ELSEVIER

Agricultural Economics 27 (2002) 65–74

AGRICULTURAL ECONOMICS

www.elsevier.com/locate/agecon

Publicly-funded UK agricultural R&D and 'social' total factor productivity

Andrew P. Barnes*

Department of Natural Resource Economics, Scottish Agricultural College, West Mains Road, Edinburgh, Scotland EH9 3JG, UK

Received 7 July 2000; received in revised form 14 December 2000; accepted 1 January 2001

Abstract

Most studies concerned with measuring the rate of return to publicly-funded agricultural R&D investment have found high returns, suggesting under-investment, and calls for increased expenditure have been common. However, the evaluation of returns tends to measure the effect of research expenditure against growth in total factor productivity (TFP), based on market inputs and outputs. When compared against growing public unease over the environmental effects of pursuing agricultural productivity growth, TFP indices become a misleading measure of growth. This paper integrates some non-market components into the TFP index. The costs of two specific externalities of agricultural production, namely fertiliser and pesticide pollution, are integrated in a TFP index constructed for the period 1948–1995. This adjusted, or 'social', TFP index is measured against UK public R&D expenditures.

The rates of return to agricultural R&D are reduced by using the 'social' as opposed to the traditional TFP index. Whilst both remain at justifiable levels, previous studies appear to have over-estimated the effect of agricultural R&D expenditures. Furthermore, with changes in policy towards more socially acceptable but non-productivity enhancing outcomes, such as animal welfare, rural diversification and organic farming, the future framework for analysing returns to agricultural R&D should not be so dependent on productivity growth as an indicator of research effectiveness.

Keywords: UK productivity; Agricultural R&D; Environmental externalities

1. Introduction

Rates of return to publicly-funded agricultural research and development (R&D) have, with few exceptions, been high (listed in Alston et al., 2000). UK studies of agricultural R&D were at first sceptical (Wise, 1986; Harvey, 1988). However, the recent work of Thirtle and his colleagues (Khatri and Thirtle, 1996; Thirtle and Townsend, 1997), has estimated a rate of return for UK public agricultural R&D at around 20% for the period 1953–1994 (Khatri and Thirtle, 1996). These high rates of return indicate a return to society, or 'social return', and hence justify increased Government expenditures towards agricultural R&D (Thirtle and Bottomley, 1988; Alston et al., 1995).

Critically, these studies have usually employed total factor productivity (TFP) indices as the basis for measurement. However, criticism has emerged of the external effects of pursuing productivity in agriculture (Stanley and Hardy, 1984; Schofield et al., 1993). Increasing farm intensification, coupled with recent food scares, has caused public distrust of industrial farming practices. Consequently, whilst most productivity measures suggest that UK

* Tel.: +44-131-535-4100; fax: +44-131-535-4322.
E-mail address: a.barnes@ed.sac.ac.uk (A.P. Barnes).

0169-5150/02/$ – see front matter
PII: S0169-5150(01)00061-5

agricultural growth has been high (Doyle and Ridout, 1985; Thirtle and Bottomley, 1992), they have excluded the negative factors which impinge on the quality of life of farmers, consumers and the general population.

Various economists have recently begun to question the validity of these productivity indicators in terms of their ability to measure agricultural growth (Archibald, 1988; Oskam, 1991). Moreover, recent European and UK agricultural policy has seen a change in emphasis towards support for non-market outputs (CEC, 1998). This has generally shown an emphasis towards rural development, animal welfare and environmental improvement; all factors which, whilst considered socially desirable, may have the effect of decreasing productivity growth. If this aspect of policy is to become more important in the future, then the validity of traditional measures of TFP growth must be questioned as a basis for measuring rates of return to public agricultural R&D.

Accordingly, this paper seeks to derive a total factor productivity index for the UK over the period 1948–1995 which includes the major external effects of agricultural production. It aims to measure the effect of this series against explanatory variables, chiefly public agricultural R&D, in order to compare them against returns using traditional measures. The next section outlines the basis for constructing TFP indices and derives a traditional TFP index for the period 1948–1995. The process of integrating externalities associated with increased pesticide and fertiliser usage is then presented, and the index is modified to produce a 'social' TFP index. Finally, both indices are compared with public agricultural R&D and advisory expenditures.

2. The concept of total factor productivity

A measure of UK agricultural productivity was first constructed before the Second World War by Beilby (1938). MAFF (1961 and 1969) constructed an aggregate productivity index which cumulatively covered the periods 1949–1967 and found an average rate of growth of 1.7% per annum. More recently, Whittaker (1983); Godden (1985) and Doyle and Ridout (1985) have gone some way to constructing a more accurate measurement of agricultural productivity changes by including factors such as land, labour, and quality adjustments. Using a Laspeyres index, the last of these studies found an average annual rate of growth of 1.8% for the period 1951–1981.

Rayner et al. (1986) used the more theoretically sound Tornqvist index procedure, which compares factor shares in output/input ratios between two successive years. In applying this method, an average rate of growth of around 1% per annum was found for the period 1956/7–1978/9. Thirtle and Bottomley (1992) adopted a similar procedure and sought to clarify some of the measurement errors involved in the UK agricultural accounts. An annual average rate of growth of 1.9% was found for the period 1967–1990. This is the procedure adopted for this paper and is explained in the next section.

2.1. Constructing a total factor productivity index for UK agriculture

The Tornqvist index relies on factor shares and on smoothing a previous year's prices and quantities, rather than relying on a single base period as with the Laspeyres index. Christensen (1975) has pointed out that the Tornqvist index reflects a situation whereby, as the price of an input increases, the producer decreases its use to keep its marginal productivity proportional to the new price. Hence, the prices from both periods are included in the Tornqvist index to represent their marginal productivities. Accordingly, the Tornqvist index tends to produce a more dynamic picture of productivity growth, whereas the Laspeyres index, with its reliance on a base year, can overstate the effects of productivity over time.

To construct a Tornqvist index, input and output series have to be disaggregated. Outputs were divided into the four headings given by the aggregate accounts, namely (i) farm crops, (ii) horticultural crops, (iii) livestock, and (iv) livestock products, which consist of wool, milk and eggs. For the input series, eight headings were used: all four major intermediate inputs, namely feeding-stuffs, fertiliser, seeds and imported livestock; as well as rent, labour (hired workers), miscellaneous expenditure, which includes pesticides after 1986, and interest on capital stock. Series for inputs and outputs were constructed using the formula recommended by Rayner et al. (1986)

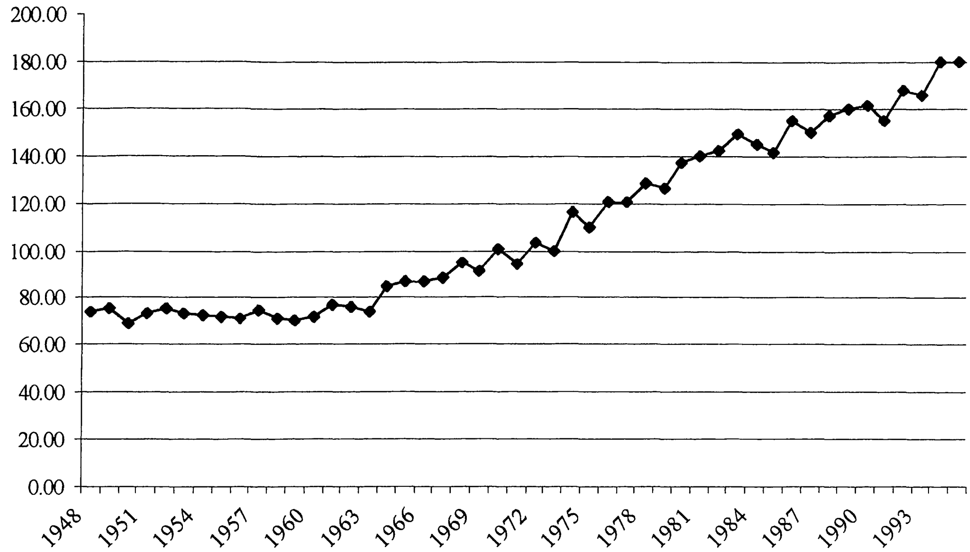

Fig. 1. UK total factor productivity, 1948–1995, using the Tornqvist index, 1970 = 100.

and the TFP index derived from

$$\ln\left(\frac{A_{t+1}}{A_t}\right)=\sum \bar{W}_{ij}\ln\left(\frac{Y_{jt+1}}{Y_{jt}}\right) - \sum \bar{C}_{ir}\ln\left(\frac{G_{rt+1}}{G_{rt}}\right) \quad (1)$$

where A_t is the level of TFP in year t, Y_{jt} the output of commodity j in year t, $\bar{W}_{ij} = (W_{jt} + W_{jt+1})/2$ is a moving average of two successive years, where W_{jt} is the value share of the jth product in total output, G_{rt} is the input of commodity r in year t, and $\bar{C}_{ir} = (C_{rt} + C_{rt+1})/2$ is a moving average of two successive years, where C_{rt} is the value share of the rth product in total input.

In order to construct a total factor productivity index, a number of sources were used. Predominantly, data were assembled from the aggregate agricultural accounts published yearly in the Annual Abstract of Statistics of the Central Statistical Office, 2001 (CSO). The procedure followed is that outlined by Thirtle and Bottomley (1992). The results were then chained, using 1970 as the base year for chaining. Consequently, the results using the Tornqvist index can be shown graphically in Fig. 1.

The first impression gained from Fig. 1 is that the series exhibits a relatively smooth growth path until the early 1970s. After this period, with entry into the Common Agricultural Policy, economic turbulence, and several drought years, the series tends to exhibit a greater, if erratic, growth rate. This is demonstrated more explicitly when Table 1 is considered.

Table 1
Growth rates for UK agriculture using the Tornqvist index

Period	Annual average growth in TFP (%)
1948–1971	0.67
1972–1995	3.25
1948–1995	1.93

Annual average growth for the entire period is around 1.9%, which agrees with the findings of Thirtle and Bottomley (1992). However, what emerges is a sharp difference before and after the early 1970s. From 1948 to 1971, growth was minimal at only 0.7%. This is below the Rayner et al. (1986) estimate of around 1% which, whilst using the same method, is not strictly comparable because of differences in time periods used. However, after this period, growth increased substantially to 3.3% per annum. Thirtle and Bottomley (1992) found a similar growth rate over the period 1972–1985.

2.2. Constructing a social total factor productivity index

The environmental and social costs of agricultural productivity have not been incorporated into the majority of studies into TFP growth. However, the level of environmental damage caused by agricultural production has led to a very real degradation in the quality of life for farmers and consumers. Specifically, awareness has been growing regarding the levels of nitrate within water supplies, the effects of ammonia on the quality of air and, more generally, the overall effects on human health of chemical application to agricultural products. Thus, Archibald (1988) studied the effect of growing pesticide resistance within the cotton-growing sector of California. Antle and McGuickan (1993) suggested that work should be conducted at a regional level to take externalities into account and then 'statistically aggregate' their cost for policy analysis. Oskam (1991) studied the effect of chemical residues in air, water and soil at an aggregate level for the Netherlands and found that annual average rates of TFP growth decreased by between 2 and 10%, depending on assumptions about the price of external effects. As no equivalent study has been conducted for UK agriculture, an attempt has been made to explore the consequences of including the costs of some of the externalities which may have been caused over the period 1948–1995 by agricultural production within the UK.

The application of a product will have an effect on the environment, and thus an externality can be considered as an output. [1] Oskam (1991) and Antle and McGuickan (1993) both accounted for externalities on the output side of the total factor productivity index. The methodology used by Oskam (1991) seemed more appropriate for this study. Accordingly, Eq. (1) can be modified to include externalities, thus:

$$\ln\left(\frac{A_{t+1}}{A_t}\right) = \sum \bar{W}_{ij} \ln\left(\frac{Y_{jt+1}}{Y_{jt}}\right) + \sum \bar{X}_{ig} \ln \times \left(\frac{E_{gt+1}}{E_{gt}}\right) - \sum \bar{C}_{ir} \ln\left(\frac{G_{rt+1}}{G_{rt}}\right) \quad (2)$$

where E_{gt} is the (positive or negative) share of the value of the external effect g, relative to total externalities, and $\bar{X}_{ig} = (X_{gt} + X_{gt+1})/2$ is a moving average of two successive years, where X_{gt} is the value share of the gth external cost or benefit in total external costs or benefits.

Generally, Eq. (2) follows the methodology of Eq. (1) where each series of externality (positive or negative) is weighted against the sum of externalities. Notably, this is added to the output series in order to accommodate the inclusion of positive externalities. [2] However, this study concentrates on two specific negative externalities, i.e. pesticide and nitrogen pollution, and the value of externalities are taken away from the output series.

Consequently, a series had to be constructed which reflected the degradation of soil, air and water quality over the period 1948–1995. Pitman (1992) offered estimates of nitrogen and pesticide application rates for certain years within the period of study. To construct a series, figures for inorganically produced nitrogen supplied for UK consumption were obtained from the CSO Annual Abstract of Statistics. The level of nitrogen produced by livestock through manure was computed by multiplying livestock by estimates of the nitrogen produced by each type of animal, taken from SAC (1998, p. 106). From this series, the quantity of nitrogen absorbed by crops and plants had to be deducted. This is a contentious issue, as nitrogen loss, or leaching, varies according to the levels of application of fertiliser, soil type and weather. In a review of the literature on this subject, Pitman (1992) offered an estimate that around 17% of all nitrogen applied would be lost through leaching on arable land and 15% on grassland. Consequently, it should be stressed that this method is only a rough approximation of environmental damage. In reality, the toxicity of run-off depends on a variety of regional characteristics, such as soil quality, weather and proximity to rivers. However, because this analysis is at aggregate levels it has to rely to a great deal on measuring average environmental effects.

In addition to these problems, levels of pesticide application were more difficult to derive as the Farm and Rural Conservation Agency (FRCA) [3]

[1] Reinhard et al. (1996) estimated a stochastic translog production frontier, using a panel of Dutch dairy farms, in which nitrogen surplus was added as an environmentally detrimental input.

[2] The inclusion of positive externalities such as improved animal welfare would, of course, have the effect of increasing social productivity growth.

[3] Previously the Agricultural Development and Advisory Service (ADAS).

only began sporadic surveys of their usage from the early 1970s, again outlined by Pitman (1992). Consequently, a moving average had to be constructed between surveys to derive a series, before this period it was assumed that levels of pesticide application remained at constant 1970 levels. Once quantities for nitrogen leaching and pesticide had been calculated, the next stage of the exercise was to establish prices for pollution caused. A number of methods are available for this, namely: (i) contingent valuation of environmental damage, principally through survey work (Johansson, 1987; Hanley, 1990); (ii) hedonic pricing, whereby goods are priced on the basis of their individual characteristics (Lancaster, 1966); and (iii) estimated costs per unit of measures taken in the future (Oskam, 1991). This last method proved more attractive as various environmental measures had recently been planned and costed. Thus, published reports were available which provided valuations for environmental schemes, and which could thus be translated into the prices for these non-market goods.

ENTEC (1998, p. 14) listed nitrate sensitive area (NSA) payments to farmers of between £60 per hectare per year for arable land, to £590 per hectare per year for areas which were unfertilised, ungrazed and rich in diverse species. Similarly, pesticide use was priced at the cost of conversion to the organic aid scheme (OSA) of MAFF. Whilst this cost varies by type of farming activity, generally the average cost of this is £400 per hectare over a 5-year period, i.e. £80 per hectare per year (MAFF (1998, p. 8)).

For nitrogen use, the median price given by ENTEC (1998) of £340 per hectare was used. This is the level of subsidy paid for land in NSA, on which producers have agreed to limit nitrogen use to 150 kg/ha with optional grazing. The prices were converted to 1970 prices, using the agricultural output price index, giving a figure of £81.5 per hectare. A simple calculation was then performed to derive the full cost of nitrogen use. For example, given the total amount of nitrogen applied in the UK in 1995, the amount lost through ammonia volatilisation and denitrification (at 17% for arable land) was 111.7 kg/ha. Thus, the cost per kilogram of nitrogen use was £81.5 divided by this figure, which gives £0.73 per kilogram per hectare in 1970 prices. This was then multiplied by the level of leaching for each year to calculate the cost per of environmental damage in kg/ha. This figure was then multiplied by the size of arable land in the UK to calculate the full cost of nitrogen use. A similar method was used to value the environmental cost of pesticide usage, at a cost per year of £80 per hectare (or £19.2 in 1970 prices). Pesticide application for 1995 was estimated at around 6.49 kg of active ingredients (a.i.)/ha. Thus, dividing the cost by the amount of pesticide gave £2.96 kg of a.i./ha. This was then multiplied by the amount of pesticide applied in 1995 to give £18.9 per kilogram of a.i./ha for 1995. Finally, this was multiplied by the arable area of the UK to give the total cost of pesticide application. The costs of environmental damage for selected years are presented in Table 2.

Table 2
Cost of nitrogen and pesticide application within UK agriculture, million pounds in 1970 prices

	Nitrogen use		Pesticide application	
	Arable land	Grassland	Arable land	Grassland
1948	237.36	6.21	86.18	2.37
1972	540.06	61.59	86.39	2.60
1995	458.29	88.83	116.02	1.26

Aggregating these data yielded the total costs of environmental damage arising from increased nitrogen and pesticide usage within UK agriculture. Using Eq. (2) they were used to derive what Oskam (1991) refers to as a 'social', as opposed to a 'private', TFP index. A comparison of the two series are presented in Fig. 2.

Fig. 2 shows the series derived for total factor productivity within the UK, 'corrected' (social) and 'uncorrected' (private) for the costs of environmental externalities. Before the 1970s, the social TFP series mimics the 'private' TFP series, indicating that fertiliser and pesticide usage were minimal. However, after 1971 the corrected measure explicitly reduces TFP growth until the late-1980s, when there is a growth in the social TFP series as levels of pesticide and nitrogen application are reduced. The full effect can be seen more clearly in Table 3.

In the first period, 1948–1971, annual average growth is reduced by around a third, from 0.7 to 0.4% per annum. This indicates a heavy cost as regards fertiliser and pesticide application over this period. However, in the latter period, 1972–1995, annual average growth increases to 2.63% which is a smaller reduction in the traditional TFP series. Accordingly,

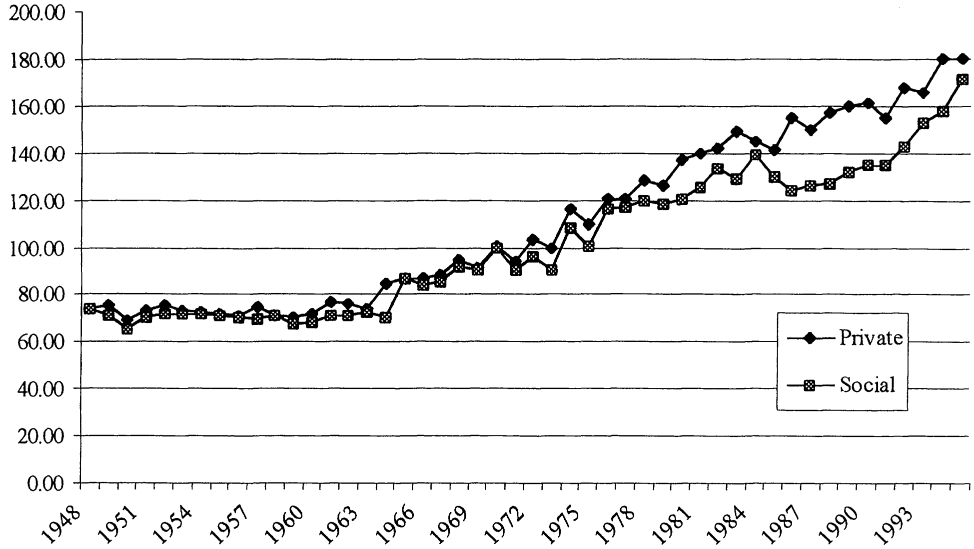

Fig. 2. Private and social total factor productivity indices for UK agriculture using the Tornqvist method, 1948–1995, 1970 = 100.

Table 3
Average annual growth rates for social and private TFP (% per annum)

	Private TFP	Social TFP
1948–1971	0.67	0.44
1972–1995	3.25	2.63
1948–1995	1.93	1.53

whilst 'social' TFP seems to diverge from 'private' TFP in the 1970s, from the mid-1980s onwards this reflects policy and legislation towards reducing the application of chemical pollutants. Overall, the integration of these negative externalities leads to a reduction of around 21% in annual growth rates over the period 1948–1995. This is almost double the amount calculated by Oskam (1991) for Dutch agriculture.

Accordingly, having derived both a 'private' and 'social' TFP index, they could then be used to give a comparison of returns to public investment in agricultural R&D and advice. This is the concern of the next section.

3. Agricultural R&D and productivity growth

The bulk of studies on agricultural research and productivity have derived some form of relationship similar to that depicted in Eq. (3) (Thirtle and Bottomley, 1988):[4]

$$P_t = \sum_{i=0}^{n} \alpha_1 R_{t-i} + \sum_{i=0}^{x} \beta_1 S_{t-i} + \beta_2 E_t + \beta_3 W_t + \mu \qquad (3)$$

where P is total factor productivity in year t, R the public expenditures on research, lagged by n years, S the public expenditure on advisory activities, lagged by x years, E is an index of the managerial ability of farmers, W is a weather index, and μ the error term.

A series for each of these variables was derived and assessed for their effect on productivity. Firstly, the University Grants Commission (UGC) records the allocation of block grants which are devoted to research on agriculture and veterinary subjects within Higher Education Institutions, for England, Wales and Scotland. Data from Northern Ireland were not available. Government research data are available from the supply estimates published by the HM Treasury. Scottish data on the development work of the Scottish Agricultural College are declared in the 'Agriculture in Scotland' series of SOAEFD, which also provides

[4] Alston et al. (1995) provide a comprehensive review of the methods available for evaluating returns to agricultural R&D.

information for the research institutes in Scotland. However, Northern Irish expenditures on R&D are not available and estimates of research expenditures were taken from Thirtle et al. (1997). The major producer of agricultural R&D in England and Wales is the Biotechnology and Biological Sciences Research Council, which from 1965 onwards has published annual statements of expenditure. Before this period, expenditure had to be obtained from the Government supply estimates of HM Treasury.

These supply estimates were also the source of advisory data for England and Wales, which include both current and capital expenditures until 1987 when charges were implemented for most advisory activities. However, the reliability of this data has to be questioned as the activities of ADAS between research and advice are not well delineated. For Scotland, the advisory work of the Scottish Agricultural College (SAC) is published in the 'Agriculture in Scotland' series.

For the index of the managerial ability of farmers, a series was derived on the number of diplomas and degrees obtained in agriculture as a percentage of the agricultural population. This series has many faults, as it assumes that all agriculture students enter farming after qualifying, though in reality they tend to enter other related industries (Burrell et al., 1990). However, it remains as the standard proxy for growing managerial ability within the farming community.

Fluctuations in humidity and precipitation have a direct effect on the yield of farm crops, as well as the quality of grassland for grazing livestock and the level of feeding-stuffs requirements. The derivation of a weather index is varied. Doyle and Ridout (1985) took a ratio of forecasted crop outputs against actual crop outputs. A similar method was used for international comparisons by Schimmelpfennig and Thirtle (1998). However, there are limitations to data availability and, because of this, most studies have used a 'de Martonne aridity' index (Oury, 1965; Thirtle and Bottomley, 1988; Hallam, 1990), which is a ratio of precipitation and temperature. Whilst not ideal, it does account for some of the weather changes responsible for productivity changes.

However, it must be stressed that, due to brevity and lack of data availability, this analysis does not take into account the effect of private sector expenditures on agricultural R&D, nor does it take into account the effect of spillovers from foreign research systems. Within the UK, only Thirtle and Townsend (1997) have attempted to study these effects, finding that rates of return to public agricultural R&D were reduced. However, this is a complex procedure and beyond the scope of the present study, which focusses solely on public agricultural R&D and extension.

3.1. Agricultural R&D and productivity change

Using E-views software (Lilian et al., 1995) the series were tested for causality and stationarity. Using Eq. (3) as a basis, the two TFP series were then fitted against the explanatory variables by imposing lags of various lengths with the objective of minimising the Schwartz criterion (Gujarti, 1995). In terms of the shape of the lag, the majority of studies have followed conceptual thought on technology adoption, which tends to assume an inverted 'U' shape. This shape is perfectly mimicked in the polynomial, or Almon lag, with both ends of the lag benefits restricted to zero. This has been used by a number of studies (Cline and Lu, 1976; Doyle and Ridout, 1985; Thirtle and Bottomley, 1988) and has been adopted here. For the private TFP series (P) the advisory series proved insignificant with all lag lengths and was dropped from the equation. For the public R&D series a lag of 15 years was used. This is specified in Eq. (4):

$$\ln P_t = \ln A + \sum_{i=0}^{15} \alpha_1 \ln R_{t-i} + \beta_1 \ln E + \beta_2 W + \mu \qquad (4)$$

Substituting the social TFP series (P^*) changed the specifications of the equation. This proved more problematic and the advisory series was again removed as it was not significant, giving lags of 15 years for the public R&D series. This gave the specifications described in Eq. (5):

$$\ln P_t^* = \ln A + \sum_{i=0}^{15} \alpha_1 \ln R_{t-i} + \beta_1 \ln E + \beta_2 W + \mu \qquad (5)$$

The imposition of a maximum 15-year-lag for public R&D seems to agree with the lower limit of lag lengths used in the majority of past studies. However, it has to be conceded, that the lack of public advice and,

Table 4
Regression results using the social and private total factor productivity indexes[a]

Variable		Lag	Coefficient	
			Eq. (4)	Eq. (5)
Constant	C	–	2.71 (13.82)	3.10 (10.99)
Weather	W	–	0.004 (2.99)	0.002 (1.24)
Education	E	–	0.24 (3.52)	0.17 (1.79)
Total public R&D	R	15	0.22 (4.84)	0.20 (3.08)
Adj. R^2			0.97	0.91
DW statistic			2.15	1.41

[a] t-Statistics in parentheses. Critical t values for 30° of freedom, one-tailed test, are 95% = 1.70.

indeed, any private series will overestimate the returns to agricultural R&D. The results from both equations are presented in Table 4.

In Table 4, actual results for the 'social' TFP series are compared against those derived for the 'private' TFP series. Significantly, the coefficients for the three explanatory variables are reduced when considering the 'social' series. This seems reasonable as the adjusted series reduces productivity and thus dampens the effect of its explanatory variables. In terms of statistical significance, it seems that the private series explains more with an adjusted R-squared of 0.97 and a DW of 2.15. The social series shows a lower R-squared of 0.91 and a DW of 1.41. However, the DW statistic whilst appearing low is within the bounds prescribed for critical value. Also, what must be noted is that the weather coefficient is not significant and the education coefficient is just significant at these levels.

Once the coefficients have been calculated, the second stage is to derive the internal rate of return (IRR) on R&D investment. This is a relatively simple task and is computed as the discount rate which will result in a value of zero for the net present value. Cline and Lu (1976) derived an inverted 'U' shape for calculating the marginal benefits of R&D as this mimics the polynomial lag imposed on the research expenditure series. The equation used is specified below (Davies, 1981):

$$\mathrm{VMP}\left[\frac{\sum_{i=0}^{n}\bar{W}_i}{(1+r)^i}\right]-1=0 \qquad (6)$$

where 'VMP' is the value marginal product of research or extension, r is the rate of return, and $\bar{W}_i=\alpha_i/\sum_{i=0}^{n}\alpha_i$ which represents the weights of the polynomial lag.

Table 5
Comparison of internal rates of return for agricultural R&D using the 'private' and 'social' TFP indices (%)

Period	Publicly funded R&D	
	Private	Social
1948–1971	26.54	23.21
1972–1995	17.52	14.87
1948–1995	22.03	19.04

Thus, the partial research coefficients (α) are divided by the sum of partial coefficients to derive an inverted 'U' shaped lag. Generally, the IRR was estimated for *the periods 1948–1971, 1972–1995 and 1948–1995*. These results are outlined in Table 5.

Table 5 compares the rate of return derived from using the 'social' and 'private' TFP indices for estimates for public R&D and advice. The first impression gained is that rates of return of 22% seem to agree with the majority of recent findings concerning UK public agricultural R&D. However, when considering two externalities, returns fall to 19%, a reduction of around 15%.

There is a definite downward trend in rates of return after 1972 and entry into the Common Agricultural Policy. Whilst this seems to agree with the findings of Doyle and Ridout (1985) and Wise (1986), it seems to question the work of Khatri and Thirtle (1996) who found no significant change in rates of return before or after entry. In terms of a comparison between the 'private' and 'social' series, the two periods show a fall in rates of return to public R&D of 13% between 1948 and 1971, but by 15% from 1972 to 1995. This seems reasonable as the negative effects of intensification may be more evident with the introduction of support for unrestrained output growth as evidenced in the 1970s and 1980s.

Nevertheless, what must be conceded is that the borderline return expected for a public investment is recommended at 8% (HM Treasury, 1991) and, as can be seen from the above table, all results still remain justified.

4. Conclusions

In assessing the cost of fertiliser and pesticide usage within agricultural productivity indices, lack of data availability and the non-quantifiable nature of most quality of life factors have led to their omission in most previous analyses. This paper has attempted to integrate some of the major costs of agricultural production within a productivity series. Accounting for some of the environmental costs caused by nitrogen and pesticide use reduces the annual rate of TFP growth by around 20% for UK agriculture. This had the effect of substantially reducing rates of return to agricultural R&D by around 15%. Whilst rates of return are still at justifiable levels, the validity of the 'under-funding argument' is weakened.

There are obvious problems in the derivation of the 'social' TFP series. Specifically, median prices for nitrogen application were used. Changing these prices will obviously have an effect on the overall assessment of the cost of fertiliser and pesticide application. In addition, no account has been made for changes in the efficiency of fertiliser and pesticide application. Further research could concentrate at a regional level, integrating fertiliser and pesticide quality along with differences in land type. The aggregation of these regional series could then provide a more accurate indicator of growth considering the externalities of production. Finally, the research does not take into account the effect of other externalities, critically animal welfare considerations, which may have the effect of increasing growth from the 1980s onwards when the positive externalities of recent animal welfare legislation are taken into account.

It seems that agriculture is undergoing a period of change. Whilst the bulk of its post-1945 development has concentrated on productivity increases, UK and EU agricultural policy has increased emphasis towards increasing the 'public good' aspects of farming (CEC, 1998). Consequently, directing subsidies towards diversification will have the effect of reducing traditional productivity growth further and thus reducing rates of return. Similarly, R&D programmes now emphasise the creation of 'sustainable technology', which is defined here as productivity growth which carries no negative external effect. Consequently, it seems that an analysis which registers the environmental impact of productivity enhancement is essential in the future as a framework for evaluating returns to public agricultural R&D. Therefore, with the adoption and improvement of social TFP indices, economists could provide policy-makers with an essential tool for ranking public R&D projects which do not solely concentrate on productivity gains. Thus, it seems that 'social', rather than 'private', TFP series will become a more desirable measure of agricultural success in the future.

References

Alston, J.M., Norton, G.W., Pardey, P.G., 1995. Science Under Scarcity. CAB International, Wallingford.

Alston, J.M., Marra, M.C., Pardey, P.G., Wyatt, T.J., 2000. Research returns redux: a meta-analysis of the returns to agricultural R&D. Aust. J. Agric. Econ. 44 (2), 185–215.

Antle, J.M., McGuickan, T., 1993. Technological innovation, agricultural productivity and environmental quality. In: Carlson, G.A., Zilberman, D., Miranowski, J.A. (Eds.), Agricultural and Resource Economics. Oxford University Press, Oxford, pp. 175–220.

Archibald, S.O., 1988. Incorporating externalities into agricultural productivity analysis. In: Capalbo, S.M., Antle, J.M. (Eds.), Agricultural Productivity: Measurement and Explanation. Resources for the Future. Washington DC, pp. 366–393.

Beilby, O.J., 1938. Changing agricultural production in England and Wales. J. R. Agric. Soc. England 100 (2), 62–73.

Burrell, A., Hill, B., Medland, J., 1990. Agrifacts: A Handbook of UK and EEC Agricultural and Food Statistics. Harvester Wheatsheaf, London.

Central Statistical Office, 2001. Annual Abstract of Statistics. HMSO, London.

Christensen, L.R., 1975. Concepts and measurement of agricultural productivity. Am. J. Agric. Econ. 57 (5), 910–915.

Cline, P.L., Lu, Y.-C., 1976. Efficiency aspects of the spatial allocation of public sector agricultural research and extension in the US. Regional Sci. Perspectives 6, 1–16.

Commission of the European Communities, 1998. Proposals for council regulations (EC) concerning the reform of the common agricultural policy. COM (1998) 158 (final).

Davies, J., 1981. A comparison of procedures for estimating returns to research using production functions. Aust. J. Agric. Econ. 25 (1), 60–72.

Doyle, C.J., Ridout, M.S., 1985. The impact of scientific research on UK agricultural productivity. Res. Policy 14 (2), 109–116.

ENTEC 1998. Economic Evaluation of the Nitrate Sensitive Areas Scheme. MAFF, London.

Godden, D.P., 1985. Technological change and demand for output at farm level in UK agriculture 1950–1980. Unpublished Ph.D. Thesis. London School of Economics, London.

Gujarti, D.N., 1995. Basic Econometrics, 3rd Edition. McGraw-Hill, New York.

Hallam, D., 1990. Agricultural research expenditure and agricultural productivity. J. Agric. Econ. 41 (3), 434–439.

Hanley, N., 1990. The economics of nitrate pollution. Eur. Rev. Agric. Econ. 17 (2), 129–151.

Harvey, D.R., 1988. Research priorities in agriculture. J. Agric. Econ. 39 (1), 81–97.

HM Treasury 1991. Economic Appraisal in Central Government: A Technical Guide for Government Departments. HMSO, London.

Johansson, P.-O., 1987. The Economic Theory and Measurement of Environmental Benefits. Cambridge University Press, Cambridge.

Khatri, Y.J., Thirtle, C.G., 1996. Supply and demand functions for UK agriculture: biases of technical change and the returns to public R&D. J. Agric. Econ. 47 (3), 338–354.

Lancaster, K., 1966. A new approach to consumer theory. J. Political Econ. 74, 132–157.

Lilian, D.M., et al., 1995. Econometric Views, Version 2.0. Quantitative Micro Software.

Ministry of Agriculture, Fisheries and Food, 1961. Productivity measurement in agriculture. Economic Trends ii–v.

Ministry of Agriculture, Fisheries and Food, 1969. Productivity measurement in agriculture. Economic Trends, pp. xxvi–xxx.

Ministry of Agriculture, Fisheries and Food, 1998. Review of the Organic Aid Scheme. MAFF, London.

Oskam, A., 1991. Productivity measurement, incorporating environmental effects of agricultural production. In: Burger, et al. (Eds.), Agricultural Economics and Policy: International Challenges for the Nineties. Elsevier, Amsterdam, pp. 186–204.

Oury, D., 1965. Allowing for weather in crop production model building. J. Farm Econ. 47 (2), 270–283.

Pitman, J.I., 1992. Changes in crop productivity and water quality in the United Kingdom. In: Hoggart, K. (Ed.), Agricultural Change, Environment and Economy. Mansell Publishing, London, pp. 89–122.

Rayner, A.J., Whittaker, J.M., Ingersent, K.A., 1986. Productivity growth in agriculture revisited: a measurement framework and some empirical results. J. Agric. Econ. 37 (2), 127–150.

Reinhard, S., Lovell, C.A.K., Thijssen, G.J., 1996. Econometric estimation of technical and environmental efficiency: an application to Dutch dairy farms. Paper Presented at the Georgia Productivity Workshop II, Athens, GA, USA.

Schimmelpfennig, D., Thirtle, C.G., 1998. The internationalisation of agricultural technology: productivity convergence, R&D spillovers and patents in the European Union and United States. Paper Presented at the Agricultural Economics Society Conference, Reading, UK, 25–28 March.

Schofield, K, Seager, J., Merriman, R.P., 1993. The impact of intensive dairy farming activities on river quality. In: Gareth-Jones, J. (Ed.), Agriculture and the Environment. Ellis Harwood, London, pp. 75–90.

Scottish Agricultural College, 1998. The Farm Management Handbook, 19th Edition. SAC, Edinburgh.

Stanley, P.I., Hardy, A.R., 1984. The environmental implications of current pesticide usage on cereals. In: Jenkins, D. (Ed.), Agriculture and the Environment. Institute of Terrestrial Ecology/NERC, Banchory, pp. 66–71.

Thirtle, C., Bottomley, P., 1988. Is publicly funded agricultural research excessive? J. Agric. Econ. 39 (1), 99–111.

Thirtle, C., Bottomley, P., 1992. Total factor productivity in UK agriculture 1967–1990. J. Agric. Econ. 43 (3), 381–400.

Thirtle, C.G., Townsend, R., 1997. Efficiency differences in European agriculture: multi-national productivity indices and the returns to R&D with spillovers. Paper Presented at EAAE Seminar on Innovation for Innovation, Zandvoort, Holland, 21–23 April 1997.

Thirtle, C.G., Piesse, J., Smith, V.H., 1997. An economic approach to the structure, historical development and reform of agricultural R&D in the UK. CAS Paper 35. Centre for Agricultural Strategy, Reading, MA.

Whittaker, J.M., 1983. An economic analysis of productivity growth in UK agriculture. Unpublished M.Phil. Thesis. University of Nottingham, Nottingham.

Wise, W.S., 1986. Calculation of rates of return in agricultural research from production functions. J. Agric. Econ. 37 (2), 151–162.