Dairy productivity growth, efficiency change and technological progress in Victoria

Research Paper 2012.5

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Economics and Policy Research Branch

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Contents

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Abstract

The research in this paper considers the question of the possible sources of total factor productivity (TFP) change in the dairy sector between 2007–08 and 2010–11. Analysis is conducted over the components of TFP growth for a subset of dairy enterprises in Victoria. Specifically, the research considers the contributions of technological progress and technical efficiency changes to TFP growth using the Malmquist index based on a decomposition of TFP change. A comparison of estimates of productivity is made to financial measures of farm performance, with an additional contrast made to qualitative assessments of field staff involved in collecting the survey data used in the analysis.

Keywords: dairy, Malmquist, technical efficiency change, technological change, total factor productivity, Victoria

1. Introduction

1.1 Productivity growth is slowing

The Australian dairy industry has targeted total factor productivity (TFP) growth at the farm level as a strategic objective to enhance its sustainable competitive advantage and improve dairy farmers' profitability (Dairy Australia 2010). The previous Victorian government's Future Farming Strategy committed to providing funding to ensure that dairy farmers have the information and technology needed to boost annual dairy industry productivity growth to levels necessary to maintain international competitiveness (DPI 2008b).

However, productivity growth in the Victorian dairy sector has not been as strong in recent years as it was in the 1980s (refer to Box 1). The apparent low long term annual rate of productivity growth challenges the industry to look for new ways to improve management practices and adopt better technologies in order to enhance productivity (Kompas and Che 2004).

In identifying opportunities for improvement and appropriate policy approaches for government, it is informative to investigate the main sources of productivity change.

Box 1: Victorian dairy industry and productivity trends

The dairy industry is an important agricultural industry in Victoria. It is Victoria's largest rural industry with a gross value of raw milk production of $2.4 billion in 2008–09 (DPI 2011b). In 2009–10, Victoria produced around six billion litres of raw milk. Around two-thirds of Australia's 8,800 dairy farm businesses are located in Victoria. On average, Victoria exports approximately 85 per cent of Australia's dairy product exports. These exports were worth $1.76 billion in 2009–10 (DPI 2011b).

The Victorian dairy industry showed strong productivity gains in the 1980s, a flat performance in the 1990s and moderate gains in the 2000s (Harris 2011). Hence, while productivity has varied over time due to both internal and external drivers, similar analysis of long term productivity trends by ABARES indicates that Victoria's dairy industry recorded a low overall annual productivity growth of 0.1 per cent over the period 1988–89 and 2008-09. This was the lowest among all states and below the national average productivity growth rate of 0.8 per cent (Gray et al. 2011). This study posits that the relatively higher productivity growth rates in other states such as New South Wales may have resulted from the greater scope for productivity gains prior to deregulation compared with the already efficient Victorian industry.

1.2 Sources of productivity growth

Productivity growth can be enhanced through two pathways—technological progress and technical efficiency improvement. Measuring and monitoring these two productivity growth measures can help guide future policy interventions. For example, technical efficiency improvement could entail inefficient farmers adopting existing practices such as better pasture and fertiliser management, improved water management and more efficient milking equipment (e.g. rotary dairies, automatic cup removers).

Technological progress, which can 'shift the technology frontier' in the future, could involve advances in both plant and animal genetics. Research in plant genetics aims to increase pasture production, nutritive value and persistence. Research in cattle genomics aims to increase the rate of genetic gain in cattle especially in key traits such as fertility, feed conversion efficiency and methane production.

Productivity indexes derived using index number methods such as the Fisher and Tornqvist indexes are frequently employed to measure TFP growth (Coelli et al. 2005, Gregg and Rolfe 2011). The derived TFP indexes reflect industry performance as a whole. However, these indexes are not necessarily informative for identifying which factors contribute to TFP growth (Coelli et al. 2005).

Another limitation of index number methods is their inability to delineate changes in productivity due to technological advances from those that result from changes in efficiency. Therefore, it is not possible to determine what drives differences in productivity and efficiency (Kompas and Che 2006). Recognising these limitations of traditional TFP indexes has led to the development of techniques that decompose productivity (O'Donnell 2009, O'Donnell 2010) — for example using a Malmquist index.

1.3 Study Objectives

This key objective of this study is to consider some of the major sources and drivers of productivity growth in the dairy sector in Victoria. This will involve estimating and decomposing productivity changes into technical efficiency and technological change using a Malmquist index.

In addition to this objective, the study has considered a couple of innovative and information extensions to the productivity analysis. First, the Malmquist productivity change estimates are compared with qualitative measures of farm level performance from field staff that collected the sample data and have an intimate working knowledge of the survey farms. This allows the productivity analysis to be validated in a manner not typically available to researchers and tests whether top performers are consistently identified in the productivity and qualitative analysis.

The second extension of the analysis examines the relationship between the measured productivity change and profitability. While farms typically aim for long-term productivity improvements, temporary declines in productivity can also occur when farmers are profit maximising. For instance, in agriculture, rational farmers may, in the short run, sacrifice productivity by maximising outputs to take advantage of improvements in commodity prices (i.e., terms of trade effects) that are expected to be temporary (Gray et al. 2011). An example of this could be where farmers expand cropping activities into marginal areas in response to expected increases in output prices. In an effort to understand this relationship between productivity and profitability, this study compares and contrasts qualitatively and quantitatively the productivity measures with farm profitability measures.

1.4 Structure of the paper

To present our analysis, the remainder of this paper is organised as follows: Section 2 introduces the model and empirical specifications; Section 3 reviews past empirical applications; Section 4 describes the data; Section 5 presents the empirical estimates and discusses results; and Section 6 provides some concluding comments.

2. Methodological overview

Two key productivity pathways are considered in this study. Technological change, representing the development and adoption of new technologies or management systems or the ‘best farms getting better’ and technical efficiency change, representing the rate of adoption of available technologies, or the rate at which the ‘average farms catch up to the best farms’ (Gray et al. 2011). Over time the level of output a farm is capable of producing may increase due to technological change that affects its ability to optimally combine inputs and outputs. Technological change causes the production possibility frontier to shift upwards as more outputs are obtainable from the same quantity of inputs. Shifts in the frontier might also occur in a biased way (non-parallel shifts) (Mahadevan 2003). This happens in the case of non-neutral technological change where technological change raises productivity of some inputs. As Box 2 illustrates, productivity improvement may be attributable to either technological advancements (frontier shift) or technical efficiency enhancements (catch-up), or both.

2.1 The Malmquist index of TFP change

The Malmquist index has been used to estimate total factor productivity change (Färe et al. 1994). Malmquist data envelopment analysis (DEA) is a non-parametric methodology that constructs a piece-wise linear production frontier over a sample of farms in each year.[5] This method has been extensively used for measuring agricultural productivity because it offers many advantages (Coelli et al. 2005). These advantages include: (1) it does not require price information; (2) it does not assume that all farms are efficient, and (3) it allows for TFP decomposition into technological change and technical efficiency change.

The Malmquist index is based on the idea of a function that measures the distance from a given input/output vector (for a particular farm) to the technically efficient frontier that is defined by the input/output vectors of the most efficient farms in the sample in that year. The measure of this distance from the production possibility frontier is an estimate of the farm’s technical efficiency. The index may be input oriented (contracting inputs while holding outputs constant) or output oriented (expanding outputs while holding inputs constant).

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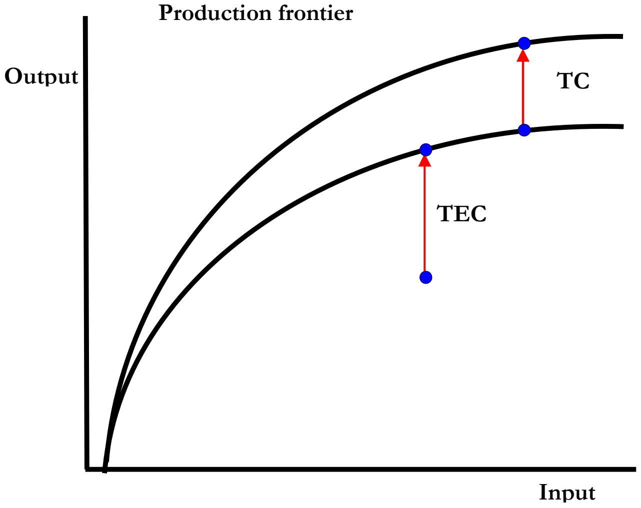
[5] See Coelli et al. (2005) for a detailed description of DEA.



Box 2: The pathways to productivity change (Source: Gray et al (2011))

TFP growth includes gains from technological change (TC) and technical efficiency change (TEC). TC captures the improvement in best practice through adoption of new technologies resulting in more efficient farming systems (i.e. the best farms getting better). TEC captures improvements in TFP arising from 'slower moving' farms adopting currently available technologies and knowledge. It reflects the aggregate influence of 'average' farms catching up to the best-performing farms.

The Malmquist index method allows total factor productivity change (TFPC) decomposition over time into a catching-up effect (technical efficiency change (TEC)) and a frontier shift effect (technological change (TC)) as depicted in Box 2. The 'catching-up' part is an index measuring change in technical efficiency between two periods. In contrast, the TC reflects the movement of the best practice frontier. It is an index measuring technological change, that is, how the best practice frontier has moved in relation to one particular farm (Färe et al. 1994).

The Malmquist index was introduced by Caves et al. (1982). The output-oriented DEA-based Malmquist productivity change index is constructed between period t and t+1, as the geometric mean of two distance function-based Malmquist indexes of the following form,

$$M_O(x^{t+1}, y^{t+1}, x^t, y^t) = \left[\left(\frac{D_O^t(x^{t+1}, y^{t+1})}{D_O^t(x^t, y^t)}\right)\left(\frac{D_O^{t+1}(x^{t+1}, y^{t+1})}{D_O^{t+1}(x^t, y^t)}\right)\right]^{1/2} \quad (1)$$

In equation 1, the first term in the brackets is the Malmquist productivity index with technology in period t as the reference technology. The distance function in the numerator, $D_O^t(x^{t+1}, y^{t+1})$, measures the maximal proportional change in the output vector y^{t+1} required to place the input-output vector (x^{t+1}, y^{t+1}) on the technology frontier in period t. The distance function in the denominator, $D_O^t(x^t, y^t)$, measures the maximum proportional change in the output vector y^t required to place the input-output vector (x^t, y^t) on the technology frontier in period t.

Similarly, the second term in the brackets represents the Malmquist productivity index using the technology in period t+1 as the reference technology. The distance function in the denominator, $D_O^{t+1}(x^t, y^t)$, measures the maximal proportional change in the output vector y^t required to place the input-output vector (x^t, y^t) on the technology frontier in period t+1, whereas the distance function in the numerator, $D_O^{t+1}(x^{t+1}, y^{t+1})$, measures the maximal proportional change in the output vector y^{t+1} required to place the input-output vector (x^{t+1}, y^{t+1}) on the technology frontier in period t+1.

The Malmquist productivity-change index in equation 1 can be decomposed into relative technical efficiency change and technology shift over time by following Färe et al. (1994).

$$M_O(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D_O^{t+1}(x^{t+1}, y^{t+1})}{D_O^t(x^t, y^t)} \times \left[\left(\frac{D_O^t(x^{t+1}, y^{t+1})}{D_O^{t+1}(x^{t+1}, y^{t+1})}\right)\left(\frac{D_O^t(x^t, y^t)}{D_O^{t+1}(x^t, y^t)}\right)\right]^{1/2} \quad (2)$$

Färe et al. (1994) gave the following interpretation to the two terms on the right hand side of this equation.

(3) Technical efficiency change (TEC) = $$\frac{D_O^{t+1}(x^{t+1}, y^{t+1})}{D_O^{t}(x^{t}, y^{t})}$$

(4) Technological change (TC) = $$\left[\left(\frac{D_O^{t}(x^{t+1}, y^{t+1})}{D_O^{t+1}(x^{t+1}, y^{t+1})}\right)\left(\frac{D_O^{t}(x^{t}, y^{t})}{D_O^{t+1}(x^{t}, y^{t})}\right)\right]^{1/2}$$

Hence, the Malmquist productivity index can be viewed as the product of the change in relative technical efficiency that occurred between periods t and t+1, and the shift in technology that occurred between t and t+1. The geometric mean of the two ratios in equation 4 can be interpreted as the TC component, measuring the shift in the frontier over time evaluated at the two data points. The improvements in this technological-change component can be interpreted as evidence of innovation in the industry (Färe et al. 1994).

The technical efficiency change (equation 3) can be further decomposed into pure technical efficiency change (PTEC) and scale efficiency change (SEC) (Färe et al. 1994), as shown in equation 5.

(5) TEC = Pure technical efficiency change (PTEC) × Scale efficiency change (SEC).

DEAP Version 2.1, a computer program developed by Coelli (1996), was used to compute the technical efficiency, technical efficiency change, pure efficiency change, scale efficiency change, technological change and TFP change for the sample dairy farms.

2.2 Comparison to qualitative measures

The second stage of this research involved comparing the Malmquist productivity change estimates with qualitative measures of farm level performance. The data described above were collected by farm economists and technically based dairy extension staff with an intimate working knowledge of the survey farms. This meant that a qualitative comparison of productivity and profitability could be undertaken by combining the farm level knowledge of the field researchers who collect the survey data with the Malmquist indices estimates. This enabled the Malmquist TFP growth results to be validated in a manner not typically undertaken in the literature.

This is an important aspect of this research as it directly compares the results generated by DEA with the experiences of the farm economists and dairy extension staff with first-hand knowledge of the sample of farmers examined. Thus, comparisons of rankings of the farms derived by the farm economists were compared to rankings derived from the DEA analysis. To further enhance these comparisons the farm economists and dairy extension staff were asked to qualitatively identify the top performing farms. This allowed us to see if the technical analysis reveals the same farms as those qualitatively viewed by the farm economists and dairy extension staff as being the top performers.

2.3 Relationship between productivity performance and profitability

The third stage examined the relationship between productivity performance and profitability. Two measures of profitability were used — earnings before interest and tax (EBIT) and return on assets (ROA). These profitability measures were compared to estimates of TFP change using Spearman's rank correlation.

3. Review of previous applications

Several studies have employed Malmquist TFP indexes, including a number in the agricultural sector (Headey et al. , Färe et al. 1994, Thirtle et al. 1995, Tauer 1998, Fraser and Hone 2001, Coelli and Rao 2005, Ludena et al. 2007). Table 1 lists a number of studies that have applied these methods to the dairy sector and summarises the outputs and inputs used in these studies to capture the dairy production process. These specifications were considered in establishing the model specification used in the current study.

Table 1: Dairy outputs and inputs used in Malmquist analyses

Author(s)	Outputs	Inputs	Country
Brummer et al. (2002)	Milk output (DM[a]) Other outputs (DM)	Intermediate inputs (DM), labour (hours), capital (DM), land (ha)	Germany, Poland and Netherlands
Doucouliagos and Hone (2000)	Real turnover ($)	Labour (number of workers employed each year), raw milk (litres), energy (petajoules), and total capital stock ($)	Australia
Latruffe and Fogarasi (2009)	Milk output (litres) Other output (€)	Utilised land (ha), labour units, capital (€), intermediate consumption (€), number of livestock units	France and Hungary
Graham (2009)	Milk sold ($)	Capital ($), labour ($) materials, services and fodder ($)	Australia
Laca-Vina (2010)	Total milk solids (kg)	Milked cows (number), area (ha), labour (total hours per year), feed (all purchased feed ($)), fertiliser ($), intermediate inputs (health, breeding, shed, feed), capital ($)	New Zealand
Mkhabela (2011)	Output (Rands)	Land (ha), labour (Rands), feed (Rands), Veterinary (Rands), milking machinery (Rands) and other machinery (Rands)	South Africa
Newman and Matthews (2006)	Milk output (gallons), Other output (€)	Size (ha), labour units, capital (€), variable costs (€)	Ireland
Tauer (1998)	Milk production (cwt[b]) Other output ($)	Labour ($), purchased feed ($), crop ($), energy input ($), livestock input ($), real estate input ($)	US
Tauer and Lordkipanidze (1999)	Dairy products sold ($)	Livestock expenses ($), feed expenses ($), production expenses ($), service flow from land, machinery and buildings ($), and operator labour (number of days worked on the farm)	US
Thirtle et al. (1996)	Milk (litres)	Labour (hours), land (ha), capital ($)	Slovenia

[a]Deutsche Marks; [b]centum weight is a unit of mass defined in terms of the pound

Of the Australian studies, Doucouliagos and Hone (2000) used the Malmquist index procedure to estimate technical efficiency change, technological progress and total factor productivity change in the Australian dairy processing industry from 1969 to 1996. They found that the dairy industry in Victoria recorded an almost zero rate of growth in TFP during the 1991–96 sub-period, which is consistent with the results reported in Gray et al (2011). This stagnant TFP growth was reflected in low technical progress results and low technical efficiency change scores.

Graham (2009) employed the Malmquist DEA approach to estimate the productivity growth of 22 dairy farms in South West Victoria over a four-year time period (1996-97 to 2000-01). This study used the same source of data as the current study, that is, the Department of Primary Industries (DPI) Victoria's Dairy Industry Farm Monitor Project data for 22 dairy farms. The mean productivity growth for these sample farms was estimated to be 12.5 per cent per annum. The study reported that a 5.8 per cent decline of technical efficiency change was offset by a 19.5 per cent increase in technological progress. These values are very large compared to most dairy industry TFP change measures which tend to be between 0 and 2 per cent per annum (e.g., see Gray et al 2011). It is likely that these measures may be influenced by short term climatic factors, which can have a large influence on estimates of TFP obtained from data on a small number of farms observed over a short time period such as this. This point is also relevant to our empirical study in this paper.

4. Study sample and data sources

The study used a sample of 35 Victorian dairy farms over a four year period (2007–08 to 2010-11) using published data from the DPI's Dairy Industry Farm Monitor Project (DIFMP) (DPI 2008a, 2009, 2010). The DIFMP conducts annual surveys to collect comparative financial and production performance information on participating farms. Its aim is to supply farmers, industry and government with relevant farm level information to help them make informed decisions that will benefit their farms and the industry.

The sample selection method used is not random or stratified. However, care is taken to ensure that a mix of farms in terms of size and location are present in the sample. When farms withdraw from the project they are replaced with similar farms. Given the nature of the project (financial analysis) it is likely that farms that are surveyed are better than what is truly 'average' in the industry. Based on anecdotal information, the farms in the sample are most likely representative of the top 30 to 40 per cent of farms in the industry.

The data were collected from the three dairying regions in Victoria: Northern Victoria, South West Victoria and Gippsland. Dairy herds in Victoria are mainly pasture fed and temperate climatic conditions allow for year-round grazing on permanent pasture. Supplementary feeding of grain is used as an aid to pasture management. The production in the South West region is mainly pasture based, with rainfall mostly occurring in winter and spring. The Northern region is predominantly irrigated land. Gippsland is relatively temperate and is normally in a high rainfall area with rainfall mainly occurring in winter and spring. In addition, production in Gippsland is mainly based on grazing, with few farms using irrigation (Kompas and Che 2004). There is also a small number of dryland farms in Northern Victoria and a small number of irrigated farms in the South West (DPI 2011b).

The data used in this research covers four out of the five years that DIFMP has existed. While a longer time series would always be preferred to account for short term variations, this data set provides the opportunity to explore sources of productivity change and regional differences within this time period.

Summary descriptive statistics for the farms for the three years are provided in Table 2. Of the 35 farms, 10 are located in Gippsland, 12 in Northern Victoria, while 13 are located in South West Victoria. On average, farms in the South West operated the largest area (373 ha) compared to the other two regions. Gippsland has a smaller average useable area (184 ha) compared to the other two regions. Overall, the mean farm size is 279 hectares. The smallest farm was 35 hectares (located in Northern Victoria) while the largest was 1,422 hectares (based in South West Victoria). The Northern Victoria region had the highest supplementary feeding, averaging 4.41 tonnes per hectare. The South West region had the highest average in terms of milk production, labour, capital value, fertiliser use, and herd size followed by the Northern Victoria region.

Table 2: Summary statistics of output and input variables

Variable	Mean	Standard deviation	Minimum	Maximum
Milk solids (kg)	172,032	117,526	37,475	628,804
Labour (FTE)	3.51	1.79	1.21	12.18
Land (ha)	279	233	35	1,422
Plant and equipment capital value ($)*	341,542	269,857	40,570	1,483,733
Supplementary feed (tonnes)	1,225	984	189	5,069
Fertiliser (tonnes)	131	149	0	779
Herd size (cows)	348	223	105	1,245
* in 210-11 dollar terms				

Another potential source of data is the ABARES Australian Dairy Industry Survey which has been conducted annually since 1979. It samples 300 farms nationally, 85 in Victoria. The data collected and productivity analyses by ABARES are reported at national and state levels but are not disaggregated to regional levels. Due to the need to maintain confidentiality, these data are not publicly available and hence could not be used in this study.

5. Specification of input and output variables

It is necessary to define a production relationship or production function that is representative of the dairy enterprises. This is done by identifying and measuring the main inputs or resources used and relating these to the main outputs produced. The inputs and outputs comprising the production function should be quantifiable and capture as many aspects of the dairy production relationship as possible.

One output and six input variables are used in this analysis as shown in Table 3. These variables were selected by the farm economists who collect the data, as the most representative of the main output and major inputs to dairy farming systems in Victoria. These input and output variables are similar to those that have been used in other studies (see Table 1).

Table 3: Output and input variables description

Variable	Units	Description
Output	Kilograms (kg) milk solids sold	Milk produced
Inputs		
Labour	Full time equivalents (FTE)	This variable refers to the total labour used (combining employed and imputed labour). One full time equivalent is equivalent to 50hrs/week * 48weeks/year = 2400 hours/year
Grazed area	Hectares (ha)	This variable covers total grazing area minus any area not used in the current season and any area used for fodder production that was not also grazed.
Plant and equipment capital value	$	Average asset value of plant and equipment for the year.
Supplementary feed	Tonnes (t)	Total dry matter including both purchased and home grown concentrates and fodder fed to each cow per year.
Fertiliser	Tonnes (t)	Total fertiliser applied.
Herd size	Number	Herd size is defined as the maximum number of cows milked for a minimum of 3 months.

A number of decisions had to be made in selecting these variables, which are discussed below.

Output: The milk measure chosen was kilograms of milk solids sold. Some other options included litres of milk sold, value of milk sold or value of all outputs sold. Given that these dairy farms are paid per kilogram of milk solids and not per litre[6], it was decided that a solids measure was preferable to a volume measure. A value of milk sold measure was also considered since it has the advantage that it could account for the fact that it is more costly to produce milk in the winter months when extra supplementary feeding is required and hence not penalise those farms which supply the fresh milk market year round. However, the downside of the milk value measure is that some farmers in some regions may not always negotiate identical prices and hence the output measure may be biased by these price differences. Overall, it was judged that few farms in this sample supply large amounts to fresh milk factories, and hence the milk solids measure was preferred. A value of all outputs sold measure was also considered as a possible output measure, since dairy farms do gain some revenue from non-milk products, such as the sale of poddy calves and cull cows. However, given that these items normally make very small contributions to farm revenue, this measure was also not preferred.[7]

Labour: The main choice in the labour measure was between a physical measure (FTE) and a monetary measure (wages). The monetary measure has the advantage that it can account for labour quality differences to some extent, but has the downside that difference in wage rates across farms may be more reflective of supply and demand in regional employment markets and not quality differences. Hence the physical measure was applied in this study.

Grazed area: A value measure could have been considered, in an attempt to reflect soil quality and climatic differences across farms. However, a physical (hectares) measure was considered the wiser choice on balance because farm land prices can be heavily influenced by other factors, such as proximity to town, etc.

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[6] Farmers are paid per kilogram of protein and per kilogram of fat. These combined are called milk solids.

[7] Note that some dairy farms do derive substantial income from non-dairy products. In these cases, the inputs used in these non-dairy enterprises were extracted from the input measures so that only dairy-related inputs remained.

Plant and equipment: A physical measure was not an option here because of the heterogeneous nature of these items across farms. The measure is taken as the average of opening and closing values for the year. Generally, items are depreciated at three to four per cent per year for fixed assets and nine to eleven per cent per year for plant and equipment. This type of capital measure is often used in TFP studies. It is an imperfect measure because it can be a biased measure of the true service capability of the capital items because of the effects of accounting depreciation and sub-optimal price deflators on the estimates. A more defendable measure would be an undepreciated replacement cost of capital measure, but these are rarely available. For further discussion of capital measurement issues, see Chapter 5 in Coelli et al (2005).

Supplementary feed: This is an aggregate of the tonnes of all grain, fodder and concentrates fed to the herd (both purchased and produced on farm). A value measure could be used instead so as to provide greater weight to the more nutritious feed items. However, it would have the downside of being affected by regional variations in feed prices. Perhaps a more optimal measure could involve the construction of a quantity index (e.g., using a Fisher index formula), however this is beyond the scope of the current study.[8]

Fertiliser: This is also a physical aggregate of tonnes of all types of fertilisers applied, ranging from complex nitrogen, phosphorus, and potassium mixes to simple lime. Similar comments to those made regarding the above feed measure could also be made here.

Herd size: This is defined as the maximum number of cows milked for a minimum of three months. This measure was chosen as it more accurately reflects the number of cows milked across the year. Using the average of the number of cows milked each month can result in lower than actual results - especially if cows have been dried off for some time prior to calving.

The above input variables capture the major inputs (in terms of their contribution to economic costs) in dairy production. Other minor input variables, such as animal health costs (vet costs, drenches, etc.), energy and irrigation are expected to contribute less than ten per cent to the economic costs of a dairy farm, and have hence not been included in this study.

6. Results and discussion

Estimates of changes in TFP, technical efficiency and technological progress are summarised in this section. Information on the means of the measures of TFP change, technical efficiency change and technological change for each dairy farm and the mean changes between years are provided.

6.1 Overall changes in TFP, technical efficiency and technological progress

The overall mean TFP did not change over the four-year period (Table 4). However, mean technical efficiency change was 1.4 per cent per year, offset by a corresponding fall in technological change. TFP grew in 2010-11 by 2.3 per cent, but fell in the two preceding years by 1.0 per cent and 1.1 per cent in 2008-09 and 2009-10, respectively. Overall, these results are not dissimilar to other productivity growth estimates for dairy farms in Victoria. Kompas and Che (2004) estimated a zero TFP growth rate for the Victorian dairy industry during the 1989-90 to 1998-99 period and a 1.3 per cent rate per annum over a longer period (1978-79 to 1998-99). The most recent estimate of long-term TFP growth for the Victorian dairy has been 0.1 per cent per annum from 1988-90 to 2008-09 (Gray et al. 2011).

Table 4: Summary of overall changes in Malmquist TFP

Year	Technical efficiency change (TEC) (%)	Technological change (TC) (%)	TFP change (TFPC) (%)
2008-09	2.8	-3.7	-1.0
2009-10	0.6	-1.7	-1.1
2010-11	0.7	1.6	2.3
Mean	1.4	-1.3	0.0

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[8] The fact that this feed variable includes fodder produced on-farm means that this measure will be affected by double-counting to some extent, given that labour, fertiliser and equipment (e.g., tractors and ploughs) used in the production of fodder are included in other variables. However, we believe that these fodder-related inputs only make a small contribution to these other input variables.

6.2 Regional changes in TFP, technical efficiency and technological progress

This section highlights differences in results across the three dairying regions in Victoria. Table 5 shows that the South West registered the best performance, followed by Gippsland, and then Northern Victoria.[9] On average, farms in the South West registered an annual positive TFP growth of approximately 3.7 per cent resulting from an increase of 2.8 per cent in technical efficiency and 0.8 per cent in technological progress. The South West region has also been the best performing region over the 2007-08 to 2010-11 period in terms of financial statistics (e.g. return on equity) collected by DIFMP.

Table 5: Summary of regional changes in annual Malmquist TFP

Region	Technical efficiency change (TEC) (%)	Technological change (TC) (%)	TFP change (TFPC) (%)
Gippsland	2.2	-0.1	2.1
Northern Victoria	-0.9	-4.6	-5.4
South West	2.8	0.8	3.7
Mean	1.4	-1.3	0.0

Gippsland was the second best performer, with a positive TFP growth of 2.1 per cent per year. This was essentially due to technical efficiency improving 2.2 per cent, along with a small decline of 0.1 per cent in technological change. The Gippsland region has the smallest farms and smallest herds. However they are run more intensively than farms in the other two regions.

Northern Victoria showed an overall negative TFP growth of 5.4 per cent per year. This decline in TFP growth is attributable to declines in both technical efficiency (0.9 per cent) and technological change (4.6 per cent). The main reasons for this poor performance is likely to be two years of low rainfall and low water allocations followed by a year of flood, as discussed below.

6.3 Discussion of TFP change measures

A combination of factors may have slowed productivity growth and resulted in differences across the three regions. This section discusses possible drivers for the TFP growth trends reported in Sections 6.1 and 6.2.

Global milk prices: Victoria’s dairy industry is predominantly export oriented and is therefore directly impacted by global milk prices. Farmers interested in increasing their profits will tend to increase production when milk prices are high and vice versa. This may produce a “terms of trade” effect where a high milk price might induce a temporary expansion of output that is profitable but not necessarily technically efficient. Global milk prices were 6.68, 5.14, 4.49, and 5.64 (in $/kg milk solids) in 2007-08, 2008-09, 2009-10, and 2010-11, respectively (Dairy Australia 2011, DPI 2011a). However, both milk production and TFP fell in 2008-09 and 2009-10 (see Tables 4 and 6) which does not provide support for the terms of trade hypothesis in this instance.

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[9] Appendix A1 presents the mean results for individual farms.

Table 6: Changes (%) in output and inputs levels

Period	Region	Milk solids	Labour	Land	Plant and equipment capital value	Supplementary feed	Fertiliser	Herd size
2007-08 to 2008-09	Gippsland	7.1	4.5	14.0	9.1	36.46	-17.9	9.1
	Northern Victoria	6.2	3.3	-3.7	5.7	10.71	-13.8	7.9
	South West	5.0	0.0	4.1	2.4	11.81	-29.9	1.7
2008-09 to 2009-10	Gippsland	-0.1	0.0	0.0	-0.1	-0.18	-0.4	0.0
	Northern Victoria	-0.1	0.0	0.0	0.1	-0.16	0.4	0.0
	South West	0.0	0.0	0.0	0.0	-0.04	0.1	0.0
2009-10 to 2010-11	Gippsland	7.4	0.3	5.6	-0.1	-9.91	-15.2	0.2
	Northern Victoria	-2.4	2.5	4.0	3.2	-6.26	-47.9	0.1
	South West	7.3	6.5	10.4	0.9	-4.91	-23.6	12.8
Mean	Gippsland	4.8	1.6	6.5	3.0	8.79	-11.1	3.1
	Northern Victoria	1.2	1.9	0.1	3.0	1.43	-20.4	2.6
	South West	4.1	2.2	4.8	1.1	2.29	-17.8	4.8
	Overall	**3.4**	**1.9**	**3.8**	**2.4**	**4.2**	**-16.5**	**3.5**

Seasonal conditions: Seasonal conditions can have a major impact on dairy farm production. A study by Kompas and Che (2006) estimated that the 1998 drought reduced Victoria’s dairy output by 10 per cent. If a climatic measure (e.g., rainfall) is not explicitly included in a TFP model, we are likely to see low rainfall result in lower pasture production and hence lower output (*ceteris paribus*) which in turn will result in a lower measure of TFP. Alternatively, the lower pasture production can induce an increase in supplementary feeding and capital investments (e.g. in feed-pad systems) so as to maintain output levels. This can also have a negative effect on TFP measures (*ceteris paribus*). We observe that 2008-09 was drier than 2007-08 across most of the state which can explain the increase in supplementary feeding. The drier conditions also meant that most farmers did not grow much pasture which could explain the reduced application of fertiliser. There were favourable seasonal conditions in 2010-11. There was good spring fodder growth across the state with 100 per cent irrigation water allocations (DPI 2011a).

Rainfall data can be used to provide an (imperfect) indicator of seasonal conditions. The Australian Bureau of Meteorology produces an aggregate summary rainfall measure for Victoria each year, which is available from their website[10] for the years 1900-2010. The mean of this series is 648 mm. In 2007, 2008 and 2009 rainfall was below average at 615, 511 and 536 mm, respectively. It was then well above average at 866 mm in 2010. Thus, low rainfall appears to coincide with low TFP levels over the time period considered in our study.

Regional differences: The differences in TFP growth across regions could be due to the differing dairying production systems in these regions. The dairy production systems depend on a range of factors including soil type, irrigation scheduling and irrigation water availability, grazing management, and the size and timing of rain events (DPI 2011a). Our results showed major differences between South West and Gippsland (positive TFP growth) and Northern Victoria (negative TFP growth). Milk production in Northern Victoria has fallen by 1.33 million litres since 2001-02, primarily due to drought conditions and shortages in water allocations (DPI 2011b).

The South West and Gippsland farms are predominantly in the high rainfall zone, while the Northern Victoria farms rely heavily on irrigation allocations to grow pasture. The recent reductions in water allocation have seen a much higher reliance on purchased supplementary feed. Northern Victoria was hardest hit over 2008-09 and 2009-10 by low water allocations which might explain the observed negative TFP growth. In addition to this, a number of dairy farms in Northern Victoria were affected by the floods in the January-March 2011 period, which damaged pastures and affected dairying operations (ABARES 2011).

While floods adversely impacted dairying operations in Northern Victoria there was good rainfall in Gippsland and the South West, which led to excellent pasture growth. It was the best season in the past five years in these two regions, which resulted in reduced reliance on supplementary feeding.[11] Pasture growth is more reliant on rainfall than on fertiliser, which explains the large reductions in fertiliser usage during favourable seasonal conditions. Other than fertiliser and supplementary feeding, the other input variables remained relatively stable. Therefore, seasonal conditions seem to amplify the regional differences in the estimated TFP growth since global market prices are uniform across all regions. This assessment is supported by DPI (2011b)

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[10] http://www.bom.gov.au/cgi-bin/climate/change/timeseries.cgi?graph=rain&area=vic&season=0112&ave_yr=T.

[11] Daniel Gilmour, Specialist - Farm Business Economist, Farm Services Victoria, DPI, 30 November 2011

who concluded that industries in Gippsland and the South West regions experienced less severe production declines because of more reliable water supplies and less exposure to drought conditions.

Technological regress: The TFP results in Table 4 indicate technological regress of 1.3 per cent per year. This may appear strange, since it is unlikely that technological advancements can be “forgotten” by dairy farmers. However, a more likely explanation can be found in the fact that the irrigated farms in the Northern region have been defining much of the production frontier (refer to Appendix A2). As an irrigation input variable has not been included in the TFP model these farms appear to be more efficient than the unirrigated farms. However, during the period of analysis these irrigated farms have experienced two years of low water allocations followed by a year of floods, reducing their TFP levels (see Table 5). Hence, this group of frontier farms has fallen “back to the pack” bringing the frontier backwards with them.

A number of past TFP analyses of dairy farms have also found some technological regress. Moreira-Lopez et al. (2006) found significant technological regress averaging 17 per cent per annum for 46 Argentinean dairy farms from 1997–98 to 2001–02. Tauer (1998) observed that 17 out of 70 New York dairy farms experienced technological regress. Brummer et al. (2002) reported 9 per cent technological regress for Polish dairy farms, while Latruffe and Fogarasi (2009) reported annual technological regress of 14 per cent for Hungary.

Technological regress can be the result of various factors, such as data measurement issues, climatic variations, environmental degradation, changes in regulatory constraints and insufficient R&D activity. Some or all of these factors may help explain the technological regress found in our study. However, we expect that the availability of irrigation water and climatic factors (in particular in the Northern Region) are likely to be the primary explanation.

Industry-level TFP change estimates: The summary measures reported in this study are unweighted sample means. These provide an estimate of the performance of the average farm, but they need not provide a good estimate of the performance of the industry if farm-level TFP growth differs by farm size.[12] For example, if larger farms experience faster TFP growth then the unweighted sample result will underestimate the industry TFP growth rate. To address this issue we have calculated a weighted geometric mean measure of TFP growth, where the weights are the output quantities. The resulting annual average TFP growth measure is 0.5 per cent (as opposed to the 0.0 per cent unweighted measure) suggesting that the industry has experienced some TFP growth over the sample period.

6.4 Decomposing technical efficiency change performance

As noted by Coelli et al (2005), it may be possible that even in the absence of any technological change and where the farm under consideration is technically efficient, there is scope to improve productivity by improving scale efficiency.

Recalling that the Malmquist measure of TEC can be decomposed into PTEC and SEC, this section summarises this TEC decomposition. The PTEC measure represents core efficiency due to improved operations and management while scale efficiency is associated with returns to scale effects. The relationship between PTEC and SEC is presented in Figure 1. The PTEC and SEC results can be interpreted as follows. For the sample of dairy farms, if PTEC is greater than the SEC, then an improvement in PTE is likely to explain most of the efficiency changes. However, if PTEC is less than the SEC it is likely that the resulting efficiency changes can be mainly attributed to improvements in scale efficiency.

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[12] For example, see Coelli et al (2005, p309).

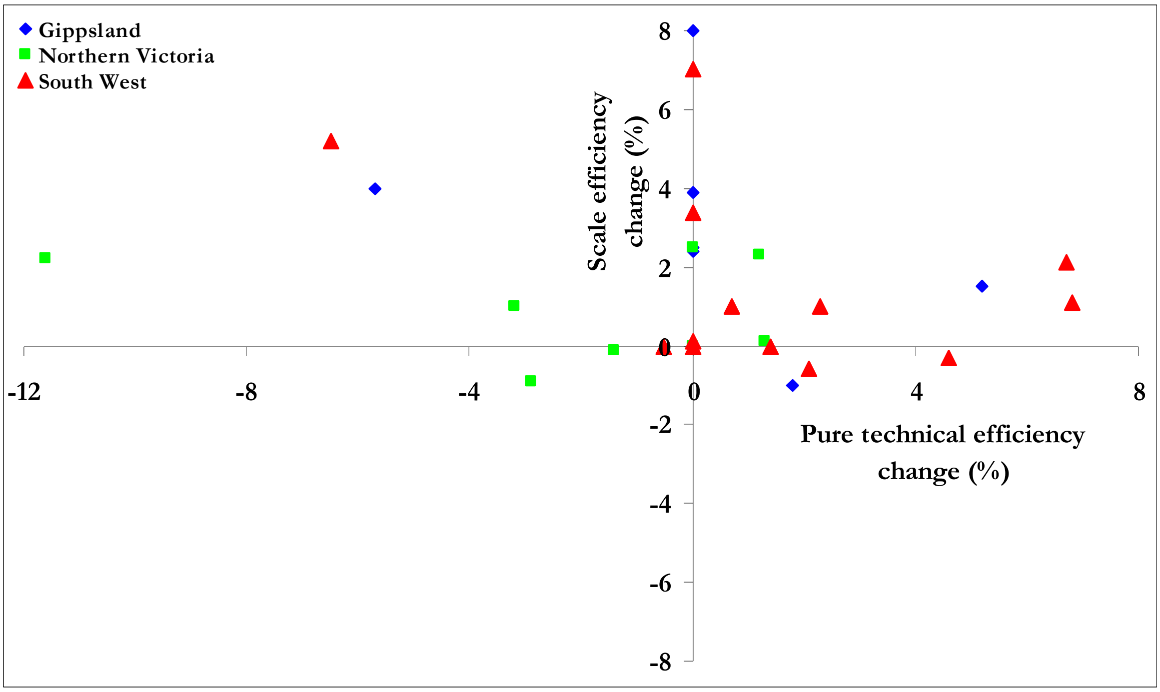

Figure 1: Relationship between PTEC and SEC

Overall, there were no changes in PTEC during the study period. However, the SEC registered an increase of 1.4 per cent. Results in Table 4 show that TEC increased by 1.4 per cent which can be wholly attributed to increased scale efficiency. There was no clear-cut relationship between PTEC and SEC (Figure 1).

Figure 2 depicts regional performances. South West and Gippsland registered improvements in PTEC. PTEC declined in Northern Victoria. South West's improved its TEC by 2.84 per cent. All regions improved their SEC. In the short term, improving technical efficiency to raise TFP could be achieved in relatively shorter timeframes and might be less costly than changing technologies to raise TFP.

The balanced panel dataset used in the calculation of the Malmquist indexes was also used to compute technical efficiency to determine the profile of the dairy farms in terms of scale economies (Appendix A2). The literature distinguishes scale efficient farms as those exhibiting constant returns to scale (CRS) and scale inefficient farms as those exhibiting increasing returns to scale (IRS) or decreasing returns to scale (DRS). Farms falling within the IRS group are too small in their scale of operations and could improve their efficiency by becoming larger than they presently are. Conversely, farms falling within the DRS group are too large in their scale of operations and may improve productivity by decreasing their size (Coelli et al. 2005).

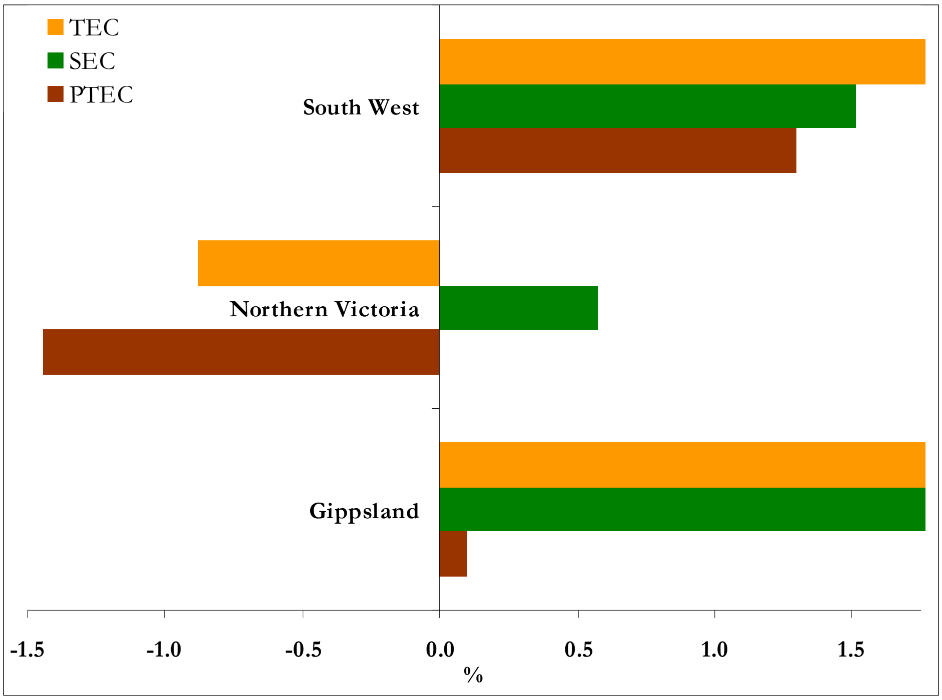

Figure 2: Decomposing technical efficiency change

Appendix A2 shows that 34 per cent of the farms exhibit CRS; 31 per cent exhibit IRS; and 34 per cent exhibit DRS. This implies that 68 per cent of the sample farms could improve their productivity by improving their scale efficiency. The majority of the farms (60 per cent) that are efficient (CRS) are located in Northern Victoria. Most of the farms exhibiting IRS were located in South West and Gippsland (46 per cent each). The majority of the farms exhibiting DRS were located in Northern Victoria and South West regions.

Although our results show that SEC improved by 1.4 per cent, Appendix A2 shows that more productivity could be achieved by further improvements in scale efficiency. Overall scale efficiency could be improved by 6 per cent. Regionally, scale efficiency could be improved by 13 per cent in Gippsland, 5 per cent in South West and 2 per cent in Northern Victoria which had the best scale efficiency levels.

6.5 Qualitative farm assessment to validate DEA results

None of the studies identified in Section 3 sought to compare their Malmquist index results with qualitative measures of farm level performance. We sought to validate the Malmquist indexes by asking the farm economists involved in collecting the sample data to assess and rate the best performing farms among the DIFMP sampled farms. The assessment was conducted by four farm business economists, one based in each of the dairying regions together with their Manager. The assessing team has on average ten years field experience in the dairy industry, with their experience ranging from four to twenty years.

The assessment to identify the best performing farms was conducted using both a financial assessment and qualitative assessment. Key financial indicators assessed included: return on assets; earnings before interest and tax, return on equity, and net farm income. Following this initial financial performance assessment, each farm was then assessed by their ability to manage the whole farm system. This included judging how the farms manipulate the biophysical, environmental, human and economic systems on their farms given the external environment and accounting for risk. Pasture and herd management were also considered. The DPI's Farm Services Victoria data collectors have an intimate understanding of the farming systems and therefore were able to make accurate judgements based on these criteria. Based on this qualitative assessment, farms F9, F16, F17, F18, F27, F32 and F33 were identified as the best performers.

The next step involved assessing how the selected farms performed in terms of the TFP change and profitability change (Figure 3). One of the interesting outcomes of this is how well the TFP change estimates derived from DEA align with the subjective rankings provided by the farm economists. Of the seven farms selected by the farm business economists, six showed positive TFP growth. Farm F9 showed a slight decline in TFP growth of -0.90 per cent. The overall profitability (EBIT) change for three farms — F16, F27 and F32 — was negative.

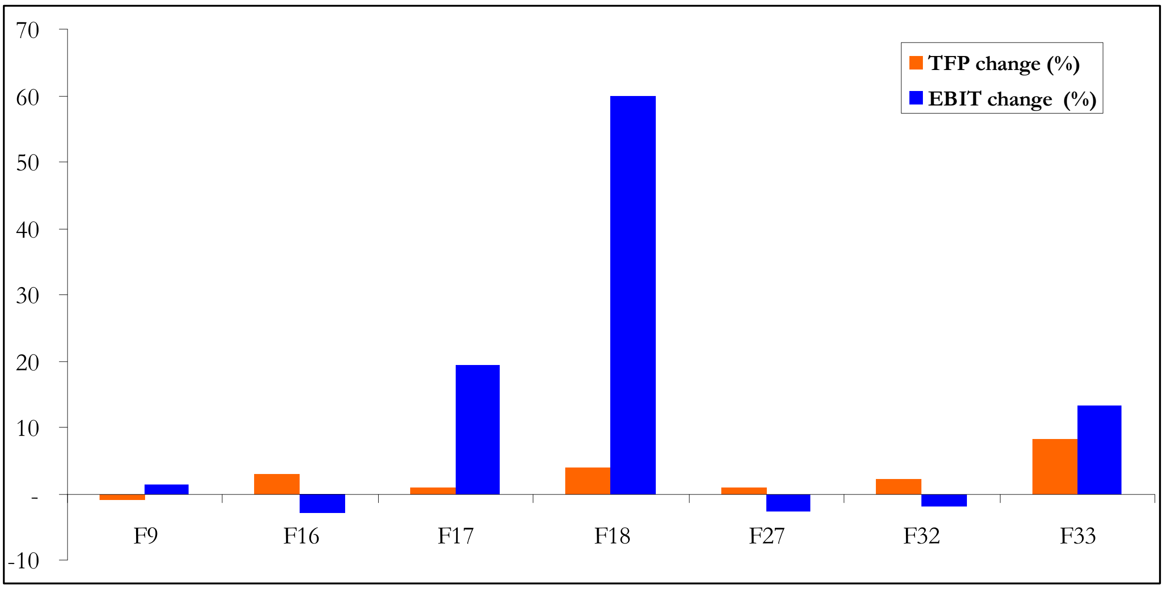

Figure 3: TFP and EBIT changes for the qualitatively selected dairy farms

There are many studies that have used techniques such as DEA without validating modelling results. This validation helps to ensure that model results can be relied upon. The interaction between data collectors and analysts is essential if DEA (and any other technical methodology) is to be relied upon to provide accurate input into policy advice. This validation of TFP provides confidence in the TFP results reported in this paper.

6.6 Comparing farm profitability with productivity

Productivity and profitability are related concepts. Profitability is determined by two factors: productivity and the terms of trade, derived as a ratio of prices received to prices paid. As agricultural output and input prices are determined largely on global markets, farm managers have a negligible influence over their terms of trade. Therefore, it is only productivity that farm managers can improve through innovation in technologies and management systems (Nossal and Sheng 2010). Hence, while profitability is typically the objective of farm managers, they most commonly influence their profits through changes in productivity.

Spearman's rank correlation was used to compare levels of farm profitability and productivity levels (measured as technical efficiency) to assess the nature of the relationship between these two attributes. Spearman's rank correlation coefficient is a non-parametric measure of statistical dependence between two variables. A Spearman correlation of +1 or −1 occurs when each of the variables is a perfect monotone function of the other while a value of 0 indicates that there is no relationship.

Technical efficiency data from this study and profitability data published annually by DIFMP were used. The DIFMP publishes farm level data relating to profitability performance of dairy farm businesses in Victoria. Using two measures of profitability — (i) EBIT/hectare; and ii) ROA — farm level performance was compared with farm specific productivity performance. EBIT/ha is selected because it does not rely on asset valuation which in many cases can be subjective. ROA is employed because it indicates how well a farm has used its assets to generate profits.

Figure 4 shows the relationship between technical efficiency (TE) and EBIT, while Figure 5 depicts the relationship between TE and ROA. Spearman's rank correlations are estimated to be 0.15 and 0.13 for EBIT versus TE and ROA versus TE, respectively. These positive values are consistent with our expectations.

The above comparisons were made between levels of profitability and technical performance. It is also of interest to examine the relationship between changes in profitability and technical performance (i.e., TFP) over time. This analysis is depicted in Figures 6 and 7. Furthermore, Spearman's rank correlations are estimated to be -0.29 and 0.10 for change in EBIT versus TFPC and change in ROA versus TFPC, respectively. A negative value is not entirely consistent with our expectations (ceteris paribus). However, the large output price changes experienced during this period have had a dominant influence on profitability (relative to the effects of TFP changes) and hence a non-positive correlation is not improbable.

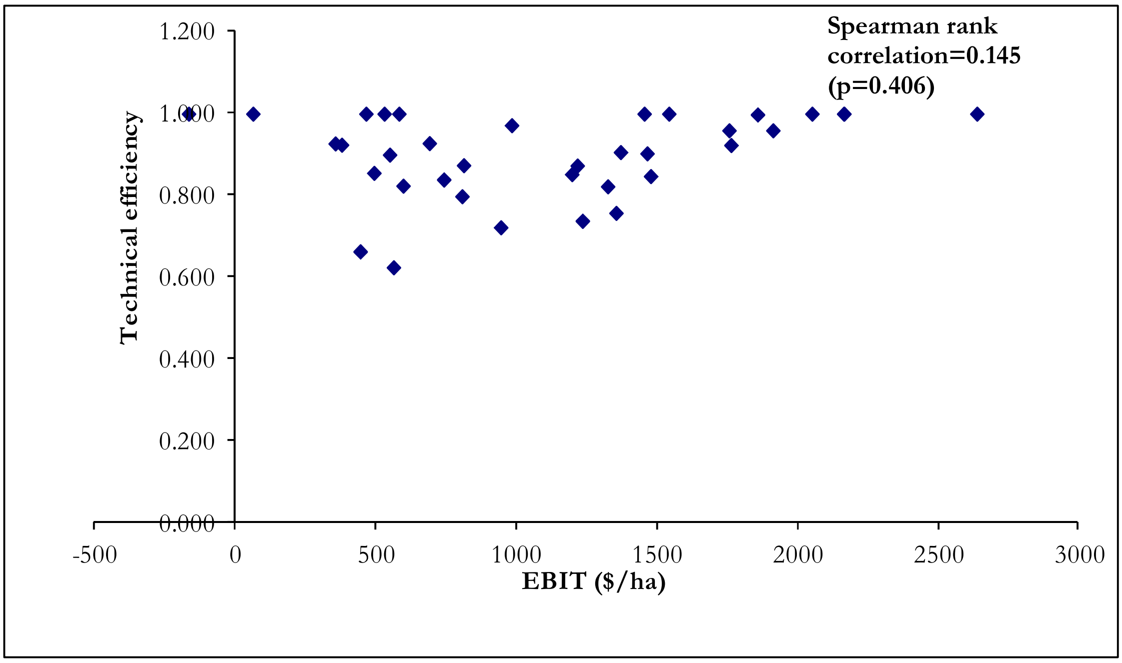

Figure 4: Relation between technical efficiency and EBIT

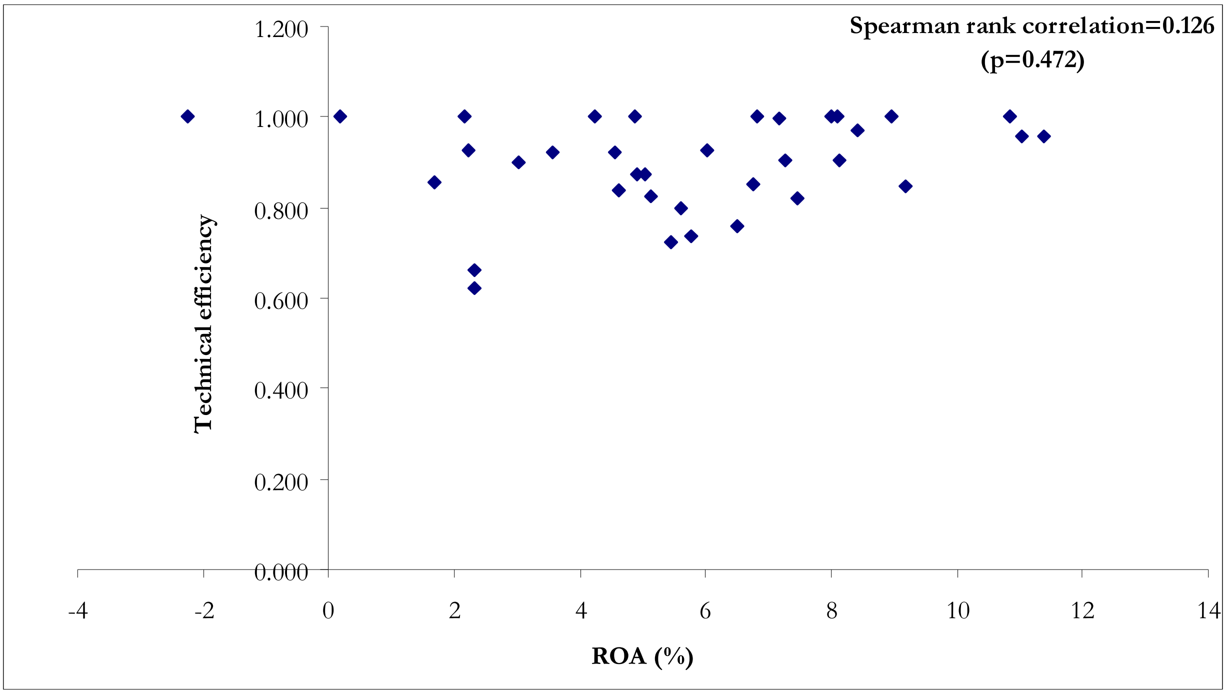

Figure 5: Relationship between technical efficiency and ROA

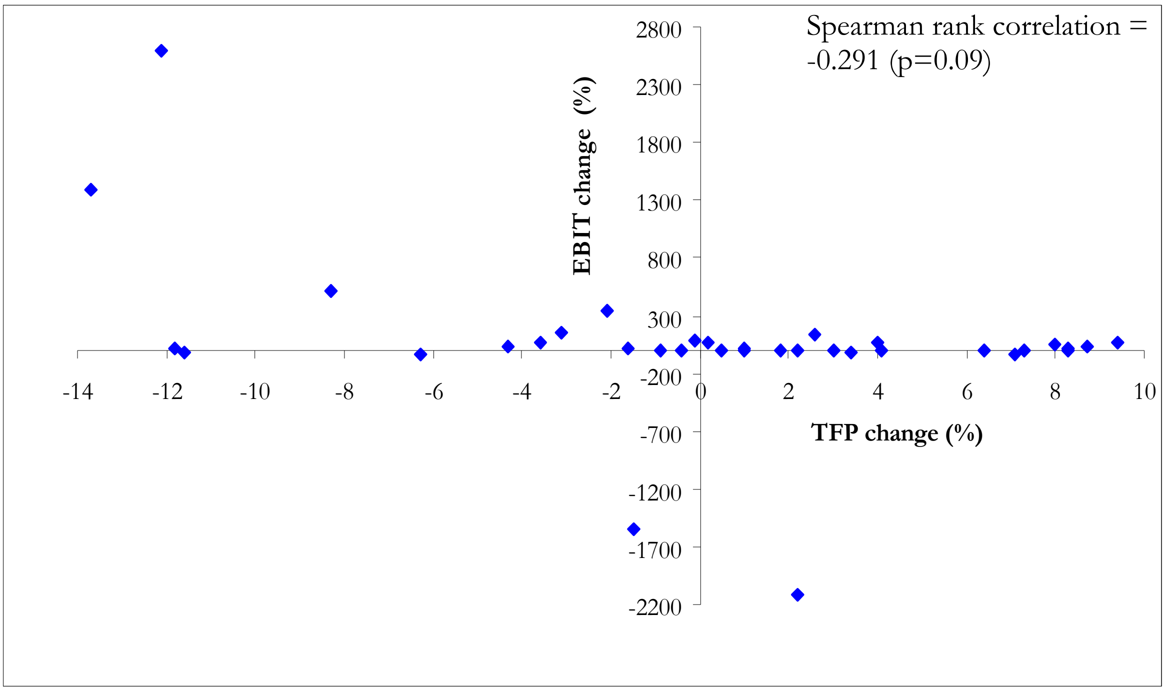

Figure 6: Relationship between TFP change and EBIT change

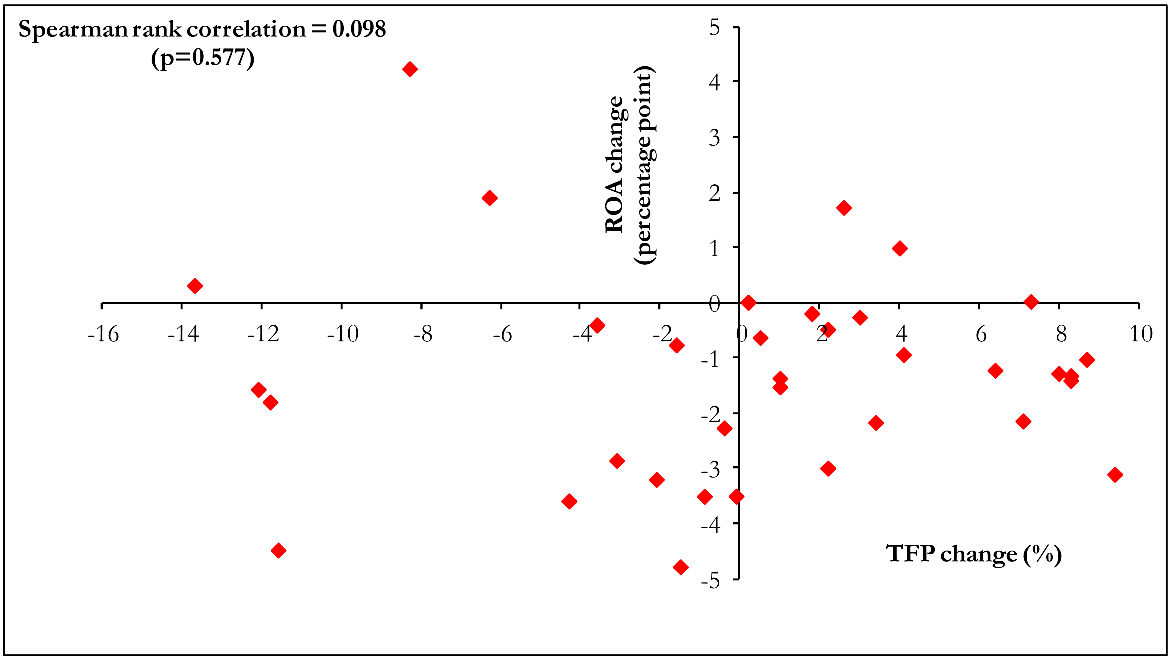

Figure 7: Relationship between TFP change and ROA change

6.7 Other considerations in TFP measurements

There are two emerging areas of research related to agricultural productivity. The first area of research relates to the impact that climate has on agricultural productivity. The second area of research relates to the impact that agriculture has on the environment. This study did not consider these two aspects due to data limitations. ABARES has embarked on advancing their productivity index methodology to investigate the effects of climate variability. This has been undertaken for broadacre agriculture, but has not yet been undertaken for the dairy industry.

Graham (2009) states that measures of the agricultural sector's performance need to take environmental impacts, whether positive or negative, into account when calculating TFP changes. Graham compared a traditional productivity analysis to social productivity (including a measure of leaching and run-off as a proxy measure of the impact that the application of fertilisers has on ground and surface water) and showed that the environmentally sensitive productivity growth was lower (8.7%) than the conventional productivity growth (12.5%) (Graham 2009). This implies that the TFP changes reported in this study might have been lower had the environmental impacts of the dairy industry been incorporated.

7. Conclusion

The main motivation for this study was to estimate and decompose productivity changes into technical efficiency and technological change for the dairy sector in Victoria and explore regional differences in productivity performance. This study utilised DPI's Dairy Industry Farm Monitor Project data set.

We make use of detailed farm-level data on 35 dairy farms observed over a four-year period from 2007-08 to 2010-11 (obtained from the DIFMP survey) to measure TFP growth using the Malmquist DEA method. This method produces TFP measures for each farm in the sample and also allows us to decompose the TFP growth measures into TC and TEC components.

The empirical results indicated that overall these farms experienced zero TFP growth over this four-year period. This result is not inconsistent with the measure of 0.1% TFP growth reported in Gray et al (2011). However, regional TFP growth measures differ substantially across the three main dairying regions in Victoria, ranging from 3.7% in the South West and 2.1% in Gippsland, to minus 5.4% in Northern Victoria. Much of the poor performance in the North can be explained by external factors that were not under the control of farm managers. In particular, low irrigation water allocations in 2008 and 2009, followed by damaging floods in 2010.

Thus, if the Northern region is omitted from the analysis, average TFP growth measures in excess of 2% per year, which are higher than the national average TFP growth of 0.8% per year reported in Gray et al (2011) for the 1988-89 to 2008-09 period. However, we note that our analysis period is short and ends in a year when seasonal conditions were quite favourable for pasture production in these regions. In addition, as noted earlier, the sample of firms included in DPI's Dairy Industry Farm Monitor Project data set are likely to be farms that are better than what is truly 'average' in the industry. Based on anecdotal information, farms in the sample are most likely representative of the top 30 to 40 per cent of farms in the industry.

Our TFP change measures were also decomposed into TEC and TC measures, providing an average TEC measure of 1.4% offset by an equivalent amount of TC decline. This apparent "technical regress" in the frontier can be explained by the fact that a number of irrigated farms in the Northern region had been defining the frontier, but had "fallen back to the pack" when affected by low water allocations and flood and had hence brought the measured frontier back with them. It would be expected that in a study involving a longer time-period, these types of external events would average out and positive technical progress may then be observed. Additionally, the short time period of the analysis is likely to fail to capture the productivity benefits of technological and operational improvements made to maintain output during the drought.

One of the main contributions of this paper is the qualitative assessment used to validate the DEA results. Many studies use techniques such as DEA without validating modelling results. Validation helps to ensure that model results can be relied upon. The majority of the dairy farms assessed by the farm business economists as best performers were also found to have strong TFP growth. This validation provides confidence in the TFP results reported in this paper. The study also finds a positive relationship between farm profitability and technical efficiency.

Overall, our results indicate that Victorian dairy industry TFP growth has been quite strong in recent years, when adjustments are made for the effects of external factors in the Northern region. However, further research is needed on a longer time series of data in order to obtain better estimates of TFP growth that are less affected by external factors, such as climatic events. Furthermore, policymakers and the dairy industry should aim to ensure that improving dairy productivity from the current levels is a major goal for the industry. The government has a role to play in developing policies that promote agricultural productivity growth. These policies should be included within an agricultural development framework that helps increase technical efficiency, transfer technology and the implementation of best agricultural practices.

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Appendices

Appendix A1: Decomposition of the Malmquist total factor productivity change index

Region	Dairy farm	Pure technical efficiency change (A)	Scale efficiency change (B)	Technical efficiency change (C=A*B)	Technological change (D)	TFP change (E=C*D)
Gippsland	F1	1.000	1.025	1.025	1.000	1.026
	F2	1.000	1.080	1.080	1.006	1.087
	F3	1.000	1.039	1.039	1.002	1.041
	F4	1.000	1.024	1.024	1.010	1.034
	F5	1.018	0.990	1.008	1.014	1.022
	F6	1.000	1.000	1.000	0.957	0.957
	F7	1.052	1.015	1.067	1.025	1.094
	F8	0.943	1.040	0.980	0.999	0.979
	F9	1.000	1.000	1.000	0.991	0.991
	F10	1.000	1.000	1.000	0.984	0.984
Northern Victoria	F11	1.000	1.000	1.000	0.937	0.937
	F12	1.012	1.023	1.036	0.849	0.879
	F13	1.000	0.999	0.999	0.970	0.969
	F14	0.968	1.010	0.978	1.025	1.002
	F15	0.986	0.999	0.984	0.979	0.964
	F16	1.013	1.001	1.014	1.015	1.030
	F17	1.000	1.000	1.000	1.010	1.010
	F18	1.000	1.000	1.000	1.040	1.040
	F19	1.000	1.025	1.025	0.841	0.863
	F20	1.000	1.000	1.000	0.917	0.917
	F21	0.884	1.022	0.903	0.977	0.882
	F22	0.971	0.991	0.962	0.919	0.884
South West	F23	1.046	0.997	1.043	1.020	1.064
	F24	1.067	1.021	1.090	0.994	1.083
	F25	1.000	1.000	1.000	0.985	0.985
	F26	1.007	1.010	1.017	1.001	1.018
	F27	1.000	1.001	1.001	1.009	1.010
	F28	1.023	1.010	1.033	1.037	1.071
	F29	1.000	1.070	1.070	1.003	1.073
	F30	1.068	1.011	1.080	1.000	1.080
	F31	1.021	0.994	1.015	0.990	1.005
	F32	1.000	1.034	1.034	0.988	1.022
	F33	1.014	1.000	1.014	1.068	1.083
	F34	0.935	1.052	0.984	1.013	0.996
	F35	0.995	1.000	0.995	1.004	0.999
Mean		**1.000**	**1.014**	**1.014**	**0.987**	**1.000**

Appendix A2: Total factor productivity profiles for the dairy farms

Region	Dairy farm	CRS technical efficiency	VRS technical efficiency	Scale efficiency	RTS	Pure technical efficiency change (%)	Scale efficiency change (%)	Technical efficiency change (%)
Gippsland	F1	0.663	1.000	0.663	irs	0.00	2.50	2.50
	F2	0.738	1.000	0.738	irs	0.00	8.00	8.00
	F3	0.873	1.000	0.873	irs	0.00	3.90	3.90
	F4	0.923	1.000	0.923	irs	0.00	2.40	2.40
	F5	0.924	0.947	0.976	irs	1.80	-1.00	0.80
	F6	1.000	1.000	1.000	crs	0.00	0.00	0.00
	F7	0.822	0.860	0.956	drs	5.20	1.50	6.70
	F8	0.874	1.000	0.874	drs	-5.70	4.00	-2.00
	F9	1.000	1.000	1.000	crs	0.00	0.00	0.00
	F10	1.000	1.000	1.000	crs	0.00	0.00	0.00
	Mean	**0.859**	**0.983**	**0.876**		**0.10**	**2.10**	**2.19**
Northern Victoria	F11	1.000	1.000	1.000	crs	0.00	0.00	0.00
	F12	0.900	0.964	0.934	drs	1.20	2.30	3.60
	F13	1.000	1.000	1.000	crs	0.00	-0.10	-0.10
	F14	0.824	0.868	0.950	drs	-3.20	1.00	-2.20
	F15	0.839	0.853	0.984	drs	-1.40	-0.10	-1.60
	F16	0.959	0.961	0.998	drs	1.30	0.10	1.40
	F17	1.000	1.000	1.000	crs	0.00	0.00	0.00
	F18	1.000	1.000	1.000	crs	0.00	0.00	0.00
	F19	0.928	1.000	0.928	irs	0.00	2.50	2.50
	F20	1.000	1.000	1.000	crs	0.00	0.00	0.00
	F21	0.927	1.000	0.927	drs	-11.60	2.20	-9.70
	F22	1.000	1.000	1.000	crs	-2.90	-0.90	-3.80
	Mean	**0.955**	**0.972**	**0.983**		**-1.44**	**0.58**	**-0.88**
South West	F23	0.798	0.798	1.000	crs	4.60	-0.30	4.30
	F24	0.722	0.781	0.925	drs	6.70	2.10	9.00
	F25	1.000	1.000	1.000	crs	0.00	0.00	0.00
	F26	0.903	0.980	0.922	drs	0.70	1.00	1.70
	F27	0.998	1.000	0.998	irs	0.00	0.10	0.10
	F28	0.855	0.884	0.967	irs	2.30	1.00	3.30
	F29	0.757	1.000	0.757	drs	0.00	7.00	7.00
	F30	0.624	0.712	0.876	irs	6.80	1.10	8.00
	F31	0.906	0.926	0.978	irs	2.10	-0.60	1.50
	F32	0.852	1.000	0.852	drs	0.00	3.40	3.40
	F33	0.959	0.959	1.000	crs	1.40	0.00	1.40
	F34	0.847	1.000	0.847	drs	-6.50	5.20	-1.60
	F35	0.972	0.982	0.990	irs	-0.50	0.00	-0.50
	Mean	**0.876**	**0.922**	**0.948**		**1.30**	**1.51**	**2.84**
	Overall mean	**0.897**	**0.956**	**0.938**		**0.00**	**1.40**	**1.40**

crs=constant returns to scale; vrs=variable returns to scale

irs=increasing returns to scale;drs=decreasing returns to scale

Appendix A3: Acronyms and terminology of terms

Acronyms

ABARES	*Australian Bureau of Agricultural* and Resource Economics and Sciences
ADIS	Australian Dairy Industry Survey
DEA	Data envelopment analysis
DIFMP	Dairy Industry Farm Monitor Project
DPI	Department of Primary Industries
EBIT	Earnings before interest and tax
PTEC	Pure technical efficiency change
RD and E	Research, development and extension
ROA	Return on assets
SD	Standard deviation
SEC	Scale efficiency change
TC	Technological change
TEC	Technical efficiency change
TFP	Total factor productivity
TFPC	TFP change

Terminology

Data envelopment analysis	A linear programming method that constructs a nonparametric production frontier by fitting a piece-wise linear surface over data points.
Earnings before interest and tax (EBIT)	Gross income minus total variable costs and total overhead costs.
Full time equivalent (FTE)	Standardised labour unit. Equal to 2400 hours a year. Calculated as 50 hours a week, 48 weeks a year.
Panel data	Panel data contains observations on multiple phenomena observed over multiple time periods for the same farms. A panel is described as balanced if there is an observation for every unit of observation for every time period, and as unbalanced if some observations are missing.
Production frontier	A function that represents the maximum output that can be produced using a given amount of input(s). Production frontiers are estimated using sample data on the inputs and outputs used by a number of farms.
Return on assets (ROA)	Earnings before interest and tax divided by the value of total assets.
Scale efficiency	A measure of the degree to which a farm is optimising the size of its operations. A farm can be too small or too large, resulting in a productivity penalty associated with not operating at the technically optimal scale of operation.
Spearman's rank correlation coefficient	A non-parametric measure of statistical dependence between two variables assessing how well the relationship between two variables can be described. A perfect Spearman correlation of +1 or −1 occurs when each of the variables is a perfect monotone function of the other.
Technical efficiency	Farm’s ability to achieve maximum output given its set of inputs.
Technological change	This is an increase in the maximum output that can be produced given a set of inputs, and is reflected in a shift in the production frontier over time.
Total factor productivity	Total factor productivity is typically thought of as the ratio of a measure of total output quantity to a measure of total input quantity used in production. TFP growth compares changes in this ratio over time, and is the growth rate of outputs that is above and beyond the growth of inputs.