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THE RATE OF RETURN TO PUBLIC SECTOR R & D

A CRITICAL ASSESSMENT

Paul Bottomley, Department of Political Econom
University of Aberdeen

Colin Thirtle, Department of Agricultural
Economics, University of Manchester

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Department of Agricultural Economics

Faculty of Economic and Social Studies
University of Manchester,
Manchester U.K.

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I. INTRODUCTION: THE POLITICS OF AGRICULTURAL RESEARCH IN TWO COUNTRIES

"The nature of the agricultural sector explains why Federal R &D has a powerful effect and why econometric methods can arrive at relatively reliable estimates of this effect",

Congress of the United States, Office of Technology Assessment (1986, p.18).

"A review we (the Agricultural Research Council) have made of the published material on the cost benefit analysis of agricultural research and development (R & D) projects has convinced us that, in its present state, cost-benefit analysis does not provide a valid basis for the quantitative planning of agricultural R & D programs",

Ulbricht (1977, p.387).

"The current pressures on the R & D community can be seen as both a criticism of our failures to respond to this challenge in the past and , more positively, as a plea to do better in the future."

Harvey (1987b, p.204).

The need to evaluate research was stressed in the evidence presented to the House of Lords Select Committee on Science and Technology (1986). The first quotation above is evidence of American assurance that economics has an important role to play in such evaluations. The second statement is representative of the (persistent) Agriculture and Food Research Council (AFRC)view that economists cannot measure research benefits, and even if measurement were possible it would not be useful. It is based on the work of Wise (1975).

Two basic methodologies have dominated the calculation of returns to agricultural research. Ex-post cost-benefit analysis (confusingly called the index number approach in the American literature) has been extensively employed to calculate the net benefits to consumers and producers, using a supply and demand framework. Alternatively, production functions have been fitted, with a view to identifying the returns to the R & D input.[1]

The results of some of these studies, up to 1980, are summarised in Table 1, which shows that for the great majority of investigations, rates of return are very substantial. This result has been interpreted by the majority[2] of

Table I : Summary Studies of Agricultural Research Productivity

Study	Year	Country	Commodity	Time Period	Annual Internal Rate of Return (%)
Cost Benefit Analysis					
Griliches	1958	USA	Hybrid Corn	1940-55	35-40
Griliches	1958	USA	Hybrid sorghum	1940-57	20
Grossfield & Heath	1966	UK	Mechanical Potato Harvester	1950-67	Positive and substantial
Peterson	1967	USA	Poultry	1915-60	21-25
Evenson	1969	S.Africa	Sugarcane	1945-62	40
Barletta	1970	Mexico	Wheat	1943-63	90
Barletta	1970	Mexico	Maize	1943-63	35
Ayer	1970	Brazil	Cotton	1924-67	77+
Schmitz & Seckler	1970	USA	Tomato harvester, with no compensation to displaced workers	1958-69	37-46
			Tomato harvester, with compensation of displaced workers for 50% of earnings loss		16-28
Ayer and Schuh	1972	Brazil	Cotton	1924-67	77-110
Hines	1972	Peru	Maize	1954-67	35-40
					50-55
Hayami and Akino	1977	Japan	Rice	1915-50	25-27
Hayami and Akino	1977	Japan	Rice	1930-61	73-75
Hertford, Ardila, Rocha and Trujillo	1977	Columbia	Rice	1957-72	60-82
			Soybeans	1960-71	79-96
			Wheat	1953-73	11-12
			Cotton	1953-72	none
Pee	1977	Malaysia	Rubber	1932-73	24
Peterson & Fitzharris	1977	USA	Aggregate	1937-42	50
				1947-52	51
				1957-62	49
				1957-72	34
Wennergren and Whitaker	1977	Bolivia	Sheep	1966-75	44
			Wheat	1966-75	-48
Pray	1978	Punjab (British India)	Agricultural research and extension	1906-56	34-44
		Punjab (Pakistan)	Agricultural research and extension	1948-63	23-37
Scobie & Posada	1978	Bolivia	Rice	1957-64	79-96
Pray	1980	Bangladesh	Wheat and Rice	1961-77	30-35
Pray	1983	Punjab (British)	Agricultural research and extension	1930-47	over 30
		Punjab (Pakistan)	Agricultural research and extension	1947-75	over 30
Casimiro Herruzo	1985	Spain	Rice	1941-80	15.9-18.1
Ulrich, Furtan and Schmitz	1986	Canada	Malting Barley	1951-88	31-75
Production Function Analysis					
Tang	1963	Japan	Aggregate	1880-1938	35
Griliches	1964	USA	Aggregate	1949-59	35-40
Latimer	1964	USA	Aggregate	1949-59	not significant
Peterson	1967	USA	Poultry	1915-60	21
Evenson	1968	USA	Aggregate	1949-59	47
Evenson	1969	S.Africa	Sugarcane	1945-58	40
Barletta	1970	Mexico	Crops	1943-63	45-93
Duncan	1972	Australia	Pasture Improvement	1948-69	58-68
Evenson and Jha	1973	India	Aggregate	1953-71	40
Cline (revised by Knutson and Tweeten, 1979)	1975	USA	Aggregate	1939-48	41-50
			Research and extension	1949-58	39-47
				1959-68	32-39
				1969-72	28-35
Bredahl & Peterson	1976	USA	Cash grains	1969	36
			Poultry	1969	37
			Dairy	1969	43
			Livestock	1969	47
Kahlon, Bal, Saxena and Jha	1977	India	Aggregate	1960-61	63
Evenson and Flores	1978	Asia-national	Rice	1950-65	32-39
				1966-75	73-78
		Asia-International	Rice	1966-75	74-102
Flores, Evenson and Hayami	1978	Tropics	Rice	1966-75	46-71
		Philippines	Rice	1966-75	75
Nagy and Furtan	1978	Canada	Rapeseed	1960-75	95-110
Lu, Quance and Liu	1978	USA	Research and Extension	1939-72	25
			Increments in R & E		10-15
Lu, Cline and Quance	1979	USA	Research and Extension	1939-48	30.5
				1949-58	27.5
				1959-68	25.5
				1969-72	23.5
Davis	1979	USA	Aggregate	1949-59	66-100
				1964-74	37
Evenson	1979	USA	Aggregate	1868-1926	65
		USA	Technology oriented	1927-50	95
		USA	Science oriented	1927-50	110
		USA	Science oriented	1948-71	45
		Southern USA	Technology oriented	1948-71	130
		Northern USA	Technology oriented	1948-71	93
		Western USA	Technology oriented	1948-71	95
		USA	Farm management research and agricultural extension	1948-71	110
Hastings	1981	Australia	Increases in Research activity	1926-68	Increasing Returns
White & Havlicek	1982	USA	Research and Extension	1943-77	6.9-36
Doyle and Ridout	1985	UK	Research expenditures	1966-70	20-30
				1971-75	15-25
				1976-80	10-20
Khan and Akbari	1986	Pakistan	Research and Extension	1955-81	36

Source: Ruttan (1982), who gives references, but some items have been added. These additions are referenced in this paper.

American agricultural economists as evidence of persistent underinvestment in agricultural research. Perhaps because of the mingling of economists and scientists in the Land Grant College system, the agricultural research community simply assimilated the economists and their views, which have been published in scientific journals.[3] As a result, when the U.S. agricultural research establishment came under fire, the agricultural economics profession were able to provide a conceptual and intellectual framework, backed by a large body of empirical evidence, that proved sufficient to explain to the critics why many of their views were misguided.[4] The extent of this success can be judged by the "special case" status granted to agriculture by the political advisers, in the OTA report quoted above, that is otherwise extremely critical of the economic evaluation of R & D. The U.S. evidence is supported by American-style studies of agricultural research in Canada, Australia and the third world, as Table I shows.

In Britain, the few economist's contributions to the debate have been more sceptical[5] and have attracted less attention. The pervasive view has been that of the AFRC, frequently expressed by Wise, who has continued to stress the inaccuracy of CBA studies (Wise, 1981, 1984) and has recently extended his critique to production function analysis.[6] His conclusions (Wise, 1986, p.159-60) appear to be both that the returns to agricultural research cannot be meaningfully measured by such methods and that, according to his own calculations there is no under-investment in agricultural research. Thus, Wise appears to be at odds with agricultural economists the world over.

In the current political climate, with the AFRC unable to justify its expenditures and the Treasury cutting its budgets as a result, it seems odd that the benign American solution has not been considered. Old prejudices apparently die very hard. Part of the problem would seem to be that the AFRC dislikes the logical positivist methodology to which economists still appear to subscribe. Attempts at scientific objectivity have been allowed to get in the way of effective rhetoric (McCloskey, 1986). This mistake has not been made by the free marketeers, whose faith-based value judgements have currently gained political favour. The real contribution economists can make is to establish the case for public sector research and to return to the business of presenting persuasive rhetorical arguments in support.[7] Scientific objectivity may be a fine ideal but it is a millstone when carried into the political arena.

We intend to review the most recent developments in the production function approach, in a manner comprehensible to economists and to stress the issues of estimation which have so far been ignored. We begin by presenting the conventional model used to estimate the productivity of R & D. Next, part three, considers the data available for the UK and the manner in which it has been used in the only UK study to date (Doyle and Ridout, 1985). Part four tries to overcome the deficiencies apparent in this earlier work and the fifth section proceeds to calculate rates of return. Part six considers the evidence and tries to evaluate the methodology. The conclusion offers suggestions as to the direction of future work.

II. MODELLING R & D PRODUCTIVITY

Early empirical work in production economics attempted to explain changes in aggregate output by assuming it to be a log-linear function of aggregate capital and aggregate labour. The history of the subject and the fact that econometricians usually do not collect their own data[8] has led to the misconception that aggregation and the fitting of production functions are separate activities. In fact, index procedures used in aggregation correspond to particular restricted function forms.[9] The general problem is to reduce m outputs (maybe 100) and n inputs (perhaps 300) to h groups of outputs (often one) and k groups of aggregate inputs (perhaps half a dozen). For consistent aggregation, the input groups must be functionally separable[10].

Since technical change, resulting from R & D expenditures, occurs over time and its effect on output is subject to considerable lags, time series data are required. Since time series data for agricultural inputs are collinear, the number of inputs groups must be restricted and even then, if the full production function is fitted, parameter estimates for inputs which account for minor proportions of output may not be robust. This problem has been circumvented in the recent literature by dividing the inputs into two groups, conventional and novel, and disposing of the conventional inputs by incorporating them in a total factor productivity index.[11] Then, changes in the productivity index should be explained by the non-conventional inputs such as R & D expenditures. Using the Cobb Douglas function for simplicity, if Q is aggregate output, the X_i's are traditional inputs and the Z_i's are novel inputs and the α_i's and β_j's are parameters, then,

$$(1) \quad Q = \prod_{i=1}^{m} X_i^{\alpha_i} \prod_{j=1}^{n} Z_j^{\beta_j}$$

which gives the total factor productivity index[12] (TFP)

$$\text{(2)} \quad TFP = \frac{Q}{\prod_{i=1}^{m} X_i^{\alpha_i}} = \prod_{j=1}^{n} Z_j^{\beta_j}$$

The X_i's include all conventional inputs such as land, labour, capital, machinery, buildings, chemicals and other miscellaneous inputs. The Z_i's are normally the stock of knowledge, K, (accumulated research capital), extension services (X) and farmer education (E).

Accumulated research capital (K), could be defined very simply as the sum of past R & D expenditures,

$$\text{(3)} \quad K_t = \sum_{i=1}^{n} R_{t-i}$$

but if there is no research, there should be negative growth of K_t. The alternative to including an arbitrary depreciation factor in the calculation of K_t is to include a finite number of lagged R_{t-i}'s as explanatory variables. There is assumed to be a lag of at least one period before R & D affects productivity at all, then the effect rises to a peak, before diminishing as the new technology becomes obsolete.[13] Following this procedure and adding a constant and a stochastic error term gives the "conventional" model,[14]

$$\text{(4)} \quad P_t = \alpha_0 \prod_{i=0}^{n} R_{t-1}^{\alpha_i} X^{\beta_1} E^{\beta_2} e^{\beta_3 W_t u_t}$$

where P_t is the productivity index W_t is a weather index that explains a proportion of the variations in P_t and u_t is the remaining stochastic error that cannot be accounted for.

Taking logarithms of (4) gives the estimable linear equation,

$$\text{(5)} \quad \ln P_t = \ln\alpha_0 + \sum_{i=0}^{n} \alpha_i \ln R_{t-i} + \beta_1 \ln X + \beta_2 \ln E + \beta_3 W_t + u_t$$

However, the dozen or so lagged values of R are likely to be highly correlated and use up degree of freedom, so a distributed lag structure is often assumed. This is normally an inverted V or an Almon polynomial lag, but the Koyck model is an alternative. This type of function has been fitted to data for U.S. agriculture by Evenson (1967), Cline and Lu (1976), Lu, Quance and Liu (1978), Lu, Cline and Quance (1979), Knutson and Tweeten (1979), Evenson, Waggoner and Ruttan (1979) and White and Havlicek (1982); to Australian data by Hastings (1981) and to UK agriculture by Doyle and Ridout (1985).

III. MEASURING UK R & D PRODUCTIVITY

(A) RULE OF THUMB ESTIMATES

Before embarking on more sophisticated estimates, the relationships established in the previous section can be used for "back of the envelope" calculations of the type reported in Harvey (1987a, p.4). Godden's (1985) estimates of TFP growth for the UK agricultural sector are all around 2% (Harvey uses 1.9%) as is Rayner, Whittaker and Ingersent's (1986) figure for the 1970s. Zanias (1987) produced a slightly lower estimate of Hick's neutral technical change of 1.7% for the period 1949-83. This is also the annual average growth rate of Doyle and Ridout's productivity index from 1951-81. All therse numbers are arbitrary in the sense that they depend on particular definitions and procedures, but all suggest a number a little below 2%.

How can 2% productivity growth be converted into a value? Harvey (1987a) multiplies it by the 1985 net product figure of £4000 million, but the TFP index is not net of intermediate inputs and capital services. It is more reasonable to use final output of over £11,000 million giving a return of £220 million on the AFRC investment of £120. This gives a return on capital of 83% instead of the negative value suggested by Harvey. Definitionally, net product excludes intermediate inputs and capital and so corresponds closely to labour productivity index. Rayner, Whittaker and Ingersent's (1986) annual growth rate of labour productivity is 4.8%. This figure, multiplied by a net product of £4000 million gives a value of £192 million, for a return of 60%. Obviously, agricultural research presents a splendid opportunity for public investment.[15]

(B) ECONOMETRIC ESTIMATION

Doyle and Ridout (1985) are to be congratulated on having extended the analysis by fitting an equation similar to (5) above, in order to estimate the returns to R & D. They regressed a TFP index on a symetric inverted V-shaped lagged distribution of the log of R & D expenditures and a weather index. Their R & D and weather parameter estimates were significant and the R^2 was .844, suggesting that the variables explain 85% of the variance in TFP. Subject to various assumptions as to the level of private sector R & D, the internal rate of return estimates varied from 10% to 30% and declined over time. However, the study can be criticised on several points, which can be classified as specification, measurement and conceptual problems.

1) Specification: (a) If the specification of equation (5) is accepted as "correct", in the sense that all the independent variables are important in explaining change in TFP, then the Doyle and Ridout model may lead to biased estimators due to ommission of variables. But data on farmer education is of dubious value and ADAS does not release extension expenditures.

(b) The weather index raises problems since it is based on yield variability of U.K. cereals, which is a major component of the variance in TFP. To see the difficulty, assume that cereal yield variability explained all the variance in TFP not accounted for by R & D expenditures. In such a case the weather index would be the same as running the regression without the weather variable, retrieving the residuals and re-running the equation with the calculated residuals as the weather series. The R^2 would be unity, the Durbin Watson statistic equal to 2, and the weather coefficient would have a most odd interpretation.

(c) The model regresses the TFP index on the logarithms of the past R & D expenditures. There is no theoretical justification for this semi-log form and it is this that gives their result of declining research productivity.

(d) The symetric V shaped lag distribution is unnecessarily restrictive. It requires that the true weights of the past research expenditure lie on the inverted V. If they do not, the result will be biased and inconsistent estimators and invalid tests.

(2) Measurement: (a) The dependent variable, the TFP index, is

constructed as a price weighted value of output series, appropriately deflated, divided by a price weighted value of inputs series, that was not deflated by the appropriate price index. The inputs included labour, land and capital services, whereas the price index used for deflating to get a volume of inputs (Goods and Services Currently Consumed) does not cover these items.

(b) Similarly, the R & D expenditures were converted to a physical volume of R & D inputs by deflating with the RPI, when the appropriate deflator would be an index of the wages and salaries of scientific personnel and the price of other R & D inputs.

(c) Data for private sector R & D are not available in the U.K. and although the public figure was adjusted by a scalar multiple this will not affect the estimated R & D coefficients. Multiplicative constants end up in the intercept term in logarithmic models.

(3) Conceptual difficulties: (a) Public and private R & D are treated symetrically, when in fact their effects are usually expected to be different. Griliches (1964), for example, assumed that the private sector input companies would succeed in embodying new technology in their products and raising their prices sufficiently to appropriate all the returns to their R & D.[16] These price increases should be reflected as quality change in a properly quality-adjusted input series and will not show up as technical change in agriculture. Public sector research output must be accounted for separately, by including expenditures, exactly because it is to a large extent not appropriable and hence not charged for in the normal way. These issues are reviewed in Thirtle (1986c).

(b) The treatment of the R & D variable, or knowledge capital stock is unconventional in that it is deliberately constructed so as to stay constant rather than fall if there is no R & D expenditure. This is at odds with the usual reasoning (Bonnen, 1983), which suggests that the agricultural technology stock depreciates in the absence of maintenance expenditures.

(C) <u>APPRAISAL</u>

These difficulties combine to produce a Durbin Watson statistic of 0.74, indicating that the error structure is autocorrelated. In this case the suspicion has to be that the systematic elements in the error structure result from mis-specification in the form of omitted variables and errors in variables. Hendry (1980) has addressed the well known fact that when one variable with a strong time trend is regressed on another similar entity, large R^2's and significant coefficients mean very little. A poor Durbin-Watson statistic is about the only evidence of spurious nature of the relationship.[17]

Is it possible to improve on the Doyle and Ridout model? With this in mind we constructed a new R & D variable and regressed the same TFP index on this new series. Without the aid of a weather variable we instantly obtained a positive and significant coefficient and increased the (adjusted) R^2 to 0.89.[18]

IV. NEW ESTIMATES OF U.K. R & D PRODUCTIVITY

Many of the problems described in the last section can be overcome without too much difficulty. This section describes our data and the estimates generated by fitting the productivity model explained in section II.

(A) THE DATA

1) Productivity indices. In adddition to the Doyle and Ridout TFP index, alternative series have been constructed by Whittaker (1983) and Godden (1985). Whittaker's Tornqvist and arithmetic indices can be found in Rayner, Whittaker and Ingersent (1986). Godden's two Tornqvist indices differ in the degrees of quality adjustment incorporated and can be found in Thirtle (1986b). Rather than coming to a prior decision as to which index best represents TFP growth in UK agriculture, all five alternatives were tried.

2) The R & D Input. After experimentation with AFRC expenditure data, kindly provided by EPARD, we concluded that the R & D expenditure series used by Doyle and Ridout could not be improved upon. We did deflate it with the "implied deflator for R & D expenditure",[19] representing the price of scientific manpower, which is a more appropriate deflator than the RPI. Unfortunately, this index is available only at three yearly intervals, since 1964. As the expenditure data extend back to 1951 the RPI deflator had to be used for the early observations. Series using both the RPI and the implied R & D deflator were tried in estimating the model.

3) The Weather. Three approaches were used to account for the effects of the weather. Including individual rainfall and temperature observations in the regressions proved too costly in terms of degrees of freedom. The obvious choice of a yield index like that of Doyle and Ridout, but constructed from experiment station data proved to be impossible with the limited N.I.A.B. data at our disposal, but should be further investigated.[20] We settled for the third alternative of a weather index, constructed from precipitation and temperature data, in the manner first suggested by De Martonne (1936). It is

based on the formula,

$I = P/(T+10)$ where I is the index, P is precipitation and T is the temperature.

This index performed as well as the Doyle and Ridout index and did not raise difficulties as to how the estimates should be interpreted (particularly, the Durbin Watson statistic is not obviously biased).

4) Education. The variable used in the US studies, farmer's years of schooling, was not available. Instead, we took the ratio of graduates taking courses in agriculture (reported by Burrell, Hill and Medland, 1984) to the total farm population. This ratio appeared to perform better than years of schooling for the UK population in aggregate, but again, this type of series should be further investigated.

(B) ESTIMATION

As explained above, preliminary investigation disposed of some possible variables and no information was obtained on ADAS extension expenditures. Thus, the variable X in equation (5) had to be dropped, leaving,

$$(6) \quad \ln P_t = \ln\alpha_0 + \sum_{i=0}^{n} \alpha_i \ln R_{t-i} + \beta_1 \ln E + \beta_2 W_t + w_t$$

This equation was fitted for all five TFP indices, with R & D deflated by the two alternative price series and with the education variable included and excluded, giving a total of twenty equations. The same variables were tried under the assumption of a simple linear relationship rather than the logarithmic form of equation (6), but these results were inferior. The appropriate degree of the polynomial for the lag, and its length, were determined by trial and error. The best results were obtained with lags of eleven to sixteen years, using a second degree polynomial, with both end points set equal to zero. The general form can be expressed as

(7) $\beta_i = b_0 + b_1 i + b_2 i^2$, with $i = 0,\ldots,k$ where k is the length of the lag.

(C) RESULTS

Choosing between the results generated by the alternative models considered above was inevitably a little arbitrary. The education variable proved to be collinear[21] with R & D and its coefficient was not significantly different from zero in any of the equations. Consequently, education was omitted from the equations and is not reported in Table II (see next page).

For each of the five indices, one of the more successful equations has been reported, mostly on the basis of the value of the mean squared errors. The distributed lag coefficients (the α_i's) are the output elasticities of the R & D variable for each year of the lag. The lags are symmetric, inverted U shapes, with the effect of R & D on the productivity index rising to a maximum of between 0.04 and 0.05 and declining again to zero. In all cases, the coefficients of the R & D variable are significant, as indicated by the t statistics in parentheses.

The total effect of R & D expenditure can be judged by looking at the sum of the annual effects over the full period of the lag. Thus, for the first four TFP indices, a 1% increase in the R & D variable will increase TFP by between 0.40% and 0.47%. For these estimates, the R & D series using the implied R & D deflator proved superior. For the fifth series, the RPI deflated series was chosen, to allow comparisons. The RPI rises less quickly than the price of scientific manpower and so deflates the expenditure series less. The implied R & D deflator series thus explains the same TFP increases with lesser input changes and so attracts larger coefficients. For this reason the coefficients sum to only 0.3570 in the case of the fifth index and this value should not be taken too seriously.

The R^2 values, reported in the next row, suggest that the variables explain between 60% and 75% of the variance in the TFP index. Finally, the

Table II : Econometric Estimates of the R & D and Weather Coefficients

Coefficients of Independent Variables		Dependent Variables - TFP Indices: Godden Quality Adjusted	Godden not Adjusted	Whittaker Tornqvist	Doyle & Ridout	Whittaker Arithmetic
Distributed lag coefficients (years)	1	0.0133	0.0199	0.0135	0.0144	0.0070
	2	0.0244	0.0219	0.0248	0.0213	0.0131
	3	0.0333	0.0301	0.0342	0.0294	0.0184
	4	0.0400	0.0365	0.0414	0.0360	0.0227
	5	0.0444	0.0410	0.0466	0.0409	0.0262
	6	0.0466	0.0438	0.0497	0.0441	0.0289
	7	0.0466	0.0447	0.0507	0.0458	0.0306
	8	0.0444	0.0438	0.0497	0.0458	0.0315
	9	0.0400	0.0410	0.0466	0.0441	0.0315
	10	0.0333	0.0365	0.0414	0.0409	0.0306
	11	0.0244	0.0301	0.0342	0.0360	0.0289
	12	0.0133	0.0219	0.0248	0.0294	0.0262
	13		0.0199	0.0135	0.0213	0.0227
	14				0.0114	0.0184
	15					0.0131
	16					0.0070
t Statistics		(4.60)	(5.35)	(5.68)	(6.54)	(5.55)
Sum of lag coefficients		0.4041	0.4149	0.4710	0.4578	0.3570
Weather coefficients		0.0030 (1.97)	0.0030 (2.02)	0.0025 (1.58)	0.0053 (2.83)	0.0013 (0.64)
R^2		0.61	0.68	0.75	0.73	0.73
Durbin-Watson Statistic		1.84	1.79	1.80	1.54	1.92

Durbin Watson statistic is well in the acceptance region for all equations except for the Doyle and Ridout TFP, which falls in the indeterminate zone. So, in four out of the five cases the alternative hypothesis of serial correlation, either positive or negative, can be conclusively rejected.

V. CALCULATION OF THE MARGINAL INTERNAL RATE OF RETURN.

The calculations of the previous section suggest that a 1% increase in the R & D input results in an increase in TFP of 0.41% to 0.47%. This increase in TFP must be converted into a rise in the value of output, before the internal rate of return to R & D expenditures can be calculated.

(A) Calculation of the Value Marginal Product of R & D

Each lag coefficient α_i, is the output elasticity of R & D for that year, which may be defined as,

$$(8) \qquad \alpha_i = \frac{\partial \log P_t}{\partial \log R_{t-i}} = \frac{\partial P_t}{\partial R_{t-i}} \cdot \frac{R_{t-i}}{P_t}$$

This can be rearranged to show that the marginal physical product of R & D is equal to the elasticity multiplied by the average physical product,

$$(9) \qquad \frac{\partial P_t}{\partial R_{t-i}} = \alpha_i \left(\frac{P_t}{R_{t-i}}\right)$$

Replacing P_t/R_{t-i} by the geometric means of these variables over the period under consideration and changing to discrete aprpoximations gives,

$$(10) \qquad \frac{\Delta P_t}{\Delta R_{t-i}} = \alpha_i \left(\frac{\bar{P}}{\bar{R}_{t-i}}\right)$$

Then, the change in productivity can be converted into the change in the value of output if both sides of equation (10) are multiplied by the average net increase in the value of output caused by a one index point increase in productivity,

$$(11) \qquad \frac{\Delta P_t}{\Delta R_{t-i}} \frac{\Delta Y_t}{\Delta P_t} dP_t = \alpha_i \left(\frac{\bar{P}}{\bar{R}_{t-i}}\right) \frac{\Delta Y_t}{\Delta P_t} dP_t$$

Since $d P_t = 1$ this simplifies to,

$$(12) \quad VMP_{t-i} = \frac{\Delta Y_t}{\Delta R_{t-i}} = \alpha_i \left(\frac{\bar{P}}{\bar{R}_{t-i}}\right) \frac{\Delta Y_t}{\Delta P_t} .$$

which is the value marginal product (VMP) of R & D at time t-i. Note that the terms $\bar{P}/\bar{R}_{t-i}$ and $\Delta Y_t/\Delta P_t$ are averages but that α_i varies over the lag period, giving a series of marginal returns resulting from a unit change in R & D expenditure. The value of output, $\bar{P}\frac{\Delta Y_t}{\Delta P_t}$, is the geometric mean calculated using the value of output at constant 1975 prices and $\bar{R}_{t-i}$ is similarly a constant price geometric average.[22]

Using equation (12), the marginal internal rate of return (MIRR) can be calculated, by solving equation (13) for i.

$$(13) \quad \sum_{i=1}^{n} [VMP_{t-i}/(1-r)^i] - 1 = 0$$

where n is the length of the lag.

Performing these calculations for the five equations reported in Table II produced the result in the first row of Table III.

Table III : Marginal Internal Rates of Return

	Godden Quality Adjusted	Godden not Adjusted	Whittaker Tornqvist	Doyle & Ridout	Whittaker Arithmetic
Polynomial lag	0.836	0.706	0.724	0.643	0.535
Evenson-V-shaped lag	0.835	0.778	0.796	0.637	0.586
Bredahl-V-shaped lag	0.706	0.606	0.620	0.554	0.516

The lowest rate of return, of 53.5%, results from using the RPI deflator in calculating the R & D series for use with Whittaker's arithmetic index. The highest, of 83.6% for Godden's quality-adjusted index is also not entirely comparable with the other results. The results for the Doyle and Ridout index should also be treated cautiously due to the suspicion of serial correlation. Hence, we would opt for the results of the two remaining attempts, which come out at 70.6% and 72.4%.

The second and third rows show the results produced by applying inverted U-shaped lag structures[23] to our data, using two slightly different weighting schemes. These figures do provide a comparison and show the range of values generated by alternative assumptions concerning the lag structure. Even then, the estimated MIRR's only vary from 60% to 80%, which is almost exactly the range of the two rule of thumb guesses at the beginning of section III (p.7).

Obviously, this brief attempt does not solve all the problems. The poor education data and the total lack of extension information cannot be correct easily. Nor are we happy to have had to pin the end points of the polynomial lag in order to get robust estimators, though this seems to be true of the previous studies. Errors could also results from the averages used to reduce the computational burden in calculating the MIRR's.

VI. CAN ECONOMISTS EVALUATE AGRICULTURAL RESEARCH?

It is unfortunate that economists have failed to agree on a set of conventions for research project appraisal (Davis 1981). Probably there is no clear-cut best choice and perhaps two or three alternative MIRR calculations should always be presented and compared. This problem is only organisational.

Nor are the approximation errors stressed by Wise (1987) crucial to the health and well-being of applied econometrics. Given decent data non-linear estimates of non-linear functions are perfectly attainable. Obviously better data, suited to those types of analyses, would be a huge step forward. The next step would be to improve our understanding of the types of measures calculated from these data. Figure I below shows a comparison of the first differences of three of the TFP indices. There are large variations prior to 1975, which cannot be fully explained here.

Figure 1 : UK Agricultural Productivity Indices

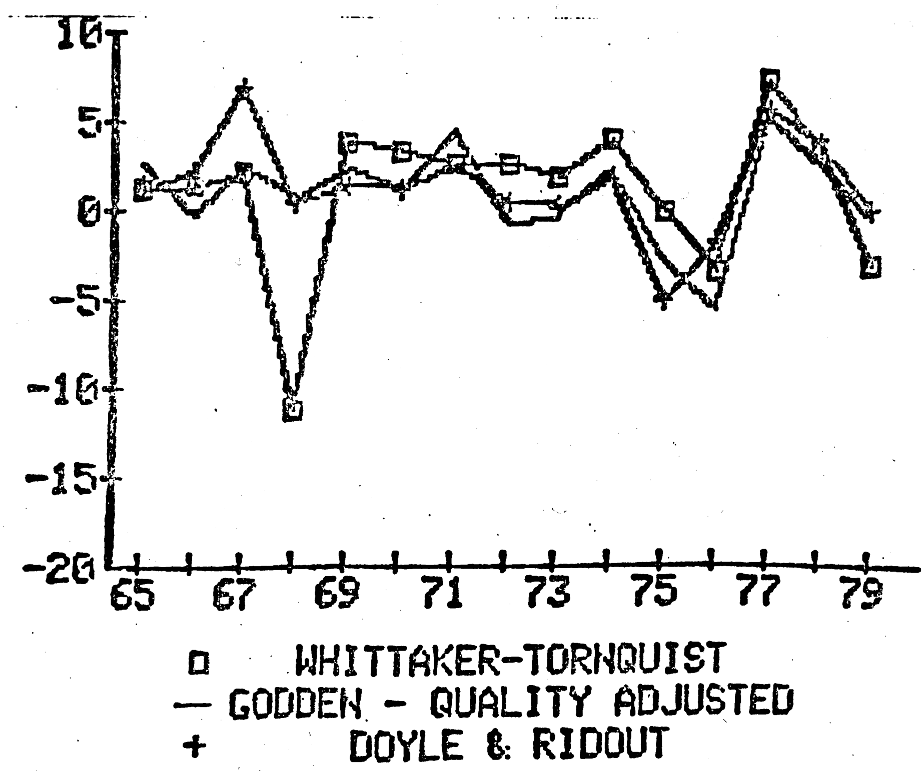

Table IV shows how low the level of agreement is, with correlation coefficients for the first differences of the series as low as 0.5.

Table IV : Comparison of Total Factor Productivity Indices: Correlation Coefficients of First Differences

	Whittaker Laspeyres	Whittaker Tornqvist	Godden, Q Adjusted	Godden Unadjusted	Doyle and Ridout
Whittaker Laspeyres	-	0.757	0.848	0.850	0.826
Whittaker Tornqvist	-	-	0.505	0.512	0.445
Godden Q Adjusted	-	-	-	1.00	.776
Godden Unadjusted	-	-	-	-	.763
Doyle and Ridout	-	-	-	-	-

The choice of index type (arithmetic, Tornqvist, etc.) is only a minor source of variation as Diewert (1978) has shown. The treatment of quality change, on the other hand, leads to large disparties[24] as does the treatment of capital on which there is still little agreement.

Even if these problems are resolved, "there are two things you are better off not watching in the making: sausages and econometric estimates" (Leamer, 1983). The highly satisfactory Durbin Watson statistics in this paper are obviously better than unsatisfactory outcomes, but should not lead to complacent acceptance of results. By way of a warning, Table V shows the results of fitting a three input Cobb Douglas function to US agriculture data for 1948-1979, taken from Ball (1985).

Table V : Regression Results - U.S. Agriculture 1948-78

Variable	Est. Coefficient	T-statistic
Constant	-1.61	-7.59
Labour	0.295	2.22
Capital	0.348	4.06
Intermediate Inputs	0.342	8.48

Returns to Scale 0.985, Adjusted R^2 = 0.974, Durbin Watson 1.37.

The estimates look appealing, but Table VI shows the effect of including a time trend. The apparently solid results of Table V vanish and only the time trend (and intercept) are significant.

Table VI : Regression Results - U.S. Agriculture 1948-79

Variable	Est. Coefficient	T-statistic
Constant	-1.75	-12.11
Labour	0.125	1.34
Capital	0.030	0.38
Intermediate Inputs	0.041	0.71
Time	0.020	5.91

The Durbin Watson statistic may be helpful, but it cannot guarantee that the model is meaningful. The value of the Durbin Watson statistic in the above example falls in the indeterminate range, but it could equally well have been entirely acceptable and yet the correlation be spurious.

Recently econometricians have shown far more interest in sensitivity analysis (Leamer 1983, 1985, McAleer et.al. 1985, McClosky 1985, 1986) and the problem of testing model specification. We lack the data to attempt much in the way of alternative specifications, but we have experimented with all the series available to us and found that the estimates appear to be surprisingly robust. We continue this process by considering model error. Whereas we have fitted the conventional model of equation (6), which is well supported in the literature, the distributed lag problem could have been dealt with in the manner developed by Koyck (1954)[25]. Applying Koyck's transformation, instead of equation (5), we get

$$(14) \quad \ln P_t = a_0(1-\theta) + \theta \ln P_{t-1} + \alpha_1 \ln R_t + B_2 \ln W_t - B_2 \theta \ln W_{t-1}$$

$$+ w_t - \theta w_{t-1}$$

This equation, which is based on continually declining weights to R & D over time and is hence entirely at odds with the reasoning behind the conventional model, fits as well, if not better. All the estimated coefficients were positive and significant (except for lagged weather), the adjusted R^2 was 0.97 and the Durbin Watson[26] was 1.9014. The reader is left to speculate on the meaning of this result which gives a MIRR of %. Along with Coase, we believe that if you torture the data long enough, nature will confess, and we have only just begun.[27]

VII. CONCLUSION - WHICH WAY FORWARD?

At high levels of aggregation, there is little feel for the data. We cannot identify individual important innovations and track their effects. The system is ill-defined so that we can do little except fish with a very blunt hook and rely on dubious statistical tests. The results at the aggregate level probably can't be significantly improved without much more and better data. A better understanding of the underlying processes would also help, but that is a tall order at this level of aggregation.

At low levels of aggregation, for example at the level of the individual project, externalities abound, and no matter how good the results, the author will be suspected of selectivity, since for every success there are n failures. In this instance, Morton's book can be avoided, by selecting an intermediate level of aggregation. We are currently embarking on a crop-specific study of technical change, with the support of MAFF. For oilseed rape we have trial plot data in addition to aggregate output and yield statistics and hopefully can identify innovations and follow their effects through the system. At least the study will give us something to talk about at the A.E.S. Conference in Manchester next year.

NOTES

1. Typically, the CBA studies tend to be of individual inventions or single crops, whereas the production function analyses are at a higher level of aggregation. However, either technique maybe employed at any level of aggregation, as Table I shows. Wise (1986, p.151) is misleading on this issue.

2. See, for example, Ruttan (1980, 1982) or Oehmke (1986) and the studies they cite. There are occasional dissenters such as Pasour and Johnson (1982). Also, Nelson (1982) concludes that market failure in R & D is not a simple matter of too few resources, but the inability of the private sector to spawn an appropriate portfolio of projects. Public sector research is qualitatively different (Thirtle, 1986a).

3. See Evenson, Waggoner and Ruttan (1979), for a widely-quoted example.

4. Argued by Schuh (1986), in his appraisal of Vernon Ruttan's contribution, for which Ruttan became the first economist to receive the von Humboldt award, for services to American agriculture.

5. For example, Grossfield and Heath (1966) and Lund, Irving and Chapman (1980) pointed out that resources must be allocated on the basis of ex-ante evaluations of costs and benefits.

6. Like the earlier papers, the emphasis is on the range of numerical outcomes resulting from different methods of calculation. Econometric issues are addressed only by assertion.

7. This is not a matter of taking sides. The legitimacy of public sector intervention has to be established since the burden of proof in the current political climate rests on those who do not accept the market solution. (Thirtle, 1986a).

8. See Griliches (1985) on the difficulties that arise when the data collectors and the data users are not the same people.

9. Thus, for example the Tornqvist-Theil discrete approximation of the continuous Divisia index is exact for the translog production function. The arithmetic index is exact for the linear production function, etc.

10. See Berndt and Christensen (1973). Given that the data were assembled for other reasons, it is unlikely that the grouping used for aggregation will be appropriate for economic studies.

11. This amounts to aggregating until there is only one output and only one input (composed of all the traditional factors). The total factor productivity index is based on the ratio of the two aggregates. This is perhaps what Wise (1986) was getting at with his one input production function.

12. The choice of functional form for the index is a minor cause of measurement error relative to the difficulties involved in handling quality change. The geometric index is exact for the Cobb Douglas function used in the example.

13. See Lu, Cline and Quance (1979, p.15) for a description of the stages involved in research and diffusion.

14. This follows Lu, Cline and Quance (1979) but is not atypical. The ubiquitous Cobb Douglas can be justified to an extent by poor data which may not be sufficient to sustain more general functional forms that are less parsimonious in parameters. This issue should be settled empirically.

15. My figures are those for 1985 from the MAFF Annual Review, which seems to be Harvey's source. How Wise (1986) arrived at his results is beyond the ken of any mere economist. Obviously, I don't intend these figures to be taken seriously. They represent the returns to extension, farmer education, improved resource allocations (due to organisational and institutional innovations as well as crop switching etc.), scale effects and any innovations not fully appropriated by the input industries, as well as to public sector R & D. Indeed, I doubt if further sophisticated analysis is warranted until the basic issue are agreed upon. For instance, what prices should be used to evaluate the output?

16. Strictly speaking, this requires the input suppliers to be monopolists. If they are not, only the cost rather than the return, will be reflected in the input price series.

17. First differences, or de-trending is attractive but the form of the lag structure in the first difference case requires further study.

18. The bad news is that the new "R & D" variable was cumulative rainfall. The good news is that the Durbin Watson does fall all the way to 0.31. This demonstration is attributable to Hendry (1980, pp.391-5).

19. This is taken from H.M.S.O. (1983).

20. This approach follows Stallings (1960). See Bottomley (1986) for further discussion.

21. The correlation coefficient for education and Doyle and Ridout's R & D index ws 0.83.

21. This is taken from H.M.S.O. (1983).

22. These averaging procedures reduce the computational burden considerably, but are an avoidable source of error. Alternatives should be investigated.

23. Davis (1980) shows that the choice of lag structure has little effect on the VMP calculations but he has argued elsewhere (Davis 1981) that alternative MIRR calculations do cause large variations. However, the pioneering results of Griliches and others are clearly gross approximations and should not be allowed to give the impression that there are measurement problems. These old results are, predictably, used in this way by Wise (1986).

24. See Griliches' (1960) comparisons of the USDA and BLS farm machinery and equipment statistics and Thirtle (1986b).

25. Suggested to us by Mike Burton.

26. The Durbin Watson statistic will be biased towards 2 in this case, due to the lagged dependent variable. The value of the appropriate statistic, the Durbin h statistic, is 0.273, which is well within the 5% confidence interval of + or - 1.96.

27. For instance, a fourth degree polynomial lag gives results very similar to the lag structure used in this paper and may lead to a model that can be fitted to first differenced data. The MIRR's produced are a little higher than those reported here.

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