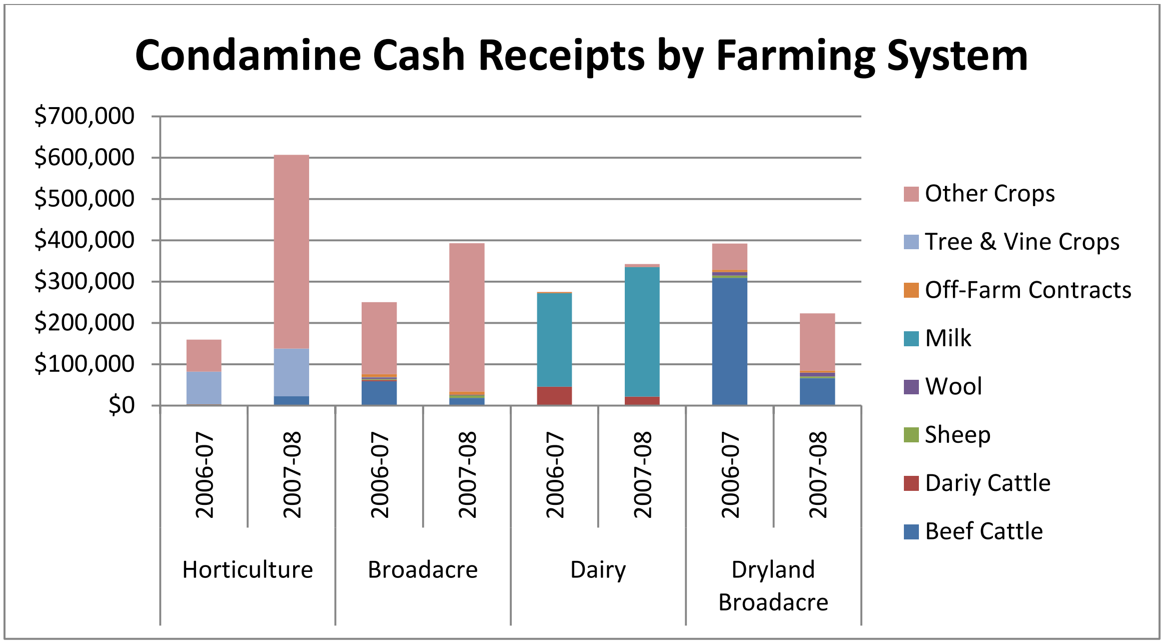

Figure 4. Cash receipts by farming system, Condamine region, 2006-07 & 2007-08

Source: ABARES (Ashton, Hooper & Oliver 2010)

Permanent water trade

In contrast to temporary trade of water allocations, which grew rapidly providing flexibility for irrigators, the rate of increase in permanent water trade was rather stagnant until 2006-07 when nearly 140 gigalitres of water licences were traded (Figure 2a). In 2008-09 this volume increased to 536 gigalitres. A close examination of this trading trend however suggests that the bulk of these permanent water transfers have been the result of government water purchases under various environmental management initiatives. These include NSW Snowy River restoration, Living Murray Initiative, and the recent buy-backs under the Water for the Future Programme. The sum of these purchases is over 750 gigalitres up to September 2010.

Transfers for agricultural purposes are limited and a more detailed study of transactions would be needed before making general conclusions about the role of permanent trade in facilitating structural adjustment, or inducing productivity or resilient impacts within the Basin.

In general, agriculture has been adapting to changes in the operating environment, including changes to water policy. Improvements in productivity have been a key source of adaptation to externally imposed changes. Water trading has been a clear source of efficiency in the use of available water during the times of low water allocations. This process of adaptation has helped agriculture to more or less maintain its share of net returns, while the costs of aproduction and the gross value of agriculture has risen significantly over the years (figure 5).

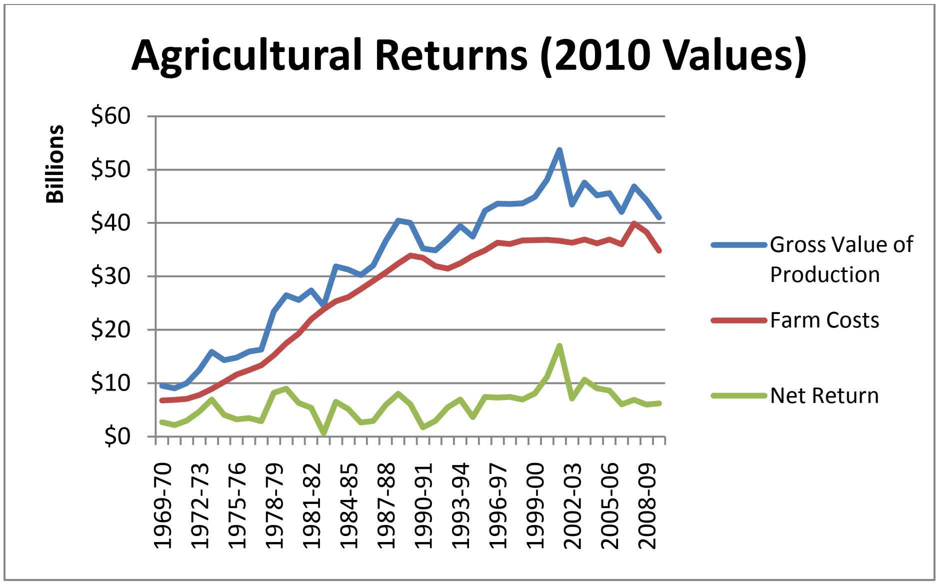

Figure 5. Farm costs and returns, 1969-70 to 2008-09.
Source: ABARE

In the next section changes in agricultural productivity over recent years are examined using ABARE farm survey data.

Econometric analysis of productivity trends

In this analysis ABARE irrigation farm survey data is used to identify any discernible trends in Total Factor Productivity (TFP). The RSMG model simulations indicates the extent of potential productivity gains at the Basin and sub catchment scale when irrigators adopt technologies consistent with agronomic recommendations within the available water supplies, with and without water trade. The productivity analysis in this section provides a theoretical benchmark to compare observed performance over time, across industries and between different farm firms.

Analysis of Total Factor Productivity (TFP)

Background and Initiatives

Productivity can be measured through total factor productivity (TFP), which shows the ratio of the total quantity of outputs to the total quantity of inputs. In the agricultural context, the primary inputs of production include land, labour, capital and material inputs, while outputs include crop and livestock products.

To understand productivity level and productivity changes across irrigated farms in the Murray-Darling basin in recent years, Inovact Consulting initiated a joint-research project with the University of Queensland and ABARES aiming to assess the productivity and efficiency impacts of the NWI.

ABARES used the irrigation farm survey data and developed an index program (based on the current broadacre-productivity estimation system and the irrigation farm survey data) to estimate the total factor productivity index for irrigated farms in the Murray-Darling Basin and provided:

- A set of farm-level TFP indexes (by using the Fisher Index approach) for the irrigation industry illustrating cross-farm productivity comparisons in the irrigated dairy, horticulture and broadacre industries across 2006-07, 2007-08 and 2008-09;
- A set of farm-level inputs (including 5 categories: Land, Labour, Capital, Materials and Services and Water) and outputs (including grain cropping, horticulture products, livestock, wool and other output--for other output) were used to develop quantity indexes for inputs and outputs using the Fisher Index approach. A corresponding price indexes were also developed for the purposes of productivity/profitability decomposition analysis;
- A set of industry-level and region-level of the input, output and TFP index due to specific requirements (to be discussed) and time constraints;

The analysis drew on data from the Australian Agricultural and Grazing Industries Survey (AAGIS). The irrigation component of this survey collects a range of financial and physical data from irrigated farms in selected regions and industries within the Murray Darling Basin. The survey provides coverage of three irrigated agricultural industries (Broadacre, Dairy and Horticulture) across ten regions of the MDB (Condamine-Balonne, Border Rivers, Namoi, Macquarie-Castlereagh, Lachlan, Murrumbidgee, Murray, Goulburn-Broken, Loddon-Avoca and Eastern Mount Lofty Ranges).

At present three complete years of AAGIS irrigation survey data are available (2006-07, 2007-08, 2008-09). In each year approximately 850 farms are sampled, providing a rotating panel data set. Irrigation survey data was available for the years 1996-97 and 2004-05, although the coverage of the datasets in these years is not as comprehensive and therefore not used in this analysis.

Farm-level TFP Index in Irrigated Agriculture

Between 2006-07 and 2008-09, farm-level productivity in irrigated agriculture has on average been increasing with an enlarged spread. Table 1 shows the descriptive statistics for the estimated TFP index at the farm level for irrigated agriculture. Over the three financial years, the average farm-level TFP index has increased from 0.6 in 2006-07 to 0.8 in 2008-09 (Figure 6). The underlying analysis indicates that irrigated farms' productivity has been increasing, partly due to technological progress and efficiency improvement. Moreover, the standard deviation of TFP index has also increased from 0.7 in 2006-07 to 0.9 in 2008-09, which implies that disparity in productivity across irrigated farms has been growing over time along with the general growing trend. In other words, the irrigated farms are becoming more diverse, in terms of productivity. As the maximum value in the distribution is declining somewhat the range of productivity performance is narrowing somewhat (Table 13). This increasing variability in productivity performance can be attributed to increasing variability in enterprise mix as farmers respond to a diverse production environment. This includes availability of irrigation water and the level of irrigation technology being adopted.

Table 13: Descriptive statistics on the farm-level TFP index for all irrigated farms: 2006-07 to 2008-09

Year	**Number of Obs.**	**Mean**	**Std. Dev.**	**Minimum Val.**	**Maximum Val.**
2006-07	823	0.625	0.727	0.000	7.821
2007-08	876	0.672	0.750	0.000	5.798
2008-09	843	0.837	0.861	0.000	7.650

Source: ABARES estimates

For irrigated agriculture, farm-level productivity has also differed across industries and regions. Tables 14 and 15 show farm-level TFP estimates by three industries; the dairy, broadacre and horticulture and by ten regions; Border Rivers, Condamine-Balonne, Goulburn, Lachlan, Loddon-Avoca, Macquarie, Eastern Mt Lofty Ranges, Murrumbidgee, Namoi and Murray.

A comparison among the dairy, broadacre and horticulture industries indicates that, broadacre farms' productivity level is much higher than that for the dairy and horticulture farms. The average TFP index of broadacre farms is 1.3, which is around three times of that for the dairy and horticulture farms (0.4 and 0.4). However, this pattern does not hold for productivity growth over time.

For the past three financial years, horticulture farms have taken the lead in productivity growth with the average TFP index increasing from 0.3 in 2006-07 to 0.6 in 2008-09 (almost doubled), followed by broadacre farms with the average TFP index increasing from 1.2 in 2006-07 to 1.4 in 2008-09. Diary farms' productivity fluctuated around 0.4 between 2006-07 and 2008-09 (Table 14).

Table 14, Descriptive statistics on the farm-level TFP index by industries: 2006-07 to 2008-09

	Horticulture Industry			**Broadacre Industry**			**Dairy Industry**		
Year	**Obs.**	**Mean**	**Std. Dev.**	**Obs.**	**Mean**	**Std. Dev.**	**Obs.**	**Mean**	**Std. Dev.**
2006-07	427	0.349	0.525	254	1.204	0.792	142	0.420	0.498
2007-08	436	0.374	0.597	297	1.255	0.740	143	0.369	0.393
2008-09	365	0.602	0.834	304	1.352	0.827	174	0.429	0.444
All Years	1228	0.433	0.663	855	1.275	0.789	459	0.407	0.447

Decline in mean productivity in the dairy industry can be attributed to high cost of dairy operations during the drought where dairy operators increased the level of purchased feed as on-farm pasture production declined. Clearly, in the absence of water trading, the levels of productivity observed for these farms would have been much lower, because during these drought years temporary trading in particular provided the flexibility for dairy farms to sell some of their water to orchards, and use the proceeds to buy feed.

Large diversity in productivity of irrigated farms has also been observed across regions over the period of 2006-07 and 2008-09. Regarding productivity level, Namoi, Lachlan and Condamine-Balonne ranked the top three with the average TFP index estimates for the three years of greater than 1, while Murray, Goulburn and Eastern Mt Lofty Ranges ranked the bottom three with the average TFP index estimates less than 0.5. As for productivity growth, irrigated farms in Border Rivers have increased by 157 per cent, followed by Lachlan (by 72 per cent), Eastern Mt Lofty Ranges (by 41 per cent) and Murray (by 38 per cent). Productivity growth iof irrigated farms in other regions was less than 20 per cent.

These disparities in productivity growth across regions demonstrate the variable capacity of different industries and firms in different regions to cope with changes in the operating environment. More detailed analysis is required to isolate specific reasons for this variability. While the analysis indicates that irrigated farms as a whole were able to maintain productivity over the drought period, with some industries recording an improvement the limited available data does not allow causal linkage to improvements in water policy during this period.

Aggregate TFP Index for Irrigated Farms

This section presents the results for the aggregated irrigation farm TFP indexes which represent productivity trends at an industry level. The aggregation procedure combines information on farm weights and farm size to with the farm level indexes to arrive at a single figure. Given the limited time series available interpreting the aggregate results is slightly problematic. There are some significant differences between the farm level results and aggregate indexes, which probably require further consideration. At this stage more focus should be paid to the farm level estimates.

The following brief conclusions can be drawn from this analysis.

- The annual growth rate of productivity for all irrigated farms is on average 1.1 per cent a year, which is mainly driven by a decrease in input usage, which includes irrigation water. While this decrease in input usage may be attributable to efficiency gains in water use, the driver of reduced water use is primarily the drought, rather than any policy changes. Policy changes, however, enabled the irrigators to better manage the water scarcity.
- By industries, horticulture industry has achieved TFP growth by 4.0 per cent a year, followed by dairy industry. However, broadacre industry has a decline in TFP growth by 3.4 per cent a year, due primarily to reduce output growth. The horticulture industry has been the leading water purchaser during this period, to offset large reductions in water allocations, which enabled them to maintain a positive output growth. In most cases the broadacre farms has been the net seller of irrigated water.
- The estimated TFP in all three industries has been lowest in 2007-08, also the year in which water availability and use was the lowest on record.
- Analysis by regions (Table 15) indicates that productivity growth increased in some regions while decreasing in others. Irrigated farms in Macquarie in NSW, for example, achieved the highest productivity growth with the annual growth rate of 11.0 per cent a year, followed by Murrumbidgee, also in NSW (of 10.7 per cent a year). In contrast, productivity of irrigated farms in Border Rivers declined by 19.5 per cent a year, followed by Namoi (of 13.2 per cent a year) and Condamine-Balonne (by 11.1 per cent a year).

Table 15 Input, Output and TFP Growth Rates by Regions: 2006-07 to 2008-09

	Input growth rate	Output growth rate	TFP growth rate
All Irrigated farms	-7.32	-6.23	1.10
Border Rivers	22.19	2.73	-19.50
Condamine-Balonne	-10.50	-21.60	-11.10
Goulburn	-16.00	-13.40	2.57
Lachlan	-1.69	-0.35	1.34
Loddon-Avoca	10.65	14.04	3.40
Macquarie	-8.80	2.21	11.01
Eastern Mt Lofty Ranges	-37.30	-40.40	-3.08
Murrumbidgee	-2.92	7.73	10.65
Namoi	3.57	-9.63	-13.20
Murray	-13.50	-7.98	5.53

These differences in regional TFP arise from the diversity of production mix, technology and water availability in these regions which variously influenced the adaptation of different industries to the continuing drought. It is notable that in general, regions that recorded an increase in productivity growth have also recorded an increase in output growth and a decrease in input growth.

Further, focussing the attention on water productivity (that is, the amount of output relative to used irrigation water) rather than TFP; there is evidence emerging that suggests that water productivity on irrigations farms in the MDB is increasing (Table 16). Although there are likely to be multiple factors at work, including water markets operating more efficiently, the dry conditions which have persisted in recent years are expected to have led some farmers to substitute various water saving technologies for purchased irrigation water.

Using an alternative panel data (fixed effects) regression model, the increases in water productivity appear greater on broadacre (1.1 per cent a year) and dairy (0.6 per cent a year) farms compared with horticulture farms (which showed no significant improvement). Across all irrigated farms, water productivity increased, on average, by 0.3 per cent a year between 2006-07 and 2008-09 (Table 16).

Table 16 Partial productivity of water on irrigations farms in the MDB

Year	Number of Obs.	Mean	Std. Dev.
2006-07	815	0.011	0.052
2007-08	805	0.025	0.073
2008-09	764	0.020	0.049
Total	2381	0.019	0.059

Whereas, in the TFP analysis the focus is at an industry and regional level, by analysing trends in farm performance at that scale, and although TFP analysis is a useful indicator of performance by industry or a collection of farms in a region, in itself is not a reliable indicator of how a particular policy or a program of activities may have contributed to productivity. The analysis however indicates broader associations between water productivity and overall TFP, both at the industry and aggregate farm level.

To enable greater insights, from the short time series of irrigation farm survey data, ABARE TFP analysis was then extended at The University of Queensland (UQ) by using the Productivity Decomposition Analysis methods developed by the UQ Centre for Productivity and Efficiency Analysis (CEPA).

Productivity Decomposition Analysis

In this section, productivity data is further analysed to identify possible contribution of NWI reforms to the observed productivity of irrigated agriculture in the Murray-Darling Basin. This will support and enrich the evidence from quantitative simulation of allocative efficiency impacts using the RSMG model.

A productivity decomposition analysis was applied to the data sets to identify the different technical change and efficiency change components of Total Factor Productivity change.

This involves unpacking the TFP index into the following components:

- Technical change refers to expansions and/or contractions in the set of technically feasible input-output combinations (the “production possibilities set”). Such changes are generally due to new scientific discoveries (e.g. new crop varieties, integrated pest management, minimum tillage) and changes in the bio-physical environment (e.g., soil quality, levels of pesticide resistance, climatic conditions). Governments can influence the rate of technical change through research and development programs and initiatives that protect the bio-physical environment.
- Technical efficiency change refers to movements by firms/industries towards or away from the boundary of the production possibilities set. Agricultural producers can move closer to the so-called production frontier by adopting new technologies (i.e. new crop varieties) and by eliminating mistakes in the production process (e.g. better timing of production operations). Governments can influence the rate of technical efficiency improvement through education, training and extension programs.
- Scale and mix efficiency change refers to changes in productivity due to (dis)economies of scale and scope. If economies of scale exist in agriculture then relatively small producers operating in the region of increasing returns to scale (IRS) can increase levels of productivity by simply expanding the size of their operations. If firms continue to expand in size then they will eventually reach a point where they experience decreasing returns to scale (DRS). Similarly, changes in the mix of inputs (e.g., capital to labour ratio) and outputs (e.g. cropping mix) can lead to productivity increases or declines. Governments can influence levels of scale and mix efficiency through price and regulatory policies that incentivise agricultural producers to change the size and structure of their production operations.

Given the nature of NWI coordinated policies, such as improvement in water markets, the main potential influence of the NWI on productivity is through scale and mix efficiency changes. Removal of barriers for trade and improvements in water information, for example make it easier to assemble the water rights required for large-scale operations, thus providing opportunities for gains in scale efficiency. Moreover, to the extent that efficient farmers find it easier to expand, and less efficient farmers have more attractive exit options, the irrigation sector could also improve technical efficiency.

The productivity decomposition analysis will enable the relative influence of these factors on observed productivity change to be estimated. Combining this information with the outcomes of the modelling analysis, desktop review and consultation will enable conclusions to be drawn on the relative influence of the NWI on the productivity of water use in the Basin.

The focus of the analysis was to use the TFP indexes evaluated by ABARES in the previous section to analyse profitability change, technical change and efficiency change.

The methods of analysis and the description of data are described in detail in Appendix A.

Results of Productivity Decomposition Analysis

Underpinning the computation and decomposition of profitability and productivity indexes is the definition of TFP as the ratio of an aggregate output to an aggregate input. This definition is employed to define a class of multiplicatively-complete TFP indexes.

Profitability change (a measure of value change) is then computed as the product of a multiplicatively-complete TFP index (a measure of quantity change) and a terms-of-trade index (a measure of price change).

Then it is shown how the TFP index can be further decomposed into measures of technical change and various measures of efficiency change.

The key observations from the productivity decomposition analysis include:

1) <u>the average profitability and productivity</u> levels were
   d) highest in the Namoi region and lowest in the Border Rivers region; and
   e) highest in broadacre agriculture and lowest in the horticulture industry.
2) <u>the terms-of-trade (ratio of output to input prices) was</u>
   f) most favourable in the Lachlan region and least favourable in the Mount Lofty Range region; and
   g) most favourable in broadacre agriculture and least favourable in the horticulture industry.
3) <u>output-oriented measures of technical efficiency (a measure of distance to the production frontier) were</u>
   h) increasing over time;
   i) highest in the Namoi region (median 0.98) and lowest in the Murray region (median 0.52); and
   j) highest in broadacre agriculture (median 0.94) and lowest in the horticulture industry (median 0.39).
4) <u>output-oriented measures of pure scale efficiency</u> (a measure of returns to scale) were
   k) highest in 2008 (median 0.94);
   l) highest in the Murrumbidgee region (median 0.94) and lowest in the Namoi region (median 0.77); and
   m) equally high in broadacre agriculture and horticulture (median 0.91) and relatively low in dairy (median 0.87).
5) <u>output-oriented measures of pure mix efficiency (a measure of returns to scope) were</u>
   n) generally extremely low throughout the sample period (median OME scores less than 0.14);
   o) highest in the Murrumbidgee region (median 0.18) and lowest in the Loddon-Avoca region (median 0.10); and
   p) highest in the horticulture industry (median 0.14) and lowest in dairy (median 0.10).
6) <u>output-oriented measures of scale-mix efficiency (a combined measure of returns to scale and scope) were</u>
   q) lowest in 2008 (on average 80% below a reference firm);
   r) highest in the Murrumbidgee region (on average 49% lower than the reference firm) and lowest in the Border Rivers region (on average 79% lower than the reference firm); and
   s) similar across all industries (on average 70% lower than the reference firm).

- An analysis of profitability indexes across years, regions and industries indicates that the average firm profitability across all 2502 firms in the sample was 22% lower than the profitability of the reference firm (Table 17). The firm profitability was on average:
  - ➢ decreasing over time;
  - ➢ highest in the Namoi region and lowest in the Border Rivers region; and
  - ➢ highest in broadacre agriculture and lowest in the horticulture industry.

Profitability change

In understanding profitability change, it is necessary to define a base reference point for comparison. In this analysis, indexes of profitability change (dPROF) were computed for all observations using observation 3414 as a base (i.e., dPROF = 1 for observation 3414). This observation is for a broadacre farm in the Murrumbidgee region in 2009. This observation was chosen as the reference firm to facilitate comparison with an ABARES TFP analysis in which the (transitive) Fisher-EKS TFP index for observation 3414 was 1.00 (rounded to two decimal places).

Table 17 provides descriptive statistics for profitability indexes across years, regions and industries. Observe from the last row of the table that average[1] firm profitability across all 2502 firms in the sample was 22% lower than the profitability of the reference firm. The remaining rows reveal that firm profitability was on average

- decreasing over time;
- highest in the Namoi region and lowest in the Border Rivers region; and
- highest in broadacre agriculture and lowest in the horticulture industry.

Table 17. Descriptive Statistics for profitability change

YEAR	Mean	Median	Max	Min.	Std. Dev.	Obs.
2007	0.859	0.369	14.072	0.000	1.511	815
2008	0.788	0.344	20.422	0.000	1.443	865
2009	0.702	0.363	11.576	0.000	1.047	822
REGION	Mean	Median	Max	Min.	Std. Dev.	Obs.
Border Rivers	0.412	0.214	2.881	0.000	0.495	117
Condamine-Balonne	0.777	0.508	9.612	0.000	1.113	198
Goulburn	0.613	0.287	10.822	0.000	1.084	310
Lachlan	0.891	0.391	13.554	0.000	1.619	130
Loddon-Avoca	0.926	0.443	10.348	0.000	1.507	193
Macquarie	0.870	0.442	11.077	0.000	1.368	130
Eastern Mt Lofty Ranges	0.738	0.297	9.277	0.000	1.313	168
Murrumbidgee	0.971	0.518	11.028	0.000	1.266	323
Namoi	1.156	0.718	14.072	0.000	1.731	102
Murray	0.727	0.257	20.422	0.000	1.451	831
INDUSTRY	Mean	Median	Max	Min.	Std. Dev.	Obs.
Horticulture	0.611	0.217	20.422	0.000	1.318	1224
Broadacre	1.060	0.638	14.072	0.000	1.374	838
Dairy	0.735	0.308	12.364	0.000	1.316	440
All	0.783	0.361	20.422	0.000	1.351	2502

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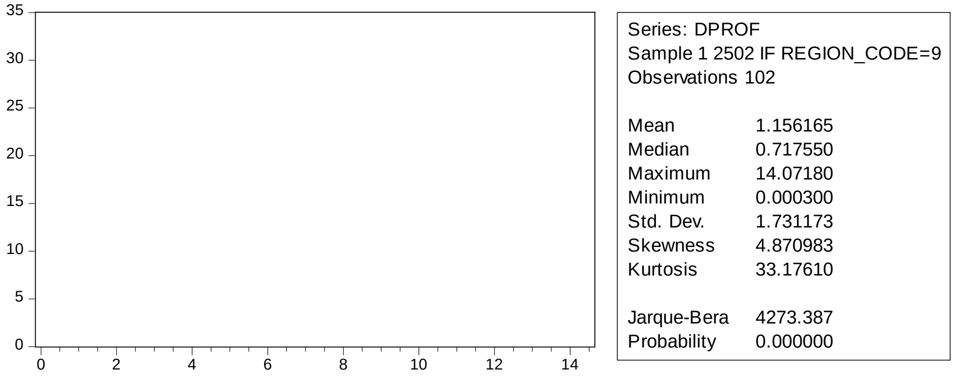
[1] The averages reported in Table 17 are arithmetic Means. If the reported average measures of profitability change are to decompose exactly into the measures of average technical change and efficiency change reported later in this section then they would need to have been computed as geometric averages.

There are large differences in the mean and median values reported in Table 17, indicating that the distribution of profitability indexes is highly skewed. To show the degree of skewness, the distribution of profitability indexes for firms in the Namoi region is depicted in Figure 6. For highly asymmetric data or where there are outliers, it is common to use the median as a measure of central tendency instead of the mean.

The median values reported in Table 17 suggest that, compared to the reference firm, profitability was

- fairly constant over time (in any year the profitability of the median firm was between 63% and 66% lower than the profitability of the reference firm);
- highest in the Namoi region and lowest in the Border Rivers region (in the Namoi region the profitability of the median firm was 28% lower than the profitability of the reference firm, and in the Border Rivers region the profitability of the median firm was 79% lower);
- highest in broadacre agriculture and lowest in the dairy industry (in broadacre agriculture the profitability of the median firm was 36% lower than the profitability of the reference firm, and in the dairy industry the profitability of the median firm was 78% lower).



```
Series: DPROF
Sample 1 2502 IF REGION_CODE=9
Observations 102

Mean          1.156165
Median        0.717550
Maximum       14.07180
Minimum       0.000300
Std. Dev.     1.731173
Skewness      4.870983
Kurtosis      33.17610

Jarque-Bera   4273.387
Probability   0.000000
```

Figure 6. Distribution of Profitability Indexes: Namoi Region (observation 3414 = 1)

However, it is difficult to relate the changes in profitability between these industries and their link to changes in water policy in this period from this analysis alone. However, taken together with the analysis of ABS water use and farm production and ABARE farm survey data, a broad indication is that the broadacre farms that irrigated during this period were efficient operators that produced high value outputs such as hay and silage, sold mainly to the dairy industry that was substituting purchased feed for lost pasture production. For the horticulture industry in particular, availability of water trading helped maintain outputs, which enjoyed relatively favourable terms of trade during the period.

Generally high profitability in the Namoi region is clearly related to the cotton industry in that region, where adaptation to water scarcity is facilitated by a range of agronomic management options and the availability of groundwater. Recent R&D in the cotton industry has led to improved water management in the cotton-based farming systems across the Basin

TFP Change

Table 22 provides descriptive statistics for Lowe indexes (dTFP) comparing the TFP of each observation in the sample with the TFP of the reference observation (so dTFP = 1 for observation 3414). This observation was chosen as the reference firm to facilitate comparison with an ABARES study in which the (transitive) Fisher-EKS TFP index for observation 3414 was 1.00 (rounded to two decimal places). The last row of Table 18 reveals that average firm TFP was 33% lower than the TFP of the reference firm.

The mean values reported in the remaining rows reveal that firm TFP was on average

- decreasing slightly over time (average TFP in 2007 was 29% lower than the TFP of the reference firm, average TFP in 2008 was 35% lower, and average TFP in 2009 was 36% lower; ABARES found that average TFP was 37%, 33% and 16% below the TFP of the reference firm in these years).
- highest in the Namoi region and lowest in the Border Rivers region (average TFP in the Namoi region was no different to the TFP of the reference firm, but average TFP in the Border Rivers region was 69% lower; ABARES found that average TFP in the Namoi region was 58% higher than the TFP of the reference firm, and average TFP in the Border Rivers region was 29% lower)
- highest in broadacre agriculture and lowest in the horticulture industry (average TFP in broadacre agriculture was 19% lower than the TFP of the reference firm, and average TFP in the dairy industry was 42% lower; ABARES found that average TFP in broadacre agriculture was 28% higher than the TFP of the reference firm, and average TFP in the dairy industry was 42% lower).

Table 18. Descriptive Statistics for DTFP, change compared to the reference firm

YEAR	Mean	Median	Max	Min.	Std. Dev.	Obs.
2007	0.714	0.313	12.856	0.000	1.284	815
2008	0.655	0.279	19.213	0.000	1.252	865
2009	0.636	0.322	11.565	0.000	0.980	822
REGION	Mean	Median	Max	Min.	Std. Dev.	Obs.
Border Rivers	0.309	0.175	1.765	0.000	0.346	117
Condamine-Balonne	0.612	0.377	8.131	0.000	0.852	198
Goulburn	0.540	0.250	9.476	0.000	0.947	310
Lachlan	0.751	0.284	11.226	0.000	1.485	130
Lddon-Avoca	0.755	0.367	8.461	0.001	1.234	193
Macquarie	0.725	0.342	11.738	0.000	1.267	130
Eastern Mt Lofty Ranges	0.667	0.277	6.733	0.000	1.114	168
Murrumbidgee	0.831	0.472	7.726	0.000	1.102	323
Namoi	1.002	0.566	12.856	0.000	1.590	102
Murray	0.633	0.236	19.213	0.000	1.286	831
INDUSTRY	Mean	Median	Max	Min.	Std. Dev.	Obs.
Horticulture	0.584	0.210	19.213	0.000	1.257	1224
Broadacre	0.808	0.463	12.856	0.000	1.113	838
Dairy	0.634	0.277	8.050	0.000	1.059	440
All	0.668	0.308	19.213	0.000	1.181	2502

Again, the distribution of TFP indexes is highly skewed and followed a similar pattern to that for profitability change.

The median values reported in Table 18 suggest that, compared to the reference firm, TFP was

- fairly constant over time (in each year the TFP of the median firm was between 68% and 72% lower than the TFP of the reference firm);
- highest in the Namoi region and lowest in the Border Rivers region (in the Namoi region the TFP of the median firm was 43% lower than the TFP of the reference firm, and in the Border Rivers region the TFP of the median firm was 82% lower);
- highest in broadacre agriculture and lowest in the horticulture industry (in broadacre agriculture the TFP of the median firm was 54% lower than the reference firm, and in the horticulture industry the TFP of the median firm was 79% lower).

Changes in the terms of trade

The profitability change discussed earlier can be decomposed into the product of a term-of-trade index and a TFP index. The similar patterns of variation in the profitability and TFP indexes reported above (e.g., fairly constant over time, highest in the Namoi and lowest in the horticulture industry) suggest that most firms in the sample face similar terms of trade (i.e., they purchase inputs and sell outputs in the same, or at least fairly highly integrated, markets). This is evident in the Table 23 where we present descriptive statistics for indexes (dTT) comparing the terms of trade of each observation in the sample with the terms of trade of the reference firm. The last row of Table 19 reveals that the terms-of-trade for the median firm were 7% more favourable than the terms-of-trade for the reference firm.

Table 19. Descriptive Statistics for DTT, change compared to the reference firm

YEAR	Mean	Median	Max	Min.	Std. Dev.	Obs.
2007	1.018	1.092	5.579	0.003	0.583	815
2008	1.055	1.096	9.529	0.005	0.616	865
2009	1.390	1.043	27.959	0.004	2.435	822
REGION	Mean	Median	Max	Min.	Std. Dev.	Obs.
Border Rivers	1.122	1.118	9.993	0.005	0.994	117
Condamine-Balonne	1.171	1.176	3.225	0.006	0.482	198
Goulburn	1.059	1.088	18.822	0.005	1.148	310
Lachlan	1.474	1.178	27.437	0.004	2.508	130
Lddon-Avoca	1.142	1.132	2.213	0.006	0.360	193
Macquarie	1.360	1.102	27.959	0.005	2.536	130
Eastern Mt Lofty Ranges	1.090	1.023	12.488	0.006	1.484	168
Murrumbidgee	1.200	1.044	21.171	0.003	1.655	323
Namoi	1.206	1.164	2.715	0.104	0.293	102
Murray	1.095	1.048	23.587	0.004	1.561	831
INDUSTRY	Mean	Median	Max	Min.	Std. Dev.	Obs.
Horticulture	1.032	1.003	27.959	0.003	1.947	1224
Broadacre	1.369	1.253	23.587	0.006	0.993	838
Dairy	1.077	1.103	2.006	0.009	0.220	440
All	1.153	1.078	27.959	0.003	1.488	2502

Again focusing on the median values, the remaining rows indicate that the terms-of-trade were

- fairly constant over time (in each year the TT of the median firm was between 4% and 9% higher than the TT of the reference firm);
- most favourable in the Lachlan region and least favourable in the Eastern Mt Lofty Range region (in the Lachlan region the TT of the median firm was 18% higher than the TT of the reference firm, and in the Eastern Mt Lofty Range region the TT of the median firm was 2% higher);
- highest in broadacre agriculture and lowest in the horticulture industry (in broadacre agriculture the TT of the median firm was 25% higher than the TT of the reference firm, and in the horticulture industry the TT of the median firm was the same as the TT of the reference firm).

Of course, the median firms in Table 19 are not necessarily the same firms as the median firms in Tables 17 and 18, so the patterns that are evident in the median values reported in Tables 17 to 19 can provide a misleading picture of the relationship between profitability, productivity and the terms-of-trade. A clearer picture is provided in Figure 7 where we depict the relationship between profitability change (dPROF), TFP change (dTFP) and Terms of Trade change (dTT) for firms 661, 827, 426, 921, 1418 and 784 over the sample period.

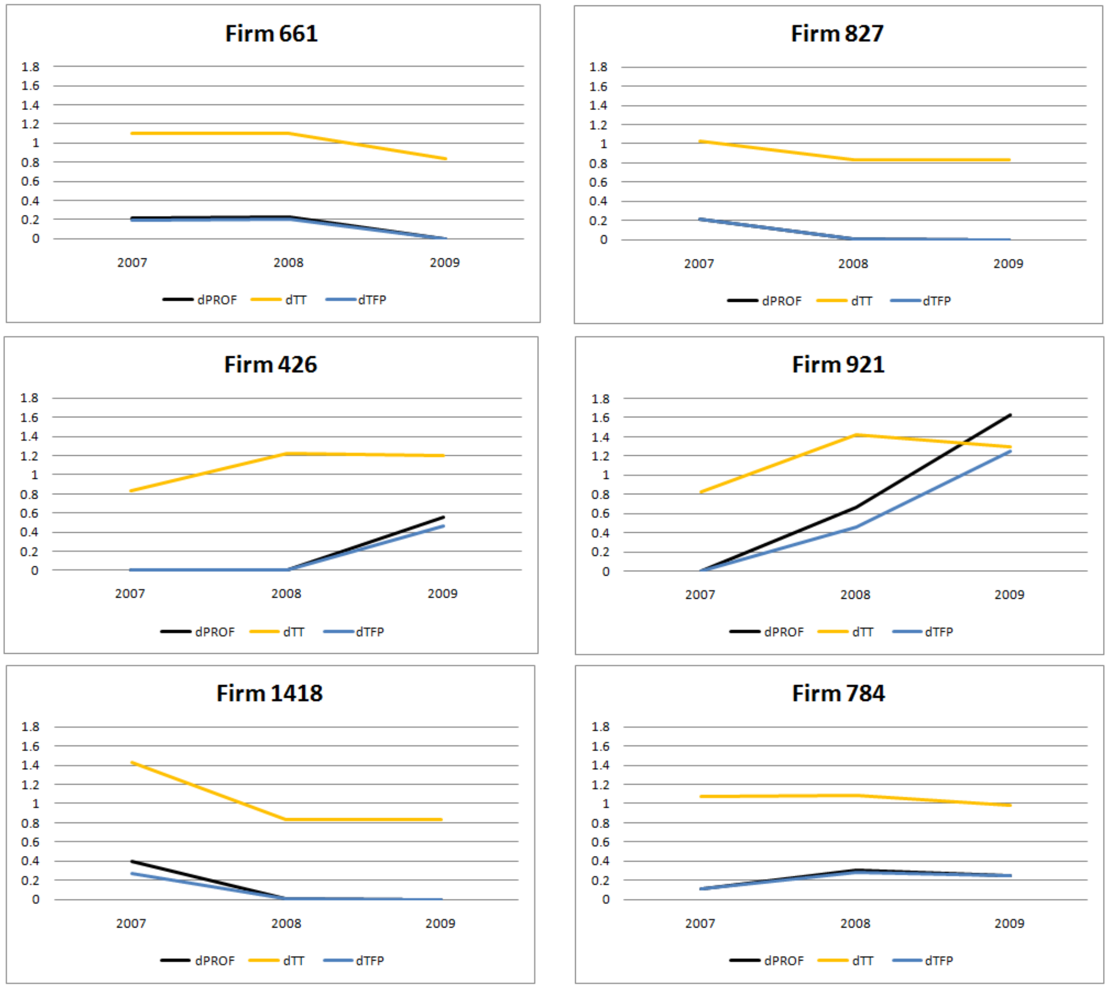


Figure 7. Decomposing Profitability Change: dPROF = dTT x dTFP

The top-left panel, in Figure 7 reveals that firm 661 faced slightly more favourable terms-of-trade than the reference observation (observation 3414) in 2007 and 2008, and 20% less favourable terms-of-trade than the reference observation (still observation 3414) in 2009; firm 661 was only 20% as profitable as the reference observation in 2007 and 2008, and in 2009 relative profitability fell to zero as TFP also fell to zero. The bottom right-hand panel reveals that firm 784 was the only firm in the group that remained unchanged throughout the sample period. However, the productivity of this firm was consistently well below the productivity of the reference observation, and with virtually no change in the terms-of-trade, profitability was also consistently low.

Estimates of the components of TFP Change

In this study, we use data envelopment analysis (DEA) to compute and decompose the Lowe TFP indexes derived above. DEA is used because it is fast, it avoids the need to make assumptions about functional forms or error distributions, and it allows us to avoid technical (endogeneity) problems that arise in the estimation of distance functions. Even so, it is still necessary to make assumptions concerning the nature of technical change and the shape of the unobserved production frontier.

Levels of Technical, Scale and Mix Efficiency

Drawing on the estimates of output and input-oriented measures of technical, scale and mix efficiency for each observation, a set of descriptive statistics are provided in Table 20 to 22. Focusing on the median values (for the reasons of skewness discussed in previous sections), it is evident that levels of output-oriented technical efficiency (OTE)

- have been increasing over time;
- are highest in the Namoi region (median 0.98) and lowest in the Murray region (median 0.52); and
- are highest in broadacre agriculture (median 0.94) and lowest in the horticulture industry (median 0.39),

Table 20. Descriptive Statistics for Output Oriented Technical Efficiency (OTE)

YEAR	Mean	Median	Max	Min.	Std. Dev.	Obs.
2007	0.594	0.568	1.000	0.024	0.319	815
2008	0.631	0.654	1.000	0.028	0.300	865
2009	0.644	0.710	1.000	0.025	0.316	820
REGION	Mean	Median	Max	Min.	Std. Dev.	Obs.
Border Rivers	0.549	0.544	1.000	0.026	0.331	117
Condamine-Balonne	0.730	0.813	1.000	0.024	0.275	198
Goulburn	0.590	0.538	1.000	0.051	0.301	310
Lachlan	0.765	0.855	1.000	0.027	0.284	130
Lddon-Avoca	0.712	0.798	1.000	0.080	0.271	192
Macquarie	0.754	0.854	1.000	0.052	0.281	130
Eastern Mt Lofty Ranges	0.575	0.518	1.000	0.025	0.288	167
Murrumbidgee	0.621	0.690	1.000	0.042	0.326	323
Namoi	0.895	0.982	1.000	0.234	0.150	102
Murray	0.535	0.480	1.000	0.024	0.309	831
INDUSTRY	Mean	Median	Max	Min.	Std. Dev.	Obs.
Horticulture	0.473	0.386	1.000	0.024	0.306	1223
Broadacre	0.870	0.939	1.000	0.026	0.168	837
Dairy	0.573	0.524	1.000	0.105	0.243	440
All	0.623	0.643	1.000	0.024	0.312	2500

Levels of output-oriented scale efficiency (OSE)

- increased in 2008 but decreased in 2009;
- are highest in the Murrumbidgee region (median 0.94) and lowest in the Namoi region (median 0.77); and
- are equally high in broadacre agriculture and dairy (median 0.91) and relatively low in horticulture (median 0.87).

Levels of output-oriented mix efficiency (OME)

- are generally extremely low throughout the sample period (median OME scores less than 0.14)
- are highest in the Murrumbidgee region (median 0.18) and lowest in the Loddon-Avoca region (median 0.10)
- are highest in the dairy industry (median 0.14) and lowest in horticulture (median 0.10)

Low levels of mix efficiency may reflect the fact that farmers often specialise in the production of a small number of outputs in order to maximise profits, not productivity.

These observations are consistent with the changes in the availability of water that prompted changes in input use during this period, and the specialised nature of dairy and horticulture enterprises. Moreover the regional enterprise mix and the level of water allocations and the water entitlement mix, including access to groundwater are important determinants of TFP and profitability change.

Table 21. Descriptive Statistics for Output Oriented Scale Efficiency (OSE)

YEAR	Mean	Median	Max	Min.	Std. Dev.	Obs.
2007	0.820	0.874	1.000	0.077	0.184	815
2008	0.856	0.943	1.000	0.164	0.181	865
2009	0.819	0.892	1.000	0.100	0.197	820
REGION	Mean	Median	Max	Min.	Std. Dev.	Obs.
Border Rivers	0.770	0.856	1.000	0.237	0.236	117
Condamine-Balonne	0.814	0.859	1.000	0.188	0.196	198
Goulburn	0.829	0.896	1.000	0.203	0.184	310
Lachlan	0.839	0.909	1.000	0.345	0.193	130
Lddon-Avoca	0.824	0.890	1.000	0.348	0.182	192
Macquarie	0.813	0.879	1.000	0.239	0.195	130
Eastern Mt Lofty Ranges	0.831	0.906	1.000	0.315	0.183	167
Murrumbidgee	0.859	0.936	1.000	0.190	0.172	323
Namoi	0.745	0.772	1.000	0.278	0.220	102
Murray	0.850	0.921	1.000	0.077	0.177	831
INDUSTRY	Mean	Median	Max	Min.	Std. Dev.	Obs.
Horticulture	0.839	0.909	1.000	0.077	0.182	1223
Broadacre	0.830	0.910	1.000	0.230	0.197	837
Dairy	0.817	0.868	1.000	0.282	0.186	440
All	0.832	0.904	1.000	0.077	0.188	2500

Table 22. Descriptive Statistics for Output Oriented Mix Efficiency (OME)

YEAR	Mean	Median	Max	Min.	Std. Dev.	Obs.
2007	0.259	0.141	1.000	0.000	0.298	815
2008	0.205	0.093	1.000	0.000	0.265	865
2009	0.261	0.142	1.000	0.000	0.297	817
REGION	Mean	Median	Max	Min.	Std. Dev.	Obs.
Border Rivers	0.203	0.106	1.000	0.000	0.256	117
Condamine-Balonne	0.182	0.111	1.000	0.000	0.222	198
Goulburn	0.188	0.098	1.000	0.000	0.233	310
Lachlan	0.268	0.120	1.000	0.000	0.329	130
Lddon-Avoca	0.215	0.095	1.000	0.000	0.279	191
Macquarie	0.253	0.137	1.000	0.000	0.300	130
Eastern Mt Lofty Ranges	0.287	0.122	1.000	0.000	0.344	167
Murrumbidgee	0.293	0.177	1.000	0.000	0.296	322
Namoi	0.222	0.136	1.000	0.000	0.229	102
Murray	0.253	0.128	1.000	0.000	0.303	830
INDUSTRY	Mean	Median	Max	Min.	Std. Dev.	Obs.
Horticulture	0.287	0.138	1.000	0.000	0.332	1222
Broadacre	0.209	0.127	1.000	0.000	0.233	836
Dairy	0.176	0.095	1.000	0.000	0.222	439
All	0.241	0.125	1.000	0.000	0.288	2497

For instance Murrumbidgee region is a typical 'food basket' region, where in recent times the agricultural activity has significantly diversified consistent with the composition of water entitlements for the region to improve the output oriented scale efficiency. These adjustments were assisted by the availability of water trading.

Dairy, for example, is largely a single output industry, except for other activities such as cropping and other livestock often associated with some dairy enterprises.

The Technical Change and Efficiency Change Components of TFP Change

Estimates of changes in both input-oriented and output-oriented efficiency were also estimated. Tables 23 to 24 report descriptive statistics for one particular output-oriented decomposition of TFP change, namely dTFE, defined using already discussed components of productivity.

dTFP = dTech x dOTE x dOSME

Where dOSME is the change in the measure of scale and mix efficiency change.

In this study, all farms were assumed to have access to the same production possibilities set (production technology) and so experience the same rate of technical change (dTech).

The estimates reported in Table 23 indicate that the maximum level of productivity possible in 2007 (i.e., TFP^{*}_{2007}) was 11% higher than the maximum level of productivity possible in 2009 (i.e., TFP^{*}_{2009}), and that the maximum productivity possible in 2008 was 66% higher than the maximum productivity possible in 2009. These rates of technical change are measures of expansions and contractions in the production possibilities set in the region of optimal scale and scope, and are most likely a reflection of changes in seasonal conditions in those years – for any given level of inputs, the maximum output (and therefore productivity) that is possible in a poor season is less than the maximum that is possible in a good season, and vice versa.

Table 23. Descriptive Statistics for index of rate of technical change (DTECH)

YEAR	Mean	Median	Max	Min.	Std. Dev.	Obs.
2007	1.112	1.112	1.112	1.112	0	815
2008	1.661	1.661	1.661	1.661	0	865
2009	1.000	1.000	1.000	1.000	0	822

Table 24. Descriptive Statistics for rate of Output Oriented Technical Efficiency Change (DOTE)

YEAR	Mean	Median	Max	Min.	Std. Dev.	Obs.
2007	0.916	0.876	1.542	0.036	0.492	815
2008	0.973	1.009	1.542	0.044	0.463	865
2009	0.993	1.095	1.542	0.038	0.487	820
REGION	Mean	Median	Max	Min.	Std. Dev.	Obs.
Border Rivers	0.846	0.838	1.542	0.040	0.511	117
Condamine-Balonne	1.126	1.253	1.542	0.037	0.424	198
Goulburn	0.909	0.830	1.542	0.079	0.465	310
Lachlan	1.180	1.318	1.542	0.042	0.439	130
Lddon-Avoca	1.097	1.230	1.542	0.124	0.417	192
Macquarie	1.162	1.316	1.542	0.080	0.433	130
Eastern Mt Lofty Ranges	0.886	0.799	1.542	0.038	0.444	167
Murrumbidgee	0.958	1.064	1.542	0.064	0.503	323
Namoi	1.380	1.514	1.542	0.360	0.231	102
Murray	0.826	0.740	1.542	0.036	0.476	831
INDUSTRY	Mean	Median	Max	Min.	Std. Dev.	Obs.
Horticulture	0.729	0.596	1.542	0.036	0.472	1223
Broadacre	1.341	1.447	1.542	0.040	0.259	837
Dairy	0.884	0.808	1.542	0.161	0.374	440
All	0.961	0.991	1.542	0.036	0.481	2500

For these irrigated farms, the maximum productivity possible peaked in 2008, and then came down in 2009.

The changes in output-oriented technical efficiency (dOTE) reported in Table 24 reflect the earlier discussion of Table 21. Specifically, levels of output-oriented technical efficiency

- have been increasing over time;
- are highest in the Namoi region (on average 51% higher than the reference firm) and lowest in the Murray region (on average, 26% lower than the reference firm); and
- are highest in broadacre agriculture (on average 45% higher than the reference firm) and lowest in the horticulture industry (on average 45% lower than the reference firm),

The indexes of change in output-oriented scale-mix efficiency (dOSME) reported in Table 30 reveal that this measure of efficiency

- was lowest in 2008 (on average 80% below the reference firm);
- is highest in the Murrumbidgee region (on average 49% lower than the reference firm) and lowest in the Border Rivers region (on average 79% lower than the reference firm); and
- was similar across all industries (on average 70% lower than the reference firm)

Changes in scale-mix efficiency occur as technically-efficient firms change the scale and mix of their operations in order to maximise their objective functions (e.g., expected profits). Levels of scale-mix efficiency are plausibly low in industries where there exist economies of scale and scope and where firms aim to maximise net returns rather than productivity.

Table 25. Descriptive Statistics for index of output-oriented measure of scale and mix efficiency change (DOSME)

YEAR	Mean	Median	Max	Min.	Std. Dev.	Obs.
2007	0.715	0.392	7.501	0.000	0.933	815
2008	0.431	0.197	7.501	0.000	0.642	865
2009	0.682	0.369	7.501	0.000	0.882	817
REGION	Mean	Median	Max	Min.	Std. Dev.	Obs.
Border Rivers	0.363	0.213	2.144	0.000	0.418	117
Condamine-Balonne	0.508	0.277	4.744	0.000	0.681	198
Goulburn	0.508	0.291	5.529	0.000	0.697	310
Lachlan	0.573	0.219	6.550	0.000	0.957	130
Lddon-Avoca	0.611	0.284	4.926	0.000	0.866	191
Macquarie	0.534	0.262	4.582	0.000	0.751	130
Eastern Mt Lofty Ranges	0.625	0.263	4.490	0.000	0.831	167
Murrumbidgee	0.825	0.512	4.854	0.001	0.939	322
Namoi	0.584	0.353	7.501	0.000	0.875	102
Murray	0.630	0.281	7.501	0.000	0.880	830
INDUSTRY	Mean	Median	Max	Min.	Std. Dev.	Obs.
Horticulture	0.686	0.301	7.501	0.000	0.947	1222
Broadacre	0.510	0.294	7.501	0.000	0.687	836
Dairy	0.567	0.306	4.697	0.000	0.733	439
All	0.606	0.300	7.501	0.000	0.835	2497

Once again, the “median firms” in Tables 23 to 25 are not necessarily the same firms, so the patterns that are evident in the median values reported in these tables can be misleading. Again, a clearer picture of the relationship between TFP change, technical change and different measures of efficiency change is provided in Figure 11. For firms 661, 827, 426, 921, 1418 and 784, Figures 10 and 11 together provide a complete decomposition of profitability change into terms-of-trade change and TFP change, as well as technical change, technical efficiency change and scale-mix efficiency change.

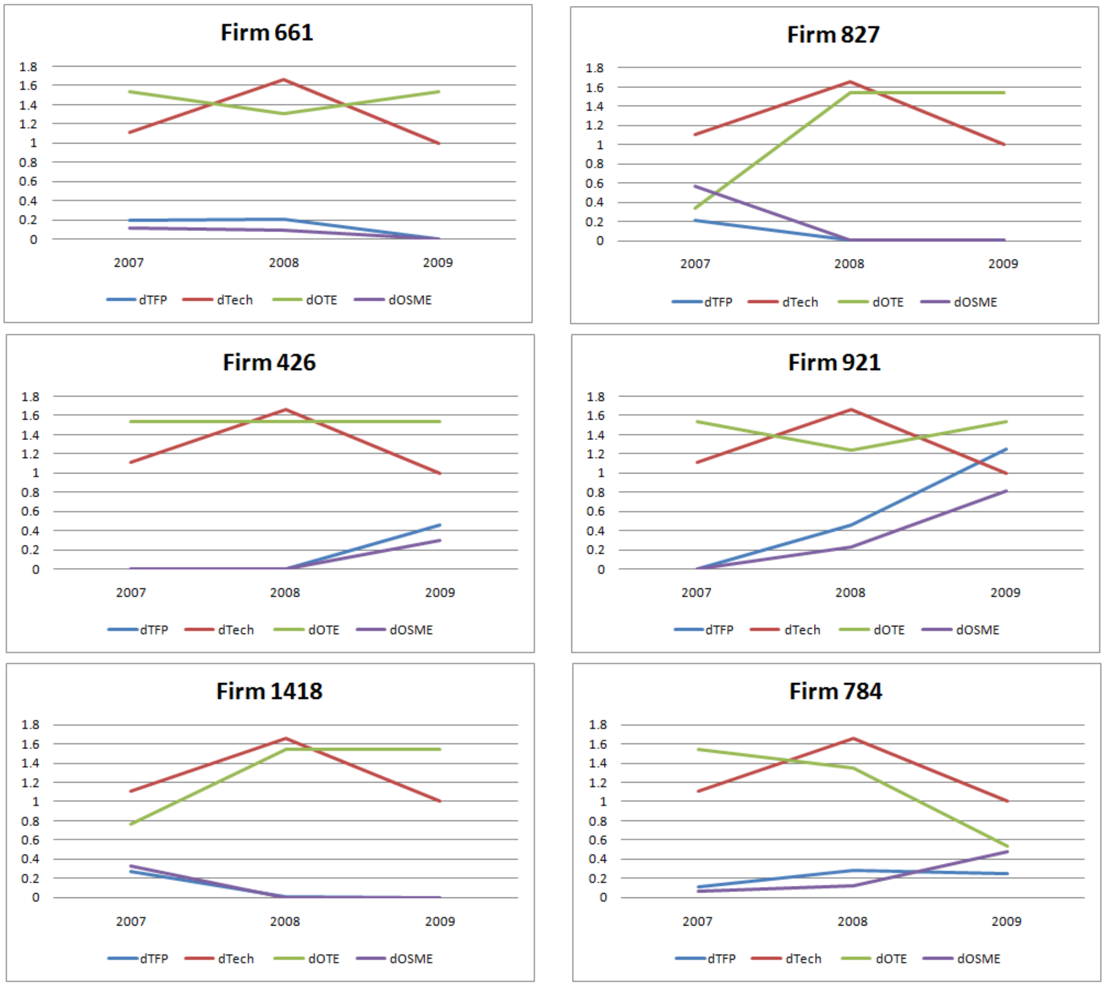


Figure 8. Decomposing TFP Change: dTFP = dTech x dOTE x dOSME

The general conclusion that can be reached from this analysis is that there is significant variability in productivity performance across the three industries and within them. The relatively short period in which the NWI has been in operation, combined with the fact that drought conditions prevailed across the Basin within the same period, means that any general trends in productivity performance are masked by a variable response to drought adaptation by different firms.

There is some evidence that the rate of output oriented technical efficiency has improved over the three years, and in that the improvements in the broadacre and dairy industry are greater than that for the more specialised horticulture industry.

While a link can be drawn between change in technical efficiency and improvements in water management for irrigated farms, a clearer picture on the effectiveness of NWI could only be obtained using a longer time series.

It is clear, however, that across irrigation industries, the more water intensive industries such as horticulture and dairy has been able to maintain output growth despite severe cut backs to irrigation supplies.

Conclusion

In this study analysis was conducted to examine productivity and efficiency implications for irrigated industries of the implementation of the NWI. As outlined in the introduction, the primary focus of NWI was considered in this analysis to be the deregulation of the water markets and provision of water related information that in turn acted as a trigger for a number of water property rights, infrastructure and information related reform.

The modelling and analysis presented in this study attempted to identify the extent to which NWI-led water market reform has resulted in efficiency and productivity improvements on irrigated farms. The assessment acknowledges the ongoing nature of water reform and identifies the extent to which the original NWI aspirations can be met in the future through continued implementation of the NWI (figure 1).

The general conclusion that can be reached from this analysis is that there is significant variability in productivity performance across the three industries and within them. The relatively short period in which the NWI has been in operation, combined with the fact that drought conditions prevailed across the Basin within the same period, means that any general trends in productivity performance are masked by a variable response to drought adaptation by different firms.

The three-part assessment process that drew on (a) RSMG economic model simulations at the catchment scale across the Basin; (b) a contextual analysis of irrigation farming in the Basin over the past decade; and (c) an econometric analysis of ABARES farm survey data to estimate Total Factor Productivity and its components leads to the following general insights.

RSMG model simulations indicate that:

- Water trading has provided flexibility for reallocating irrigation water during seasons of low availability (dry years);
- In catchments where there is greater flexibility (relevant technological options) to respond to changes in seasonal conditions, such as in the Murrumbidgee, the return for irrigation are greater in the medium term;
- The net productivity benefit from water trading in the Basin would be around $300 million per year assuming no changes in commodity prices and unimpeded trade across the Basin. ABARE econometric analysis estimated that in 2007-08, where there were some restrictions for trade, the benefits of water trade to South Australia were around $31 million (Mallawaarachchi & Foster 2009); and
- Over the medium term, water use may increase in NSW and Qld broadacre industries to take advantage of more flexible farming systems. Farming systems such as rice and cotton, for example, can provide productivity benefits in particular over Wet and Normal seasons.

It must be noted that original water licences were issued progressively by each jurisdiction as development was occurring and that there were restrictions for movement of resources across borders. Although some of these restrictions have been lifted recently, further relaxation of trade restrictions allowing water to be matched to economically superior water uses, could expect to lead to a contraction in the irrigation area (Table 7). These changes are expected to occur in all Australian States and territories within the Basin excluding Qld where there is opportunity for expansion in irrigation following more efficient water use within the Cap.

Analysis of irrigation in the MDB over the past decade indicates that:

- Despite irrigation allocations falling to record lows in many regions including a zero allocation in a number of irrigation regions both the level of irrigated output and the gross value held reasonable stable over the period. Reallocation of water within irrigation industries through water trading and substitution of other inputs for water has been the primary driver of this outcome.

Water trading has been the single dominant policy influence on irrigation since water policy reform began. This is because it provides the flexibility for irrigators to manage water shortages in an efficient manner. An analysis based on the time series of water trading statistics since 1996-97 illustrates the following points.

- While the permanent sale of water entitlements has been an instrument for reallocating water between irrigators, including new developers pursuing greenfield developments to assist restructuring of activities, the temporary water trade has largely been an instrument of choice to meet seasonal water shortages. This is clearly evident in recent statistics where in 2008-09, 41 per cent of water used for agriculture in the Basin has been recorded as traded.
- There have also been changes in the mix of agricultural production. The commodities that contributed most to the value of irrigated production during 2006-07 in the Basin were fruit and nuts ($1,207 million or 24%), dairy production ($763 million or 15%) and grapes ($651 million or 13%). These were also the crops that received most of the irrigation water (Table 11).
- In comparison, during 2000-01, cotton, an annual crop, contributed most to the total value of irrigated production ($1,111) with a share of 22 per cent of total Basin GVIAP. In 2006-07 cotton only accounted for $457 million or 9 per cent of total Basin GVIAP. This is largely reflected in the decrease in the volume of water applied to cotton.
- As a consequence, the ratio of real GVIAP to volume of water applied in the Basin increased from $585/ML in 2000-01 to $1,107/ML in 2006-07. However, these GVIAP estimates do not in themselves suggest that horticultural crops provide the best use for water. Rather, it is a reflection that these perennial crops require continued supply of water, even at a high cost, to maintain productive life.

Productivity analysis based on three years of ABARES farm survey data indicates that the productivity performance of irrigated industries have varied across the three years with a general pattern of a decrease in input use and evidence of increases in output oriented technical change.

- The annual growth rate of productivity for all irrigated farms is on average 1.1 per cent a year, which is mainly driven by a decrease in input usage, which includes irrigation water. While this decrease in input usage may be attributable to efficiency gains in water use, the driver of reduced water use is primarily the drought, rather than any policy changes. Policy changes, however, enabled the irrigators to better manage the water scarcity.
- By industries, horticulture industry has achieved TFP growth by 4.0 per cent a year, followed by dairy industry. However, broadacre industry has a decline in TFP growth by 3.4 per cent a year, due primarily to reduce output growth. The horticulture industry has been the leading water purchaser during this period, to offset large reductions in water allocations, which enabled them to maintain a positive output growth. In most cases the broadacre farms has been the net seller of irrigated water.
- The estimated TFP in all three industries has been lowest in 2007-08, also the year in which water availability and use was the lowest on record.
- Analysis by regions indicates that productivity growth increased in some regions while decreasing in others. These variations in productivity are consistent with variability in production systems, level of water reform and local conditions influencing input and output levels.

Thus NWI-led water trading reform has ensured an efficient means to reallocating existing water between users, reflecting demand and supply conditions. In the absence of trading the impact on the irrigation sector would have been severe.

There is some evidence that the rate of output oriented technical efficiency has improved over the three years, and in that the improvements in the broadacre and dairy industry are greater than that for the more specialised horticulture industry. While a link can be drawn between change in technical efficiency and improvements in water management for irrigated farms, a clearer picture on the effectiveness of NWI could only be obtained using a longer time series.

It is clear, however, that across irrigation industries, the more water intensive industries such as horticulture and dairy has been able to maintain output growth despite severe cut backs to irrigation supplies.

These results illustrate the need to further reduce restrictions on water trade to allow for a medium term equilibrium in land use to reflect economic rather than political realities.

Appendix A: Productivity decomposition analysis

1. INTRODUCTION

Several methods are available for computing indexes of total factor productivity (TFP), but a very limited number of methods are available to break these indexes down into economically-meaningful components. This study uses methodology developed by O'Donnell (2008, 2010) to compute and decompose profitability and TFP indexes for 1612 irrigated farms over the period 2007-2009.

Underpinning the computation and decomposition of profitability and productivity indexes is the definition of TFP as the ratio of an aggregate output to an aggregate input. Section 2 uses this definition to define a class of multiplicatively-complete TFP indexes. Section 3 explains that profitability change (a measure of value change) can be decomposed into the product of a multiplicatively-complete TFP index (a measure of quantity change) and a terms-of-trade index (a measure of price change). Section 4 shows how the TFP index can be further decomposed into measures of technical change and various measures of efficiency change. Sections 5 to 9 report an application of this methodology to ABARES data on irrigated farms. Key findings are that

1) average profitability and productivity levels were
   a) highest in the Namoi region and lowest in the Border Rivers region; and
   b) highest in broadacre agriculture and lowest in the horticulture industry.
2) the terms-of-trade (ratio of output to input prices) was
   a) most favourable in the Lachlan region and least favourable in the Mount Lofty Range region; and
   b) most favourable in broadacre agriculture and least favourable in the horticulture industry.
3) output-oriented measures of technical efficiency (a measure of distance to the production frontier) were
   a) increasing over time;
   b) highest in the Namoi region (median 0.98) and lowest in the Murray region (median 0.52); and
   c) highest in broadacre agriculture (median 0.94) and lowest in the horticulture industry (median 0.39).
4) output-oriented measures of pure scale efficiency (a measure of returns to scale) were
   a) highest in 2008 (median 0.94);
   b) highest in the Murrumbidgee region (median 0.94) and lowest in the Namoi region (median 0.77); and
   c) equally high in broadacre agriculture and horticulture (median 0.91) and relatively low in dairy (median 0.87).
5) output-oriented measures of pure mix efficiency (a measure of returns to scope) were
   a) generally extremely low throughout the sample period (median OME scores less than 0.14);
   b) highest in the Murrumbidgee region (median 0.18) and lowest in the Loddon-Avoca region (median 0.10); and
   c) highest in the horticulture industry (median 0.14) and lowest in dairy (median 0.10).
6) output-oriented measures of scale-mix efficiency (a combined measure of returns to scale and scope) were
   a) lowest in 2008 (on average 80% below a reference firm);
   b) highest in the Murrumbidgee region (on average 49% lower than the reference firm) and lowest in the Border Rivers region (on average 79% lower than the reference firm); and
   c) similar across all industries (on average 70% lower than the reference firm).

2. PRODUCTIVITY CHANGE

Let q_{nt} and x_{nt} denote the vectors of outputs and inputs of firm *n* in period *t*. Mathematically, the TFP of the firm is defined as (e.g., (Chambers & Pope 1996), (O'Donnell 2008)):

$$(1) \qquad TFP_{nt} = \frac{Q_{nt}}{X_{nt}}$$

where $Q_{nt} \equiv Q(q_{nt})$ is an aggregate output and $X_{nt} \equiv X(x_{nt})$ is an aggregate input. The only requirements placed on the aggregator functions *Q*(.) and *X*(.) are that they be non-negative, non-decreasing and linearly homogeneous. It follows that the index number that measures the TFP of firm *n* in period *t* relative to the TFP of firm *m* in period *s* is ((O'Donnell 2008))

$$(2) \qquad TFP_{ms,nt} = \frac{TFP_{nt}}{TFP_{ms}} = \frac{Q_{nt} / X_{nt}}{Q_{ms} / X_{ms}} = \frac{Q_{ms,nt}}{X_{ms,nt}}$$

where $Q_{ms,nt} = Q_{nt} / Q_{ms}$ is an is an output quantity index and $X_{ms,nt} = X_{nt} / X_{ms}$ is an input quantity index. Thus, TFP growth can be viewed as a measure of output growth divided by a measure of input growth. Computing measures of productivity change is effectively a matter of selecting and computing appropriate output and input quantity indexes. (O'Donnell 2008) demonstrates that this is equivalent to selecting appropriate aggregator functions.

Price-based output and input quantity indexes are obtained using aggregator functions defined over prices. Prices are used because they reflect the relative importance, or value, of different outputs and inputs to the firm. Different choices of functional form (e.g., linear, quadratic) and price weights (e.g., period *s*, period *t*) lead to different quantity indexes, including the familiar Laspeyres, Paasche and Fisher output and input quantity indexes.

Distance-based output and input quantity indexes are obtained by aggregating individual output and input quantities using a special type of weighting function known as a distance function. Distance functions are commonly used by production economists to represent all the input-output combinations that are feasible using the available technology (i.e., available knowledge). Different choices of distance functions (e.g., output-oriented, input-oriented) and available technologies (e.g., period *s*, period *t*) again lead to different quantity indexes, including the Malmquist output and input quantity indexes.

When individual quantities are aggregated in this way to form output and input quantity indexes, and when these quantity indexes are then used to form a TFP index as in equation (2), the resulting TFP index is said to be multiplicatively-complete (O'Donnell, 2008). The class of multiplicatively-complete TFP index numbers includes Paasche, Laspeyres, Fisher, Tornquist, Lowe and Hicks-Moorsteen TFP indexes. The property of multiplicative-completeness is fundamentally important because it means that the TFP index number is compatible with the most basic definition of TFP given by equation (1).

3. THE RELATIONSHIP BETWEEN PROFITABILITY AND PRODUCTIVITY CHANGE

Let p_{nt} and w_{nt} denote the vectors of output and input prices received/paid by firm *n* in period *t*. Profitability is defined as the ratio of revenue to cost and is easily expressed in terms of aggregate prices and quantities:

(3) $$PROF_{nt} = \frac{p'_{nt} q_{nt}}{w'_{nt} x_{nt}} = \frac{P_{nt} Q_{nt}}{W_{nt} X_{nt}}$$

where $P_{nt} \equiv p'_{nt} q_{nt} / Q_{nt}$ and $W_{nt} \equiv w'_{nt} x_{nt} / X_{nt}$ are aggregate output and input prices respectively. It follows that the index number that measures the profitability of firm *n* in period *t* relative to the profitability of firm *m* in period *s* is ((O'Donnell 2008)):

(4) $$PROF_{ms,nt} = \frac{PROF_{nt}}{PROF_{ms}} = \left(\frac{P_{nt} / P_{ms}}{W_{nt} / W_{ms}} \right) \left(\frac{Q_{nt} / Q_{ms}}{X_{nt} / X_{ms}} \right) = \left(\frac{P_{ms,nt}}{W_{ms,nt}} \right) \left(\frac{Q_{ms,nt}}{X_{ms,nt}} \right) = TT_{ms,nt} \times TFP_{ms,nt}$$

where $TT_{ms,nt} = P_{ms,nt} / W_{ms,nt}$ is a terms-of-trade index measuring growth in output prices relative to input prices. Thus, profitability change (a measure of value change) can be decomposed into the product of a terms-of-trade index (a measure of price change) and a multiplicatively-complete TFP index (a measure of quantity change). (O'Donnell 2010b) uses this relationship to explain why deteriorations in the terms-of-trade tend to be associated with improvements in productivity.

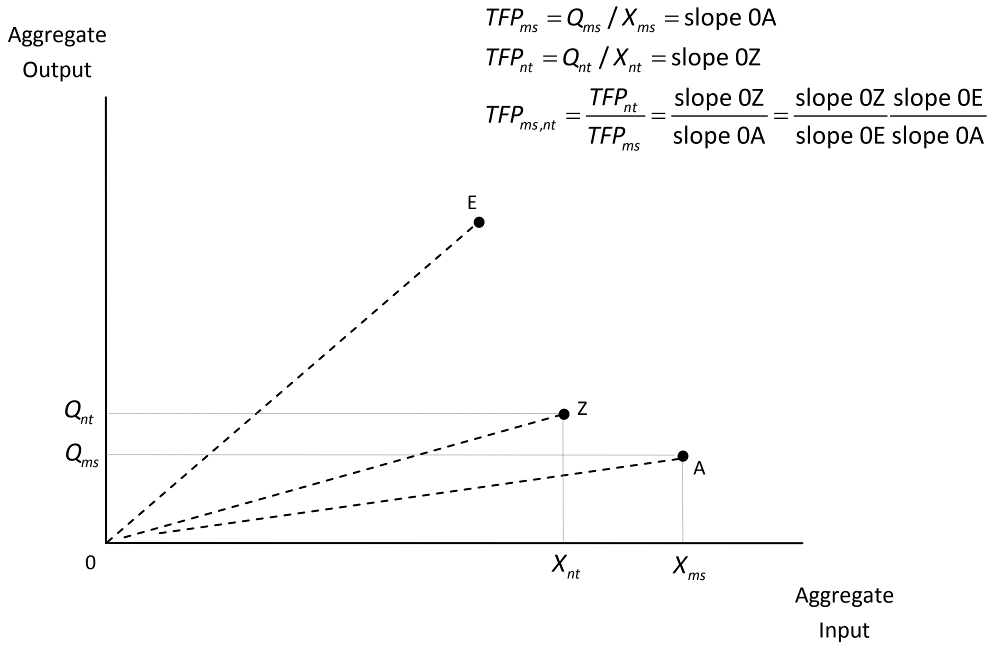
4. THE COMPONENTS OF PRODUCTIVITY CHANGE

(O'Donnell 2008) uses an aggregate quantity-price framework to demonstrate that all multiplicatively-complete TFP indexes can be decomposed into a measure of technical change and several measures of efficiency change. This demonstration is aided by the ability to depict the TFP of a multiple-input multiple-output firm in two-dimensional aggregate quantity space. The basic idea is illustrated in Figure 1. In this figure, the TFP of firm *m* in period *s* is given by the slope of the ray passing through the origin and point A, while the TFP of firm *n* in period *t* is given by the slope of the ray passing the origin and point Z. Thus, the TFP index that measures the change in TFP between the two firms/periods can be compactly written $TFP_{ms,nt} = \text{slope 0Z} / \text{slope 0A}$. This ability to represent a multiplicatively-complete TFP index using slopes of lines in aggregate quantity space is used by (O'Donnell 2008) to conceptualise several alternative decompositions of TFP change. For example, let E be <u>any</u> non-negative point in aggregate quantity space. Then it is clear, both mathematically and from Figure 1, where the change in the TFP of the two firms can be decomposed as $TFP_{ms,nt} = (\text{slope 0Z} / \text{slope 0E})(\text{slope 0E} / \text{slope 0A})$.

Within this framework, a potentially infinite number of points E can be used to effect a decomposition of a multiplicatively-complete TFP index. (O'Donnell 2008) focuses only on those points that feature in measures of efficiency that are common in the economics literature. Expressed in terms of aggregate quantities, three of the many efficiency measures that feature in an input-oriented decomposition of TFP change are:

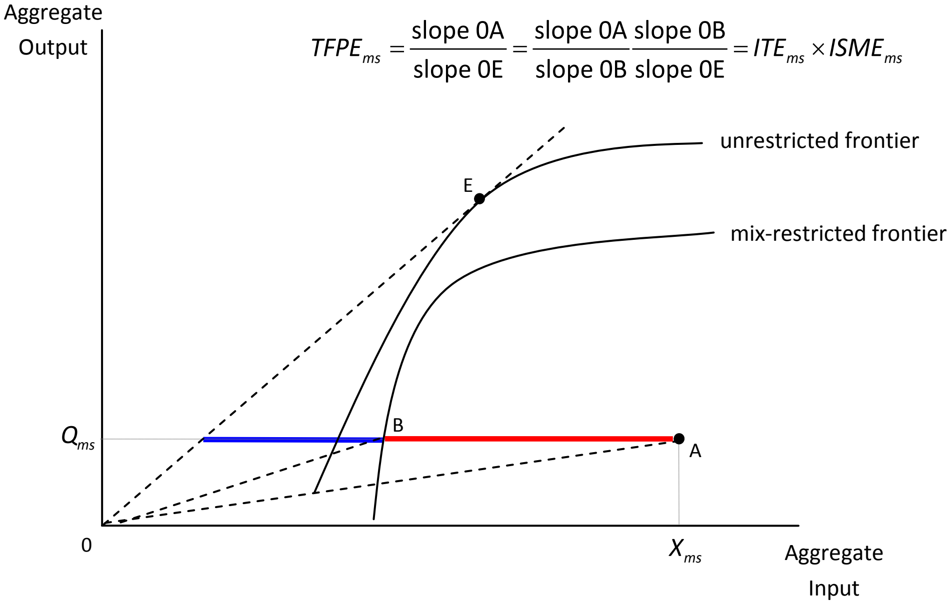
- <u>Input-oriented Technical Efficiency</u> (ITE) measures the difference between observed TFP and the maximum TFP possible while holding the input mix, output mix and output level fixed. This concept is illustrated in Figure 2, where the curve passing through point B is the frontier of a “mix-restricted” production possibilities set. The production possibilities set is mix-restricted in the sense that it only contains (aggregates) of input and output vectors that can be written as scalar multiples of the input and output vectors at point A. ITE is a ratio measure of the horizontal distance from point A to point B. Equivalently, it is a measure of the difference in TFP at points A and B: $ITE_{ms} = \text{slope 0A} / \text{slope 0B}$.

- <u>Input-oriented Scale-Mix Efficiency</u> (ISME) measures the difference between TFP at a technically-efficient point and the maximum TFP that is possible using the production technology (i.e. allowing output and input levels and mixes to vary). This measure of efficiency is represented in Figure 2 as a movement from point B to point E: $ISME_{ms} = \text{slope 0B} / \text{slope 0E}$. In Figure 2, the curve passing through point E is the boundary of the unrestricted production possibilities set (there are no restrictions on input or output mix). (O'Donnell 2008) refers to point E as the point of maximum productivity (MP).



$$TFP_{ms} = Q_{ms} / X_{ms} = \text{slope 0A}$$
$$TFP_{nt} = Q_{nt} / X_{nt} = \text{slope 0Z}$$
$$TFP_{ms,nt} = \frac{TFP_{nt}}{TFP_{ms}} = \frac{\text{slope 0Z}}{\text{slope 0A}} = \frac{\text{slope 0Z}}{\text{slope 0E}} \frac{\text{slope 0E}}{\text{slope 0A}}$$

Figure 1. Measuring and Decomposing TFP Change



$$TFPE_{ms} = \frac{\text{slope 0A}}{\text{slope 0E}} = \frac{\text{slope 0A}}{\text{slope 0B}} \frac{\text{slope 0B}}{\text{slope 0E}} = ITE_{ms} \times ISME_{ms}$$

Figure 2. An Input-Oriented Decomposition of TFP Efficiency

- TFP Efficiency (TFPE) measures the difference between observed TFP and the maximum TFP possible using the available technology. This measure of efficiency is represented in Figure 2 as a movement all the way from point A to point E: $TFPE_{ms} = TFP_{ms} / TFP_{s}^{*} = \text{slope 0A} / \text{slope 0E}$ where TFP_{s}^{*} denotes the maximum TFP possible using the technology available in period *s*.

Figure 2 illustrates just one of many pathways from A to E, and therefore illustrates just one of many decompositions of TFP efficiency:

$$(5) \qquad TFPE_{ms} = \frac{TFP_{ms}}{TFP_{s}^{*}} = ITE_{ms} \times ISME_{ms}$$

(O'Donnell 2008) discusses several other input- and output-oriented decompositions of TFP efficiency, each one corresponding to a different pathway from point A to point E in Figure 2. Such decompositions provide a basis for an output or input-oriented decomposition of any multiplicatively-complete TFP index. The easiest way to see this is to rewrite (3) as $TFP_{ms} = TFP_{s}^{*} \times ITE_{ms} \times ISME_{ms}$. A similar equation holds for firm *n* in period *t*. It follows that

$$(6) \qquad TFP_{ms,nt} = \frac{TFP_{nt}}{TFP_{ms}} = \left(\frac{TFP_{t}^{*}}{TFP_{s}^{*}} \right) \left(\frac{ITE_{nt}}{ITE_{ms}} \right) \left(\frac{ISME_{nt}}{ISME_{ms}} \right)$$

The first term in parentheses on the right-hand side of equation (6) measures the difference between the maximum TFP possible using the technology available in period *t* and the maximum TFP possible using the technology available in period *s*. Thus, it is a natural measure of technical change. The economy/industry experiences technical progress or regress as this term is greater than or less than 1. The other ratios on the right-hand side of (6) are obvious measures of technical efficiency change and scale-mix efficiency change. (O'Donnell 2008) derives the output-oriented counterparts to equations (5) and (6) and demonstrates that the input- and output-oriented measures of technical change are plausibly identical.

5. DATA

ABARES supplied an unbalanced panel of farm-level quantity indexes for four outputs and five inputs:

Q1 = cropping products
Q2 = livestock products and wool
Q3 = dairy products
Q4 = other farm products and services

X1 = land
X2 = capital
X3 = labour
X4 = materials
X5 = irrigation water

These quantity indexes were computed using Fisher-EKS methodology “in order to maintain ... transitivity across farms and over time”. A problem with the EKS methodology is that, although the resulting indexes satisfy the transitivity test, they do not satisfy the identity axiom. This means that the index numbers that compare the outputs, inputs and productivity of two farms will not take the value 1 even when the outputs and inputs of the two farms are identical. For this reason, this study uses Lowe indexes. Lowe indexes are easier to compute and satisfy all economically relevant axioms and tests from index number theory, including transitivity and identity – for details, see (O'Donnell 2010c).

ABARES also supplied "corresponding price indexes for the purposes of productivity/profitability analysis". The price indexes are "corresponding" insofar as the product of the quantity and price indexes is a measure of revenue change (in the case of outputs) or cost change (in the case of inputs) – see equation (12) below.

ABARES supplied an unbalanced panel of 2557 observations on 1612 firms over the period 2007-2009. The firms were cross-classified by the following regions and industries.

Region 1 = Border Rivers
Region 2 = Condamine-Balonne
Region 3 = Goulburn
Region 4 = Lachlan
Region 5 = Loddon-Avoca
Region 6 = Macquarie
Region 7 = Eastern Mt Lofty Range
Region 8 = Murrumbidgee
Region 9 = Namoi
Region 11 = Murray

Industry 1 = Horticulture
Industry 2 = Broadacre
Industry 3 = Dairy

A total of 55 observations were regarded as unreliable and deleted from the data set, leaving 2502 observations for analysis. The 55 deleted firms/observations used the same non-zero amount of labour input, and that amount was more than 50 times lower than the labour input of any other observation/firm in the sample; 51 of the 55 observations also used the same small non-zero amounts of 3 other inputs and produced the same small non-zero amounts of 3 outputs. These observations were deleted because they were implausible and because small incorrect input values will lead to significantly biased estimates of the technical change component of productivity change.

6. ESTIMATES OF PROFITABILITY CHANGE

Let p_{knt} and q_{knt} denote the price and quantity of the k-th output of firm n in period t, and let $r_{knt} \equiv p_{knt} q_{knt}$ denote the associated revenue. If there are K outputs then the total revenue of the firm is:

$$(7) \qquad R_{nt} \equiv \sum_{k=1}^{K} r_{knt} = \sum_{k=1}^{K} p_{knt} q_{knt}$$

On the input side, let w_{jnt}, x_{jnt} and $c_{jnt} \equiv w_{jnt} x_{jnt}$ denote the price, quantity and cost of the j-th input. If there are J inputs then total cost is given by:

$$(8) \qquad C_{nt} \equiv \sum_{j=1}^{J} c_{jnt} = \sum_{j=1}^{J} w_{jnt} x_{jnt}$$

The profitability of the firm is the revenue-cost ratio:

(9) $$PROF_{nt} \equiv \frac{R_{nt}}{C_{nt}} = \frac{\sum_{k=1}^{K} r_{knt}}{\sum_{j=1}^{J} c_{jnt}} = \frac{\sum_{k=1}^{K} p_{knt} q_{knt}}{\sum_{j=1}^{J} w_{jnt} x_{jnt}}$$

The index number that compares the profitability of firm *n* in period *t* with the profitability of, say, firm 1 in period 1 is:

(10) $$PROF_{11,nt} = \frac{PROF_{nt}}{PROF_{11}} = \frac{R_{nt}/C_{nt}}{R_{11}/C_{11}} = \frac{R_{11,nt}}{C_{11,nt}}$$

where $R_{11,nt} \equiv R_{nt}/R_{11}$ and $C_{11,nt} \equiv C_{nt}/C_{11}$ are simple revenue and cost indexes.

This study makes use of the fact that it is possible to compute measures of revenue, cost and profitability change using price and quantity indexes of the type supplied by ABARES. To see this, let $Q_{k11,knt} = q_{knt}/q_{k11}$ denote a quantity index that compares the *k*-th output of firm *n* in period *t* with the *k*-th output of firm 1 in period 1. Then the revenue index $R_{11,nt} \equiv R_{nt}/R_{11}$ can also be computed as:

(11) $$R_{11,nt} = \frac{R_{nt}}{R_{11}} = \frac{\sum_{k=1}^{K} p_{knt} q_{knt}}{R_{11}} = \sum_{k=1}^{K} \left(\frac{p_{knt} q_{k11}}{R_{11}} \frac{q_{knt}}{q_{k11}} \right) = \sum_{k=1}^{K} P_{k11,knt} Q_{k11,knt}$$

where

(12) $$P_{k11,knt} = \frac{p_{knt} q_{k11}}{R_{11}} = \frac{p_{knt} q_{knt}}{p_{k11} q_{k11}} \frac{q_{k11}}{q_{knt}} = \frac{r_{knt}}{r_{k11}} \frac{q_{k11}}{q_{knt}} = \frac{R_{k11,knt}}{Q_{k11,knt}}$$

is the implicit price index corresponding to the quantity index $Q_{k11,knt}$.

7. ESTIMATES OF TFP CHANGE

Selecting a TFP index number formula involves selecting, usually implicitly, aggregator functions that can be used to form the aggregate outputs and inputs in (1) and (2). This study uses a very simple linear aggregator function to obtain Lowe TFP index numbers that satisfy all economically-relevant index number axioms and tests. Specifically, outputs and inputs are aggregated using the functions

(13) $Q(q_{nt}, \bar{p}) = \bar{p}' q_{nt}$ and

(14) $X(x_{nt}, \bar{w}) = \bar{w}' x_{nt}$

where $\bar{p}$ and $\bar{w}$ are pre-determined firm- and time-invariant reference prices. The associated index numbers that measure the output, input and TFP of firm *n* in period *t* relative to firm *m* in period *s* are

(15) $$Q_{ms,nt} = \frac{Q(q_{nt}, \bar{p})}{Q(q_{ms}, \bar{p})} = \frac{\bar{p}' q_{nt}}{\bar{p}' q_{ms}}$$

$$X_{ms,nt} = \frac{X(x_{nt}, \bar{w})}{X(x_{ms}, \bar{w})} = \frac{\bar{w}' x_{nt}}{\bar{w}' x_{ms}} \quad \text{and} \tag{16}$$

$$TFP_{ms,nt} = \frac{Q_{ms,nt}}{X_{ms,nt}} = \frac{\bar{p}' q_{nt}}{\bar{p}' q_{ms}} \frac{\bar{w}' x_{ms}}{\bar{w}' x_{nt}} \tag{17}$$

The quantity indexes (15) and (16) are ratios of the values of different baskets of goods evaluated at the same set of reference prices. They are types of Lowe index, named after (Lowe 1823). Lowe price indexes are used by many statistical agencies to compute consumer price indexes. Lowe TFP indexes have recently been used to compute and decompose measures of agricultural productivity change by (O'Donnell 2010c).

Any pair of price vectors may be used as reference prices in (13) to (17), including hypothetical vectors. In this study we use sample average prices as reference prices. Using (12), the reference price for the *k*-th output, for example, is

$$\bar{p}_k = \frac{1}{NT} \sum_{n=1}^{N} \sum_{t=1}^{T} p_{knt} = \left(\frac{R_{11}}{NTq_{k11}} \right) \sum_{n=1}^{N} \sum_{t=1}^{T} P_{k11,knt} = \left(\frac{R_{11}}{NTq_{k11}} \right) \bar{P}_{k11} \tag{18}$$

where $\bar{P}_{k11} \equiv \sum_n \sum_t P_{k11,knt}$. Thus, the output index (15) can be written in terms of the output quantity and (sample average) output price indexes supplied by ABARES:

$$Q_{ms,nt} = \frac{\sum_{k=1}^{K} \bar{p}_k q_{knt}}{\sum_{k=1}^{K} \bar{p}_k q_{kms}} = \frac{\sum_{k=1}^{K} \bar{P}_{k11} Q_{k11,knt}}{\sum_{k=1}^{K} \bar{P}_{k11} Q_{k11,kms}} \tag{19}$$

8. ESTIMATES OF CHANGES IN THE TERMS OF TRADE

Recall from equation (4) that profitability change can be decomposed into the product of a term-of-trade index and a TFP index. The similar patterns of variation in the profitability and TFP indexes reported above (e.g., fairly constant over time, highest in the Namoi and lowest in the horticulture industry) suggest that most firms in the sample face similar terms of trade (i.e., they purchase inputs and sell outputs in the same, or at least fairly highly integrated, markets).

9. ESTIMATES OF THE COMPONENTS OF TFP CHANGE

In principle, any multiplicatively-complete TFP index can be decomposed using the framework outlined in Sections 2 and 4 – for more details, see (O'Donnell 2008). In practice, decomposition involves estimating (points on) the period *s* and period *t* production frontiers. Common methods for estimating frontiers are explained in (Coelli et al. 2005). In this study, we use data envelopment analysis (DEA) to compute and decompose the Lowe TFP indexes derived in Section 7. DEA is used because it is fast, it avoids the need to make assumptions about functional forms or error distributions, and it allows us to avoid endogeneity problems that arise in the estimation of distance functions (common primal representations of multiple-input multiple-output production technologies). Even so, it is still necessary to make assumptions concerning the nature of technical change and the shape of the unobserved production frontier. This study allows the production possibilities set to exhibit variable returns to scale, technical progress and technical regress. The justification for the technical change assumptions is provided by (O'Donnell 2010b). All computations were performed using the DPIN 2.0 software by (O'Donnell 2010a).

The Technical Change and Efficiency Change Components of TFP Change

Estimates of changes in various output- and input-oriented measures of efficiency are also reported observation-by-observation in a separate EXCEL file. Tables 26 to 27 report descriptive statistics for one particular output-oriented decomposition of TFP change, namely:

$$TFP_{ms,nt} = \frac{TFP_{nt}}{TFP_{ms}} = \left(\frac{TFP_t^*}{TFP_s^*}\right)\left(\frac{OTE_{nt}}{OTE_{ms}}\right)\left(\frac{OSME_{nt}}{OSME_{ms}}\right) \quad (20)$$

where OSME is an output-oriented measure of scale and mix efficiency change. Equation (20) is the output-oriented analogue of equation (6). This decomposition can be written compactly as:

(21) dTFP = dTech x dOTE x dOSME

where the interpretations of the terms are obvious.

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