

Public investment in agricultural R&D and extension: an analysis of the effects on Australian broadacre farming productivity

1. Introduction

Australian agriculture today is one of the least protected and among the most efficient examples in the world. The remarkable performance of Australian agriculture offers tremendous insight for other countries to consider (Zhou, 2013). Total factor productivity (TFP) in Australian broadacre agriculture grew at an average annual rate of almost 2 per cent a year between 1952–53 and 2006–07, well above that of other OECD countries.

In the long run, agricultural productivity growth largely reflects technical change, and this has been the experience of Australia's broadacre farming sector. For the past 50 years, technical change was the key driver of productivity growth in the cropping industry. Public investment in research and development (R&D) and extension has been a key 'lever' that Australian governments have used to promote technical change and achieve improvements in agricultural productivity. Public R&D has been an important means of developing new technologies and management practices. Also, facilitating adoption of such innovations through extension has served to achieve long-term growth in agricultural productivity. However, growth in public agricultural R&D expenditure has slowed since the late 1970s. Coincidentally, the rate of technical change and, as a consequence, the growth in broadacre TFP has also declined since the mid-1990s (Sheng *et al.*, 2011). As a result, there is renewed debate about the role that governments should play in funding agricultural R&D and extension (Productivity Commission, 2011).

As a contribution to the debate, this study uses regression analysis to evaluate impacts of public investment in agricultural R&D and extension on productivity growth in Australian broadacre agriculture over the post war period. In particular, we calculated the contributions

of public agricultural R&D and extension investment to productivity growth of the broadacre industry and also measured their profitability by calculating the corresponding internal rates of return (IRR).

We find that public investment in agriculture R&D and extension has positive and significant impacts on agricultural productivity. During the period of 1952–53 to 2006–07, public investments in R&D and extension in Australia and overseas contributed almost two-thirds of average annual growth in TFP in the broadacre farming sector. Over the same period, the average IRR to domestic public investment in broadacre R&D and extension was 28.4 per cent and 47.5 per cent respectively.

This study made a number of contributions to the existing literature. First, the study uses an extended dataset for the period from 1952-53 to 2006-07, which helps to improve the knowledge of long-term effects of public R&D investment. Second, the study employs more sophisticated econometric techniques than previous work, in particular the testing and selection of the appropriate length of the lag effects of public R&D investment and their distribution profiles and the econometric analysis techniques. Third, the study separates the contribution of public R&D investment and extension spending to the growth in TFP in the Australian broadacre farming sector. And fourth, the study takes into account spill-in effects from overseas public R&D investment on growth in TFP in Australian farming.

The paper is structured as follows. Section 2 describes the trends in public agricultural investment in R&D and extension and broadacre productivity, and briefly reviews the literature analysing the relationship between public investment in R&D and extension and agricultural productivity in Australia and overseas. Section 3 presents the model specification and estimation strategy. Section 4 defines the variables and sources of data used in the analysis. Section 5 presents the results and provides estimates of the effects of public investment in R&D and extension on broadacre productivity and the internal rate of return to

public investment in agricultural research. Section 6 summarises the main findings and provides policy implications.

2. Public investment in agricultural R&D and extension and broadacre productivity: phenomenon and literature

Trends of public investment in agricultural R&D and broadacre productivity in Australia

In Australia, public investment in agricultural R&D has, in real terms (2006–07 dollars), increased over the past 50 years from \$131 million in 1952–53 to around \$778 million in 2006–07 (Figure 1). Historically, total investment in agricultural R&D was dominated by the public sector. For example, Australian federal and state government research agencies undertook 22 per cent and 53 per cent of agricultural R&D in 1995 respectively (Mullen, 2010).

[Insert Figure 1 here]

However, a strongly increasing trend in public agricultural R&D expenditure has changed over time. Since the late 1970s, the average annual growth in public agricultural R&D investment has declined from around 7 per cent between 1952–53 and 1977–78 to around 0.6 per cent from 1977–78 to 2006–07. Moreover, research intensity (the ratio of public R&D expenditure to agricultural gross domestic product [GDP]) peaked at over 5 per cent in 1977–78, but declined to 3 per cent in 2006–07.

The importance of public extension has also declined, from 24 per cent of total public agricultural R&D and extension in 1952–53 to around 19 per cent in 2006–07. This decline reflects the withdrawal of state governments from providing extension services, which has been accompanied by increasing private sector involvement.

Reduced growth of investment in public agricultural R&D and extension arouses the concern that a slowdown in long-term productivity growth in Australian broadacre agriculture will occur. Coincidentally, a slowdown in broadacre productivity growth since the mid-1990s has been witnessed (Sheng *et al.*, 2011). Agricultural broadacre TFP growth averaged around 2.2 per cent a year before 1993–94, but dropped to 0.4 per cent a year thereafter. Although a range of factors, including droughts, is likely to have contributed to the slowdown, the stagnating public investment in R&D should also be regarded as a contributing factor.

Public investment in R&D and agricultural productivity: a literature review

The contribution from investment in R&D and extension spending to growth in agricultural productivity is different because these two expenditures have quite different impacts. Research is an investment providing a flow of effects over many subsequent years as producers adopt an innovation. Extension on the other hand has the characteristics of an annual expenditure with an immediate response in achieving a certain level of adoption. There is an extensive body of literature evaluating the effect of public investment in agricultural R&D and extension on farm performance.

Economic evaluations from overseas and Australia indicate that the returns to public investment in agricultural R&D are high. For example, Echeverria (1990) reviewed over 200 projects and aggregate level analyses of agricultural R&D globally, and found that most estimated rates of return were greater than 20 per cent. Evenson (2001) confirmed this finding and found that the majority of estimated rates of return exceeded 20 per cent. Alston *et al.* (2000a) and Evenson (2001) report that overall, the median rate of return to research has exceeded 40 per cent. Researchers have also reported high returns to public extension. Alston *et al.* (2000b) found an overall median rate of return to extension of 63 per cent,

which was higher than the median return to research (48 per cent). This may be due to the more immediate effect of extension on productivity (Huffman and Evenson, 2006).

In Australia, high internal rates of return (IRR) to public investment in R&D and extension have also been achieved. In their study of Australian broadacre agriculture, Mullen and Cox (1995) estimated returns to have averaged 15 per cent between 1952–53 and 1987–88. Mullen (2007) also found that similar rates of return had persisted over the period 1952–53 to 2002–03.

Some commentators have questioned the credibility of these findings. For instance, several have pointed to the possibility of selection bias which could mean that successful research programs that report high returns to public investment are over-represented (Evenson, 2001; Productivity Commission, 2011). In addition, estimates are typically sensitive to model specification, including the choice of R&D and extension variables, the limited availability of time series R&D investment data, and the use of datasets covering different time periods (Alston *et al.*, 2010; Productivity Commission, 2011).

Nevertheless, the pool of evidence overwhelmingly points to relatively high returns to public investment in agricultural R&D and extension, at least well beyond a risk-free rate of return. Evaluations of aggregate level R&D and extension programs, which are unlikely to suffer from selection bias by including both successful and unsuccessful programs, also report consistently good returns to public investment. In this respect, Evenson (2001) argues that high returns are consistent with actual experience of productivity growth. However, in evaluating the effects of R&D and extension on agricultural productivity, two issues are important and should be given particular attention.

First, agricultural productivity in a given year does not depend on the current level of R&D and extension expenditure, but on the stock of usable knowledge derived from past investments (Alston and Pardey, 2001). The standard method in econometric studies is to

model the change in productivity as a function of a knowledge stock constructed from distributed lags of past research investment in R&D, as a proxy for the (unobserved) stock of knowledge available to farmers and extension expenditure as an indication of extension activity designed to make farmers aware of innovation research. Choices about the assumed length and shape of the distribution of the lagged effects of R&D investment have important implications for the estimation results, and errors in estimates of, or assumptions about, the lag profile can result in overstated or understated estimates of the returns to R&D (Alston *et al.*, 2000a).

Approaches to estimating the lag profile include estimating ‘free-form’ lags and the use of distributed lag models. However, the approach of ‘free-form’ lags is not recommended as it requires too many coefficients to be estimated given available time series data (Huffman and Evenson, 2006). Moreover, due to high multicollinearity between lagged research variables, coefficients tend to alternate between positive and negative values (Evenson, 2001; Alston *et al.*, 2009).

The literature commonly uses a range of functional forms and distributions for the lag profile including the trapezoid distribution (Huffman and Evenson, 1993; Mullen and Cox, 1995); the geometric distribution (reflecting the perpetual inventory method) (Shanks and Zheng, 2006); and the gamma distribution (Alston *et al.*, 2010). The most appropriate distribution for the lag profile is not apparent, although the perpetual inventory method is considered inconsistent with the expectation that agricultural R&D investment has little effect in the early years because of long lags in adoption. Alston *et al.* (2010) concluded that the lagged returns to investment in U.S. agricultural R&D were best represented by a gamma distribution, but it is difficult to discriminate econometrically between the trapezoidal, gamma and other broadly similar distributions.

Second, in addition to domestically generated knowledge, Australian agricultural productivity is likely to be affected by spillovers of technology from other countries. R&D conducted overseas, when combined with domestic extension for localisation, can generate spill-in technology that can deliver productivity gains, whether as ideas gained from the research of others or through foreign technology adapted to suit local conditions. The extent to which technology and knowledge ‘spill-ins’ influence agricultural productivity in Australia is not well understood, although Mullen (2010) speculates that it could account for productivity growth of up to 0.8 percentage points a year in broadacre agriculture. A possible consequence of not taking into account spillovers from R&D in other countries is that rates of return to domestic public R&D may be overstated (Alston and Pardey, 2001; Alston *et al.*, 2009).

Foreign R&D may be especially important for small, open economies such as Australia’s. Openness to trade and investment can increase the transfer of knowledge and technology between countries and facilitate access to the outputs of foreign R&D (Gutierrez and Gutierrez, 2003). Overseas studies that have considered foreign spillovers have found that foreign R&D is as important—if not more so—as domestic R&D (Alston, 2002; Alston *et al.*, 2010). For example, in a study of economic growth in G7 and 15 smaller countries, Coe and Helpman (1995) found that a country’s productivity growth also depended on the R&D knowledge stocks of trading partners, and that this effect was strongest for smaller and more open economies. In general, productivity gains from external R&D are greater when the technology or knowledge is sourced from regions (or countries) that have similar agro-ecological conditions, as less investment in adaptive research is needed (Gutierrez and Gutierrez, 2003).

Drawing on the experiences and taking into account the shortcomings of the existing literature, this study adopts a comprehensive estimation strategy first to investigate the

contributions of public investment in broadacre R&D and extension to broadacre productivity and then to estimate the returns to public investment in Australian broadacre R&D and extension. An important advance over earlier studies of the returns to Australian agricultural research is to account for broadacre productivity gains arising from technology spill-ins from overseas research, and to distinguish between the relative contributions of foreign and domestic R&D and domestic extension to broadacre TFP growth.

3. Methodology of analysis

The impact of public R&D investment on agricultural productivity is sensitive to the method used to construct knowledge stocks, as well as variable choice and model specification. In these matters, economic theory does not suggest an obvious estimation strategy, although past empirical studies can provide some guidance (e.g. Mullen and Cox, 1995; Alston *et al.*, 2010).

Base model

Following the literature (e.g. Griliches, 1979; Mullen and Cox, 1995), Australian broadacre TFP is assumed to be a function of the current stock of knowledge available to farmers, as well as other control variables not explicitly reflected in the TFP index. The stock of knowledge is mainly determined by past R&D and extension expenditure. Therefore, a model representing the relationship between TFP and the R&D and extension knowledge stocks and other variables is given by:

$$\ln(TFP_t) = \alpha + b_1 \ln(DS_t^{kj}) + b_2 \ln(PS_t^{kj}) + b_3 \ln(EXT_t) + b_4 \ln(FS_t^{kj}) + \gamma \ln(Z_t) + \varepsilon_t \quad (1)$$

where TFP_t is the broadacre TFP index in time t and DS_t , PS_t , EXT_t and FS_t are knowledge stocks in time t , pertaining to past expenditures on domestic public R&D, domestic private R&D, domestic extension and foreign public and private R&D, respectively. The superscripts k and j denote the lag length (16 or 35 years) and distribution (Gamma, Gamma_T, Gamma_P, Trapezoid and PIM) of the research lag profile of the R&D knowledge stocks, and the extension variable was a weighted sum of expenditure over 4 years.

The model includes a vector of other variables (Z_t) namely, soil moisture availability, the terms of trade, and farmers' level of education.

Soil moisture availability can substantially depress TFP estimates in drought years because the broadacre industries (grain, beef and sheep production) are predominately dryland (rain fed) enterprises. Soil moisture availability is therefore an important factor contributing to volatility in the broadacre TFP index.

Human capital formation is a driver of agricultural productivity growth which, beyond experience, is partly reflected by the education level of farmers. However, ABARES survey data differentiates labour only according to whether it is hired labour, or owner-operator and family members (with services provided by shearers for wool production specifically separated). Therefore, the effect of improved human capital on broadacre productivity will not be captured by the TFP index, but will be reflected in the TFP model estimates.

Changes in the terms of trade may, in the short run, induce farmers when choosing profit-maximising combinations of inputs and outputs to select those that reduce their overall productivity (Productivity Commission, 2008; O'Donnell, 2010). For example, farmers may expand cropping into relatively marginal land in response to increases in expected output prices.

Other factors that could influence agricultural productivity are not included in the vector of control variables. For example, the agriculture sector has experienced spillover

productivity gains from government investment in transportation and communication infrastructure (Parham, 2004). Productivity growth in the wider economy could be a contributing factor to growth in agricultural productivity. However, to the extent these variables are not correlated with the knowledge stock variables, excluding them is unlikely to result in biased estimators for the public R&D and extension knowledge stocks.

Due to multicollinearity problems resulting from the high correlation between the variables that contribute to the stock of R&D knowledge, it is not possible to estimate equation (1) directly. Past approaches have usually excluded any variable for foreign R&D knowledge and combined the inputs from domestic public R&D and extension activities. However, excluding knowledge stock variables that are correlated with other explanatory variables in equation (1) may result in endogeneity and bias the relationship between domestic public R&D and extension knowledge (b_1 and b_3). In this study, two constraints were imposed on equation (1) to deal with these specification issues.

First, following Mullen and Cox (1995), private R&D knowledge stocks (PS_t^{kj}) were excluded from equation (1) due to data inadequacy. Omitting private R&D knowledge stocks could potentially bias the estimation results. However, the effects are likely to be minor for Australian agriculture. In Australia, the private share of agricultural R&D has been small relative to public investment, exceeding 10 per cent only in recent years. Given the long lags between research investments and their contributions to the stock of knowledge, it is likely that the effect of domestic private R&D on broadacre TFP has been small. Nevertheless, excluding foreign private R&D remains a possible source of bias and an area for future research.

Second, rather than estimating the individual effects of domestic and foreign public knowledge, it was necessary to construct a total public research knowledge variable to avoid their high correlation. Foreign public R&D is expected to contribute directly or indirectly to

productivity growth in Australia through cross-country technology spillovers, including direct adoption of advanced farming techniques and management skills developed overseas; learning by doing through international cooperation; import of foreign machinery and materials; and receipt of foreign direct investment. Failing to control for the effect of foreign public knowledge may result in bias due to an omitted variable (most likely overestimating the contribution of domestic research if domestic and foreign public knowledge stocks are positively correlated), so a total public R&D knowledge stock variable was preferred.

Two assumptions guided construction of the total public R&D knowledge stock variable: a) domestic and foreign public R&D knowledge stocks were assumed to have the same lag profiles and b) the foreign public R&D knowledge stock was assumed to have a smaller effect on broadacre TFP than the domestic public R&D knowledge stock. In the latter case, factors such as differences in agricultural production techniques and possible trade and non-trade barriers to agricultural knowledge transfers may reduce the efficiency with which technology is transferred between countries.

The weight given to foreign public R&D knowledge stocks (π) was similar to the approach used by Alston *et al.* (2010), which was based on the degree of similarity in production patterns in the United States and Australia. The weight on foreign public R&D knowledge stocks (π) was set to 0.1. This yielded the total public R&D knowledge stock variable, TS_t^{kj} , such that

$$\ln(TS_t^{kj}) = \ln(DS_t^{kj}) + \pi \ln(FS_t^{kj}).$$

Time series analysis: An ARIMA model

Given these specifications, the model for examining the relationship between public R&D and extension knowledge stocks and broadacre TFP is:

$$\ln(TFP_t) = \alpha + \beta_1 \ln(TS_t^{kj}) + \beta_2 \ln(EXT_t) + \gamma_1 \ln(WSI_t) + \gamma_2 \ln(EDUC) + \gamma_3 \ln(TOT_t) + \varepsilon_t \quad (2)$$

Comparing equations (1) and (2), $\ln(Z_t)$ has been replaced by three specific variables, soil moisture availability (a water stress index (WSI_t)); farmers' education attainment as a proxy for the unobserved human capital of broadacre farmers ($EDUC_t$); and the farmers' terms of trade for Australian agriculture (TOT_t).

In previous studies, the ordinary least squares (OLS) technique was usually used to estimate equation (2). However, OLS regression may produce spurious relationship between TFP and the explanatory variables if the time series data are non-stationary (Granger and Newbold, 1974), and also even though broadacre TFP and the explanatory variables are co-integrated, OLS estimates are not necessarily efficient (Greene, 2007).¹ Therefore, in this study a time series regression technique—the autoregressive integrated moving average (ARIMA) model—was used to examine the relationship between broadacre TFP and the R&D knowledge stocks and extension activity.

4. Data sources and variable specification

Broadacre total factor productivity

The measure of productivity used in the analyses is the ABARES broadacre TFP index. ABARES broadacre TFP estimates are defined as a ratio of a Fisher quantity index of total

output for broadacre agriculture to a Fisher quantity index of total inputs.² All related data used for estimating the broadacre input and output indexes were collected through the ABARES broadacre farm surveys. ABARES has collected survey data since 1952–53. However, changes in 1977–78 to the data collected mean that comparable TFP estimates for the broadacre industries based on a consistent methodology are calculated only for the period from 1977–78 to the present.

To calculate a longer but still consistent TFP series, for the period between 1952–53 and 2006–07, outputs were directly aggregated into four time-consistent indexes of crops, livestock, wool and other outputs at the industry level. Inputs were directly aggregated into four time-consistent indexes of land, capital, labour and materials and services at the industry level. The four output indexes and four input indexes were then aggregated to give a total output index and a total input index, using the corresponding output and input price indexes as weights.

Public R&D and extension expenditures

In this study, domestic public R&D investment in agriculture was defined as Australian federal, state and territory governments' expenditure on public R&D on plants and animals (excluding fish and forestry). Data were obtained from two sources: data for 1994–95 to 2006–07 were sourced from the Australian Bureau of Statistics Biannual Australian Research and Innovation Survey (ABS, 2008), and data for 1952–53 to 1993–94 were drawn from Mullen *et al.* (1996), who sourced data from the Commonwealth Department of Science and the published financial statements of the state departments of agriculture.

The absence of a long time series on R&D expenditure prior to 1952–53 also presented a challenge. Given previously identified research lags up to 35 years, public R&D expenditure data from 1917–18 were needed to make full use of the TFP dataset from 1952–

53. To address this problem, public R&D expenditure data for the period 1917–18 to 1952–53 were generated by backwards extrapolation using a regression of log real R&D data against a time trend for the period between 1952–53 and 1971–72.

Data on extension were derived from state departments' total expenditure records. As a breakdown of total expenditure on R&D and extension is generally unavailable, extension expenditure was estimated using past department surveys of time spent by staff on functions such as research, extension and regulation. The share of extension in total research expenditure for the period from 1952–53 to 1993–94 ranged from 27 per cent (in 1964–65) to 39 per cent (in 1957–58), with no apparent trend (Mullen and Cox, 1995). The impact of extension spending was derived as a weighted sum of expenditure over 4 years with weights of 0.125, 0.125, 0.25 and 0.5 following Huffman and Evenson (2006)'s geometric distribution, since this specification has been widely favoured in previous literature (Alston *et al.*, 2010). Data on investment in extension prior to 1952–53 were backcast with the proportion of public spending on extension assumed to be one-third of the state departments' total expenditure on R&D and extension. The approach taken in constructing the extension dataset in this manner may affect the results, but the nature and extent are not clear.

Public R&D and extension spending for the broadacre industries (as distinct from the agriculture sector as a whole) was derived by multiplying broadacre agriculture's share of the total value of production in agriculture to total public investment in agricultural R&D and extension. The GDP deflator was used to calculate real public R&D and extension expenditure.

Due to data constraints, the U.S. public expenditure on R&D related to agricultural production was used as a proxy for foreign public R&D. This treatment is justified because the U.S. has a pivotal role in global agricultural R&D. This is not only in terms of the size of its investment, but also because it largely invests in areas that may be readily adapted or

applied to Australian farming systems. Data for the period 1970 to 2007 were obtained from the Economic Research Service of the U.S. Department of Agriculture. The pre-1970 data were aggregated state-level data from Huffman and Evenson (2006). To ensure consistency with Australian public R&D data, calendar year data were converted into financial year data by taking the average of expenditure in consecutive years.

Since the 1980s, developing countries' share of global public agricultural R&D investment has increased dramatically, to 55.7 per cent of total public investment in 2000, predominantly in the newly industrialised economies, like China, India, Brazil, Thailand and South Africa (Pardey and Alston, 2010). However, it is reasonable to assume that developing country R&D is not yet a significant source of technology spillover, as Australia mainly imports agricultural technologies from developed countries. Consequently, excluding developing country spillovers is unlikely to bias the analysis.

Therefore, in this study Australian and the U.S. public research expenditures were aggregated to form the corresponding knowledge stocks. Behind this treatment, the potential assumption is that the public investments in agricultural R&D from domestic and overseas origins are perfectly substitutable.

Control variables

Soil moisture availability (WSI_t) is approximated by a water stress index for broadacre agriculture which was based on an annual wheat water stress index (Potgieter *et al.*, 2002). The index was constructed from three data sources. The annual wheat water stress index at the national level between 1952–53 and 1987–88 was obtained directly from the Agricultural Production Systems Research Unit (APSRU). Due to data constraints, the national level water stress index was approximated by a weighted average of the annual wheat water stress index

at the farm level for the period 1988–89 to 2003–04, and a weighted average of farm-level total rainfall for the period 2003–04 to 2006–07.

The proportion of school-age students in the total population enrolled in schools was used as a proxy for broadacre farmers' education attainment ($EDUC_t$) using ABS data (see Mullen and Cox, 1995). Enrolment was defined as 'school attendance'. The education index used here is a crude proxy for the real variable of interest, the human capital stock of broadacre farmers. Since farmers' education attainments are likely to differ from those of the total population, future research would possibly benefit from development of a more appropriate measure (such as education levels of the rural population) for the human capital stock of farmers.

The farmers' terms of trade (TOT_t) is defined as the ratio of the average price farmers received for their outputs to the average price paid for farm inputs. It covers all agriculture, not just broadacre farming (ABARE, 2009).

5. Results

This section presents the results of the time series regression analysis, and provides estimates of the contribution of public R&D and extension to growth in agricultural productivity and the internal rate of return to public investment in agricultural R&D and extension in Australia.

Model selection tests

To ensure efficient estimates of the relationship between broadacre TFP and the R&D investment and extension spending were generated, a range of models that differed with regard to research lag profile, the treatment of knowledge stock variables, functional form, and estimation methods were tested and compared according to a number of criteria. The test

statistics suggest that, first, combining domestic and foreign R&D data to construct a variable to represent the total stock of public research knowledge was preferred to the past practice of omitting foreign R&D (as in Mullen and Cox, 1995); second, a 35-year lag period for capturing the effects of past R&D expenditure was preferred to a 16-year period; third, the standard gamma distribution with peak impact occurring after seven years was preferred over alternative distributions (the regression results with alternative distributions, Gamma_T, Gamma _P, Trapezoid and PIM, are also provided as robustness checks); fourth, the log-linear functional form for equation (2) was preferred to linear and quadratic functional forms; and finally, a time series regression technique—the autoregressive integrated moving average (ARIMA) model—was used to examine the relationship between broadacre TFP and the stock of R&D knowledge and extension spending.³

The effects of R&D and extension knowledge stocks on broadacre TFP

The estimated elasticity of broadacre TFP with respect to public R&D knowledge stocks is positive and significant for all distribution profiles (Table 1). In the preferred gamma specification, the coefficient on public R&D knowledge stocks is 0.23, implying that a 1 per cent increase in the public R&D knowledge is likely to lead to a 0.23 per cent increase in broadacre productivity.

[Insert Table 1 here]

Similarly, the results suggest that an increase in public extension activity has a significant and positive effect on productivity, with an elasticity of around 0.1 per cent. The effect of extension activity on TFP is, on average, around half that of increasing the stock of public knowledge created by R&D, where R&D investment and extension activity both increase at the same rate.

Of the three control variables, soil moisture availability and the farmers' terms of trade have significant effects on broadacre TFP. The estimated elasticity of TFP with respect to soil moisture availability is 0.28. In contrast, the elasticity of TFP with respect to the farmers' terms of trade is -0.27 in the preferred gamma distribution. A possible explanation is that improvements in the terms of trade may induce farmers, when profit-maximising, to choose combinations of inputs and outputs that, in the short term, reduce their overall productivity.

The elasticity of TFP with respect to the level of education attainment is positive but insignificant. To some extent this is unexpected since human capital can facilitate technology adoption and improve farmers' ability to organise and maintain complex production processes. As suggested, the national education attainment index used in the analysis may not be a good proxy for the human capital stock of broadacre farmers.

The contributions of R&D and extension activity to broadacre TFP growth

The relative contributions of R&D and extension knowledge stocks to broadacre TFP growth over the past five decades can be estimated using the elasticities of broadacre TFP to its determinants. For example, the contribution of total public R&D can be calculated by multiplying the broadacre TFP elasticity (from Table 1) by the annual growth rate of the corresponding total public R&D knowledge stocks. This provides an estimate of the annual percentage broadacre TFP growth attributable to growth in the total public R&D and extension knowledge stocks between 1952–53 and 2006–07.

Table 2 shows, between 1952–53 and 2006–07, growth in public R&D and extension knowledge stocks accounted for almost two-thirds the annual TFP growth in the broadacre industry. Broadacre TFP growth averaged around 1.96 per cent a year between 1952–53 and 2006–07. Over this period, growth in public R&D knowledge stocks accounted for

approximately half the broadacre TFP growth (around 0.96 percentage points a year). This comprised 0.33 percentage points a year from the accumulation of domestic public R&D knowledge stocks and 0.63 percentage points a year from the accumulation of foreign public R&D knowledge stocks. Growth in public extension activity contributed around 0.27 percentage points a year to TFP growth.

[Insert Table 2 here]

Return to public investment in agricultural R&D and extension

The above analysis provides evidence of the significant productivity effect of public investment in agricultural R&D and extension on broadacre agriculture. However, it is of further interest from a policy perspective to weigh these payoffs and investment costs within a cost–benefit framework.

Internal rate of return (IRR) to public investment can be calculated from estimated elasticities when the model used to convert past investments in R&D and extension into the corresponding knowledge stocks is known. Estimates of the IRR to public investment provide a measure of the return to public expenditure on agricultural R&D and extension (in terms of increased productivity), which can be used to evaluate past and inform future investments.

Using the elasticities estimated in the ARIMA model, over the period 1952–53 to 2006–07, the average IRR to domestic public investment in broadacre R&D was 28.4 per cent a year in the preferred model, but ranged from 14.0 to 51.9 per cent in other specifications (Table 3).⁴

[Insert Table 3 here]

Domestic public extension generated significantly higher average IRRs than those for domestic public R&D. Over the period 1952–53 to 2006–07, the IRR of domestic public extension estimated from the preferred gamma specification for the public R&D knowledge stocks was 47.5 per cent, ranging from 32.6 per cent to 79.5 per cent in other specifications. These are relatively consistent with the median rates of return in the international literature reported in Alston *et al.* (2000b).

6. Conclusion and policy implication

The main purpose of this study is to investigate empirically the contribution of public investment in agricultural R&D and extension on broadacre productivity growth in Australia. The study has provided the following main findings.

First, there is strong evidence of the significant productivity effect of public investment in agricultural R&D and extension on broadacre agriculture. During the period of 1952–53 to 2006–07, knowledge and technology accumulated from past public investments in R&D in Australia and overseas and expenditure on extension have contributed almost two-thirds of average annual growth in TFP in the broadacre farming industries in Australia.

Second, spill-ins from overseas public investment in agricultural R&D is an important source of growth in domestic agricultural productivity. The study reveals that knowledge and technology accumulated from past public investment in agricultural R&D in foreign countries have contributed almost one-third of average annual TFP growth in the broadacre industry in Australia. This finding is an important contribution to the existing literature on Australian agricultural productivity.

Third, in terms of the profitability of public investment in agricultural R&D and public extension spending, the cost-benefit analysis reveals that, during the period from 1952–53 to 2006–07, the average IRR to domestic public investment in broadacre R&D and

extension was 28.4 per cent and 47.5 per cent a year respectively, well beyond a risk-free rate of return.

Drawing on the main findings, this study provides some policy implications especially for developing countries in which growth in agricultural productivity is very important not only to provide sufficient food supply but also to maintain social stability of the country. First, the strong empirical evidence indicates that public investment in agricultural R&D and expenditure on extension are effective ways for governments to promote growth in agricultural productivity and, in turn, changes in agricultural R&D policies will significantly affect productivity growth rate in the long run. Therefore, increasing public investment in agricultural R&D and extension spending and at the same time maintaining agricultural R&D policy stability are equally important for governments to consider in order to achieve sustained long-term growth in agricultural productivity.

Second, as the study reveals that the return from public spending on agricultural extension is higher than the return from public investment in agricultural R&D, policy makers have to maintain a balanced view as well as have a long-term appreciation of the relative values generated from public investment in agricultural R&D and extension spending. Although public spending on agricultural extension has a higher rate of return, from a long-term point of view, public investment in agricultural R&D is essential for long-term growth of agricultural productivity. This point is especially important for developing countries given their limited financial resources in agricultural R&D and extension.

Third, the study reveals that overseas investment in agricultural R&D is an important source of growth in Australia's agricultural productivity. Therefore, maintaining an open trade and investment regime is important to benefit from foreign knowledge and technology spillovers generated from overseas investment in agricultural R&D in order to maintain growth in Australia's agricultural productivity. This condition is especially important for

developing countries where public investment in agricultural R&D and extension spending is constrained by lack of financial resources from governments. Therefore, the existence of foreign knowledge and its introduction may be a necessary condition for achieving growth in agricultural productivity in developing countries.

In this study, due to data constraints, we did not include domestic and foreign private investments in agricultural R&D in the regression although we know that both of them are increasing, which may affect our estimates of the coefficients of public knowledge stock variables if private and public knowledge stocks are correlated. In addition, we used the national education attainment index in the analysis which may not be a good proxy for the human capital stock of broadacre farmers. These are the areas which should be taken into account in future study.

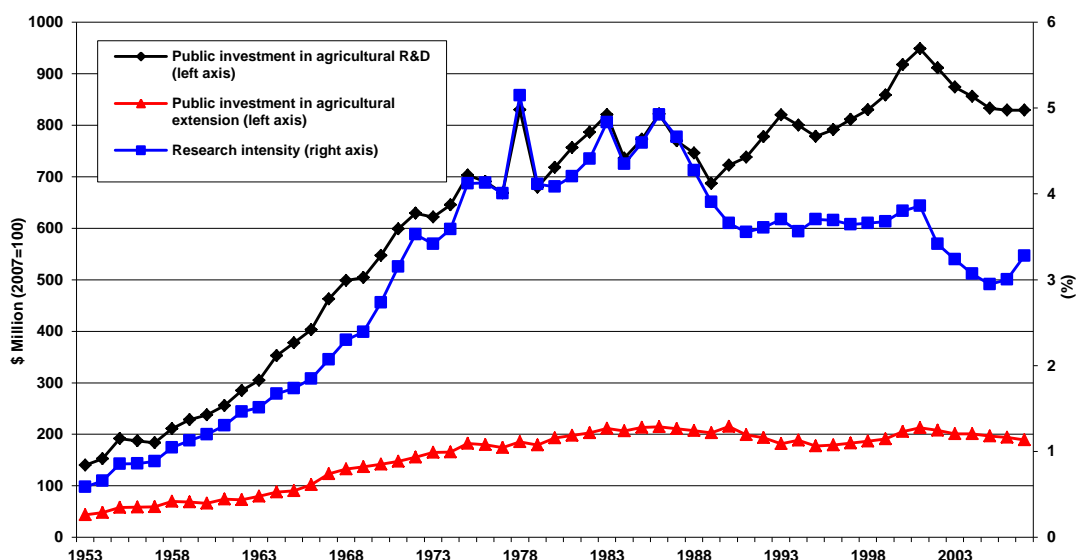
¹ Test results show that $\ln TFP_t$ and the (lagged) knowledge stock variables were non-stationary, and broadacre TFP and the explanatory variables are co-integrated.

² An exposition of the concepts, theories and empirical methods underlying the ABARES TFP estimates for the broadacre (and dairy) industries can be found in Gray *et al.* (2011) and Zhao *et al.* (2010).

³ Test statistics are available from authors upon request.

⁴ To some extent the variation in IRR across the distributions is due to the different weights assigned to the lagged years, since the estimated elasticities are quite similar in magnitude. Generally, distributions that assigned greater weights to more recent years generated higher IRR.

Figure 1. Real public investment in agricultural R&D and extension in Australia (1952–53 to 2006–07)



Notes: Public agricultural R&D and extension includes expenditure by Australian federal, state and territory governments, and research institutions and universities. Funds from research and development corporations (excluding grower levies) and other external funders for agriculture (excluding research in fisheries and forestry) are also included.

Sources: Data are from ABARE (2009) and Mullen (2010).

Table 1. Elasticities of broadacre TFP to public R&D investment, stocks of extension knowledge, and other explanatory factors

| | Gamma | Gamma_T | Trapezoid | Gamma_P | PIM |
|----------------------------------|----------------------|---------------------|----------------------|----------------------|----------------------|
| Dependent variable: $\ln(TFP_t)$ | | | | | |
| $\ln(TS_t)$ | 0.234*** (0.051) | 0.225*** (0.053) | 0.202*** (0.046) | 0.242*** (0.057) | 0.201*** (0.048) |
| $\ln(EXT_t)$ | 0.100*** (0.035) | 0.104*** (0.034) | 0.143*** (0.033) | 0.072** (0.036) | 0.146*** (0.034) |
| $\ln(WSI_t)$ | 0.275*** (0.054) | 0.270*** (0.055) | 0.276*** (0.055) | 0.264*** (0.055) | 0.275*** (0.056) |
| $\ln(EDUC_t)$ | 0.562 (0.368) | 0.662* (0.379) | 0.019 (0.398) | 0.853** (0.386) | 0.293 (0.385) |
| $\ln(TOT_t)$ | -0.266*** (0.081) | -0.240** (0.096) | -0.262*** (0.084) | -0.255*** (0.095) | -0.261*** (0.088) |
| Constant | -0.325 (1.693) | -0.853 (1.817) | 1.843 (1.570) | -1.372 (1.906) | 0.614 (1.646) |
| /sigma | 0.063*** (0.007) | 0.065*** (0.007) | 0.063*** (0.007) | 0.065*** (0.007) | 0.064*** (0.007) |

Number of observations 55 55 55 55 55

Notes: ARIMA model of equation (2), broadacre TFP as a function of a total public R&D knowledge stock, a domestic extension knowledge stock, and the control variables. Statistical significance at the 1 per cent, 5 per cent and 10 per cent levels are represented by ***, ** and *. The values in parentheses are standard errors. ‘Gamma’ refers to the preferred model specification in which a standard gamma distribution was used to construct knowledge stocks, with a peak impact occurring seven years after investment.

Source: Authors’ own calculation.

Table 2. Contribution of R&D knowledge and extension activity to broadacre TFP growth (1952–53 to 2006–07)

| | Growth rate (%) | Elasticity ^a | Average annual TFP growth (%) |
|--|-----------------|-------------------------|-------------------------------|
| Total R&D knowledge stocks (TS_t) | 4.13 | 0.234 | 0.97 |
| Domestic R&D knowledge stocks (DS_t) | 7.71 | | 0.33 |
| Foreign R&D knowledge stocks (FS_t) | 2.29 | | 0.63 |
| Extension (EXT_t) | 2.65 | 0.100 | 0.27 |
| Other factors ^b | – | – | 0.73 |
| Broadacre TFP Growth (TFP_t) | – | - | 1.96 |

Notes: Contribution of R&D knowledge stocks and extension activity to broadacre TFP growth calculated for the preferred gamma R&D distributed lag model with 35-year lags and a peak impact occurring seven years after investment, estimated using the ARIMA model. ^a from Table 1. ^b includes the control variables and other unobserved factors not in equation (2).

Source: Authors’ own calculation.

Table 3. Average IRR to domestic public investment in broadacre R&D and extension spending (%)

| | Gamma | Gamma_T | Trapezoid | Gamma_P | PIM |
|------------|-------|---------|-----------|---------|------|
| Public R&D | 28.4 | 14.0 | 15.4 | 38.2 | 51.9 |
| Extension | 47.5 | 35.0 | 32.6 | 57.1 | 79.5 |

Note: IRRs are calculated by using the elasticities estimated in the ARIMA model. For R&D knowledge stock the lags are 35 years and for extension spending the lags are 4 years.

Source: Authors’ own calculation.

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