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Accounting for Productivity Differences in European Agriculture: Cointegration, Multilateral TFPs and R&D Spillovers[1]

INTRODUCTION

The substantive contribution of this paper is to report and compare multilateral total factor productivity (TFP) calculations for ten European Community (EC) countries[2] and the USA. The simultaneous advances in duality theory, flexible functional forms and the linkages between production theory and index numbers have transformed TFP measurement. At the same time over which intertemporal indices have improved, the pioneering work of Jorgensen and Nishimizu (1978), on inter-country comparisons, has been developed rapidly, generating material on multilateral indices which allow competitiveness to be measured both intertemporally and interspatially. The theoretical issues are discussed in Caves *et al.* (1982) and applied to agriculture by Capalbo *et al.* (1990) and Capalbo *et al.* (1991). Empirical work on EC agriculture can be found in Terluin (1990) and Bureau *et al.* (1992), whose indices are used in this study.

The TFP indices are formed as the ratio of aggregate output to aggregate input. As Evenson *et al.* (1987) show, changes in TFP can be explained by means of 'determining' variables, like R&D, extension and farmer education. They call this approach to explaining technical change the 'two-stage decomposition', as opposed to the 'integrated' approach, in which the 'determining' variables are incorporated directly into the estimation of the production, cost or profit function. Both approaches are common in the considerable literature on the returns to agricultural R&D that has been surveyed by Echeverría (1990).

However, all previous estimates of the returns to R&D for European agriculture (see Rutten, 1992; Thirtle and Bottomley, 1992, for example) fail, owing to lack of data, to allow for the spillovers between research jurisdictions. Evenson and Pray (1991) have shown that spillovers can be important. Thus the third section of this study uses data for all the ten EC countries and the United States to compare the values of the elasticities of the determining variables, with and without spillovers. It concentrates on spillovers between

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the public National Agricultural Research Systems (NARS) in the EC and also allows for the effects of intercontinental spill-ins from the US system and from private-sector research. Cointegration is used to determine the structure of spillovers between the EC countries (and the United States) and to avoid spurious regressions. The results lead to the conclusion that the returns to R&D are seriously biased if spillovers are ignored.

MULTILATERAL PRODUCTIVITY COMPARISONS FOR THE EC10 AND THE UNITED STATES

Bureau *et al.* (1992) construct Fisher TFP indices for the ten EC countries and the United States, for 1973–89. Then, to allow international, as well as intertemporal comparisons, agricultural sector purchasing power parity (PPP) exchange rates were used to make the outputs and inputs of the 11 countries comparable. This allowed construction of an EKS (from Elteto, Koves and Szulc) spatial index, for 1985, which was used to calibrate the time series for each country, giving the multilateral indices shown in Table 1.

The Fisher index, which is the geometric average of the well-known Laspeyres and Paasche indices, was chosen because it satisfies more desirable properties than the Tornqvist, when used for inter-country comparisons. Diewert (1992) shows that both indices can be viewed as ideal approximations, in the sense that they are consistent with economic theory. The sectoral PPPs are spatial price indices that compare several countries in the same year with a base of 100 for a particular country. The method is similar to GDP-based PPPs, but the basket of goods is different, being just the inputs and outputs of the agricultural sectors.

Since a matrix of bilateral Fisher indices can give inconsistent comparisons, multilateral index numbers have been developed to construct sets of consistent indicators. The multilateral version of the Fisher index is the EKS index, which is widely used in international comparisons, especially by the OECD. The EKS index is the geometric mean of the ratios of bilateral indices. It satisfies the form symmetry test, is transitive and, although not directly derived from a flexible functional function, it is close to a superlative index (Diewert, 1976).

The source of the data for the ten EC countries is Eurostat's *Economic Accounts for Agriculture, Forestry and Fisheries*. If TFPs are to be compared internationally, it is also crucial that the data be entirely comparable. Eurostat has tried to impose this uniformity on the EC10, while the US series were reconstructed to make them compatible with the European material. The most obvious differences occur in calculating capital stocks of buildings and machinery, hence all series were specially constructed by Ball *et al.* (1993).

The first row of Table 1 shows that in 1973 the United States was more efficient than all the European countries, except the Netherlands and Belgium/Luxembourg. However, there are considerable annual variations, so it is better to base the comparison on an average. Thus the lower part of the table shows the efficiencies of the EC countries and the United States, relative to the aggregate of the EC countries, averaged over 1973–5. On this basis, the Neth-

TABLE 1 *TFP comparisons for ten EC countries and the United States, 1973–89*

Year	Belg	Den	Eire	Fra	Ger	Gre	Ita	Neth	UK	USA	EC-10
1973	108.2	85.8	70.4	87.8	73.2	67.5	62.6	110.3	86.3	104.0	79.0
1974	111.7	98.1	73.7	87.4	76.7	68.2	63.7	115.2	89.9	93.0	80.7
1975	104.2	87.3	77.0	85.9	75.7	71.4	67.0	113.4	84.8	99.1	80.1
1976	103.2	84.6	73.6	83.5	74.5	71.0	64.2	114.4	82.4	86.8	78.1
1977	106.7	91.8	78.4	86.3	78.5	67.0	65.4	118.5	89.1	105.2	81.0
1978	111.4	91.5	78.1	91.6	80.6	73.1	66.3	122.5	91.7	98.2	83.9
1979	110.8	91.5	72.9	97.3	79.8	70.2	69.9	124.3	92.3	102.2	86.0
1980	112.8	94.4	75.7	96.9	81.1	76.5	73.5	123.3	97.6	98.0	88.3
1981	115.9	99.4	74.3	97.7	82.0	77.0	75.0	130.4	99.4	112.1	89.9
1982	119.4	106.5	79.7	108.2	89.5	77.7	77.2	135.6	103.7	115.1	96.0
1983	118.1	103.5	81.0	105.7	87.2	74.0	81.2	131.6	101.3	100.2	95.1
1984	122.9	118.8	88.4	111.9	91.7	76.7	78.7	139.7	111.9	119.0	99.4
1985	123.5	120.9	87.4	113.6	88.8	78.5	82.0	137.2	109.6	129.9	100.0
1986	126.7	123.6	84.9	115.8	94.3	82.7	83.9	143.3	108.7	130.0	102.8
1987	123.9	119.9	89.2	119.4	91.7	81.4	87.7	139.0	110.2	132.4	103.9
1988	128.4	128.3	90.3	121.0	95.9	91.3	88.1	142.8	110.6	127.5	106.6
1989	129.7	134.1	90.1	124.5	98.0	95.9	91.0	147.5	114.2	137.5	109.9
Spatial index, 1973–5 average, base of 100 for the EC-10 aggregate											
	135.0	113.0	92.0	109.0	94.0	86.0	81.0	141.0	110.0	124.0	100.0
Spatial index, 1987–9 average, base of 100 for the EC-10 aggregate											
	119.0	119.0	84.0	114.0	89.0	84.0	83.0	134.0	105.0	124.0	110.0
Annual average growth rates, per cent, from 1973–5 to 1981–9											
	1.2	2.5	1.4	2.4	1.7	1.9	2.3	1.7	1.7	2.1	2.1

erlands and Belgium/Luxembourg performed better than the United States, but Italy and Greece were at less than 70 per cent of the US efficiency level. On average, the EC countries achieved 81 per cent of the US rate.

The growth rates shown in the last row indicate that France, Italy and Denmark had faster growth than the United States, while all the rest of the EC countries fared worse. Thus, as the spatial index in the penultimate row shows, by 1987–9, the French and Italians had closed the gap with the United States a little; Germany, the UK, Eire and Greece had fallen further behind; and the United States had closed the gap with the Netherlands and overtaken Belgium/Luxembourg. Since the growth rates of the ten EC countries in aggregate and the United States were equal, at 2.1 per cent, the EC10 in total continued to achieve only 81 per cent of the US efficiency level at the end of the period. We now turn to explaining these interspatial and intertemporal efficiency differences.

EXPLAINING TFP GROWTH: THE RETURNS TO AGRICULTURAL R&D

The model and data

Changes in the TFP index should be explained by the 'conditioning' factors that shift the static production function over time. In the basic model these are R&D expenditures, which generate new technology, extension expenditures transmitting the results to the farmers, so diffusing technology, and the education level of the farmers, which affects both their own creative and managerial abilities (hence endogenous technological change) and their skill in appraising and adapting exogenous technologies. A weather variable is normally included to explain some of the residual errors and several other explanatory variables have been used in the extensive literature in this area. This study incorporates spillovers between the EC countries and from the United States, and spillovers from the private-sector input industries.

Conceptually, considering the EC countries as a group is similar to working with data for the United States, rather than handling the states individually. This has been shown to matter since there are considerable spillovers of research benefits between the state jurisdictions (Evenson, 1989). Thus technological spillovers between the EC countries should be incorporated. If spillovers are important there are policy implications, in that national research systems may be duplicating each other's efforts and wasting resources. Such a finding would support the case for centralized management, or even EC-wide research facilities.[3] Including the United States allows for the possibility of intercontinental spillovers. Technical change in the input industries should be captured in the input series, but these are unlikely to fully account for quality changes (Cooper *et al.*, 1993), so private-sector activity is measured by patent data.

The R&D expenditures for each country are measured in constant 1980 PPP US dollars; the extension data is from Evenson and Pray (1991) and is in constant 1980 US dollars; education is an index of years of secondary education, constructed from the World Bank *World Tables*; the weather variable is cereal yield deviation around a time trend; private-sector chemical and mechanical patents pertaining to agriculture are patent counts for all US and foreign patents registered in the United States.

All the variables except the weather may well have lagged effects on TFP, so the model becomes:

$$TFP_t^e = \sum_{i=1}^{m} \alpha_i RD_{t-i}^e + \sum_{j=1}^{n} \beta_j RD_{t-j}^f + \sum_{k=1}^{p} \delta_k X_{t-k}^e + \sum_{h=1}^{r} \gamma_h E_{t-h}^e + \sum_{g=1}^{s} \phi_g P_{t-g} + \theta W_t^e + u_t \quad (1)$$

where the TFP index of country e at time t is a function of its own R&D expenditures (RD^e), lagged from one to m periods, foreign country (or countries) R&D (RD^f), lagged from one to n years, the lagged effects of own-country extension (X^e) and education (E^e), the lagged effects of the stock of international patents (P) and the current weather (W_t^e). All the variables, except the weather index, are in logarithms and u_t is a stochastic error term.

There are several alternatives for modelling the lagged variables, but including anything up to 15 lagged values of own-country and foreign-country R&D, plus shorter lags for extension, education and patents is not feasible, owing to lack of degrees of freedom and collinearity. Instead, a second-degree polynomially distributed lag structure, specific individual lags or a perpetual inventory knowledge stock is used for R&D. The inverted 'U'-shaped polynomial lag is common in the literature (Thirtle and Bottomley, 1989) and so is the perpetual inventory model (PIM). We assume a value of 10 per cent for the depreciation parameter, δ, (based on the estimated lag lengths) in the PIM:

$$K_t = (1 - \delta)\, K_{t-1} + RD_t \quad (2)$$

where K_t is the knowledge stock in year t.

The lags on extension, education and patents are shorter and are dealt with by constructing two- to five-year moving averages, or by simply using a single lagged value. In most cases lags on these variables did not improve the results. It is also possible to avoid dealing with the long lags for spillovers from foreign R&D by using the foreign county's TFP index as the indicator of potential technology spillovers, rather than the research expenditures (Bouchet *et al.*, 1989).

Determining the choice of variables: cointegration

In the literature on industrial R&D spillovers, TFPs are often explained by knowledge stocks only (Coe and Helpman, 1993), but in agriculture the number of explanatory variables is considerable in the first place. Once R&D spillover effects are included, a large number of combinations and permutations are possible. To deal with this, and to minimize the chance of spurious regressions, cointegration techniques are used to establish valid long-run relationships between the variables. The concept of cointegration is based on the idea that, if variables are linked by some theoretical relationship, then the deviation from the long-run equilibrium path should be bounded.

Two conditions must be satisfied for variables to be cointegrated. First, the series for the individual variables must have the same statistical properties; that is, they must be integrated of the same order.[4] Second, if the variables are cointegrated, then there should exist a linear combination of the variables which is integrated of order one less than the original variables; that is, if the variables are integrated of order one, which is true for the majority of variables in this case, the error term from the cointegrating regression should be stationary. The Dickey–Fuller (DF) test, the augmented Dickey–Fuller (ADF) test, or the cointegrating regression Durbin–Watson (CRDW) proposed by Sargan and Bhargava (1983) are used to establish both the order of integration of the variables and the stationarity of the error term in the cointegrating regressions. These tests, and Johansen's (1988) more general test for the existence of multiple cointegrating vectors, were used by Schimmelpfennig and Thirtle (1994) to establish that, with these data, cointegrating regressions could be found for all nine countries, without spillovers.

However, a stationary error term does not imply sensible parameter estimates and the reliance to be placed on cointegration tests for such short series is dubious. Hence a more pragmatic approach is taken here. The variable combinations that led to cointegrating regressions were tried first in the explanation of TFP change, and then the combinations were altered to produce reasonable results (that is, elasticities between zero and one). Then these regressions were tested, to ensure that the cointegration tests did not lead to rejection of the equations used. For all the countries, the TFPs and the weather indices are integrated of order one, and the same is true of R&D, extension and education, with some exceptions. In particular, the education series for Eire, Greece and Italy appear to be integrated of order two and should not be able to explain the TFPs. The results of the regressions to explain TFP change confirm the usefulness of the cointegration tests, in that these variables do not improve the results and are best omitted (see the results in Table 4). The same is true of extension expenditures for Greece, which is I (0), and for the Netherlands, which is I (2). Also the R&D series for Belgium appears to be integrated of order two, which suggests that the country regression may be spurious. In all other cases, there could be cointegrating relationships between the variables that appear to be integrated of order two, as note four explains. The cointegrating regression results for the regressions without spillover effects are reported in Table 2.

If the objective of the tests was simply to establish cointegration, and hence the existence of a long-run relationship, the Johansen method is the most powerful, and both Johansen tests find at least one cointegrating vector (the test statistics are greater than the 95 per cent critical values, in brackets, except for the Eigenvalue test for Greece). Similarly, the CRDW tests suggest cointegration in all cases except for Belgium,[5] but the DF tests lead to rejection of the hypothesis that there is a cointegrating vector (the test statistic is less than the critical value in the bracket) in all cases except for France and perhaps

TABLE 2 *Cointegration tests for ten EC countries, without spillovers, 1974–89*

Country	Regression dep. var. = TFP	DF test	CRDW	Johansen Model VAR = 2 Eigenvalue Test	Trace Test
Belgium	RD EXT W	–2.3197 (–4.88)	0.84	31.9 (28.1)	75.6 (53.1)
Denmark	RD EXT ED W	–3.4385 (–5.35)	1.58	87.1 (34.4)	138.6 (76.1)
Eire	RD EXT CPAT W	–4.2075 (–5.59)	1.81	86.4 (34.4)	125.3 (76.1)
France	RD EXT W	–4.9897 (–4.86)	2.33	57.5 (34.4)	109.8 (76.1)
Germany	RD EXT ED	–3.4910 (–5.05)	1.79	48.2 (28.1)	132.7 (53.1)
Greece	RD MPAT W	–3.0651 (–4.91)	1.27	17.1 (28.0)	35.3 (34.9)
Italy	RD EXT W	–3.6341 (–4.86)	1.65	38.8 (28.1)	83.7 (53.1)
Netherlands	RD ED W	–3.3559 (–4.86)	1.72	43.0 (28.1)	103.0 (53.1)
UK	RD EXT W	–4.8018 (–4.86)	2.06	37.2 (28.1)	96.3 (53.1)

Notes: All variable are in logarithms, except the weather index. TFP = total factor productivity; RD = research expenditures; EXT = extension; ED = education; W = weather index; CPAT = chemical patents; MPAT = mechanical patents. R&D is lagged five years in the Johansen tests, to allow for the long lags, since the maximum lag allowable in the variable autoregressions (VARS) is two, because of lack of data.

TABLE 3 *Cointegration tests for ten EC countries, with spillovers, 1974–89*

Country	Regression dep. var. = TFP	DF test	CRDW	Johansen Method VAR = 2 Eigenvalue Test	Trace Test
Belgium	RD W TFPF CPAT	–3.6373 (–4.98)	1.59	80.2 (34.3)	145.1 (76.1)
Denmark	RD EXT W RDUS	–3.5990 (–5.59)	1.83	143.3 (34.3)	253.7 (76.1)
Eire	RD W TFPG CPAT	–3.5990 (–5.59)	1.79	47.8 (28.1)	84.4 (53.1)
France	RD EXT W TFPG TFPUS	–5.0900 (–5.89)	2.03	51.1 (40.3)	175.4 (102.1)
Germany	RD EXT W TFPF TFPN TFPUS	–4.8476 (N.A.)	2.32	92.9 (46.5)	224.7 (131.7)
Greece	RD TFPI MPAT	–5.2683 (–5.05)	1.73	22.3 (22.0)	39.1 (34.9)
Italy	RD EXT TFPF	–4.1101 (–4.86)	1.85	72.0 (28.1)	108.9 (53.1)
Netherlands	RD EXT W TFPD TFPG TFPUS	–5.7440 (N.A.)	2.15	135.9 (46.5)	271.1 (131.7)
UK	RD EXT W RDF TFPF TFPUS	–4.5081 (–5.81)	2.75	65.2 (40.3)	163.6 (102.1)

Notes: The variables are the same as in Table 2, with the spillover variables added. Thus TFPF is the French TFP index; RDUS is the US knowledge stock; TFPG is the German TFP, and so on.

the UK. Since the objective is to discriminate between variable combinations and determine the most acceptable regression equations, the DF tests provide a useful filter. Although it is unlikely that the relationships are spurious, the hypothesis is that the regressions are misspecified, and should improve when spillovers are included.

Repeating the same exercise with the spillovers included (Table 3) shows that there is some truth to this supposition. The DF test values, for the variables actually used in the explanatory regressions still fail to establish cointegration for most countries,[6] but are larger, in all cases, except for the UK. The CRDW tests and both of the more powerful Johansen tests suggest that cointegrating vectors do exist. The spillovers identified by the cointegration tests appear to be reasonable and will be discussed in the next section, which presents the results of the regressions that explain TFP change, with and without spillovers.

Results at the national level, with and without spillovers

The well established methodology for explaining the growth of TFP is followed here, with some refinements. The first row of Table 4 shows the results of simply regressing TFPs on the knowledge stocks, to ensure that there is some correlation. Irish R&D appears to be hardly related to TFP and the fit is very poor for Denmark, but the other results are reassuring. The rest of the top half of the table reports the results of explaining TFP, using extension, education, the weather and a second-degree polynomial lag of R&D expenditures. All the variables except the weather index are in logarithms, so the coefficients may all be interpreted as elasticities, with the sum of the lagged values reported for R&D (the total elasticity).

A row of Table 4 shows that the lags vary from four to 13 years,[7] and the next row reports the elasticities of R&D, which are all positive (except for Eire), ranging from 0.191 to 0.591, and significantly different from zero. For Ireland, it appears to be extension, the weather and private R&D that explain TFP growth. Extension is positive and significant for five countries, not significant for two, and excluded for the remaining two countries, on the basis of the tests for the order of integration. Education is positive and significant for only two countries, insignificant for one, and excluded for the others, in three cases (Eire, Greece and Italy) because of the order of integration, and for Belgium, Germany and the UK, because of collinearity with R&D. The weather variable performed well in seven cases, but was not significant for Greece and Italy.

The adjusted R^2s show that the majority of the variance is explained in all cases, with an average of 0.9. Although Greece and Germany fit less well than the rest, over 90 per cent of the variances are explained in six of the nine cases. The Durbin–Watson statistics show that the errors are serially correlated for Belgium, Germany, Greece and the Netherlands. This deficiency is not removed by using autoregressive correction techniques; instead the misspecified equations are improved by allowing for research spillovers.

The lower part of Table 4 reports the results when the spillovers are included. Some of the changes are quite startling, but entirely plausible. For instance, once the French TFP is included in the Belgian equation, it is significant, with a large elasticity of 0.65, and so are private-sector chemical patents. The lag on Belgian R&D shortens to six years and it becomes insignificant. Perhaps the small Belgian research system uses the output of the very much larger French system and the private chemical industry and does adaptive research, to tailor the French technology to suit Belgian conditions. Danish TFP is explained by Danish R&D, extension, the weather and by a considerable spill-in from the US system, rather than from European neighbours. It is certainly possible that the advanced Danish animal sector draws on the technology generated by the world's largest and generally most advanced research system. Ireland's productivity growth is a function of private-sector activity, the weather and German technology. It should be no surprise that Ireland, as a small country, adapts foreign technology, but the prior hypothesis would be that the main provider would be the UK; however, the UK R&D series tends to be I (2) (because of a reduction to near-zero growth from 1982 onwards) and would not cointegrate with Irish TFP, whereas German TFP does.

The other countries have spill-ins that can be explained by obvious factors, such as size, efficiency, geographical proximity and common interests in terms of crops and other enterprises. The total effects of the spillovers appear to outweigh the effects of the national efforts for all the countries considered. Thus, for France, it is Germany (the large next-door neighbour) and the United States (more basic research) that matter. For Germany, the contributors are France (next door) and the Netherlands (advanced animal production and the leader of this sample in terms of productivity), plus the United States. Greek productivity depends on Italian R&D far more than on national research, which is possible since Italy produces similar products, tends to lead technologically and has a far larger research effort. Private-sector machinery patents, lagged for four years, are also significant for Greece. For the Italians, French technology seems to dominate the local system, while the Netherlands benefits from Germany, the large neighbour, Denmark, the specialized animal producer, and the United States. Lastly, the UK draws on French and US technology and, perhaps surprisingly, UK technology does not appear to affect any continental TFPs.

There is a hierarchical pattern to the spillovers, with the United States affecting the TFPs of the more obviously innovative countries, which perhaps have more effective research systems capable of exploiting the US output of technology; these are Denmark, France, Germany, the Netherlands and the UK. The remaining countries, that spend less on research, are Belgium, Eire, Greece and Italy. Of this group of relative laggards, two do not have positive returns to their own R&D and have very short lags, all have spill-ins from European neighbours and, for three of the four, private patents are significant. These results together tend to suggest that this group concentrates on adapting technology developed by others to suit local conditions, to a greater extent than the more research-oriented countries.

Comparing the two sets of results makes the consequences of ignoring the spillovers clear. Without the spillovers, the evidence of cointegration was less persuasive (Tables 2 and 3) and the Durbin–Watson statistics in the top half of Table 4 confirm that the equations are probably misspecified. Including the

TABLE 4 *Explaining the growth of TFP*

Variables	Belg	Den	Eire	Fra	Ger	Gre	Ita	Neth	UK
Without spillovers All variables are in logarithms, except the weather index. Critical *t* values with 8 dof, one-tailed test, are 90% = 1.4, 95% = 1.86									
Knowledge stock	0.326	0.43	0.201	0.464	0.663	0.27	0.32	0.673	0.505
(coefficient	8.09	1.50	0.903	10.95	6.54	3.95	6.74	9.29	9.68
t-stat. & R^2)	0.80	0.26	0.12	0.89	0.72	0.46	0.73	0.85	0.87
Lag length	13	7	7	11	13[a]	4	12	14	9
R&D coeff.	0.312	0.585	–0.667	0.591	0.384	0.523	0.191	0.261	0.356
t-stat.	3.98	6.43	–8.13	17.7	6.08	5.81	3.56	2.24	5.94
EXT COEFF.	N.S.	0.639	0.322	0.179	N.S.		0.351		0.433
t-stat.		2.42	9.28	3.24[b]			3.83		6.33[c]
ED COEFF.		0.313		N.S.				0.556	
t-stat.		1.78[d]						1.88	
WEATHER	0.153	0.306	0.209	0.227	0.463	N.S.	0.108	0.169	0.233
t-stat.	2.52	3.03	5.85	2.61	1.99		1.17	2.09	3.92
PATENTS		CHEM	0.151		MECH	0.128	CHEM	0.158	
t-stat.		PATS	5.85		PATS	1.46[e]	PATS	2.05	
Adj R^2	0.87	0.95	0.97	0.96	0.71	0.78	0.97	0.93	0.95
D–W stat.	0.89	2.22	2.24	2.12	0.46	0.78	1.88	1.26	1.99
With spillovers									
Lag length	6	12	11	10	9	4	12	9	15
R&D coeff.	–0.141	0.549	–0.41	0.442	0.157	0.235	0.127	0.286	0.255
t-stat.	–0.78	2.33	–3.13	2.74	1.56[f]	2.46	2.30	8.36	2.39

EXT COEFF.		0.924		0.131	N.S.		0.226	N.S.	0.226
t-stat.		3.45		1.41			2.02		2.34
ED COEFF.				N.S.	N.S.				
WEATHER	N.S.	0.391	0.098	0.224	N.S.	0.169	N.S.	0.114	0.192
t-stat.		3.45	1.54	4.0		2.46		4.43	4.56
DENMARK TFP								0.156	
t-stat.								2.67	
FRANCE TFP	0.652				0.214		0.333		0.133
(KS for UK)	3.3				1.51		1.93		1.41
GERMANY TFP			0.732	0.703				0.195	
t-stat.			7.19	1.79				1.61	
ITALY TFP						0.603			
t-stat.						3.97			
NETH TFP					0.590				
t-stat.					2.14				
US TFP (KS for		0.343		0.212	0.350			0.099	0.238
DEN & GER)		1.89		1.95	2.21			3.19	3.19
CHEM PATENTS	0.062		0.164		MECH	0.167			
t-stat.	1.78		4.23		PATS	2.74			
Adj. R^2	0.92	0.91	0.93	0.97	0.98	0.90	0.97	0.99	0.98
D–W stat.	1.73	2.23	1.70	2.42	2.54	1.17	2.05	2.56	2.59

Notes: [a]For Germany, there was a three year lead time before the lagged R&D effects begin.
[b]French extension is a four-year moving average.
[c]UK extension is lagged three years.
[d]Danish education is lagged two years.
[e]Mechanical patents for Greece lagged four years.
[f]For Germany, with spillovers there is a one-year lead time before returns begin.
Lags were not used for the other countries, as they did not improve the results.

spillovers cures the serial correlation problems in all cases except for Greece, for which the data are poor. The adjusted R^2s in the top half of the Table include three relatively poor results and on average 90 per cent of the variance in TFP is explained. With the spillovers, at least 90 per cent of the variance is explained for all the countries and the average adjusted R^2 is 0.95. Simply stated, the regression equations are considerably improved by including spillovers.

If the variables that are omitted from the misspecified equations are positively correlated with the variables that are included, the expectation is that there will be a systematic upward bias to the estimated coefficients of the variables that are included. This would seem to be the case here; all but one R&D elasticity for smaller research expenditures are lower when the spillovers are allowed for, and the average of the elasticities (excluding Eire) is 0.400 without spillovers and 0.256 when spillovers are included (counting Belgium as zero). This suggests that, all else being equal, the elasticity of R&D is biased upward by 56 per cent if spillovers are ignored. Thus not including spillovers may be a significant cause of the generally high rates of return to R&D noted by Echeverria (1990). Similar statements may apply to extension and education; extension is significant in only four cases once spillovers are included, and the average elasticity is slightly lower. Education failed to make any contribution to explaining TFP growth once spillovers were included. In part, this may be because the variable measures only general levels of secondary education, but it does appear to be true that the spillover variables have more explanatory power than extension and education.

Pooled data estimates for the United States of Europe

The estimates in the last section appear to be reasonably robust, but for the individual countries there are usually less than ten degrees of freedom. This problem can be partially overcome by pooling the time series, which gives ample observations, but introduces econometric difficulties. Pooling may be viewed as a means of aggregation, so the results indicate the effects of the variables for the ten EC countries taken as a group. The parameter estimates are thus the same for all the countries; for any parameter, β_{ij}, where i is the country and j is the parameter identifier, the restriction is that $\beta_{ij} = \beta_j$. With much the same variables as in the previous section (an output to input price ratio is added) and using weighted generalized least squares with within and between-group corrections for heteroscedasticity and autocorrelation, the estimates are as in Table 5.

The pooled regression draws on the prior information generated by Schimmelpfennig and Thirtle (1994) who used these data to find that R&D expenditures were causally prior to TFP with lags of two, nine, ten and 11 years. This suggests that, for the pooled sample (which includes the United States), the inverted 'U' shape of the second-degree polynomial lag structure may be incorrect. However, the PIM knowledge stock implies a geometrically declining lag, which also seems not to fit these data. Instead, we assume that there are two distinct outputs from the national research efforts. There is

TABLE 5 *Pooled results for ten EC countries, with spillovers*

	National effects					Spillovers of foreign knowledge stocks					
Variable	R&D	EXT	ED	WEA	TOT	FRA	GER	ITA	NETH	UK	USA
Elasticity	0.19	0.0028	0.05	0.17	–0.17	0.042	0.065	0.068	0.023	0.047	0.061
t-stat.	12.3	11.9	1.03	11.4	–2.5	9.70	1.01	14.5	0.62	10.4	10.2

adaptive, near market research, such as field trials, which affect TFP after a very short lag of only two years, and more basic activity, such as plant-breeding programmes, that have an average gestation period of ten years. In treating the two separately, there is the usual problem that the lagged R&D terms are collinear and are also collinear with extension. The best results were obtained by aggregating R&D lagged two periods with extension, to produce a 'near market' research variable and using a moving average of R&D lagged nine, ten and 11 periods, to pick up 'more basic' research activities. The spillovers were allowed for by using PIM knowledge stocks, for lack of a better alternative, and tests show that the results do not seem to be particularly sensitive to the form used.

Thus, for the 'United States of Europe', the own-country, long-term R&D expenditures have an elasticity of 0.19, which is a little lower than the unweighted average of 0.256 for the individual countries. Extension and short-term R&D expenditures have a small elasticity of 0.0028, but are highly significant.[8] Education is not significant but the weather index behaves as it should. The terms of trade variable (TOT) is the ratio of the aggregate output prices to the price of intermediate inputs, taken from Eurostat, like the TFP data. The negative coefficient suggests that output growth, which may be partly attributed to technical change, has lowered output prices over the period, in the manner of the 'technology treadmill' model (Cochrane, 1979).

The spillover effects shown on the right of Table 5 are now aggregate effects for the group of countries. French, German and American technology spillovers, which affected several other countries, remain important, but Danish R&D (not shown) was found to have an insignificant effect and the same is true for the Netherlands. However, UK research does have an effect on the group that could not be established by looking at the individual countries. The total elasticity of the significant intra-EC spillovers is 0.22, which is already greater than the effects of the NARS, and including the transatlantic spillovers from the United States gives a total spillover elasticity of 0.28, so the spillover effects taken together easily outweigh the own-country R&D effects.

RATES OF RETURN TO R&D

The coefficients of the R&D variables, however they are estimated, are output elasticities relating R&D expenditures to the TFP index, but they can be converted to marginal value products to allow calculation of the marginal internal rate of return (MIRR) to R&D. Thus a_i in equation (3), can be

$$\alpha_i = \frac{\partial LnTFP_t}{\partial RD_{t-i}} = \left[\frac{\partial TFP_t}{\partial RD_{t-i}}\right]\left[\frac{\overline{RD}_{t-i}}{\overline{TFP}_t}\right] \tag{3}$$

approximated by (geometric) mean values ($\overline{RD}$ and $\overline{TFP}$), so that the marginal product of R&D in year i is

$$MP_{RD_{t-i}} = \alpha_i\left[\frac{\overline{TFP}_t}{\overline{RD}_{t-i}}\right] \tag{4}$$

However, (4) is still in terms of the effect of R&D on TFP and, for a rate of return to be calculated, the change in productivity must be converted into a value. Since the TFP index is the logarithmic ratio of an output index to an input index, it is reasonable to use the value of the surplus: of output value minus the value of the inputs. Thus both sides of equation (4) are multiplied by the change in the value of the surplus from the beginning to the end of the period (ΔS), divided by the change in the value of TFP (ΔTFP) over the period.[9] This gives a value marginal product, with both R&D and the surplus being measured in 1980 US dollars.

$$VMP_{RD_{t-i}} = \alpha_i\left[\frac{\overline{TFP}_t}{\overline{RD}_{t-i}}\right]\left[\frac{\Delta S}{\Delta TFP}\right] \tag{5}$$

Note that, although the last two terms are averages, α_i varies over the lag period, giving a series of marginal returns resulting from a unit change in R&D expenditure. The marginal internal rate of return (MIRR) can be calculated from equation (6):

$$\sum_{i=1}^{n}\left[\frac{VMP_{t-i}}{(1+r)^i}\right] - 1 = 0 \tag{6}$$

in which i is the length of the lag, for each expenditure term, and the MIRR for a one-dollar change in R&D expenditure is calculated by solving for r. Performing these calculations using the values of α_i reported in Table 4,[10] both with and without spillovers, gives the MIRRs reported in Table 6.

These results show how sensitive the MIRR calculations are with respect to quite reasonable variations in the data. For five of the nine (Belgium, Germany, Italy, the Netherlands and the UK) the results are within the range of outcomes that have been frequently reported in past studies. The MIRRs are

TABLE 6 *Marginal internal rates of return to R&D, with and without spillovers, per cent*

	Belg	Den	Eire	Fra	Ger	Gre	Ita	Neth	UK
No spillovers	107	464	177	316	48	1 219	115	59	99
Spillovers	0	220	0	277	57	564	85	102	44

overestimates (especially without spillovers), in the sense that EC prices are well above world prices and no account is taken of negative externalities.[11] These high returns are the usual support for the proposition that there has been underinvestment in agricultural research. What is different here is that there are enough results, calculated in the same manner, to show that the variations really are huge. The high returns for Eire, and especially Greece, result from low R&D expenditures, rather than great successes, in terms of either TFP growth or the size of the surplus. Indeed, the correct interpretation of the Greek result is that the government is failing to exploit an excellent investment opportunity. For Denmark and France, TFP growth is good, but not good enough to give the huge returns shown, which really are a function of the size of the surplus relative to R&D expenditures. The French spend only about 70 per cent of the UK figure, while the value added by the French agricultural sector is about three times as great (Terluin, 1990) and the Danes, with value added at about 40 per cent of the UK figure, spend less than one-tenth as much as the British.

The upshot is that these results suggest that, for many countries, it is not reasonable to expect an 'acceptable' rate of return to agricultural R&D; some countries really do seem to have quite extraordinary MIRRs. The calculation based on this work which can be taken more seriously is for the MIRR for the EC10, taken together, assuming that the R&D lag is nine to 11 years. This result, from the pooled estimations, gave a rate of return to R&D and extension combined of 32 per cent, even when spillovers are included. This would suggest that the EC has some way to go before facing any danger of over-investing, but the importance of the spillovers may indicate that more collaboration is called for.

SUMMARY AND CONCLUSIONS

This paper uses cointegration techniques to establish that non-spurious regression equations can be determined to explain changes in TFP. Ignoring spillovers between countries leads to relatively poor cointegrating regressions, some of which are serially correlated and explain a relatively low proportion of the variance in TFP. Including measures of the spillovers between national research (and, less importantly, from the private sector) gives more convincing cointegrating regressions that are not serially correlated and have greater explanatory power. Failing to include the spillovers between the members of 'the United States of Europe' biases the elasticities of R&D upwards by an average of 56 per cent, so we would suggest that ignoring spillovers is a major cause of the inflated estimates of the returns to investments in national agricultural research that are often reported. Pooling the sample of countries shows that the total effect of the R&D spillovers is 47 per cent greater than the impact of national research, which appears to have an average MIRR of 32 per cent. The spillover variables appear to have greater explanatory power than commonly used series like extension and education, which contribute little to explaining TFP growth for these European countries.

NOTES

[1]Phil Pardey (IFPRI, Washington, DC) provided research expenditure data; John Cantwell (University of Reading) produced the agricultural patent data; Yogi Khatri (University of Reading) helped with the lag distributions and David Hadley (University of Reading) and David Schimmelpfennig (USDA) contributed invaluable research assistance. We thank them all, as well as the Nuffield Foundation and the Resources and Technology Division of the USDA, for the financial support which made this project possible. The views expressed are not necessarily those of the USDA or INRA.

[2]The ten are Belgium, Denmark, Eire, France, Germany, Greece, Italy, Luxembourg, the Netherlands and the UK. Luxembourg is included with Belgium, giving nine TFP series.

[3]The EC has 333 million ECU allocated for 1990–94 to a broad-ranging Agriculture and Agro-Industrial Research Programme.

[4]If a series is stationary after differencing n times, then it is said to be integrated of order n, denoted I (n). However, two explanatory variables that are integrated of order two I (2), may cointegrate to order one and thus may together cointegrate with a dependent variable that is I (1).

[5]The critical values depend on the number of variables and are not well established, but all the other countries should pass.

[6]If this were the sole objective, the best cointegrating regressions would be chosen, and all countries except Eire and Greece pass the DF test as well. However, the tests shown in the table are for the variable combinations that best explained the TFPs, and the inclusion of as many variables as possible pushes up the critical values.

[7]The short series cause two problems here. First, the lag length should be determined by including unrestricted lag terms in the regressions, but this leaves no degrees of freedom, so the polynomial had to be used, with the length decided on the basis of the Akaike and Schwartz criteria. Second, it is likely that the short time series tend to truncate the lags.

[8]Attempts to keep extension entirely separate from the R&D variable led to negative elasticities for extension, as a result of collinearity with R&D.

[9]For both the surplus and the change in TFP, the average for 1973–5 is subtracted from the average for 1987–9, in order to avoid the effects of unusual years. The ratio of the change in the surplus to the change in TFP is simply a conversion factor, from TFP changes to real value changes.

[10]The table reports only the sum of the α_is; here, the annual values are used.

[11]A less commonly made point is that, if technology does lead to price reductions to consumers, then the returns are being underestimated, in the real sense that the counterfactual history would have had higher prices.

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