The Australian Journal of
Agricultural and
Resource Economics

AARES
AUSTRALASIAN AGRICULTURAL & RESOURCE ECONOMICS SOCIETY

Australian Journal of Agricultural and Resource Economics, 64, pp. 477–504

Deregulation reforms, resource reallocation and aggregate productivity growth in the Australian dairy industry*

Yu Sheng, Will Chancellor and Thomas Jackson†

Deregulation reforms in the Australian dairy industry had long-lasting repercussions for Australian agriculture and the wider Australian economy. Using farm-level data from 1979 to 2013, we investigate the effect of these reforms on productivity in the Australian dairy industry which arose from correcting resource misallocation between farms and across segregated state milk markets. Our results demonstrate that after the dairy reforms in 2000, relative market share shifted from less productive farms to more productive ones, and between farms using different production systems – generating additional productivity gains for the farm sector, but imposing some costs on downstream manufacturers by strengthening the seasonality of milk supply. Lessons from the Australian experience provide timely guidance for those countries exploring deregulation now or in the future to improve the industry-level agricultural productivity growth through facilitating resource reallocation from less efficient to more efficient farms.

Key words: Resource Reallocation, Industry-level TFP, Deregulation Reform, Dairy Industry in Australia.

1. Introduction

The global dairy industry has experienced rapid expansion and structural change over the past decade, and the effect of these changes has been uneven across countries. Imbalanced growth between demand and supply caused international prices of all dairy products to decline from their 2013 peak after a decade-long increase, in particular for skim milk powder and whole-milk powder (OECD 2016). A key factor underlying the recent worldwide 'milk crisis' was a decline in demand growth from developing and transitional

*The authors acknowledge the data and financial support from the Australian Bureau of Agricultural and Resource Economics and Sciences for this research; the support from State Natural Sciences Foundation (No. 71873005), State Natural Sciences Foundation (No. 71742002), Agricultural Trade and Market Access Cooperation program (ATMAC) (No. 43643) and Chinese Academy of Engineering (Nos. 2018-ZD-07-1 and 2018-ZD-07-06-1); and the financial support from Data Centre for Management Science, PKU-NSFC (No. 2018KEY06). All errors belong to the authors.

†Yu Sheng (emails: ysheng.ccap@pku.edu.cn; yu.sheng@agriculture.gov.au) is Associate Professor at China Centre for Agricultural Policy, SAAS, Peking University, Haidian District, Beijing, China. Yu Sheng is Senior Economist, Will Chancellor is Principal Economist and Thomas Jackson is Principal Economist are with Productivity Section, Department of Agriculture and Water Resource, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, Australian Capital Territory, Australia.

doi: 10.1111/1467-8489.12351

countries such as China and Russia. Continued production growth between 2014 and 2015 in major milk exporters including Australia (4 per cent), the European Union (2 per cent), New Zealand (5 per cent) and the United States (1 per cent) also played an important role.

It is widely believed that the implementation of market-oriented institutional reforms in the European Union (EU) and the United States (US), as well as in other key exporting countries, significantly contributed to the increased global supply of dairy products. For example, after the European Union removed its milk quota in April 2015 – milk deliveries for the 2014-15 marketing year (April to March) increased by 18.5 per cent in Ireland, 3.7 per cent in Germany, 2.9 per cent in the United Kingdom and 11.9 per cent in the Netherlands (OECD 2016). In the United States, adjustments to institutional arrangements have also assisted to raise the milk supply, with milk yields increasing by 1.1 per cent per annum on average over the past decade (OECD 2016). While there is no doubt that market-oriented institutional reforms have increased the global milk supply, little is known about whether they have also helped to improve the aggregate productivity of the industry.

Theoretically, market-oriented institutional reforms may affect productivity growth in the dairy industry through two channels (Balk 2001). On one hand, deregulation and the removal of trade barriers facilitated the uptake of new technologies, thereby enhancing technological progress and the production efficiency of dairy farms. On the other hand, deregulation facilitated product market integration and triggered more rigorous resource reallocation between farms. In a competitive market environment, both primary inputs and market share are likely to move from less productive to more productive farms, generating productivity gains for the industry as a whole (Sheng *et al.* 2017). Although the two channels usually interact with each other to promote long-term aggregate productivity growth, the effects of resource reallocation between farms are often under-estimated in practice due to a lack of knowledge about the process of resource allocation between farms and its interaction with institutional arrangements.

This paper investigates the impact of dairy industry deregulation on industry-level productivity growth through integration of the milk market and facilitation of cross-farm resource reallocation. Using Australia as a case study, we apply an unbalanced panel of farm-level data to measure the contribution of resource reallocation to industry-level productivity growth between 1979 and 2013 at both the aggregate and state level – linking change in resource reallocation effects after 2000 to deregulation reform, using both structural break and regression analyses. We show that the reform contributed to industry-level productivity growth, not only by raising average within-farm technological progress, but also through resource reallocation between farms with different productivity. Moreover, resource reallocation effects differ between farms across regions. In particular, after this reform, relative market share shifted more significantly from less productive farms to more productive ones and from farms using the ‘year-round’ production system to those using the 'seasonal' production system – generating additional productivity gains for the farm sector, but imposing some costs on downstream manufacturers by strengthening the seasonality of milk supply, while manufacturers would prefer a more stable milk supply throughout the year. As such, further improvement in industry-level productivity could result from the reallocation of resources between farms using the 'seasonal' production system.

To our knowledge, this paper contributes to the literature from at least two perspectives. First, it is the first to examine the impact of deregulation on the industry-level productivity growth of Australian dairy industry in the context of resource reallocation by applying structural break analysis to unbalanced panel data to analyse the causality between resource reallocation and deregulation reforms. Second, we distinguish dairy farms by production system (either 'year-round' or 'seasonal') to identify the source of resource reallocation effects after the deregulation: both between farms with different productivity; and across the two production system types. In Australia, dairy farms operate using both the relatively high-cost year round and the relatively low-cost seasonal production systems to optimise the efficiency of downstream factories between regions by flattening the milk supply curve (PWC 2015). This provides an important and wide-reaching contribution at a pivotal time such that countries considering or commencing dairy industry deregulation may benefit from a better understanding of the Australian experience.

Our study is related to a strand of literature assessing the impact of deregulation reforms on the Australian dairy industry. For example, Kompas and Che (2004, 2006) used farm-level data and found that average farm-level productivity growth slowed after deregulation reforms were introduced in 2000 compared with the 1980s and the 1990s. Similarly, Balcombe *et al.* (2006) used cross-sectional farm survey data for the year 2000 and found that only dairy farms in New South Wales and Victoria achieved higher technological efficiency following deregulation, and that the gains were modest. Although these studies have assessed the impact of deregulation in terms of technological progress and efficiency improvements within farms, they neglect the fact that deregulation reform can facilitate market integration by equalising the farm-gate milk price – affecting farmer decisions regarding business scale and entry or exit. As such, their findings cannot capture the effect of deregulation on industry structural adjustment and cross-farm resource reallocation that this induces (Harris 2004). While Gray *et al.* (2014), followed by Sheng *et al.* (2017), examined the role of resource reallocation due to deregulation reforms in affecting productivity growth of all agricultural sectors in Australia since the 1970s, neither of these studies focused on the Australian dairy industry in particular, leaving room for this paper.

The structure of the paper is as follows. Section 2 briefly reviews the history of Australian dairy deregulation. The methodology and hypotheses underlying this study are outlined in Section 3. In section 4, we specify our dataset and generate descriptive statistics to provide context for this research. Overall results and the impact of deregulation on dairy industry productivity growth are presented and discussed in Section 5. A series of robustness checks follow in Section 6 and Section 7 concludes the paper.

2. Deregulation reforms in the Australian dairy industry

The dairy industry is an important sector in Australian agriculture, producing more than 9.2 billion litres of milk in 2013 – nearly half of which was exported to the international market. The industry is comprised of a large number of heterogeneous farms using one of two production technologies (the 'seasonal' and 'year-round' production systems). In the seasonal production system, cows calve during the peak period of pasture availability each year, which enables farms to save feeding costs and improve productivity. In the year-round production system, calving and milk production are spread evenly throughout the year, which increases feeding costs and lowers productivity. Depending on factors such as climate conditions, market demand and government policies, farms choose between the two systems in different states (Figure 1) and thus have different productivity performance, which has important implications for industrial structure adjustment and cross-farm resource allocation as deregulation reforms integrate the domestic milk market.

Historically, the Australian dairy industry has been highly regulated by both State and Commonwealth Governments, motivated by a desire to secure the domestic supply of fresh milk and to promote the export of manufactured milk. Immediately before deregulation reforms took effect in 2000, the rate of industry assistance was 51 per cent – far higher than the 6 per cent rate of assistance given to the agricultural industry as a whole (Productivity commission 2001). This high level of assistance was mainly provided through statutory marketing authorities (SMAs) and the Domestic Market Support (DMS) mechanism, which in turn lead to milk market segregation and resource misallocation between farms with different productivity and across the different production systems.

The SMAs were responsible for issuing licences to milk producers, overseeing milk quality, regulating milk trade between states and setting different farm-gate prices for different types of milk (such as fresh milk and manufactured milk products) within each state. They used two policies to manage milk markets in different states. In Victoria, Tasmania and South Australia, the majority of farms adopted the 'seasonal' production system for producing manufactured milk, and SMAs used a policy known as 'equitable marketing' to allocate the price premium for market milk across all farmers. In Queensland, New South Wales and Western Australia, the majority of farms adopted the 'year-round' production system, mainly for producing fresh milk. To determine which farms produced market milk, SMAs attached milk quotas to individual parcels of land.

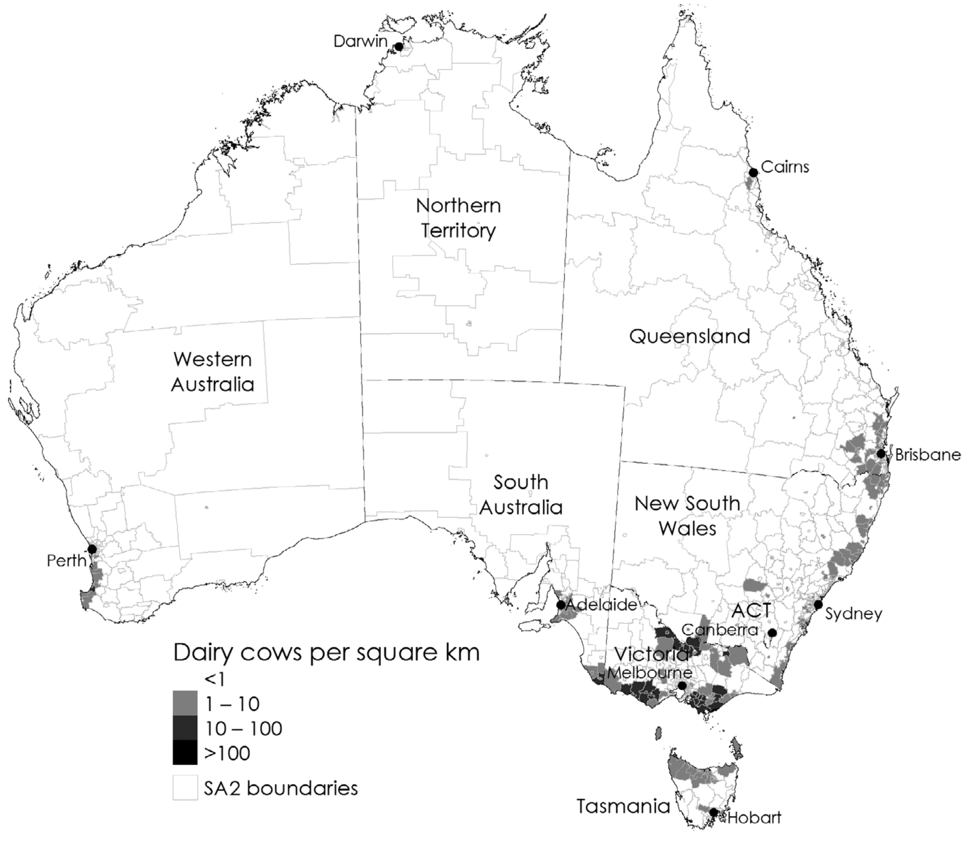

Figure 1 Heat map of geographical distribution of dairy farms in Australia.
Source: Authors' estimation by using data from ABARES (2015).

The DMS was established in 1986 and was administered by the Commonwealth Government as an industry-funded instrument to subsidise the export of manufactured dairy products. Under this arrangement, a levy (tax) was imposed on all farms regardless of their production system, and the proceeds were distributed to exporters as subsidies for manufactured dairy products. However, the subsidy had an undesirable flow-on effect for the domestic market; that is, the levy was largely passed on to domestic consumers of fresh milk and manufactured dairy products (Edwards 2003). In addition, the DMS generated levy transfers between states – since some states exported a greater amount of milk than others.

The SMAs and DMS regulatory arrangements curtailed market competition between farms and across regions, distorting the demand and supply of Australian dairy products on domestic and international markets. First, the SMAs used their monopoly powers to restrict interstate trade in milk, which generated a cross-state price gap for fresh milk. Second, the quota scheme allowed farmers to extract economic rents as the controlled price departed from the competitive price in the presence of inelastic domestic demand. This created an inclination to produce excess fresh milk against variation in demand for over-quota sales (Alston and Quilkey 1980). By 1999, the price of fresh milk was more than twice that of manufactured milk, which far exceeded the difference in production costs between farms using the year-round and seasonal production systems. Third, the pricing policies of State Governments hindered innovation in marketing and transport as discussed in Edwards (2003).

Under regulation, the milk market was fragmented at the state level, with an artificial segregation between manufactured and fresh milk within each state – distorting the allocation of resources between farms using different production systems and across regions. For decades prior to 2000, the market segregation led to the over-supply of market milk in Queensland, New South Wales and Western Australia where the industry is dominated by farms that mainly use the 'year-round' production system that has relatively high production costs. In contrast, there was an under-supply of manufacturing milk in Victoria, Tasmania and South Australia where the industry is dominated by farms that mainly use the 'seasonal' production system that has relatively low production costs. The high price premium imposed on domestic consumers by the SMAs and DMS regulatory arrangements covered the additional production costs of farms using the 'year-round' system, and in turn led to significant resource misallocation between farms and lower efficiency in milk production across the industry.

On 1 July 2000, the Australian Government deregulated the dairy industry in line with economy-wide reforms that were implemented in the 1990s (Productivity Commission 2001; Gray *et al.* 2014). This reform was mainly driven by the threat of New Zealand imports displacing domestic Australian sales following the Uruguay round of multilateral trade negotiations in 1995. Deregulation involved abolishing the marketplace regulations, including the SMAs in each state – restoring a market-based mechanism for setting the price of milk (Productivity commission 2001; Edwards 2003). As a consequence, there was a strong tendency for the prices of fresh milk across states to converge to the export price of manufactured milk. The weighted average milk price in Australia immediately dropped by 22 cents per litre and has since gradually increased in line with international market prices (PWC 2015) (Figure 2).

The deregulation in 2000 largely integrated milk markets across the Australian states and ended the price segregation of manufactured and fresh milk. At the same time, it also placed significant pressure on dairy farms in states – particularly those using the 'year-round' production system. During the decade following deregulation, the total number of dairy farms declined from 12,960 to 7,514 and average farm size (measured in terms of real output value) more than doubled – although there were significant differences in these trends between states. Ultimately, the majority of total industry output

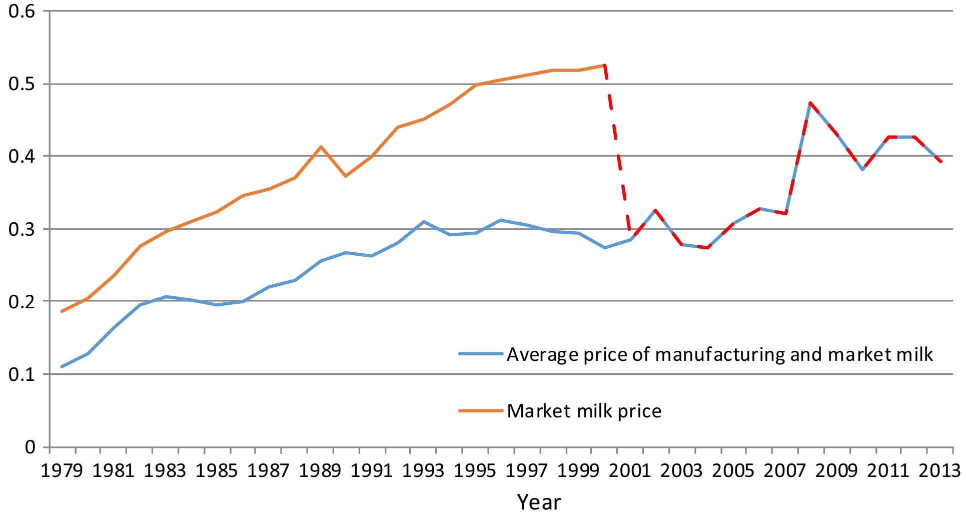

Figure 2 Impact of deregulation on Australian milk prices.
Source: Authors estimates using ADIS data. [Colour figure can be viewed at wileyonlinelibrary.com]

(more than 60 per cent) transitioned to Victoria, where the 'seasonal' production system was dominant. These changes suggest that deregulation reforms altered the structure of the dairy industry and facilitated resource reallocation between farms and across regions, providing an indirect channel for industry-level productivity growth.

3. Deregulation reform and resource reallocation: methodology for hypothesis test

To investigate the impact of deregulation reforms on dairy industry productivity through resource reallocation, we start by defining aggregate industry-level productivity at period t (Π_t) as a weighted sum of farm-level productivity. In doing so, we assume that productivity growth is driven by technical progress and resource reallocation – where resource reallocation refers to the movements of aggregate inputs between farms and the corresponding changes in farm-level output shares:

$$\Pi_t = \sum_{i \in \Omega_t} s_{it}\pi_{it} \tag{1}$$

where s_{it} denotes the share of farm i in the industry at time period t (i.e. revenue or cost shares) and π_{it} denotes the measure of farm-level total factor productivity. Ω_t represents the set of all farms in the same period. Following Olley and Pakes (1996), dairy industry productivity (as shown in Equation (1)) can be represented by two components:

$$\Pi_t = \overline{\pi}_t + \sum_{i \in \Omega_t} (s_{it} - \overline{s}_t)(\pi_{it} - \overline{\pi}_t) = \overline{\pi}_t + \text{cov}_t \tag{2}$$

where $\overline{\pi}_t = \frac{1}{N}\sum_{1}^{N} \pi_{it}$ is the unweighted mean of farm-level productivity, and is $\overline{s}_t = \frac{1}{N}\sum_{1}^{N} s_{it}$ the average revenue or cost share of farm i in the industry[1]. The second component (cov_t) reflects the responsiveness of the relative size of individual farms to their relative productivity differences. Taking the first difference on both sides of Equation (2) yields the following expression for the change in industry-level productivity:

$$\Delta\Pi_t = \Delta\overline{\pi}_t + \Delta\text{cov}_t \tag{3}$$

The change in industry-level productivity as in Equation (3) consists of two components. The first component is the contribution of within-farm productivity improvements ($\Delta\overline{\pi}_t$), and the second component is the contribution of resource reallocation between-farms (Δcov_t) which occurs as a result of change in the size of the farms. When farms enter or exit and their impacts are accounted for, within-farm productivity improvements should be interpreted as capturing the average technology in use by all dairy farms.

Equations (2) and (3) provide a measure of resource reallocation effects and thus allow us to examine whether deregulation reforms contributed to industry-level productivity and its growth through this channel. Our hypothesis is that deregulation restored market competition and encouraged less viable (and presumably less productive) dairy farms to reduce market share or exit the industry. On the one hand, as these farms reduced market share, scarce resources became available and a process of resource reallocation ensued (i.e. as the market shares of these less productive, exiting farms

[1] There are three methods to measure resource reallocation effects in the literature: the BHC (Baily *et al.* 1992), OP (Olley and Pakes 1996), and PWR (Petrin & Levinsohn 2012). Each of these methods is designed to examine different aspects of resource allocation. The BHC approach uses the covariance between firms' relative productivity growth and relative changes in market share over time to measure resource reallocation. Since firms' productivity growth over time is volatile and independent of their productivity level, this measure is more likely to reflect the high-frequency change. In contrast, the OP uses the covariance between firms' relative productivity level and relative market share and its change as indicator for resource reallocation, which is more stable and more likely to capture the low-frequency changes. Petrin and Levinsohn's (2012) criticism of the OP approach is mainly related to the difference between output and input when used to estimate the market share, which also applies to the BHC approach (Sheng *et al.* 2017). In this sense, we choose to use the OP approach in this paper. We have also used the OP method because the data used in this analysis are drawn from a survey rather than a census, which limits the extent to which we can accurately identify the impact of farms' entry and exit on resource reallocation, something which is an important requirement of the BHC method.

were absorbed by more productive farms).[2] On the other hand, farms' exits from the industry may reduce the total amount of resource available and thus improve the industry-level total factor productivity (TFP) by strengthening competition among surviving farms. However, this decomposition method is unable to demonstrate the causality between deregulation and resource reallocation, nor can it identify the differing impacts on the two farming systems (seasonal and year-round).

We addressed this by recategorising dairy farms into to the states in which they were located, and then divided the states into two groups (according to whether the majority of farms used the seasonal or year-round production systems before deregulation). This grouping is meaningful because of the pre-reform segregation that existed between states, and between farms using different production systems. After comparing aggregate dairy industry estimates to those for farms using the seasonal and year-round production systems, we analysed structural breaks to examine the impact of deregulation. We then applied the autoregressive distributed lagged model (ARDL) with fixed effects to further measure the impact of deregulation reforms. In both exercises, we controlled for factors other than deregulation that could affect aggregate dairy farm productivity, including farm-level technological progress, market demand fluctuations and climate conditions.

Following Andrews and Fair (1988), Hansen (1997), Hansen (2001), we used a 'Wald test' to examine whether there are structural breaks in aggregate TFP at the time when deregulation reforms were implemented in 2000. We did this by analysing coefficients for T in a time-series regression of the log TFP:

$$TFP_t^k = \alpha^k + \rho^k T(t > \tau) + \gamma^k Z_t(l) + \varepsilon_t^k \tag{4}$$

In Equation (4), TFP_t^k denotes the aggregate TFP of k at time t, where k refers to dairy industry productivity for the year-round (yr) and seasonal (se) production systems. T is the time trend, τ refers to reformed year (say, 2000), and $Z_t(l)$ denotes a group of control variables including within-farm technological progress (TEC_{it}^k), climate conditions (Wat_{it}^k and Tem_{it}^k) and milk price (MP_{it}^k). The multi-pronged hypotheses underlying the above method are that if a structural break in the TFP series is detected, then the deregulation reforms had a significant effect on productivity growth, and whether or not the productivity impacts of deregulation are different between dairy farms that used different production systems (i.e. 'seasonal' and 'year-round').

[2] It is widely believed that cross-region price differentials pre- and post-reform could also cause resource reallocation among farms, which may not be the consequence of deregulation. As a robustness check, we eliminate this price effects by repeating the exercise using the farm-level TFP measure only excluding the price impact, the obtained results are consistent with what we have obtained here.

To implement the structural break test, we apply the method in Hansen (2001) and demonstrate that changes in $\mu^k = \frac{\alpha^k}{1-\rho^k}$ are identical to changes in the trend of productivity growth when $t > \tau$ (i.e.$\tau = 2000$). As the implementation of dairy deregulation was exogenous to productivity growth in 2000, we apply a Wald statistic to test for a break for μ^k at $\tau = 2000$. This test was completed separately for all dairy farms and for those using the seasonal and year-round production systems respectively.

Although this structural break test is informative, it could not account for regional specific effects – which may have contributed to change in productivity when comparing the pre- and post-reform periods. We therefore re-estimate TFP at the state level, categorising state-level estimates into the two production system groups. It is then possible to apply the structural break test method for the unbalanced panel following the work of Bai and Perron (1998), Bai (2010):

$$TFP_{i,t}^k = \alpha_i'^k + \rho_i'^k T(t > \tau) + \gamma'^k Z_{i,t}(l) + \sigma \varepsilon_{i,t}^k \quad (5)$$

where i refers to the states of Australia and $\alpha_i'^k$ refers to the state-specific means. The common change point is denoted as $\tau = 2000$, corresponding to the enactment of dairy deregulation in Australia. The amount of the break in mean, which can also differ by panel, is denoted by $\rho_i'^k$. We assume that the sequences of panel disturbances $\varepsilon_{i,t}^k$ are independent, and within each panel, the errors form a weak stationary sequence with a common correlation structure. We again use the Wald test to check for trend breaks in productivity by production system and for the overall dairy industry.

After completing the structural break tests, we again look to the ARDL model and measure the impact of deregulation reforms on productivity in aggregate and by production system:

$$TFP_t^k = \beta_0^k + \beta_1^k DREG_t^k + \gamma^k Z_t(l) + v_t^k \quad (6)$$

$$TFP_{i,t}^k = \beta_0'^k + \beta_1'^k DREG_{it}^k + \gamma'^k Z_{i,t}(l) + u_i^k + \varepsilon_{i,t}^k \quad (7)$$

where TFP_t^k and $TFP_{i,t}^k$ are the logarithms of aggregate TFP at the industry and state levels; $DREG_t^k$ and $DREG_{it}^k$ are the dummy variables for deregulation reform. These dummy variables take a value of 0 before 2000 and 1 otherwise, while $Z_t(l)$ and $Z_{i,t}(l)$ are control variables previously defined and u_i^k is state-specific effects. The estimated coefficients for the deregulation variables provide insights into how the deregulation affected dairy industry productivity as a whole and the differing impact on dairy production system types. We anticipate that deregulation reforms imposed different impacts on resource reallocation according to dairy production system type and therefore expect the estimated coefficients β_1^k and $\beta_1'^k$ to be significantly different from each other.

Next, we use the decomposition method to examine resource reallocation between dairy farms using different production systems, following Melitz and Polanec (2015) and Collard-Wexler and De Loecker (2015). In doing so, we extend the Olley and Pakes (1996) method (or OP method) and distinguish between farms according to production system type. Our approach is to use differences in the distributions of weights within and between these two groups in an effort to identify the direction that resources shifted after deregulation (Foster *et al.* 2008). Using Equations (2) and (3), we decompose aggregate productivity growth for each grouping of farms (all, seasonal, and year-round), enabling us to disentangle the contribution of resource reallocation on productivity growth, such that:

$$\Pi_{\phi t} = \overline{\pi}_{\phi t} + \sum_{i \in \Omega_{\phi t}} \left[s_{it} - \overline{s}_{\phi t}\right]\left[\pi_{it} - \overline{\pi}_{\phi t}\right] = \overline{\pi}_{\phi t} + \mathrm{cov}_{\phi t} \tag{8}$$

where $\overline{\pi}_{\phi t}$ denotes the average productivity of a group of farms using a particular production system (ϕ), and $\overline{s}_{\phi t}$ denotes the average revenue or cost share of farms within this group. These 'within-group effects' ($\Pi_{\phi t}$) capture the change in productivity caused by group-specific effects, such as technological progress on individual farms and the reallocation of resources between farms within each group.

Moreover, we can treat each group of farms as a combined production unit and thus measure resource reallocation effects between groups by allowing interaction between the change in relative revenue or cost shares and relative productivity at the group level, as follows:

$$\Pi_t = \overline{\Pi}_{\phi t} + \mathrm{cov}_t\left[S_{\phi t}, \Pi_{\phi t}\right] \tag{9}$$

where $S_{\phi t}$ and $\Pi_{\phi t}$ are farm group productivity and market share. Equation (9) suggests that industry-level productivity is represented by the unweighted average productivity of M groups ($\overline{\Pi}_{\phi t} = \frac{1}{M}\sum_{j \in \Omega_\phi} \Pi_{\phi t}$) and a covariance term which measures the extent to which resources have been reallocated between groups of firms – that is the 'between-group effects'[3] (Melitz and Polanec 2015).

Equations (8) and (9) provide measures of the 'within-group effects' of resource reallocation between dairy farms within each group (defined by production system or state) and 'between-group effects' across groups. Taking the first difference on both sides of these two equations reveals the contribution of each effect to industry-level productivity growth. Analysis of

[3] Between-group effects are usually caused by differences in average productivity between groups of firms.

both the level and change in resource reallocation effects before and after deregulation thus provides insights into the productivity effects brought about by this policy change.

4. Data source and variable definition

The data used in this paper were extracted mainly from the Australian dairy industry survey (ADIS), conducted annually by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) since 1979. This survey provides comprehensive physical and financial information about dairy farm businesses. Within the scope of this collection, dairy farms are defined as businesses engaged in 'dairy cattle farming' as per subclass 0160 of the Australian and New Zealand Standard Industrial Classification (ANZSIC). These dairy farms must have an estimated annual value of agricultural operations greater than or equal to AU$40,000[4] and derive more than 50 per cent of their total output value from the production of milk and other dairy products.

The ADIS survey collection uses random sampling to select dairy farms from the Australian Bureau of Statistics (ABS) agricultural census. The survey population is stratified according to farm size and region, and weights are assigned to ensure that the sample is representative of the dairy farm population. Drawing on ADIS, we obtain an unbalanced panel of dairy farms operating between 1979 and 2013. The dataset contained 10,726 observations and represented a population of 20,951 farms in 1979 to 7,086 farms in 2013 after applying the sample weights (Zhao *et al*. 2012). From this sample, approximately 47 per cent of farms were represented in the survey for two consecutive years, and more than 92 per cent of farms in the sample are surveyed in at least two years. We therefore consider that although the dataset is an unbalanced panel, it is suitable for analysis across farms and over time.

The most important variables used in this paper are farm-level TFP and farm-level market share. We measure farm-level TFP by dividing aggregate output by aggregate input. We use the gross output model to aggregate 12 outputs (categorised into three groups: crop, livestock and other agricultural products) into an output quantity index, and aggregate 28 inputs (categorised into four groups: land, capital, labour and intermediate inputs) into an input quantity index. This is done for each farm in each year, with the prices or value shares of outputs and inputs used as weights. A Fisher quantity index – the geometric mean of Laspeyres' and Paasches' quantity indexes – is used for the aggregation of outputs and inputs for each farm. We use the Fisher index

[4] The threshold for inclusion in the ABARES farm survey program has changed over time (ABARES 2011). The current threshold for inclusion in the survey was used since 1994. Between 1983 and 1994, the threshold was $20,000-22,500, and from 1979 to 1983, it was $5,000.

because it approximates any transformation (or production) function at the second order (Diewert 1992) and thus captures possible differences in production technologies used by different dairy farms when aggregating outputs and inputs. The EKS procedure (Eltetö and Köves 1964; Szulc 1964) ensures transitivity and consistency in the comparison between individual farms.

Farm-level market shares are defined as the real output value of each farm divided by the real output value of the industry in the same year. Real output values are estimated by deflating nominal gross output values with a farm-level output price index. As for other control variables, we use unweighted average farm-level productivity (or milk yield per cow) as indicators for within-farm production technology, the market price for whole milk is used as an indicator for market conditions, and total rainfall and average temperature for the growing season are used to measure climate conditions. Finally, the data used to calculate growing-season rainfall and temperature were obtained from the Australian Bureau of Metrology (BOM 2018). These climate variables include daily rainfall, maximum and minimum temperature as derived from 2,300 weather stations distributed across the country. To use these data, we match weather stations to farms based on geospatial proximity (Sheng *et al*. 2018).

Table 1 provides some summary statistics every five years on the dairy industry. Between 1979 and 2013, gross output value (both in terms of milk and in terms of total output) has increased while the number of dairy farms has declined, particularly after 2000 when the deregulation reform was implemented. This indicates that structural change in the dairy industry may have accelerated following the deregulation reform and thereby potentially contributed to productivity growth.

Between 1979 and 2013, the gross output value (in terms of milk and total output) increased, yet the number of dairy farms declined – particularly after 2000 (Figure 3). Moreover, changes in the number of milking cows and milk production are considerably different between states when comparing the pre- and post-reform periods. Namely, the total number of milking cows declined

Table 1 Descriptive statistics of dairy farms in Australia: 1979 to 2013

Year	Dairy farm Population	sample	Dairy Cows ('000)	Gross Value of Production (A$ m)	Milk Val. (A$ m)	Milk yield (L/cow)
1979	20951	301	1869	881.8	620.1	2905
1984	19019	287	1809	1437.3	1141.1	3338
1989	14736	293	1698	1931.8	1577.3	3688
1994	14059	402	1821	2534.5	2180.6	4506
1999	14003	309	2171	3179.2	2822.7	4996
2004	10178	219	1942	3126.0	2652.9	5215
2009	7500	307	1596	4386.8	3969.1	5653
2013	7086	277	1647	3929.6	3588.7	5691

Source: Authors' estimates based on the ADIS surveys.

after deregulation in New South Wales, Queensland and Western Australia, where the seasonal production system was dominant before 2000. The total number of milking cows increased in Victoria, South Australia and Tasmania, where the main production system before 2000 was the seasonal approach (Figure 4). As a result, the production of milk after 2000 became more concentrated in Victoria, South Australia and Tasmania (Figure 5) – with many year-round producers in Queensland, New South Wales and Western Australia exiting the industry. This implies that structural change in the dairy industry may have accelerated following deregulation.

To better understand how resource reallocation between farms changed following deregulation, we compared the sample as two separate groups according to production system type: seasonal; and year-round. We split this sample by individual states, since milk markets were formerly controlled by individual State Government agencies. This treatment allows us to decompose resource reallocation into 'between-group effects' and 'within-group effects' according to production system and market.

Figure 6 compares the distribution of dairy farm productivity before and after deregulation in 2000. After deregulation, the distribution of aggregate dairy farm productivity shifts to the right (red line), implying that the proportion of more productive dairy farms has increased. The two-sample Kolmogorov–Smirnov test (Corder and Foreman 2014) shows that the null hypothesis for equality of two farm-level productivity distributions is rejected at the 1 per cent level. This suggests that after the introduction of dairy industry deregulation in Australia, resources moved from less productive to more productive farms, contributing to aggregate productivity growth. Our observations also suggest a difference in productivity depending on production system type. Typically, those farms using the seasonal system are more

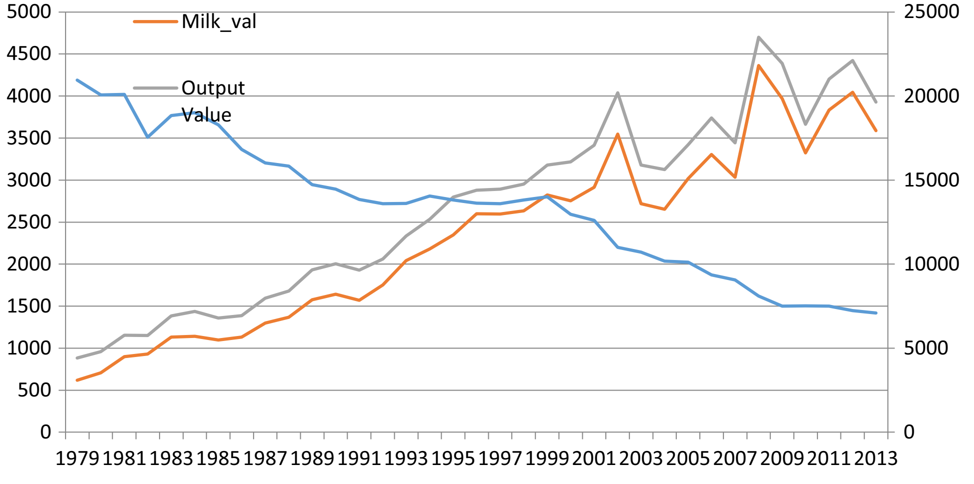

Figure 3 Gross output and milk value and dairy farm population, 1979-2013.
Source: Authors estimates based on the ADIS surveys. [Colour figure can be viewed at wileyonlinelibrary.com]

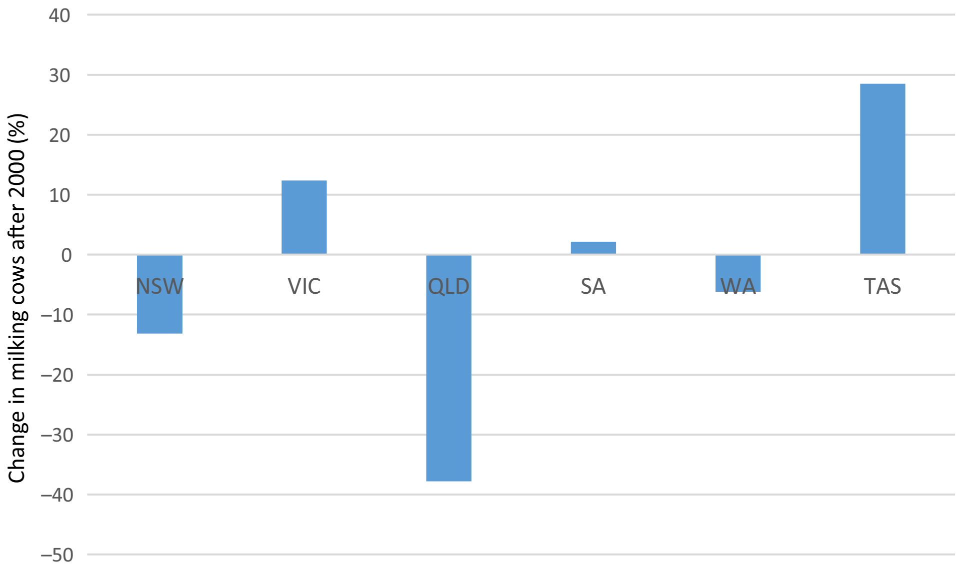

Figure 4 Change in the number of dairy cows by state post-reform relative to 2000 (expressed as a percentage, %).
Source: Authors estimates based on the ADIS surveys. [Colour figure can be viewed at wileyonlinelibrary.com]

likely to have higher productivity than farms using the year-round system (Figure 7). A two-sample Kolmogorov–Smirnov test indicates that the null hypothesis for equality of farm-level productivity distributions between farms using the two production systems is rejected at the 1 per cent level.

Although the descriptive statistics provide useful insights into the effects of deregulation, it is still not known how resource reallocation between farms is related to the deregulation reform and to what extent this differs by production system type. Before reaching any conclusions, it is necessary to conduct more thorough empirical tests and examine the causality between deregulation and resource reallocation.

5. Productivity growth, deregulation reforms and resource reallocation

We discuss the empirical results in three stages. First, we use the farm-level data to generate productivity estimates for the overall dairy industry and according to the different dairy production systems. Using these estimates, we decompose industry-level productivity growth into within-farm technological progress and resource reallocation effects. Second, we apply structural break and regression analysis to the time series and unbalanced panel data, in an effort to examine the causality between dairy industry productivity and deregulation reforms. Third, we apply the extended OP decomposition approach to measure the effect of resource reallocation on dairy farms using the seasonal and year-round production systems across regions.

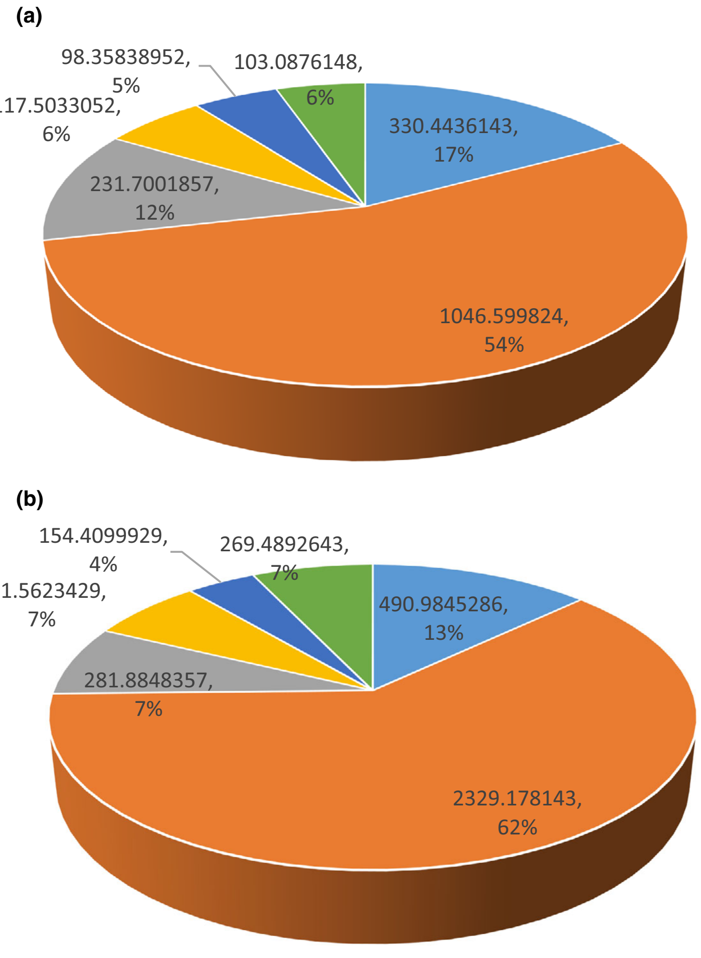

Figure 5 Cross-state comparison of whole-milk production: 1979-1999 vs. 2000-2013 (unit: ML). Source: Authors estimates based on the ADIS surveys. [Colour figure can be viewed at wileyonlinelibrary.com]

5.1 Industry-level productivity growth and resource reallocation

The Australian dairy industry has experienced gradual productivity growth from 1979 to 2013, increasing by approximately 1 per cent per annum on average (Figure 8). This productivity growth was driven by both increased output (0.6 per cent per annum) and reduced input (−0.5 per cent per annum).

Technological progress and resource reallocation have played different roles in contributing to this industry-level productivity growth. To expand on this, we consider three separate survey periods: 1979-1990; 1990-2000; and 2000-2013. This reveals that aggregate productivity growth has not evolved evenly over time. As is shown in Table 2, the aggregate productivity growth

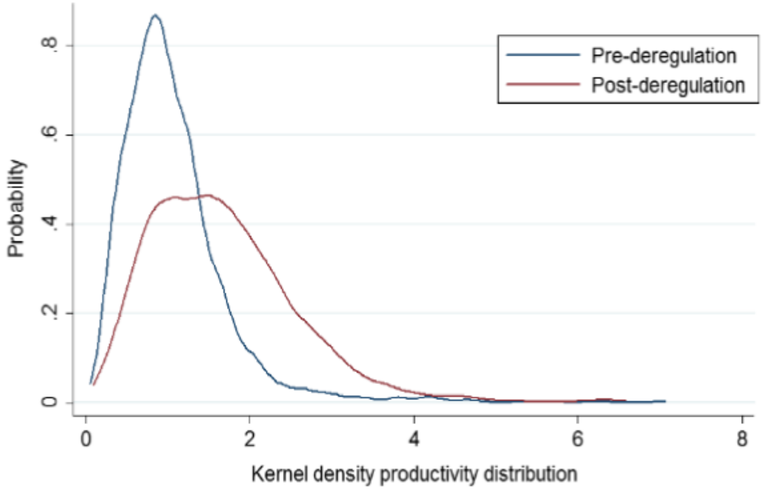

Figure 6 Comparison of aggregate dairy farm productivity (before and after deregulation). Source: Authors estimates based on the ADIS surveys. [Colour figure can be viewed at wileyonlinelibrary.com]

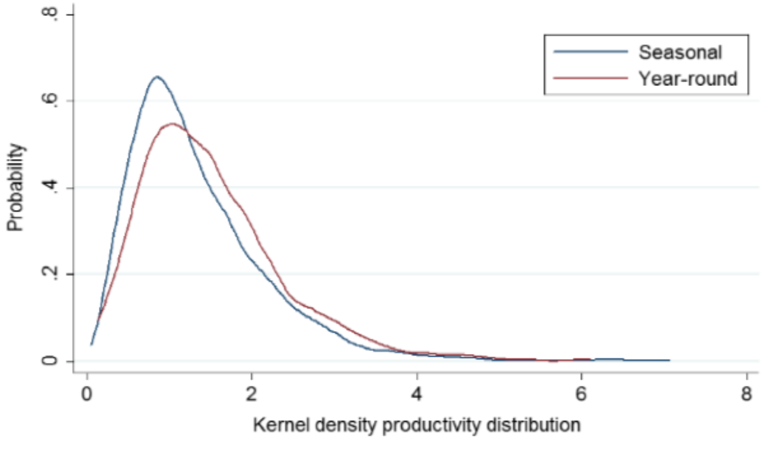

Figure 7 Comparison of productivity distribution for dairy farms using different production systems, post-deregulation.
Source: Authors estimates based on the ADIS surveys. [Colour figure can be viewed at wileyonlinelibrary.com]

rate has increased steadily, from 0.9 per cent per annum from 1979 to 1990, 1.7 per cent per annum from 1990 to 2000 and 1.9 per cent per annum from 2000 to 2013. Underlying the industry-level productivity growth is a strong growth of within-farm technological progress represented by unweighted farm-level TFP (which has also increased over time – although not steadily) from 0.7 per cent per annum from 1979-1990 to 2.3 per cent per annum from 1990-2000 and to 1.8 per cent per annum from 2000-2013. Similar to the period as a whole, unweighted farm-level TFP growth dominates industry-

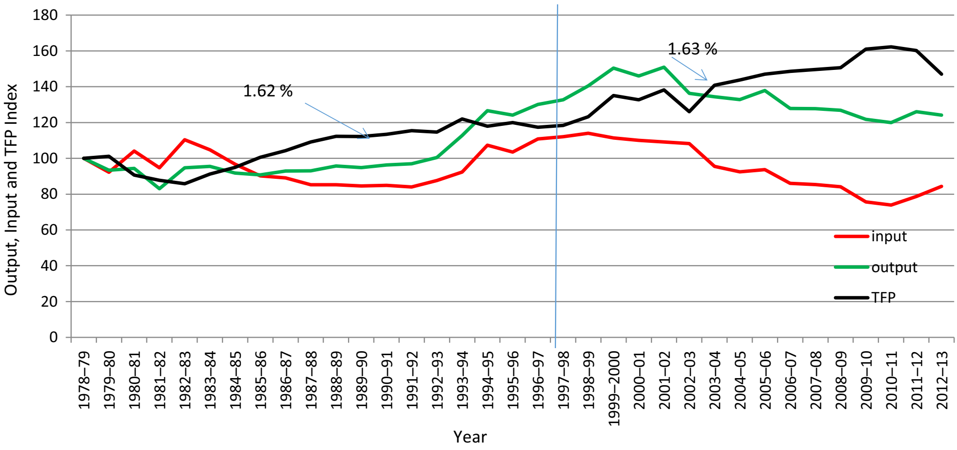

Figure 8 Aggregate output, input and TFP in the Australian dairy industry: 1979-2013. Source: Authors estimates using ADIS data. [Colour figure can be viewed at wileyonlinelibrary.com]

level TFP growth in each subperiod, supporting the finding that within-farm technological progress is consistently an important driver of productivity growth in the Australian dairy industry.

The contribution of resource reallocation between farms to the industry-level productivity growth shows a distinct pattern. Initially, resource reallocation contributed 0.2 per cent per annum to dairy productivity growth between 1979 and 1990, but subtracted 0.6 per cent per annum between 1990 and 2000 (Figure 9). However, following deregulation in 2000 resource reallocation effects became positive, contributing 0.2 per cent per annum to aggregate productivity growth – somewhat offsetting the slowdown in within-farm productivity growth. Generally, the contribution of resource reallocation between farms to dairy industry productivity growth tends to increase when within-farm technological progress slows down, suggesting that the two effects are, substitutes (Sheng *et al.* 2017).

Table 2 Resource reallocation and its contribution to industry-level TFP

Year	TFP levels (in logarithm)			Annual % TFP growth (change in log point)		
	Aggregate TFP	Unweighted TFP	COV	Aggregate TFP	Unweighted TFP	ALL COV
1979–2013	0.478	0.399	0.078	0.011	0.013	−0.001
1979–1990	0.279	0.178	0.098	0.009	0.007	0.002
1990–2000	0.451	0.367	0.083	0.017	0.023	−0.006
2000–2013	0.669	0.610	0.058	0.019	0.018	0.002

Source: Authors estimates using ADIS data.

5.2 Testing the causality between resource reallocation effects and the deregulation reform

It is widely believed that the deregulation reform implemented in 2000 has played an important role in reshaping the structure of the Australian dairy industry, correcting resource misallocation between farms and boosting productivity. A simple comparison of resource reallocation effects before and after deregulation shows that the misallocation of resources between dairy farms mainly occurred in the pre-reform decade when the industry was highly regulated by the Commonwealth and State Governments (Figures 8 and 9).

However, this change in pre- and post-2000 resource reallocation effects could also be affected by many other factors. Technological progress, climate, market conditions and measurement error could all potentially contribute to estimated dairy industry productivity growth over time. To examine the causality between the deregulation reform and resource reallocation, we first apply structural break analysis to the time-series data, focusing on the period of deregulation (2000). In doing so, we examine whether there are significant trend changes in aggregate productivity by production system type, when controlling for other determinants of productivity and resource reallocation.

When controlling for within-farm technology progress, total rainfall, average temperature and the market price of milk, the null hypothesis of no structural break in the aggregate TFP trend for year 2000 is rejected at 1 per cent level (Table 3, columns 1 and 2). Moreover, to account for cross-state-specific effects, we apply the structural break analysis to the panel data and examine whether there is a common trend change at 2000. The results align to those from the time-series structural analysis (Table 3, columns 3 and 4). These findings imply that deregulation reforms in 2000 contributed to dairy

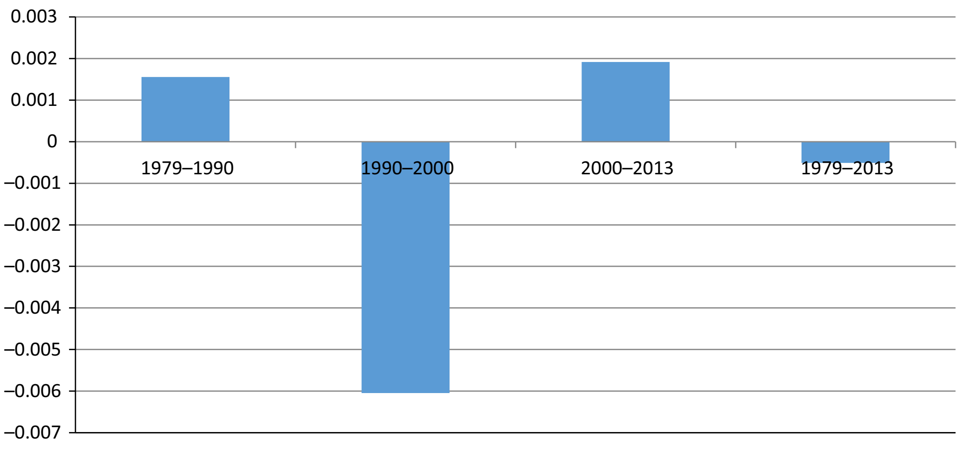

Figure 9 Contribution of resource reallocation to industry-level TFP growth: 1979-2013. Source: Authors estimates using ADIS data. [Colour figure can be viewed at wileyonlinelibrary.com]

industry productivity at the national and state level through channels other than within-farm technological progress and technical efficiency.

We then split the sample into two groups according to the type of dairy production system and apply the structural break analysis, as the deregulation reforms could generate different resource reallocation effects for different types of farms. As shown in Table 3, the impact of the deregulation reforms on resource reallocation for farms using the two production systems differs.

When controlling for within-farm technology progress, total rainfall, average temperature and the market price of whole milk, the null hypothesis of no structural break in the time-series model at 2000 for farms using the year-round production system is rejected at 1 per cent level. In contrast, the null hypothesis of no structural break at 2000 for farms using the seasonal production system is not rejected at the 10 per cent level. These findings are consistent with those obtained when applying the common structural break analysis to the panel data model, once cross-state disparities are well accounted for. These findings imply that the deregulation reforms are more likely to affect resource reallocation between farms using the 'year-round' production system than between farms using the 'seasonal' production system.

To further measure the impact of the deregulation reforms on productivity at the industry and production system type level, we apply the autoregressive distributed lag (ARDL) model to the panel data regression (with fixed effects) using dummy variables for deregulation reforms. As the deregulation reform was initiated by the central Government to alleviate trade issues, it is relatively exogenous to aggregate productivity – suggesting endogeneity is not a major problem. After controlling for within-farm technology progress, total rainfall, average temperature and the market price of whole milk, the deregulation reforms positively contribute to dairy industry productivity.

The estimation results indicate that the coefficients for the deregulation reform are positive and significant at 1 per cent level in both the ARDL model and the panel data regression model (Table 4). As within-farm technological progress is controlled for in these models, the effects associated with the dummy variable are more likely to reflect the impact of the deregulation reforms on aggregate productivity through resource

Table 3 The structural break test for the deregulation reform at 2000

	Time-series model		Panel model	
	Wald test statistics	*P*-value	Wald test statistics	*P*-value
All farms	12.057	0.002	20.710	0.000
Year-round farms	46.802	0.000	15.600	0000
Seasonal farms	2.017	0.365	0.040	0.834

Note: All other variables including within-farm technological progress, total rainfall, average temperature and market price of whole milk have been controlled when the structural break tests are applied to the time-series and the panel data regression models.
Source: Authors estimates using ADIS data.

Table 4 Impact of the deregulation reform on the aggregate TFP

	Time-series ARDL Model			Panel model with fixed effects		
	All farms	Year-round farms	Seasonal farms	All farms	Year-round farms	Seasonal farms
Dependent variable: Aggregate TFP within-farm technological progress	0.213*** (0.073)	0.762*** (0.074)	1.018*** (0.066)	0.226** (0.100)	0.788*** (0.060)	0.979*** (0.053)
Total rainfall (log)	−0.006 (0.064)	−0.012 (0.038)	0.023 (0.047)	0.197* (0.098)	0.008 (0.030)	0.084** (0.035)
Average temperature (log)	0.737* (0.374)	0.085 (0.216)	−0.074 (0.276)	0.680 (0.604)	0.182 (0.250)	−0.214 (0.306)
Market milk price (log)	0.287*** (0.070)	0.002 (0.040)	−0.057** (0.027)	0.203*** (0.064)	−0.0169 (0.023)	−0.043** (0.017)
Dummy for deregulation reform	0.143*** (0.023)	0.069*** −0.018	−0.046*** (0.015)	0.165*** (0.030)	0.064*** (0.018)	−0.039** (0.016)
Constant	−1.957*** (0.329)	−0.054 (0.144)	0.263*** (0.085)	−3.416 (1.772)	−0.495 (0.714)	−0.276 (0.841)
Number of Time Periods	34	34	34	35	35	35
R−squared	0.924	0.9848	0.9838	0.9071	0.9858	0.924

Note: The ARDL model has been used for the time-series analysis, which use aggregated TFP as dependent variables and up to three periods of lags in all independent variables are included as controlled variables. *P* value key *** 1%, ** 5%, * 10%.
Source: Authors' estimates using ADIS data.

reallocation. One possible explanation is that government regulations generated price premiums for market milk producers and segregated the milk market between states during the pre-reform period (Edwards 2003; Harris 2004; ADIC 2008). This subsequently restricted the movement of resources to more efficient farms using the year-round production system before 2000. As deregulation reforms stimulated market competition and dissipated the long-standing institutional barriers – resource reallocation was greatly facilitated, leading to improved efficiency and productivity in the dairy industry.

When splitting the sample into two groups according to farms using different production systems, we show that the deregulation reforms affected resource reallocation differently depending on production system type. The estimated coefficients for deregulation reform are positive and significant at 1 per cent for farms using the 'year-round' production system while negative and significant at 1 per cent and 5 per cent for farms using the 'seasonal' production system, consistent with different models in use. These results (consistent with what we have obtained in Table 2) suggest that the deregulation reforms positively contribute to the aggregate productivity of farms using the 'year-round' production system through resource reallocation, yet negatively contribute to the aggregate productivity of farms using the 'seasonal' production system.

As for the impact of control variables, within-farm technological progress positively contributed to productivity at the national level and for the state groupings. The measured contribution of within-farm technological progress to industry-level productivity growth slowed after 2000. This finding is consistent with Kompas and Che (2006), who concluded that the average growth in 'technical efficiency' of individual dairy farms declined in the post-reform period[5]. In addition, total rainfall is more likely to affect the productivity of dairy farms using the seasonal production system compared with those using the year-round approach. Finally, the market price of milk positively contributed to industry-level productivity, yet negatively contributed to the productivity of farms using the seasonal production system – consistent with the expected impact of the reform.

In sum, we show that the deregulation reforms positively contribute to aggregate productivity growth at the industry level as well as for farms using the 'year-round' production system by facilitating resource reallocation between farms. However, the observation that deregulation reforms tend to reduce the efficiency of resource reallocation between farms using the seasonal production system warrants further explanation because the removal of subsidies and other controls was expected to have the opposite effect on resource reallocation, as observed for dairy farms utilising the 'year-round' system. The reasons for this result are considered in the following sections.

5.3 'Seasonal' versus 'Year-round' production system

Although we test the causality between deregulation reforms and resource reallocation effects using the structural break and the regression methods, the analysis did not reveal how resources were reallocated between farms. Nor did it explain why deregulation reforms tended to worsen resource reallocation between farms using the 'seasonal' production system and hence detract from overall productivity growth. To answer these questions, we use Equations (4) and (5) to decompose the aggregate resource reallocation effects into 'between-group effects' (i.e. resource reallocation between the seasonal and year-round production systems) and 'within-group effects'[6] (i.e. resource reallocation between farms within each production system group).

First, 'between-group effects' were positive while 'within-group effects' were negative, for the period 1979 to 2013 (Figure 10). More specifically, our

[5] Despite differences in methods and data, comparison between our results and those obtained from previous studies (e.g. Kompas and Che 2006) is meaningful because the within-farm efficiency improvement is part of within-farm productivity growth.

[6] We decompose the farm-level TFP growth according to two production systems only. In a sensitivity test presented in Section 6, we introduce the state dimension into the decomposition.

estimates show that over time, farms using the 'seasonal' production system obtained more resources (or market share) from those using the 'year-round' production system. As is mentioned in Section 2, farms using the 'seasonal' production system generally have higher average productivity than those using the 'year-round' production system. Thus, when the deregulation reforms facilitate the reallocation of resources from farms using the 'year-round' production system to those using the 'seasonal' production system, industry-level productivity will increase.

Second, the deregulation reforms affect the 'between-group effects' and 'within-group effects' in different ways. In particular, 'between-group effects' were negative in the decade prior to the reform and became positive in the decade after. This implies that the deregulation reforms helped to facilitate the movement of resources from farms using the 'year-round' production system compared to those using the 'seasonal' production system and thus corrected a misallocation of resources between farms with different production systems. In comparison, 'within-group effects' were less influenced by the reform, shifting from having a negative effect on productivity in the two decades prior to 2000, to having no effect in the decade after. This implies that resource reallocation between dairy farms using the same production system did not obtain its expected impact.

Third, a further decomposition of 'within-group effects' (between farms using the 'year-round' production system and those using the 'seasonal' production system) revealed that the insignificant net contribution of 'within-group effects' to aggregate productivity growth after deregulation most likely reflects negative resource reallocation effects between farms using the 'seasonal' production system. This presumably offset any positive resource

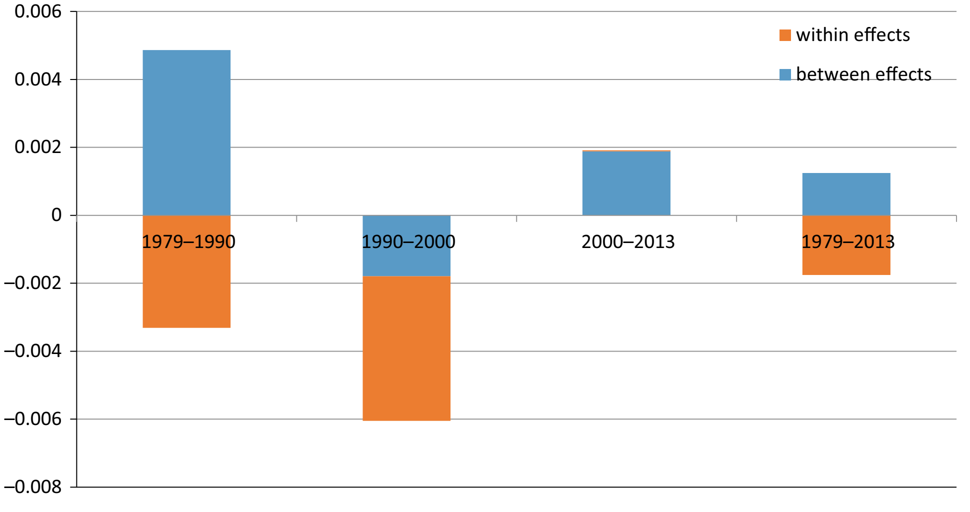

Figure 10 Decomposition between 'within-group effects' and 'between-group effects'.
Source: Authors estimates using ADIS data. [Colour figure can be viewed at wileyonlinelibrary.com]

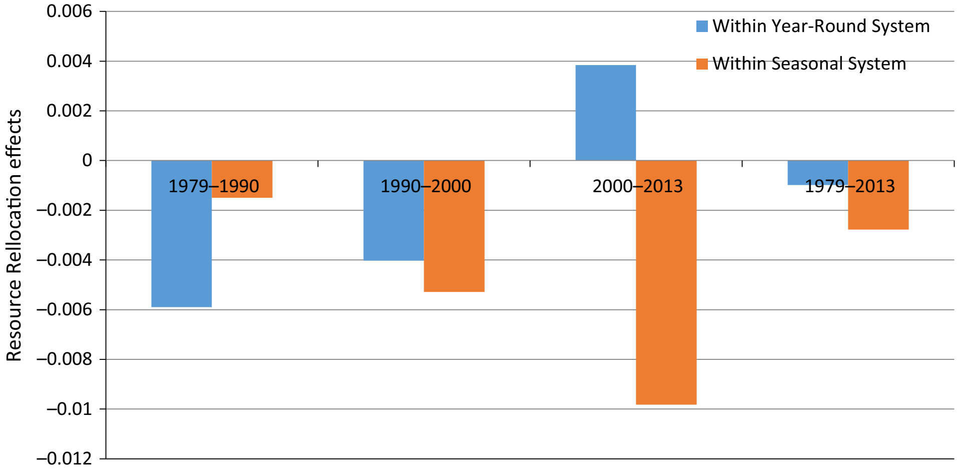

Figure 11 Comparison of within-group effects for the 'year-round' and the 'seasonal' production systems.
Source: Authors estimates using ADIS data. [Colour figure can be viewed at wileyonlinelibrary.com]

reallocation effects among farms using the 'year-round' production system (Figure 11). The finding of negative within-effects for the 'seasonal' production system following deregulation is thus consistent with the regression analysis results.

Two idiosyncratic factors are likely responsible for the negative within-effects in the seasonal production states following deregulation. These factors include a structural adjustment package that was provided to dairy farmers in 2000-01 and droughts in 2002-03 and 2006-07 (Gray *et al.* 2014; Sheng *et al.* 2017). Substantially negative within-effects are observed in these years, largely reflecting negative effects on input use and productivity associated with these events. Excluding the effects of the adjustment package and drought eliminates the negative misallocation effects within the seasonal states. This result is a useful reminder for other countries considering deregulation reforms that outcomes are not always as expected and that aspects of reform implementation (such as compensation mechanisms) and entirely exogenous factors like the climate can have significant effects.

6. Robustness check

To ensure the robustness of our findings, we tested the sensitivity of the results to five key assumptions embedded in the empirical strategy. First, the measure of resource reallocation between farms relies heavily on reliable estimates of farm-level productivity. To avoid a potential inaccuracy in Fisher index based the farm-level productivity estimates, we applied the Wooldridge-LP (Wooldridge 2009) regression method. Using this method, we re-estimated farm-level TFP and repeated the decomposition exercises[7]. The results from this test indicated that the contribution of resource reallocation to productivity growth when estimated using alternative methods were generally consistent with those obtained when using the index method.

Second, the decomposition of dairy industry productivity could be sensitive to prices used in the aggregation of real values of outputs and inputs. In particular, as the composition of outputs and inputs may differ substantially between farms, revenue-based farm-level TFP estimates could depart significantly from those obtained from physical quantities of input and output (Foster *et al.* 2008). We estimated TFP using both methods and found the resource reallocation effects obtained when using revenue-based TFP estimates were generally consistent with those obtained when using quantity-based TFP estimates.

Third, to investigate a possible bias that might result from the restricted movement of resources between states (due to either physical or market access constraints), we re-estimated ‘between-group effects’ and ‘within-group effects’ after regrouping the farms into states (instead of production systems). The results suggested that the deregulation reforms assisted to facilitate resource reallocation between states, and within states using the ‘year-round’ production system, but not within states using the seasonal production system. In particular, resource reallocation between dairy farms in Victoria (where the seasonal production system accounts for around 60 per cent of milk production) became more negative after the deregulation reforms were introduced.

Fourth, the sample rotation strategy used in ADIS is likely to be influenced by entry and exit of dairy farms, which could bias estimated farm entry and exit effects in the decomposition analysis. To examine the impact of such measurement errors on our analysis, we calculate the contribution of farm entry and exits to aggregate TFP growth. The estimation results demonstrate that the net impact of farm entry and exit is consistently positive throughout the whole sample period, and there is little change in the magnitude before and after the deregulation reform in 2000. This implies that our findings on resource reallocation are robust to dairy farm entry and exit and related measurement errors.

Fifth, to further explore whether the deregulation reform caused resource reallocation between dairy farms, we conduct a granger causality test (Granger 1969) to directly examine the relationship between the covariance terms and the dummy for deregulation reform at the industry level. The results indicate that the null hypothesis of no causality between resource reallocation effects and the deregulation reforms are rejected at 1 per cent

[7] In addition, there is another strand of the literature which attempts to use the directional distance function (i.e. stochastic frontier analysis (SFA) and data envelopment analysis (DEA)) to estimate farm-level TFP. Theoretically, the TFP estimates obtained from using this method are consistent with those obtained when using the regression method (Färe *et al.* 2008). In this study, we will not repeat this exercise.

level, providing some supportive evidence for the causal relationship between the two.

Finally, we also examine the sensitivity of our empirical results to outliers in our sample, by excluding farms with TFP level ranking at the top 5 per cent and the bottom 5 per cent. The results are generally consistent with what we have obtained, suggesting that our findings are not sensitive to outliers. In summary, the results obtained in this paper are generally robust to changes in the key assumptions underlying the methods used to estimate farm-level productivity, and to the way farms are grouped.

7. Conclusions

This paper combines structural break analysis, regression analysis and an extended OP decomposition method to investigate the impact of resource reallocation due to deregulation on industry-level productivity in the Australian dairy industry between 1979 and 2013. The results show that the deregulation reforms facilitated the movement of resources from farms using the 'year-round' production system to those using the 'seasonal' production system, as reflected in significantly increased 'between-group effects' in the post-reform decade. However, the impact of deregulation reforms on the movement of resources between farms within each farm group was insignificant, mainly because of an increase in resource misallocation between farms using the 'seasonal' production system. As such, one implication for policymakers from the Australian deregulation experience is that these reforms can have unexpected outcomes, particularly when more resources become available to one group of farms following market integration.

In examining the historical effect of dairy deregulation on productivity and resource reallocation, our Australian case study provides useful lessons for countries undergoing significant dairy reforms, as well as those with regulated dairy industries (such as the United States and Canada). In particular, we have demonstrated how dairy deregulation can reshape this industry while contributing to overall productivity growth and improved welfare of consumers. Globally, the dairy industry continues to evolve and in recent times has been characterised by increasingly large-scale production, and a corresponding decrease in the total number of farms. As such, resource reallocation has become an increasingly important driver of industry-level productivity growth, while technological progress continues to play an important role. Focusing on resource reallocation, our study noted the important impact of policy factors on productivity, as institutional barriers are removed and market competition is strengthened. Such changes facilitate the movement of scarce resources between farms – namely, from less productive farms exiting the industry to more productive farms with ambitions of increasing scale and harnessing technological progress.

Data Availability Statement

We hereby make the statement that the program used for generating the results for the paper is open to the public. Yet, the original farm-level data are confidential to the Australian government and will only be accessed through approval.

References

ABARES (2011). *Survey methods and definitions. ABARES Methodology Paper, August 2011*. Available from URL: http://www.agriculture.gov.au/sitecollectiondocuments/abares/surveys/survey-definitionsmethods.pdf., https://rirdc.infoservices.com.au/items/10-161. [accessed 13 Nov 2019].

ABARES (2015). Australian commodity statistics. ABARES Public Releases, December 2015, Canberra.

ADIC (2008). Dairy industry submission to Australian government review of export policies and programs. Australian Dairy Industry Council Inc., May 2008.

Alston, J.M. and Quilkey, J.J. (1980). Insurance milk, *Australian Journal of Agricultural Economics*, 24, 283–290.

Andrews, D.W. and Fair, R.C. (1988). Inference in nonlinear econometric models with structural change, *The Review of Economic Studies*, 55, 615–640.

Bai, J. (2010). Common breaks in means and variances for panel data, *Journal of Econometrics*, 157, 78–92.

Bai, J. and Perron, P. (1998). Estimating and testing linear models with multiple structural changes, *Econometrica*, 66, 47–78.

Baily, M.N., Hulten, C., Campbell, D., Bresnahan, T. and Caves, R.E. (1992). Productivity dynamics in manufacturing plants, *Brookings Papers on Economic Activity. Microeconomics*, 1992, 187–267.

Balcombe, K., Fraser, I. and Kim, J.H. (2006). Estimating technical efficiency of Australian dairy farms using alternative frontier methodologies, *Applied Economics*, 38, 2221–2236.

Balk, B.M. (2001). Scale efficiency and productivity change, *Journal of Productivity Analysis*, 15, 159–183.

BOM (Bureau of Meteorology, Australia) (2018) Weekly rainfall totals for Australia. Available from URL: http://www.bom.gov.au/jsp/awap/rain/index.jsp?colour = colour&time = latest&step = 0&map = totals&period = week&area = nat. [accessed 13 Nov 2019].

Collard-Wexler, A. and De Loecker, J. (2015). Reallocation and technology: evidence from the US steel industry, *American Economic Review*, 105, 131–171.

Corder, G.W. and Foreman, D.I. (2014). *Nonparametric statistics: A step-by-step approach*. John Wiley & Sons, Melbourne. ISBN 978-1118840313

Diewert, W.E. (1992). Fisher ideal output, input and productivity indexes revisited, *Journal of Productivity Analysis*, 3, 211–248.

Edwards, G. (2003). The story of deregulation in the dairy industry, *Australian Journal of Agricultural and Resource Economics*, 47, 75–98.

Eltető, O. and Köves, P. (1964). On a problem of index number computation relating to international comparison, *Statisztikai Szemle*, 42, 507–518.

Färe, R., Grosskopf, S. and Margaritis, D. (2008). Efficiency and productivity: Malmquist and more, *The Measurement of Productive Efficiency and Productivity Growth*, 5, 522–622.

Foster, L., Haltiwanger, J. and Syverson, C. (2008). Reallocation, firm turnover, and efficiency: Selection on productivity or profitability? *American Economic Review*, 98, 393–425.

Granger, C.W. (1969). Investigating causal relations by econometric models and cross-spectral methods, *Econometrica: Journal of the Econometric Society*, 37, 424–438.

Gray, E., Oss-Emer, M. and Sheng, Y. (2014). Australian agricultural productivity growth: past reforms and future opportunities, ABARES research report 14.2, Canberra, February.
Hansen, B.E. (1997). Approximate asymptotic p values for Structuras-change tests, *Journal of Business & Economic Statistics*, 15, 60–67.
Hansen, B.E. (2001). The new econometrics of structural change: dating breaks in US labour productivity, *Journal of Economic Perspectives*, 15, 117–128.
Harris, D.N. (2004). Producer adjustment to policy reform: A case study on the Australian dairy industry (No, 415–2016-26216).
Kompas, T. and Che, T.N. (2004). Productivity in the Australian dairy industry, *Australasian Agribusiness Review*, 12, 1,631–1,641.
Kompas, T. and Che, T.N. (2006). Technology choice and efficiency on Australian dairy farms, *Australian Journal of Agricultural and Resource Economics*, 50, 65–83.
Melitz, M.J. and Polanec, S. (2015). Dynamic Olley-Pakes productivity decomposition with entry and exit, *The Rand Journal of Economics,* 46, 362–375.
OECD (2016). OECD-FAO Agricultural Outlook 2016-2025, OECD Paris. Available from URL: http://dx.doi.org/10.1787/agr_outlook-2016-en.
Olley, S. and Pakes, A. (1996). The dynamics of productivity in the telecommunications industry, *Econometrica*, 64, 1263–1298.
Petrin, A. and Levinsohn, J. (2012). Measuring aggregate productivity growth using plant-level data, *The RAND Journal of Economics*, 43, 705–725.
Productivity Commission (2001). Trade and assistance review 2000–01. Annual Report Series 2000–2001, AusInfo, Canberra.
PWC (2015). The Australian dairy industry: From family farm to international markets–the basics, dairy Australia. Available from URL: www.pwc.com.au.
Sheng, Y., Jackson, T. and Gooday, P. (2017). Resource reallocation and its contribution to productivity growth in Australian broadacre agriculture, *Australian Journal of Agricultural and Resource Economics*, 61, 56–75.
Sheng, Y., Yang, S.S. and Zhao, S.J. (2018). Climate change, adaptation and agricultural TFP: A cross regional comparison of Australian broadacre farms. ABARES Technical Report No. 201803, Canberra, Australia.
Szulc, B. (1964). Indices for multiregional comparisons, *Przeglad Statystyczny*, 3, 239–254.
Wooldridge, J.M. (2009). On estimating firm-level production functions using proxy variables to control for unobservables, *Economics Letters*, 104, 112–114.
Zhao, S., Sheng, Y. and Gray, E.M. (2012). Measuring productivity of the Australian broadacre and dairy industries: concepts, methodology and data, in Fuglie, O.K., Wang S. and Ball E.V. (eds), *Productivity Growth in Agriculture: An International Perspective*, CABI press, Washington, DC, pp. 73–108.