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Review Article

Has Growth in Productivity in Australian Broadacre Agriculture Slowed? A Historical View

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Abstract

This paper uses the adjusted Cumulative Sum Square (CUSQ) index to examine the stability of historical productivity trend in Australian broad acre agriculture over the period of 1953 to 2007. The results show that a significant structural break in agricultural productivity occurred around the mid 1990s, and these results are robust across different industries and states. Further analysis of relative impacts of climate variability and investment in real agriculture Research and Development (R&D) shows that the slowdown in productivity growth is more likely to be driven by a long-term decline in public R&D investment than climate variability.

Keywords: Total Factor Productivity; Structural Change Analysis; CUSUM Index

Introduction

Productivity growth in Australian agriculture has long been regarded as an important source of wealth in Australia. The real value of agricultural production in Australia has been over $40b (2008 $A's) per annum since the late 90s (Figure 1). As productivity has grown at the rate of 2 per cent per annum, about two thirds of the value of production in recent years can be attributed to productivity growth since 1952-53. Agricultural productivity growth has been strong relative to other sectors of the Australian economy and relative to the agricultural sectors of other rich countries [1].

Recent data however suggest that similar to other developed countries such as US, Germany and Netherland etc., productivity growth in Australian agriculture may have slowed. In particular, the long-term annual growth rate of productivity in the broadacre cropping and livestock industries has declined from 2.1 per cent between 1978 and 1999 to 1.5 per cent between 1978 and 2007 (ABARES, 2009). At the same time, public investment in agricultural research in Australia, which has been the predominant source of funding in Australia, has not grown for three decades. Other causes of the decline in productivity are a series of bad seasons extending back to 2000 which may, in part, be attributed to climate change.

The objectives of this paper are:

- To review productivity growth within the broadacre agriculture industry (which comprise the cropping and livestock industries) in Australia and its determinants, using gross output-based TFP measures from the ABARES farm survey data;

- To assess whether or not productivity growth in the Australian broadacre agriculture has slowed in recent decades; and if such structural breaks did happen, when they did they start;

- To identify the extent to which real agricultural R&D investments and severe droughts have affected the trend stability of productivity growth in Australian broadacre agriculture.

Productivity Growth in Australian Broadacre Agriculture

The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) has conducted farm surveys since 1953 for broadacre agriculture (including most of the extensive grazing and cropping industries) and since 1989 for the dairy industry. Data from these surveys have been used to monitor trends in productivity using gross value measures. Most farms in Australia jointly produce a range of crop and livestock commodities. Thus, ABARES also follows productivity within segments of broadacre agriculture such as crop, beef and sheep specialists (but only from stratified samples from their overall farm survey).

In 2008, the total value of crop production was A$21.4billion, comprised of A$ 9.0 billion of grains and oilseeds. Over the same period, the total value of livestock production was A$19.8billion, of which dairying contributed A$4.6billion and wool, A$2.6billion and livestock slaughtering (including extensive and intensive stock), A$12.1billion [2].

Mullen [3] assembled a TFP series from 1953 to 1994 using ABARES farm survey data. Since then the series has been extended

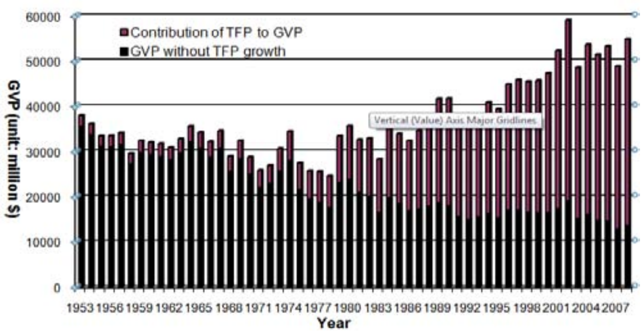

Figure 1: Gross output value of broadacre agriculture in Australia: 1953-2008.

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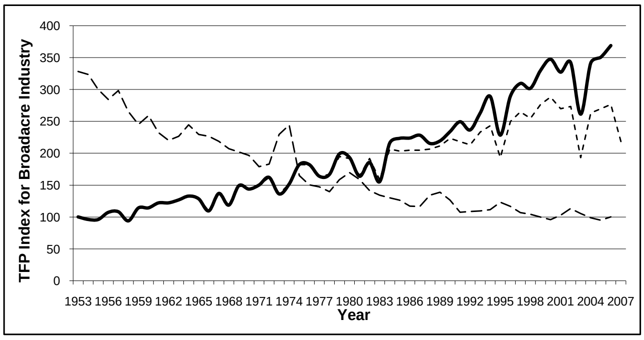

Figure 2: TFP trends as estimated by ABARES for broadacre agriculture and by the Productivity Commission for agriculture, fisheries and forestry.

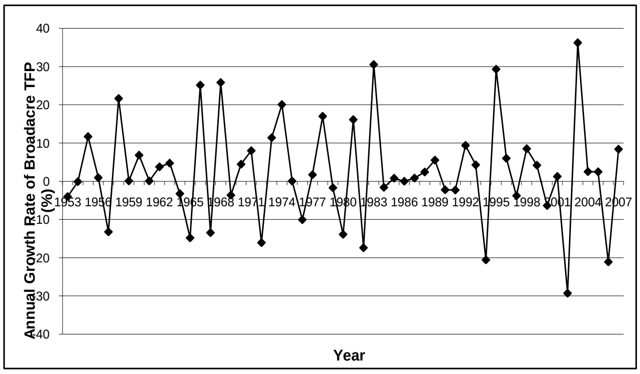

Figure 3: Annual growth rates for broadacre TFP.

in a piecemeal fashion, again using ABARES data, in several papers, most recently Mullen [4]. Recently ABARES assembled a consistent productivity dataset back to 1978 and this series has been used to extend Mullen's original series from 1978. Revisions to the sampling frame and the definition of some inputs and outputs used in the new dataset have meant that broadacre productivity growth is likely to have been overstated in papers by Mullen and ABARES until very recently. For example broadacre TFP grew at the rate of 2.7 per cent from 1978 to 2004 using the dataset from Mullen [4] whereas the new dataset used here suggests that the rate of growth over this same period was 1.7 per cent. Hence, in reviewing the literature for evidence of change in the rate of productivity growth in Australian agriculture, the contribution of changes in measurement approaches needs to be borne in mind.

Productivity for Australian broadacre agriculture rose almost 3 times from 100 in year 1953 to 288 in 2000. It then declined to 193 in 2003, reflecting the drought in that year, before reaching 277 in 2006 and then falling to 218 in the drought year of 2007 (Figure 2). The index is highly variable, falling in 20 of the 55 years, reflecting adverse seasonal conditions as well as some other unobserved factors (Figure 3). Such variability makes it difficult to discern trends in the underlying, more stable rate of technical change. The average annual rate of growth over the entire period was 2.0 percent per annum, 0.5 per cent lower than the long term rate previously reported by Mullen.

Productivity growth has been compared with the terms of trade as a partial indicator of whether Australian agriculture is becoming more competitive. The conventional wisdom has been that the terms of trade for Australian agriculture has been declining inexorably. However, while the trend in the terms of trade did decline for about 40 years from 1953 (Figure 2), since the early 1990s, the rate of decline has been much slower, at least for the sector as a whole. While the TFP index grew from 100 in 1953 to 215 in 2007, the terms of trade declined from about 335 to 100, at the rate of 2.3 percent per annum over the same period, exceeding the rate of productivity growth in broadacre agriculture. However, the rate of decline was 2.6 percent per annum from 1953 to 1990, and from 1991 to 2007, it was less than 1.0 percent per annum. The decline in the terms of trade over the last 17 years has been much slower than previously, a fact rarely recognized in much literature.

Productivity growth in broadacre agriculture from that ABARES dataset can also be compared with the Productivity Commission (PC) estimates for the agriculture, fisheries and forestry series (Figure 2). For the period 1978 to 2006, annual growth rates were 1.6 per cent and 2.5 per cent for the ABARES and PC approaches respectively. The series tracked each other closely except for post-2001 when that ABARES series dipped while the PC series continued to rise. As noted, the PC series includes forestry and fisheries. In addition, broadacre agriculture now comprises less than 60 per cent by value of the output of the agricultural sector and does not include the dairy, horticulture and viticulture industries for example. Hence a slowdown in productivity growth in broadacre agriculture relative to these other industries may explain the divergence between the ABARES and PC estimates. However the extent of the divergence is somewhat puzzling. It implies productivity growth in small industries well above that in the larger industries. There is no empirical evidence and little anecdotal evidence to support this suggesting that this may be an area of fruitful joint research between the two agencies in the future.

Productivity growth in broadacre agriculture since 1978 came from output growth of 0.8 per cent per year and input use declining at the rate of -0.6 per cent per year [5]. Labour use declined (-1.7 per cent) more than the use of capital (-1.2 per cent) and land (-0.7

Table 1: Growth in TFP for broadacre industries and by State, 1978 to 2007 (unit: %).

	TFP Growth	Output Growth	Input Growth
Total Broadacre	1.5	0.8	-0.6
Cropping	2.1	3.1	1
Mixed crop/livestock	1.5	0.1	-1.5
Beef	1.5	1.7	0.1
Sheep	0.3	-1.4	-1.8
By State			
NSW	1.2	0.3	-0.9
VIC	1.4	0.6	-0.8
QLD	0.8	0.6	-0.2
SA	2	1.5	-0.5
WA	2.4	1.8	-0.6
TAS	0.8	-2.1	-2.9
NT(Beef)	1.7	1.6	-0.1

Source: Nossal et al. [5] for the industry data. The state data comes from the same database but was not published in Nossal et al. [5].

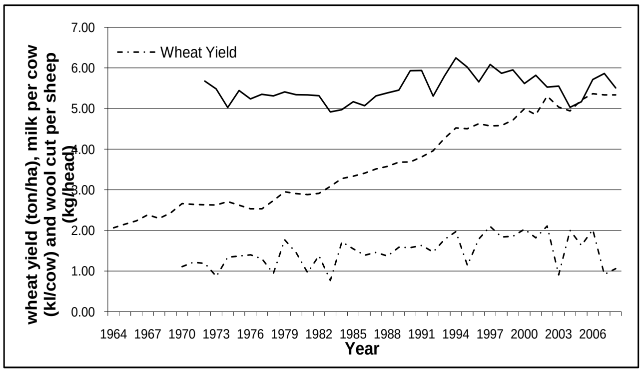

Figure 4: Yields of milk, wheat and wool.

per cent) while the use of purchased inputs increased (2.4 per cent) resulting in higher rates of growth in partial factor productivity (PFP) of labour (2.5 per cent) and capital (2.1 per cent).

As noted above, the ABARES broadacre dataset has been stratified to provide estimates of productivity growth by the enterprise or industry from which a large proportion of income is derived. The stratification regularly used by ABARES of total broadacre, cropping, mixed crop – livestock, beef, and sheep has been used here. More detail about beef and slaughter lamb producers defined using slight different 'rules' can be found in Nossal et al. [6] but there are few additional insights.

Since 1978 cropping (2.2 per cent) specialists have achieved much higher rates of TFP growth than beef (1.5 per cent) and sheep (0.3 per cent) specialists (Table 1). Generally output has grown while input use has been static or declining. However, for cropping specialists there was a large increase in the use of purchased inputs (4.0 per cent) and reduced use of labour(-0.2 per cent) and capital (-0.4 per cent) and strong growth in partial productivity of labour and capital [5]. A switch towards reduced tillage cropping also associated with more diverse cropping rotations and opportunistic cropping to exploit available soil moisture (as opposed to fixed rotations and fallows) partly explains the changes in input use and the strong rate of productivity growth.

Wheat yield, which in good years is now about 2t/ha, has been growing at the rate of 0.9 per cent per year since 1972 or at the rate of 1.5 per cent per year if the drought years of 2007 and 2008 are omitted (Figure 4). Wool cut per head, which in good years approaches 6 kg/head, has been growing at the rate of 0.2 per cent per annum. Perhaps growth in these yields has slowed since the mid 90s but a run of poor seasons confounds any firm conclusions.

Why TFP in cropping has grown more quickly than in livestock, particularly sheep, is uncertain [4]. The production cycle in livestock is much longer than in cropping which may mean it is more difficult to demonstrate to farmers the benefits of new technologies. Perhaps genetic gains have been more rapid in crops than in livestock over this period. Perhaps specialist crop farmers have a greater range of input substitution and output transformation opportunities than specialist wool growers for example. However Mullen and Crean [7] pointed out that the productivity grains of mixed farmers, who presumably have the greatest opportunities for economies of scope, while greater than those of specialist livestock farms, were less than those of specialist crop farmers.

The Productivity Commission [8] pointed to a rapid advance in cropping technologies as an explanation for this divergence in TFP growth. These technologies included higher yielding, disease resistant varieties; improved fertilisers and pesticides; and reduced tillage.

Productivity growth has also varied by State with productivity growth much faster in Western and South Australia than in New South Wales and Victoria (Table 1). Hailu and Islam using a multilateral approach to comparing TFP across States from 1977 to 1999 found faster growth in WA and SA meant that levels of TFP were converging across states.

In several of his papers, Knopke [9,10] enquired into sources of Australian agricultural productivity growth. The most robust of his findings was that size matters. Large farms have higher levels of productivity growth than small farms. Dividing the farms into three groups by size (measured in terms of carrying capacity), Knopke et al. [9] found that productivity growth was 3.1% pa for the group of largest farms, 1.9 per cent pa for the group of medium-sized farms and 0.9 per cent pa for the group of smallest farms. In the 2000 study, Knopke found that productivity growth rates were 3.5, 2.7 and 2.4 per cent pa respectively for the three groups of farms.

While other factors contribute to productivity growth [11-13], a major source of productivity growth has been technological change arising from investment in R&D. The public sector, financed to a significant degree in recent decades by levies on production, has been the major provider of R&D services in Australia. In a series of analyses (most recently [4]), Mullen has found that so far, the returns to this investment in broadacre agriculture have remained high (within a range of 15 - 40 per cent) despite declining public support. However the downward revision of the ABARES productivity series for broadacre agriculture, noted above, is likely to mean that the returns to research are towards the bottom of the range.

Why might Broadacre TFP be Slowing?

Some argue that it is not surprising that TFP is drifting down because 'all the big gains have been made'. However research agronomists still seem confident that there are still practical research opportunities and opportunities for farmers to grow crops more

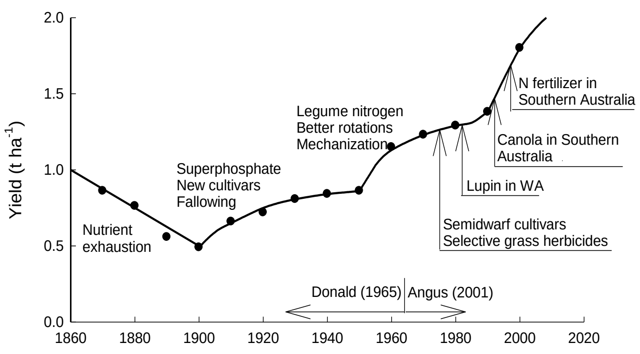

Figure 5: Trends in average wheat yield in Australia 1860 to 2000.
Source: Donald (1965), modified by Angus 2001.

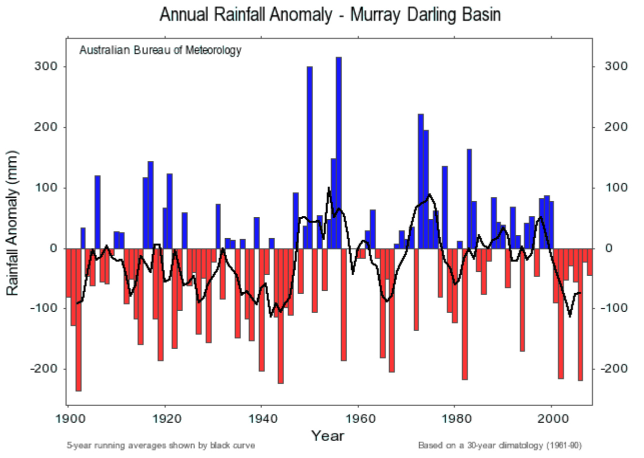

Figure 6: Annual Rainfall Anomaly-Murray Darling Basin.
Source: the Bureau of Meteorology.

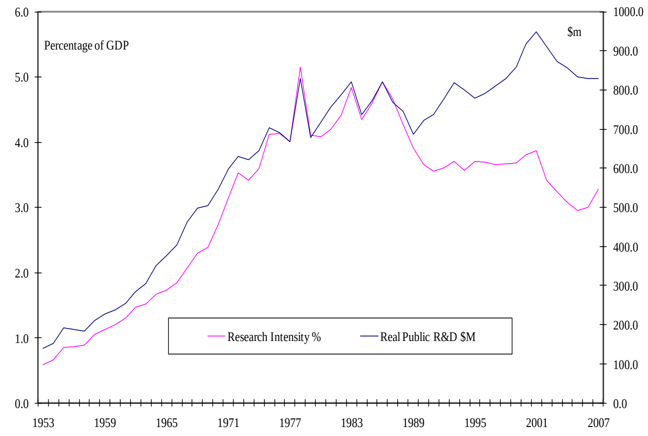

Figure 7: Real public investment and research intensity in Australian agriculture: 1953–2007.

efficiently. Trends in Australian wheat yields are displayed in Figure 5 and show little signs of slowing down.

Angus [14] (World Wheat Book, in press) said:

'Despite the new technology, the mean yield is only 2 t/ha, about half of the water-limited potential….. Further research will be needed to increase yield closer to the water-limited potential. The gains are most likely to come from tactics that enable crops to take advantage of the more favorable seasons in the variable climate, and concentration of inputs on the parts of farms with the highest yield potential.'

Two other factors likely to explain a significant portion of productivity growth in broadacre agriculture are climate or seasonal conditions and public investment in agricultural research

The annual rainfall anomaly for the Murray Darling Basin (Figure 6) published by the Bureau of Meteorology shows the annual deviation in rainfall from average annual rainfall between 1961 and 1990. There have now been 8 consecutive years of below average rainfall. We make no judgment here about the extent to which long term climate change has contributed to this run of poor seasons and below we simply refer to climate. If farmers are using inputs in expectation of a normal season but a dry season eventuates then TFP falls. In addition, perhaps farmer's expectations about seasons are now more conservative such that they are operating on a less efficient part of the production function. This is an area for future research.

The way in which the data on R&D investment has been assembled from ABS sources and a previous data set developed by Mullen, Lee and Wrigley is described in Mullen [4]. R&D expenditure data below relate to financial years, but the convention of referring to the 2002–03 year, for example, as 2003 has been adopted. Expenditure is attributed to research providers, rather than funders. As a result, expenditure by state departments of agriculture or universities, for example, includes funds obtained from rural RDCs. Attention is focused on farm production research and investment in R&D in fisheries and forestry is not included.

Total public expenditure on agricultural R&D in Australia has grown from A$140 million in 1953 to almost A$830 million in 2007 (in 2008 dollars). Figure 7 shows that expenditure growth was strong to the mid-1970s. The trend in expenditure has essentially been static since that time although there was a spike in investment (nearly $950m) in 2001. Likewise, agricultural research intensity, which measures the investment in agricultural R&D as a percentage of GDP, grew strongly in the 1950s and 1960s, but has been drifting down from about 4 -5% annually of GDP in the period 1978–86 to about 3.0% in recent years (as compared to 2.6% in developed countries). In our analysis below of trends in broadacre TFP, investment in R&D in broadacre agriculture has been derived as a proportion of this total public investment in agricultural R&D.

Is Productivity Growth in Agriculture Slowing?

There is some concern that productivity growth in Australian agriculture may have slowed as is the experience of the agricultural sectors of other developed economies. A particular concern is that any slowing in growth may arise from a slower rate of technical change associated with stagnant (at best) public investment in agricultural research [4]. In Australia, a decade of poor seasonal conditions has made it difficult to discern whether and why productivity growth has slowed from only a simple descriptive statistics.

According to PC [15], productivity growth in the agriculture, fisheries and forestry sector has remained strong (excluding the drought year of 2007) despite a weakening in the rest of the economy. In fact productivity growth in the sector has been faster since 1989-90 (3.6 per cent to 2005-06) than before (1.4 per cent for 1974-75 to1989-90). On the other hand however, ABARES estimates for

Table 2: Growth rate of TFP for broadacre industries, 1978 to 2007 (%).

	All broadacre	Cropping	Mixed crop-livestock	Sheep	Beef
1980 to 1989	2.2	5.8	2.9	0.4	-0.9
1985 to 1994	1.8	5.7	3.2	-1.7	3.1
1989 to 1998	2.0	1.9	1.4	-1.2	1.6
1994 to 2003	0.7	-1.2	0.0	3.4	1.0
1998 to 2007	-1.4	-2.1	-1.9	0.5	2.8
1978 to 2007	1.5	2.1	1.5	0.3	1.5

Source: Nossal et al. [5].

broadacre agriculture suggest that productivity growth has slowed in the ten years to 2006-07. In this period the level of TFP peaked at 288 in 1999-00 and the next peak was 276 in 2005-06 (Figure 2) and there was no statistically significant trend in TFP over this period (excluding 2002-03 and 2006-07, two obvious drought years).

Trends in productivity have not been even across industries within broadacre agriculture (Table 2). For cropping specialists, TFP grew at the rate of 5.8 per cent from 1979-80 to 1993-94 but declined at the rate of -2.1 per cent per year for the ten years to 2007. For this period TFP for all broadacre agriculture fell at the rate of -1.4 per cent. There seems much less evidence of a slowing in TFP growth for beef and sheep specialists. Nossal et al. [5] speculated that productivity growth amongst sheep specialists, usually ranking the lowest amongst the industry groups, might finally be catching up. Since extensive livestock production is more resilient to poor seasons than crop production, it seems likely that climate variability and perhaps a contribution from climate change explain much of this slowing in TFP in the cropping and mixed farming industries. In addition, perhaps the decline in public investment in R&D since the 1970s may now being reflected in a slowing rate of technological progress in cropping industries.

No attempt has been made to empirically assess the relative contribution of these three influences – climate change, climate variability and investment in R&D. Also, there is uncertainty about why these three factors may have had a much stronger impact on ABARES' broadacre agriculture than on the PC's agriculture, fisheries and forestry sector, though different industry coverage of the two measures has already been discussed. In the following section, we use the adjusted cumulative sum square (CUSQ) index (one of the structure change analysis approach) to examine the stability of the TFP index for Australian broadacre agriculture from 1953 to 2007 and the contribution of factors like climate and R&D investment to changes in trend.

Structural Change Analysis: Baseline Scenario

Structural change analysis, an extension of time-series analysis in econometrics, was developed to examine the stability of time-series variables and their determinants. Many methodologies, including the cumulative sum square (CUSQ) index method, super likelihood maximum (super-LM) method, rolling regression etc., were classified in this category (reviewed in Perron [16]). Following Andrews [17], Inclan and Tiao, Hansen [18] and Deng and Perron [19], we chose the adjusted CUSQ index to examine the stability of Australian broadacre productivity. The aim is to answer the following three questions:

- Has there been any structural change in TFP of the Australian broadacre industry over time?
- If so, how many breaking points have there been and when did they occur?
- What are the most important (possible) factors which contributed to these structural changes?

One of the most popular tools used for tracing possible structural breaks in agricultural productivity is the CUSQ index which is based on tracing out the path of the residual, recursively estimated, squared and summed through time (a detailed explanation of the statistic is presented in an appendix) from a series of regressions of the log of TFP against a time trend and (or) other determinants. The path of this statistic is expected to fluctuate around zero as new observations are added but it gives an out-of-control signal once the recent values of TFP are significantly different from their previously expected levels. Given the estimation system (or the model specification), the value of CUSQ index generally starts with some value close to zero and ends with some value close to zero. If there is no structural break in productivity over time, the estimated CUSQ index will be roughly constant for the examination period-subject to estimation error; however, if there is a structural break, the estimated CUSQ index will vary systematically. When the absolute value of the adjusted CUSQ index exceeds the pre-determined critical value (i.e. 1 per cent or 5 per cent), one can conclude that there is a significant structural break in productivity growth and specify the exact time for the breaking point by identifying the first peak of the adjusted CUSQ index out of the boundary.

Using the ABARES TFP estimates for the Australian broadacre industry between 1953 and 2007, we calculate the CUSQ index based on the OLS regressions of logged TFP on time, a measure of climate based on a crop water stress index, knowledge stocks generated by public investment in agricultural R&D, farmer's education and the terms of trade facing broadacre farmers in three scenarios. The first was to regress logged TFP on time, with the results obtained from this scenario treated as the benchmark for comparison with other scenarios. The second was to regress logged TFP on time, climate and a knowledge stock, and the third was to regress logged TFP on time, climate and a knowledge stock, and education and terms of trade indexes respectively. The results obtained from the second and third scenarios were compared with the first scenario to examine how drought and R&D investment may have affected the stability of agricultural productivity.

Figure 8 shows the estimated CUSQ index from the first scenario, with both the 1 per cent and 5 per cent Andrews criteria, for the period of 1953 to 2007. There is an obvious trend in the estimated CUSQ index with a global peak of 2.09 occurring in 2002 (after a decade of monotonic increase). This value easily exceeds the Andrews 5 per cent and 1 per cent critical values, 1.36 and 1.63, and the hypothesis of no structural break in the TFP series for Australian broadacre agriculture is rejected.

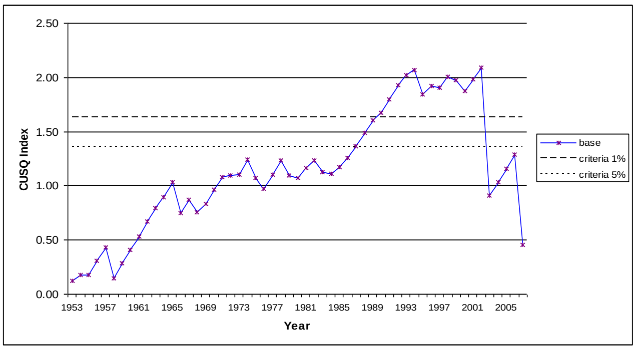

Figure 8: Testing for TFP Structural Change in Australian Broadacre Industry 1953 to 2007: A Baseline Scenario.

Figure 8 Testing for TFP Structural Change in Australian Broadacre Industry 1953 to 2007: A Baseline Scenario.

Given that we find evidence of structural breaks, the next step is to sort out: (1) how many breaks there are, and (2) when do they occur? To identify the number of breaks, Figure 8 shows that there have been generally three waves of systematic changes in estimated CUSQ index over time, occurring in the early 1960s, the 1970s and the 1990s respectively. The first wave of change reaches a high of 1.03 in 1965, while the second and third reach highs of 1.24 in 1974 and 2.07 in 1994 (or later 2.09 in 2002). All of them can be treated as candidate structural breaks. However, when compared with the Andrews 5 per cent and 1 per cent critical values, only the potential structural break in 1990s survives suggesting that there is just one significant structure break for the period from 1953 to 2007. This finding suggests that the structure change in broadacre productivity only occurs in the recent decade.

As for dating the turning points of structure changes, there have been different views in the current literature. Some studies, including Picard [20] and Bai [21], Bai and Perron [22], tend to use the criteria method: they generally use the time when the CUSQ index breaks through the critical value as the break-date which in this case would be 1987 at the 5% level and 1990 at the 1% level. Other studies, including Chong [23], Bai [24] and Hansen [18], prefer to use the local or global peak point to identify the change in structure. In this study, we took the latter view by using the time when the CUSQ index reaches its first peak out of the criteria boundary as the break-date. Thus, the turning-point for broadacre TFP (in Figure 8) is identified as 1994 when the CUSQ index reaches its first peak of 2.07. This result suggests that the growth patterns of broadacre productivity are significantly different before and after 1994. Although our finding from this analysis seems contradict visual inspection of the TFP series (which appears to show the structural change in productivity occurs after 2000), it is not surprising since the year-to-year fluctuation of productivity can often muffle its long-term trend (Figure 2).

Finally, since the annual TFP growth rate for the period from 1953 to 1994 (2.2 per cent) was significant higher than that for the period from 1994 to 2007 (0.4 per cent), this implied that the identified structural change was driven by a slowing TFP growth for broadacre industry (Table 2).

Behind Structure Change: Climate Changes, R&D Investment and Other Factors

As is mentioned above, severe climate conditions and a decline in public R&D investment are widely believed to be two important factors causing agriculture productivity in the broadacre industry to slow down in recent years. To investigate further, we extend the estimation of the CUSQ index by accounting for possible impacts from climate (crop water stress index), real agriculture R&D investment with 35 and 16 year lag structures (obtained and updated from Mullen [4])), education and the terms of trade facing broadacre agriculture. The estimated CUSQ indexes are shown in (Figures 9-11), along with our baseline scenario. Figures 9, 10A and 10B focus on climate and R&D and Figures 11A and 11B, on education and the terms of trade. The 'A' figures are for the 35 year lag research profile and the 'B' figures are for the 16 year lag research profile.

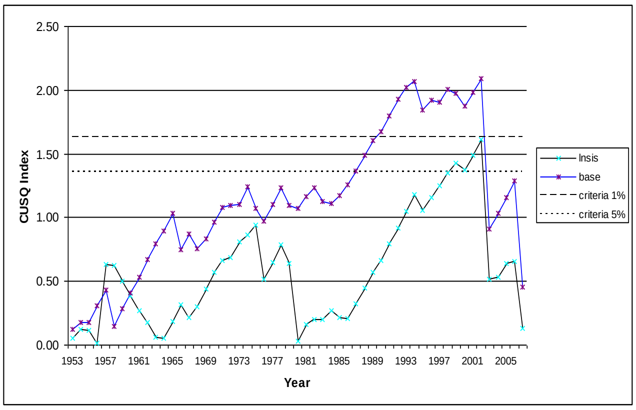

Figure 9: Impact of Climate Change on Agricultural Productivity Structural Change.

When the impact of climate is considered (Figure 9), the structural change analysis shows that the CUSQ index becomes more stable for the period of 1953 to 2007.Compared with the baseline model the estimated CUSQ index controlling for climate is generally lower throughout the whole period and it reaches the peak of 1.62 in 2002 (smaller than 2.09 in 2002 and less than the 1% significance criteria). This result implies that as expected, climate (in particular, drought) in recent years is an important factor contributing to the instability of the productivity trend. However, since the CUSQ index after controlling for climate (in 2002) is still more than the Andrew 5 per cent and close to the 1 per cent critical values, we can see that there may be further structural change in productivity growth that is in dependent of severe droughts. In other words, drought may not fully explain the slowing of broadacre productivity in the most recent decade.

As for the breaking date after controlling for climate, the first peak of CUSQ index approaching 1% Andrew boundary occurs in 2002 (with the value of 1.62) rather than in 1994 (with the value of 2.07) obtained in the baseline model. This result suggests that: the identified turning point for broadacre productivity growth controlling for climate conditions is more likely to be 2002 rather than 1994. In other words, if there had not been severe drought in the mid 90s, broadacre TFP would have kept growing at its trend rate until 2002 (from a statistical perspective). A possible explanation for this phenomenon is that severe climate conditions (or droughts) in mid late 1990s imposed an adverse impact on farmers' outputs (given inputs) and dragging down their productivity growth for the period of 1994 to 2002. This impact is an additional impact of adverse seasonal conditions beyond its general impact on the stability of broadacre productivity throughout the whole period of 1990s to 2000s.

What about the impact of real agriculture R&D investment on the structural break in broadacre productivity? To see this, we add the 16 year and 35 year knowledge stock variables assembled from real public R&D investment in the Australian broadacre agriculture into the structural change analysis (with climate still included in the model), and re-estimate the adjusted CUSQ index.

Figures 10A and 10B compare the adjusted CUSQ index obtained from the scenario accounting for both climate and a knowledge stock.

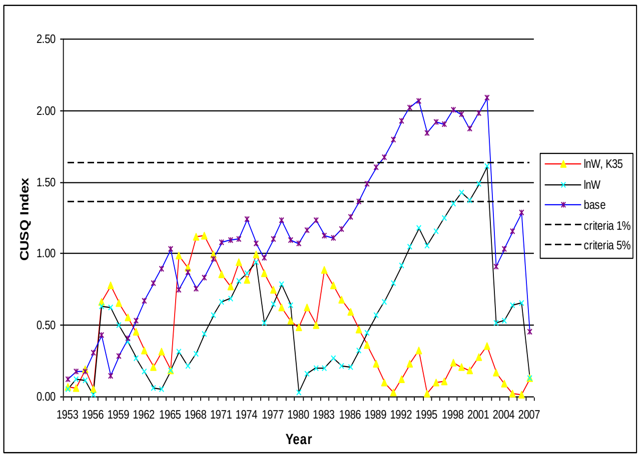

Figure 10A: Impact of Climate Change and R&D Investment (35-year lag) on Agricultural Productivity Structural Change.

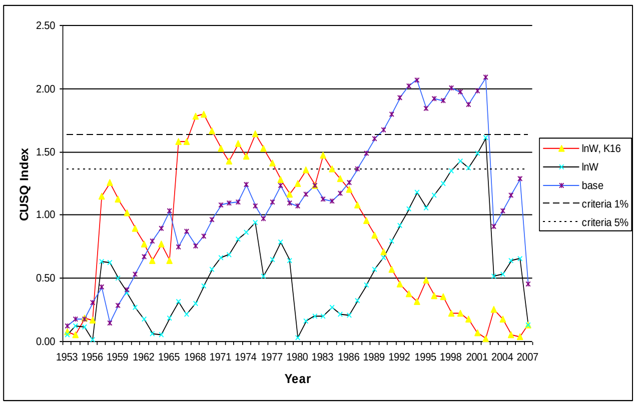

Figure 10B: Impact of Climate Change and R&D Investment (16-year lag) on Agricultural Productivity Structural Change.

After controlling for the impacts of real agricultural R&D investments, the variability in the CUSQ index further decreased especially for the past two decades. Throughout the whole period of 1953-2007, the CUSQ index reaches the two peaks of 1.13 (or 1.80 for the 16 year lag research profile) in 1969 and 0.89 (or 1.47 for the 16 year lag research profile) in 1983, which in the case of the 35 year lag profile are less than the Andrew 5 per cent value. In particular, there is no longer a significant out-of-control pattern for the CUSQ index, which implies that there is no strong evidence of structural change in productivity growth in recent years (after controlling for real agricultural R&D investments and climate). Comparing this result with those obtained from both the baseline model and the model accounting for climate (where structural changes are identified at different statistical significance levels), we can say that real agriculture R&D investment is an important factor affecting the stability of broadacre productivity in the past two decades. In particular, it contributes to explaining the recent slowing-down trend of broadacre productivity since 2002.

Comparing the relative impact of the 16 to 35 year research profiles, our analysis seems to lend support to the view that the lags involved in agricultural research are more likely to be in the order of 35 years than 16 years. The reason is that the pattern of estimated

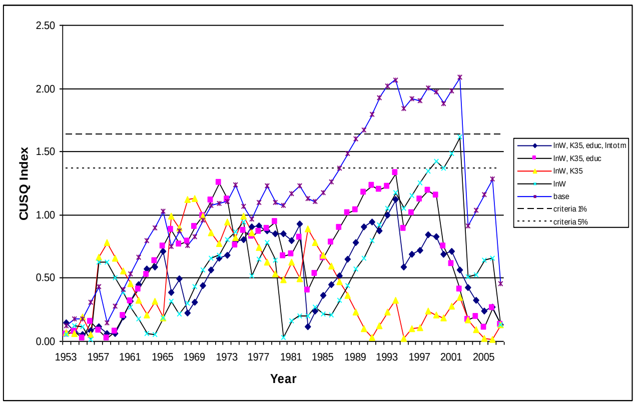

Figure 11A: Impact of Education and Terms of Trade on Agricultural Productivity Structural Change (35-year lag for R&D).

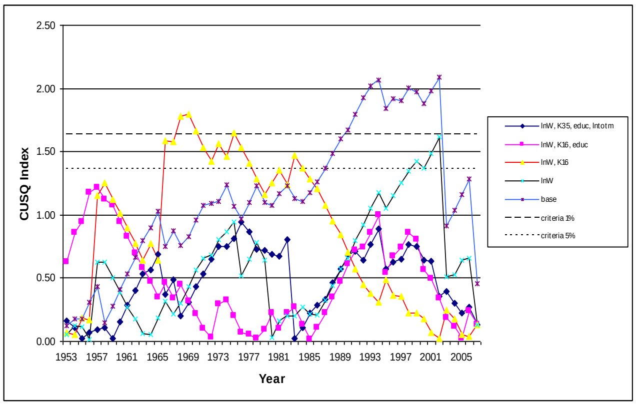

Figure 11B: Impact of Education and Terms of Trade on Agricultural Productivity Structural Change (16-year lag for R&D).

CUSQ index with the 35 year lag profile in agricultural research is more stable than that with the 16 year lag profile.

We expect that productivity growth after controlling for climate and real agriculture R&D investment would be more stable over time since it would be more likely to be a random process given the nature of technology progress. Of course, the above statistical results are only valid if the strict assumptions about the impact of agricultural R&D on productivity represented by the alternative lag profiles remain unchanging over time.

Finally, to examine the impact of some other factors, such as education and terms of trade, on the structural break in agricultural productivity, we also add the education and terms of trade indexes into the structural change analysis (with both climate and real agricultural R&D investments controlled in the model). Figures 11A and 11B show the estimated CUSQ index (under the assumption of real agricultural R&D investments with 35-year/16-year lags respectively). Compared with the model only accounting for climate and real agriculture R&D investment, the estimated CUSQ indexes from the model accounting for education and terms of trade additionally are less stable especially since the mid 1980s. This result, combined with our observation of continuing education-level improvement and flattening terms of trade in the past two decades

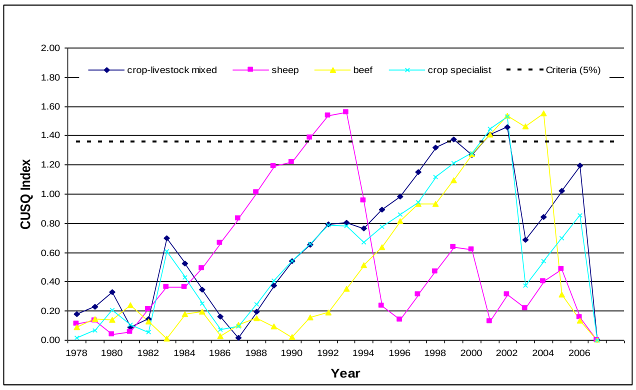

Figure 12: Testing Structural Change of Agriculture Productivity by Industries.

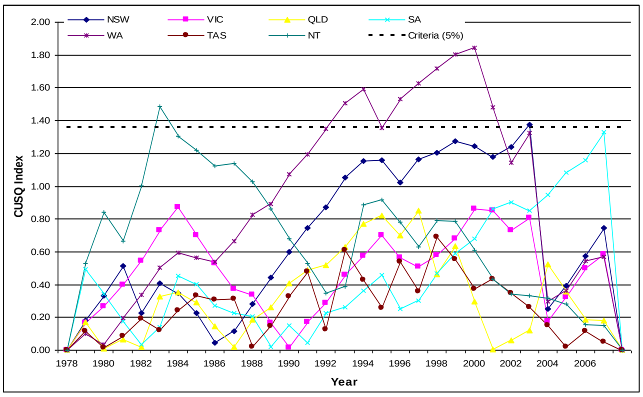

Figure 13: Testing Structural Change of Agriculture Productivity by States.

(Figures B3 and B4), suggests that changes in education level and terms of trade contribute to weakening the structural change of productivity and favouring broadacre productivity growth in recent years. However, since the estimated CUSQ indexes are not out of the 5% and 1% Andrew boundary, we can conclude that they are not as important as climate and real agricultural R&D investment in affecting broadacre productivity.

Robustness Check

As a robustness check, this section carries out a series of structural change analysis focusing on the industry- and state- level broadacre productivity. In doing so, the broadacre agriculture is decomposed into four industries, including the crop specialist, crop-livestock mixed, sheep industries at first and seven states, including New South Wales, Victoria, Queensland, West Australia, South Australia, Tasmania and Northern Territory. The purpose is to test the sensitivity of our results to industry and state specification.

The estimated CUSQ indexes with industry-level data (Figure 12) show that broadacre productivity in three out of four industries has experienced significant structural change (at 5% level) around 2001 except for the sheep industry (whose structural change is more likely to happen in early 1990s when the wool system collapsed). This result is consistent with our finding at the aggregate level, providing some evidence on the structural change in broadacre productivity in recent years.

The estimated CUSQ indexes with state-level data (Figure 13) show that broadacre productivity in Western Australia, New South Wales and South Australia has experienced some structural change (around 5% level) after 1990, despite of their different breaking time. Since these three states are the most important regions for broadacre industry, this provides some evidence on the structural change in broadacre productivity in recent years from a regional perspective.

In sum, the analysis with the industry and state level data shows that: Controlling for year-to-year fluctuation, broadacre productivity growth at the industry and state level has experienced some structural change. This lends support to our findings from the structural break analysis with the aggregate level data.

Conclusion

Productivity growth in the Australian agriculture, fisheries and forestry sector has, according to ABS statistics [25], remained strong relative to the rest of the Australian economy and relative to the agricultural sectors of other developed countries. For this broad sector the rate of growth in productivity has been about 2.5% per year since 1978, with no evidence of a slowdown in the past decade, compared to 1.2% per annum TFP growth rate for the Australian economy as a whole.

However, ABARES farm survey data suggest that the story for Australian broadacre agriculture is less rosy with growth in the industry perhaps a little more than TFP growth in the economy as whole and strong evidence that there has been no growth over the most recent decade to 2007 particularly amongst crop specialists. For cropping specialists, TFP grew at the rate of 4.8 per cent from 1979-80 to 1993-94 but declined at the rate of -2.1 per cent per year for the ten years to 2007. For this last decade TFP for all broadacre agriculture fell at the rate of -1.4 per cent. There seems much less evidence of a slowing in TFP growth for beef and sheep specialists.

Using the structural change analysis, we examined the stability of the trend in broadacre TFP for the period of 1953 to 2007. We found statistical evidence of a significant structural change in broadacre productivity in the mid 1990s. A further comparison of productivity growth before and after this turning point in 1990s shows this structure change led to a decline in the rate of productivity growth. There has been a long run of poor seasons and public investment in agricultural R&D investment has shown no growth since the 1970s. Our analysis suggested that while climate has had an important impact on lowering growth in broadacre TFP over the last decade, it alone did not fully account for the slowdown. It was only when account was taken of the reduced investment in public R&D extending back to the 1970s that there was a return to a stable path for broadacre TFP.

Acknowledgement

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