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An Inter-Country Comparison of Agricultural Productivity with Intertemporal DEA

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AN INTER-COUNTRY COMPARISON OF AGRICULTURAL PRODUCTIVITY WITH INTERTEMPORAL DEA[a]

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Abstract
This paper is concerned with the estimation of productivity and technical progress based on DEA applied to complete panel data (intertemporal-DEA). Instead of assuming unchanged technology, productivity measure in intertemporal-DEA encompasses a wide variety of alternative specifications on technical change and efficiency levels. Patterns of productivity change and the decomposition into efficiency and technical change elements can be accomplished by means of restrictions on the general structure of the distances in intertemporal-DEA. The assumption here is that the technology level in period t for each country is the maximum productivity index obtained until this period. Deviation from the maximum technology level in period t is measured as inefficiency. The methodology is applied to the analysis of agricultural productivity in the European Union countries.

Keywords: productivity, technical progress, intertemporal DEA, inefficiency, agriculture.

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1. Introduction

Agriculture in the EU underwent major structural changes during the last quarter of the 20th century. In these recent decades, productivity growth was the major source of growth in farm output in EU countries. All EU countries experienced positive output growth, but the majority had small negative growth rates for total input use with a large decline in farm labor employment and a large increase in intermediate inputs and capital inputs used (OECD, 1995). In general, land shows no growth. Thus, input growth is wholly accounted for by the rapid increase in intermediate inputs and capital goods. Several studies (Bureau et al., 1995; Thirtle et al., 1995) highlighted the high rates of growth in Total Factor Productivity (TFP) for the agrarian sectors of the European Union (EU) countries.

It seems important to establish the relative position of each country in terms of potential agricultural production. Thus, there is undoubted interest in comparing and explaining differences in productivity. It is obvious that the measure of TFP of countries is only significant when compared to their own past growth rates or the performance of other countries. TFP is essentially a condensed measure of the ratio between outputs and inputs. However, there is no single way of measuring this relationship in agriculture, a multiple-output multiple-input industry. Thus, the empirical analysis of productivity requires the imposition of strict assumptions concerning the structure of the technology

In this paper a new technique is applied to the decomposition of productivity growth in technical and efficiency levels for the agricultural sectors of the European Union countries over the 1973-1997 period, using intertemporal-DEA. It is a slight modification of the technique developed in Aldaz and Millán (2002), and applied to the agricultural sectors of the Spanish regions that only allowed the calculation of bounds to the technical and efficiency levels. The DEA methodology is a useful tool for tackling the specific problems posed by agricultural productivity. It has been applied to the calculation of Malmquist indices and compared with some index number approaches in Bureau et al. (1995) for several European countries and the United States, and in Millán and Aldaz (1998) for the Spanish regions. However, there is a practical limitation in many applications of the Malmquist approach because of short samples. Thus, an approach to productivity analysis with panel data that uses the full set of observations could alleviate the short sample problem.

The methodology is explained in the following section. After this, the main results of the empirical analysis of the agricultural sectors of the European Union countries in the 1973-97 period are presented and the main implications are discussed. The paper ends with several conclusions about methodology and results.

2. Methodology

Recently, linear programming techniques that envelop the data without specification of a restrictive functional form, and are also distribution free concerning errors, have been used. However, Lovell (1996) notes that the advantages of panel data are only fully exploited in a few instances, given that the technology is assumed to be unchanging. Tulkens and Vanden Eeckaut (1995) does not consider the possibility of technical change in 'intertemporal-DEA' (all observations in the sample), but only with 'contemporaneous-DEA' (a frontier is estimated for each period) or with 'sequential-DEA' (a frontier is estimated using contemporaneous and earlier observations).

Lovell remarks that the DEA-based Malmquist approach allows the calculation of technical progress and technical efficiency. Thus, recent research has used the measurement of adjacent period cross-distances for the calculation of Malmquist indexes. It is not necessary to assume that a country is operating at its production frontier. Therefore, improvements in total factor productivity can occur as a result of either improvements in technical efficiency (moving closer to the production frontier) or improvements in technology (outward shifts of the production frontier).

This paper presents a formulation of technical change that allows the decomposition of productivity scores obtained using linear programming methods (DEA) using intertemporal-DEA. The main assumption is the specification of monotonic non-decreasing technical progress. The model assumes that improvements over earlier productivity levels are due to technical progress and that productivity scores below the earlier maximum productivity level are due to inefficiency.

The following is an introduction to the methodology. To simplify the presentation, a balanced panel is assumed, but the methodology also applies to unbalanced panels. Let $\mathbf{x}_{it} \in R^M$ the vector of M inputs used by the country i and time t to produce the P outputs $\mathbf{y}_{it} \in R^P$. The actual data set is the panel $S=\{(\mathbf{x}_{it}, \mathbf{y}_{it}: i= N; t=1,..,T\}$, comprising NT observations.

We represent the input-oriented production technology

$$\mathbf{F}((\mathbf{y}_{it}+\mathbf{z}_{it}), E_{it} A_{it} (\mathbf{x}_{it}-\mathbf{s}_{it})) = 0 \tag{1}$$

where E_{it} measures the efficiency of country i in time t, A_{it} measures the technology index of unit i in time t, $\mathbf{z}_{it}$ and $\mathbf{s}_{it}$ are vectors of output and input specific slacks, respectively, measuring non-radial inefficiencies of unit i in time t.

With the intertemporal-DEA approach E_{it} and A_{it} are not uniquely identifiable (Lovell, 1996). In fact, the usual linear programming methods can be used to identify a radial productivity index d_{it}

$$d_{it} = E_{it} A_{it} \tag{2}$$

Then only the production frontier is fully determined as $\mathbf{F}((\mathbf{y}_{it}+\mathbf{z}_{it}), d_{it} (\mathbf{x}_{it}-\mathbf{s}_{it})) = 0$. Lovell (1996) and Tulkens and Vanden Eeckaut (1995) assume that the technology level is unchanged, and implicitly set to one. In this setting, $d_{it} = E_{it}$.

The approach in this paper is to obtain E_{it} and A_{it}, using the assumption of A_{it} non-decreasing in time. The assumption of monotonic technical progress has been usual in the non-parametric analysis of technology and producer behavior. This is a hypothesis maintained in Fawson and Shumway (1988) and Lim and Shumway (1992). More recently, Bar-Shira and Finkelshtain (1999) have accepted monotone technological progress and cost-minimizing behavior for US agriculture, but not profit maximization and monotone technological progress. The way technical progress evolves has been modeled as additive or multiplicative translations, as in Chavas and Cox (1988), with problems criticized in Chalfant and Zhang (1997). In this paper, the simpler form of non-regressive change is used ($A_{i1} \leq \ldots \leq A_{iT} = A_{imax}$).

The methodology we are suggesting is an intertemporal-DEA model over all the observations in the panel. The productivity index d_{it} is calculated using non-parametric programming techniques. There are NT production units, each one using M inputs $\mathbf{x}_{it}$, to produce P outputs $\mathbf{y}_{it}$. Each combination {it} to be analyzed is denoted with index 0. The constant returns to scale frontier in period t for country i is constructed as

$$\min_{d0,\, \lambda k}\ d_0$$

subject to

$$\sum_{k=1}^{NT} \lambda_k x_{jk} + s_{j0} = x_{j0}\, d_0 \qquad j=1,\ldots,M \qquad (3)$$

$$\sum_{k=1}^{NT} \lambda_k y_{pk} - z_{p0} = y_{p0} \qquad p=1,\ldots,P$$

$$\lambda_k,\ d_0 \geq 0$$

Thus a set $\mathbf{d}_0 = \{d_{it},\ i=1,...N;\ t=1,...,T\}$, of NT radial productivity indexes is calculated. In principle, A_{it} and E_{it}, which measure technology level and efficiency levels for each country i in the dimension t, cannot be determined separately, only their product $d_{it.}$ However, E_{it} and A_{it} can be given values in the interval (0,1] and analyzed separately giving more structure to the evolution of A_{it}. Lynde and Richmond (1999) assumed non-regressive technical change, allowing the estimation of technical change and efficiency bounds. With the assumption of non-regressive technical change and the additional assumption that improvements over earlier productivity levels are due to technical change, E_{it} and A_{it} can be given point estimates. It is worth noting that productivity measures using intertemporal-DEA are calculated, but they are interpreted sequentially, only earlier periods for the same country being considered.

The efficiency level A_{it} is obtained by assuming the previous higher productivity level. Thus,

$$A_{it} = \max\{d_{it},\ A_{i(t-1)}\} \qquad (4)$$

The first only period gives the maximum productivity score when d_1 is the maximum productivity level, and, given non regressive technology level, all deviation from d_{it} is due to inefficiency. Related to this technical change level, the efficiency level is defined given (2):

$$E_{it} = d_{it} / A_{it} \qquad (5)$$

As with Lynde and Richmond (1999), individual input efficiency is defined as the potential non-proportional reduction of each input due to slacks. Based on (1) and a given technology level A_{it}, the efficient usage of input j for observation {it} is given by

$$x_{jit}^* = E_{it}\,(x_{jit}-s_{jit}) \qquad (6)$$

The specific input efficiency indexes are measured as the ratio between efficient usage and real usage:

$$e_{jit} = E_{it}\,(x_{jit}-s_{jit})/x_{jit} \qquad (7)$$

It is worth noting that due to slacks, the time evolution of the efficiency of input j for observation {it}, e_{jit}, could differ greatly from the radial efficiency level E_{it}.

Output inefficiency is non-radial, given that an input oriented dea is formulated. Specific output efficiency indexes $e^o{}_{kit}$ are measured as the ratio between the real usage and efficient usage:

$$e^o{}_{kit} = y_{kit}/(y_{kit}+z_{kit}) \qquad (8)$$

The specific output efficiency index $e^o{}_{kit}$ measures the proportional reduction in potential output k due to technical inefficiency.

The DEA-Malmquist index is measured in every observation, without imposing any restriction in both time varying and production unit specific pattern of variation. We add that the cross-sectional comparison in each year allows for different rates of technical change, while the productive units can remain at the same efficiency level. This phenomenon contradicts the transitivity property, but we think that this is a natural extension of the coexistence of different efficient techniques.

The input-based distance function $D^t(\mathbf{x}^t,\mathbf{y}^t) = (\inf\{\delta: (\delta\mathbf{x}^t, \mathbf{y}^t)\} \in \mathbf{S}^t\})^{-1}$ defines the production technology $\mathbf{S}^t$ that models the transformation of inputs into outputs, for each time period t. This function is defined as the reciprocal of the minimum proportional contraction of the input vector $\mathbf{x}^t$, given outputs $\mathbf{y}^t$. This distance function is the reciprocal of technical efficiency measure of Farrell (1957). If observed production at t is interior to the boundary of technology at t, then $(\mathbf{x}^t,\mathbf{y}^t)$ is not technically efficient. Distance functions with respect to different periods t and t' are defined: $D^{t'}(\mathbf{x}^t,\mathbf{y}^t) = (\inf\{\delta:(\delta\mathbf{x}^t,\mathbf{y}^t)\in\mathbf{S}^{t'}\})^{-1}$. This distance function measures the minimal proportional change in inputs required to make $(\mathbf{x}^t,\mathbf{y}^t)$ feasible in relation to the technology at t'.

Färe et al. (1994) define the Malmquist productivity index with further decomposition separately measuring two components that are independent and can move in opposite ways: catching-up effects and technical progress.

$$M(x^{t'}, y^{t'}, x^{t}, y^{t}) = \frac{D^{t'}(x^{t'}, y^{t'})}{D^{t}(x^{t}, y^{t})} \left[\frac{D^{t}(x^{t'}, y^{t'})}{D^{t'}(x^{t'}, y^{t'})} \frac{D^{t}(x^{t}, y^{t})}{D^{t'}(x^{t}, y^{t})} \right]^{1/2} \tag{9}$$

The ratios inside the brackets measure shifts in technology in $\mathbf{S}^{t}$ and $\mathbf{S}^{t'}$, respectively; thus, technical change is measured as the geometric mean of those two shifts. The terms outside the brackets measure relative technical efficiency at $\mathbf{S}^{t}$ and $\mathbf{S}^{t'}$, capturing changes in relative technical efficiency over time, that is, whether production converges or diverges from the frontier. However, for the measurement of efficiency we analyze the radial distances and the non-radial slacks associated with the several inputs and output.

3. Empirical analysis

Annual data for the 1973-97 period was compiled for Belgium, Denmark, France, Greece, Luxembourg, Ireland, Italy, the Netherlands, and the United Kingdom. For Spain, the analysis begins in 1974 due to errors in the database in 1973. In the cases of Austria, Finland and Sweden, the analysis was carried out for the 1979-97 period, and for 1980-97 for Portugal, due to the non-availability of accounts from the 1970s. The former Federal Republic of Germany is analyzed for the 1973-92 period and the unified Germany for the 1990-97 period. A particularity of the new methodology is that it allows the simultaneous analysis of productive units at different levels of aggregation.

The major source of data was the Economic Accounts for Agriculture (EAA) from Cronos in Eurostat (1973-1997). This database is used to obtain the disaggregated outputs, intermediate inputs, and depreciation, in current and constant 1990 prices, and labor in annual work units (AWU), for the 1973-1997 period. Capital is measured by depreciation, in constant terms using the deflator of gross investment or, when the former is not available, by the repair price index. Land is agricultural area in hectares.

The database covers 53 outputs that were grouped into two major categories, crops and animal products. Intermediate inputs are grouped into two major categories: biological inputs (seeds and plants, feeds) and other materials (energy and lubricants, fertilizer, plant protection products, pharmaceutical products, small tools, maintenance and repair, services and other intermediate consumption). It is assumed that all intermediate inputs purchased were used within the year. Using constant 1990 values and values for the individual items, translog price indexes are estimated for crop output, animal output, biological inputs and other materials. Quantities in 1990 terms for the two outputs and the two intermediate inputs are calculated, deflating current values by the price indices. All output, intermediate input and depreciation data, originally reported in local currencies was converted into ECUs, using the 1990 exchange rates.

There are differences in the size and relative importance of agricultural inputs and products for the EU countries. Of course, there were important changes in agricultural production in the EU countries over the period considered, too. To illustrate these, Table 1 below presents the mean quantities of each input and output and the average annual growth rates for outputs and inputs.

Animal production is higher than crop production, except for the Southern Europe countries, where the opposite is true. France share its agrarian output almost equally between crop and animal production. Agricultural output increases in all countries, and with large rates of growth in the Netherlands (4.1%), Denmark (3.1%), and Greece (3.1%). Crop output increases more than animal output, except in Portugal and Ireland. The growth of the animal production is very important in Portugal (3.2%). Animal production decreases in Finland and in the unified Germany.

The consumption of biological inputs (feed and seed) increases in all countries, except in those where animal production falls. Feed and seed consumption growth is remarkably high in Spain (4.0%) and Ireland (2.8%). Other intermediate consumption grows especially Greece (3.2%), in Spain (2.8%) and in Portugal (2.7%), and decreases in Germany, Denmark and Sweden.

Table 1. Mean quantities and average rates of growth for outputs and inputs.

		Crop	*Animal*	*Feed& seed*	*Other mat.*	*Capital*	*Labor*	*Land*
Austria	Mean	1478	2999	470	1344	1296	206	3519
	Rate of growth	2.0	0.2	0.8	0.8	-2.9	-3.8	-0.4
Belgium	Mean	2171	3670	1785	1430	441	107	1545
	Rate of growth	1.9	1.2	1.4	1.6	0.9	-2.6	-0.4
Denmark	Mean	1769	4354	1608	1529	757	125	2847
	Rate of growth	3.4	1.3	2.1	-0.4	-1.1	-3.8	-0.4
Finland	Mean	1387	3245	917	1323	945	186	2449
	Rate of growth	2.7	-0.6	-1.2	0.0	-1.3	-4.2	-1.1
France	Mean	22606	21122	7921	11197	4257	1551	31224
	Rate of growth	1.3	1.0	2.1	0.9	0.8	-3.2	-0.3
Germany, FR	Mean	8576	17375	5013	9181	5640	986	12116
	Rate of growth	2.4	0.5	1.9	-0.1	-0.3	-3.4	-0.2
Germany, U	Mean	13267	19964	6129	9885	5779	841	17214
	Rate of growth	2.3	-0.8	-0.8	-1.5	-2.0	-8.9	0.2
Greece	Mean	5009	2439	673	1093	334	866	5200
	Rate of growth	3.4	0.3	1.2	3.2	3.7	-2.6	0.0
Ireland	Mean	482	3191	678	925	417	277	4805
	Rate of growth	2.0	2.0	2.8	2.1	1.5	-2.2	-0.4
Italy	Mean	21865	13705	5522	4136	7216	2529	17282
	Rate of growth	1.4	1.4	1.1	1.4	3.2	-3.0	-0.6
Netherlands	Mean	5376	8399	3975	2774	1311	248	2022
	Rate of growth	4.1	1.2	1.5	1.6	4.6	-1.0	-0.3
Portugal	Mean	2128	1935	1034	889	129	864	4003
	Rate of growth	1.7	3.2	0.3	2.7	-0.7	-4.8	0.0
Spain	Mean	13484	9573	4893	4953	2063	1438	30750
	Rate of growth	2.8	2.4	4.0	2.8	1.1	-3.5	-0.3
Sweden	Mean	1367	2948	1086	1567	810	111	3512
	Rate of growth	0.2	0.2	-0.6	-1.7	-1.8	-3.2	-1.0
U. Kingdom	Mean	6728	10991	4023	5893	2513	478	18224
	Rate of growth	1.8	0.2	0.3	0.7	-0.6	-1.7	-0.8

The evolution of capital differs among countries. Capital consumption decreases in Austria, Denmark, Germany, Finland, Portugal, Sweden, the United Kingdom, Finland and Portugal. Capital increases are particularly large for the Netherlands (4.6%), Greece (3.7%) and Italy (3.2%). Labor decreases for all countries, very remarkably in the unified Germany (-8.9%). The European Union has reduced its cultivated land very slightly in almost all countries. Only the unified Germany increased its cultivated area in the1990s.

Table 2. Malmquist. Productivity change.

	74	*75*	*76*	*77*	*78*	*79*	*80*	*81*	*82*	*83*	*84*	*85*	*86*	*87*	*88*	*89*	*90*	*91*	*92*	*93*	*94*	*95*	*96*	*97*	*Mean*
AUS							0.8	0.1	5.3	0.7	6.5	-0.4	3.3	-1.0	0.9	0.2	4.6	-2.4	0.6	5.4	2.1	0.4	1.8	0.5	1.6
BEL	6.5	-6.0	0.7	6.1	9.3	1.2	2.8	3.4	8.1	-4.4	5.0	0.8	3.3	-3.5	3.0	1.6	-0.6	5.0	7.1	-0.2	-2.7	-0.9	0.8	-1.6	1.9
DEN	12.9	-9.2	-3.1	3.9	0.6	-2.4	4.6	3.4	2.7	1.3	7.4	1.6	3.0	-1.9	5.9	2.4	1.6	2.2	-0.7	1.7	-1.3	2.7	2.1	12.0	2.2
FIN							-1.6	-1.3	-2.9	4.7	7.0	-1.0	-0.1	-7.9	-3.3	-1.0	8.7	1.1	-1.6	-9.0	7.9	4.6	2.8	1.6	0.5
FRA	-9.2	-6.2	-3.6	6.8	7.3	5.6	-1.1	-2.1	12.4	-6.4	10.1	2.6	-1.3	2.3	-1.5	6.2	3.8	-3.3	6.2	-5.2	-6.3	-3.8	4.3	1.5	0.8
FRG	5.6	-4.0	-4.9	3.1	-1.5	-1.6	2.9	1.5	5.0	-1.9	3.4	-0.7	3.7	-3.9	1.2	1.7	2.7								0.7
GER																		-10.8	7.2	6.7	2.1	1.3	3.5	1.6	1.7
GRE	-4.2	0.7	-10.1	-8.4	6.4	-3.3	7.7	-1.5	2.0	-4.8	5.4	3.4	10.2	-10.0	7.7	4.3	-12.2	17.5	-3.9	4.2	1.4	3.3	1.7	0.6	0.8
IRL	8.2	6.6	-9.5	0.1	-4.1	-11.8	7.9	-5.1	6.5	1.8	7.5	1.6	-6.1	3.1	1.0	-2.7	5.0	-0.7	5.4	-5.1	2.0	4.3	0.1	3.1	0.8
ITA	0.2	1.1	-4.1	0.0	0.8	1.6	7.3	-4.3	-1.3	6.4	-6.4	2.7	-3.9	4.6	-1.0	1.1	0.9	5.9	3.8	-3.4	-6.5	0.4	2.3	-1.6	0.3
NET	7.0	-3.8	0.6	2.2	4.4	2.9	0.4	4.4	3.3	-0.9	4.1	-0.5	5.6	-12.0	2.0	2.1	6.2	1.1	-0.3	4.0	3.6	2.1	-0.2	-3.0	1.5
POR								1.1	8.3	4.3	6.7	-23.4	20.0	2.6	-3.6	7.0	-5.6	4.1	6.6	-0.2	1.6	-0.8	13.9	-5.1	2.2
SPA		1.2	5.9	1.2	9.8	-1.0	6.2	-10.8	7.5	3.1	13.4	1.2	-7.0	12.5	4.7	0.8	5.5	4.0	0.8	-8.1	7.0	1.5	17.1	6.1	3.6
SWE							5.8	3.7	8.4	0.0	3.3	-1.6	3.9	-2.5	-3.4	1.6	10.1	1.6	-6.5	4.9	-1.2	-2.2	1.7	2.4	1.7
UKI	3.2	-5.1	-2.2	4.7	4.9	-0.6	6.1	2.0	3.1	-1.6	12.0	-2.9	-1.1	0.7	1.1	3.7	0.5	3.9	0.5	7.1	-3.1	-0.5	-1.2	5.2	1.7
	3.4	-2.5	-3.0	2.0	3.8	-0.9	3.8	-0.4	4.9	0.2	6.1	-1.2	2.4	-1.2	1.1	2.1	2.2	2.1	1.8	0.2	0.5	0.9	3.6	1.6	1.3

Table 2 shows the rates of change in the Malmquist index. With two outputs and five inputs and a maximum of only 14 observations for the calculation of distances, there are many efficient observations each year. All countries are on the reference frontier in at least one year, and seven of them (Denmark, Ireland, Italy, The Netherlands, Austria, the Federal Republic of Germany and Portugal) are on the frontier the whole period. The consequence is that almost all the variation in productivity is due to technical change, except in Spain. The mean rates of productivity change range between 0.3% for Italy and 3.6% for Spain. For the nine common countries, the results are very similar to those in Bureau et al. (1995) in spite of different output and input aggregation.

Next, the results obtained with the proposed new decomposition are presented, with the complete panel in intertemporal-DEA. The methodology explained in section 2 was applied. The analytical approach implemented is based on the assumption that technologies are evolving in time non-regressively, meaning that the analysis is able to capture productivity increases as improvements in technology, and productivity decreases as inefficiencies. The analysis covers the 1973 to 1997 period for 14 countries, with overlapping in Germany (1990-92) and some missing observations due to data availability. The data encompasses 328 observations.

Table 3 below shows a statistical summary of the results of efficiency and technical progress for each country. The first column presents the level of productivity in the first year of the analysis, and the second column is the level of technology in 1997. The third column shows the year when the maximum level of productivity was achieved. It follows the calculation of the average growth of technical level, considering all the years in the sample (not the years until the maximum is achieved). The fourth column shows the mean level of efficiency. Finally, the last column presents the observations belonging to the reference frontier.

Table 3. Intertemporal-DEA. Non decreasing technical change. Statistical summary.

	$d_m = A_m$	A_{97}	t_{max}	r_A	E	*Observations supporting the reference frontier*
AUS	0.94	1	84	0.3	0.996	84 86 88 90-94 96 97
BEL	0.85	1	93	0.7	0.984	93 95 96
DEN	0.91	1	91	0.4	0.931	91 96 97
FIN	0.95	1	84	0.3	0.971	84 93 97
FRA	0.85	1	96	0.7	0.980	96 97
FRG	0.95	1	74	0.2	0.959	74 86
GER	0.88	1	97	0.5	0.999	97
GRE	1.00	1	73	0.0	0.960	73 86 91 92 95-97
IRL	0.95	1	74	0.2	0.943	74 75 92 97
ITA	1.00	1	73	0.0	0.966	73 75 76 83 96 97
NET	0.96	1	74	0.2	0.981	74 82-84 86 94-97
POR	0.73	1	96	1.9	0.973	96 97
SPA	0.94	1	97	1.4	0.959	97
SWE	0.65	0.87	97	1.6	0.990	
UKI	0.76	0.94	92	0.9	0.980	

Notes:

(i) d_m productivity index first year of the analysis
A_{97} technology index 1997
t_{max}: year of maximum productivity score.
r_A: % annual rate of growth.
E: mean of the efficiency index

(ii) The data covers 1973-1997 except : Austria, Finland and Sweden (1979-1997); Portugal (1980-1997); FRG (1973-1990); Germany (1991-1997); Spain (1974-1997).

Two features of the proposed methodology can be highlighted. Firstly, it is easy to deal with unbalanced panels. Secondly, it is possible to tackle productive units at different aggregation levels, and even overlapped, as for Germany, before and after reunification from 1990 to 1992.

In intertemporal DEA, all the countries except Sweden and the United Kingdom appear with a productivity index of one in some period. 52 observations out of 328 support the intertemporal reference technology. Given non-regressive technical change, the assumption of unchanged technology is binding in Greece and Italy, and almost unchanged in Ireland, the Federal Republic of Germany, and the Netherlands.

On the other hand, the countries that begin with a low level of productivity and reach the maximum toward the end of the period of analysis exhibit a higher growth rate for the technology index. For all the countries the mean rates of technology change are below the mean rates of productivity change in Malmquist. There is very probably a small sample problem in Malmquist, although Bureau et al. (1995) obtain similar, and frequently inferior, measures of TFP change with Malmquist to those obtained with index number methodologies. It is worth noting that the low measures of technology change under the approach in this paper are not a characteristic of the methodology. As an example, the measures with the new approach in Millán and Aldaz (2002) are larger than the conventional TFP measures using index numbers in Aldaz and Millán (2002), on the manufacturing sectors in Spain.

A high value of the index of technical efficiency indicates that declines in productivity are not very important (unified Germany, Austria, Belgium, Denmark, France, the Netherlands, Sweden). The detailed evolution of productivity levels, technological indices and efficiency levels, and also of non-radial efficiencies, are presented for the different countries in Figures A1 to A14 in the Appendix. There is no common pattern for the evolution of the indexes of productivity among countries according to geographical criteria (north or south; Mediterranean, continental or Atlantic countries) or to crop or animal orientation

Radial efficiency measures give only a particular form of inefficiency that can be explained by a proportional contraction in input usage. There are other inefficiencies associated with the use of some inputs that can be reduced beyond a radial decrease, measured by the slacks in the linear programming results. The DEA-panel methodology imposes the most restrictive conditions on achieving efficiency, and this leads to the identification of those countries or years presenting inefficiency in specific outputs or inputs. This means an advance in non-radial productivity, which the usual Malmquist approach can hardly identify.

Table 4 presents a summary of slacks, because this kind of inefficiency occurs frequently. Crop slacks appear for several countries, but specific animal output inefficiency arises only for Italy (and only a few years in the 1990s). Biological input inefficiency appears in the Netherlands, Portugal, Greece, Italy, and in Spain in 1993. Inefficiency in other intermediate consumption is pervasive, except for Austria, Italy and

Spain. Capital inefficiency is very common in Denmark, the Federal Republic of Germany, The Netherlands, Austria, Finland, Sweden, and occasionally in some other countries. There are usually labor inefficiencies in Belgium, Denmark, the Federal Republic of Germany, Greece, Ireland, Italy, Austria and Finland. Spain is a country that usually only has non-radial inefficiency in land. Land slacks are common in France, Italy, Sweden and in the westernmost countries of Europe.

Table 4. Intertemporal-DEA. Slacks. Summary

	Crop Output	*Animal Output*	*Feed& Seed*	*Other Int. input*	*Capital*	*Labor*	*Land*
AUS	Y				Y	Y	2
BEL				Y		Y	1
DEN	Y			Y	Y	Y	1
FIN	Y			Y	Y	Y	
FRA				Y			Y
FRG	Y			Y	Y	Y	
GER				Y		1	1
GRE			Y	Y	1	Y	2
IRL	Y			Y	2	Y	Y
ITA		Y	Y		3	Y	Y
NET	Y		Y	Y	Y	Y	
POR	2		Y	Y		Y	Y
SPA			1				Y
SWE	Y			Y	Y		Y
UKI				Y			Y

4. Conclusions

This study estimates the inter-country productivity of European agriculture using a DEA methodology applied to panel data. Decomposition in efficiency and technical change elements is accomplished by means of restrictions on the general structure of the technology indices. Productivity measures are calculated using the full sample consisting of pooled cross sections of time series for the European Union agriculture from 1973 to 1997. The methodology easily accommodates unbalanced panels and overlapping observations corresponding to the Federal Republic of Germany and the unified Germany.

In addition to the possibility of combining observations (Germany), some considerations can be made about the methodology. First of all, DEA panel methodology allows a broaching of those productivity analyses with a very limited number of observations, resulting in the lack of power to discriminate inefficient units. In the DEA-panel approach, the results appear as a consequence of the comparison between all units, so it has a higher discriminatory capacity. Specifically, this allows a more detailed analysis of non-radial inefficiency through time.

There are major differences in the data and methodology used in previous studies of productivity in EU agriculture. Many of the differences stem from the measures of capital and land, and the valuation of labor. However, the output and intermediate input series are generally very similar. The results for the common period in this paper using the Malmquist methodology are close to those in Bureau et al. (1995).

There are a relatively high number of observations in the reference set in the earlier years of the analysis. The consequence of earlier observations with the highest productivity measures is the identification of inefficiency and deviation from the reference frontier. Thus, technical progress cannot be measured for these measures. On the other hand, even for countries with almost continuous productivity improvements, the rates of productivity growth are lower than with other approaches. Taking into account that lower rates of productivity growth are not imposed by the new methodology, as other applications have shown, the main conclusion is that the increases in TFP usually measured for European Union agriculture could be overvalued.

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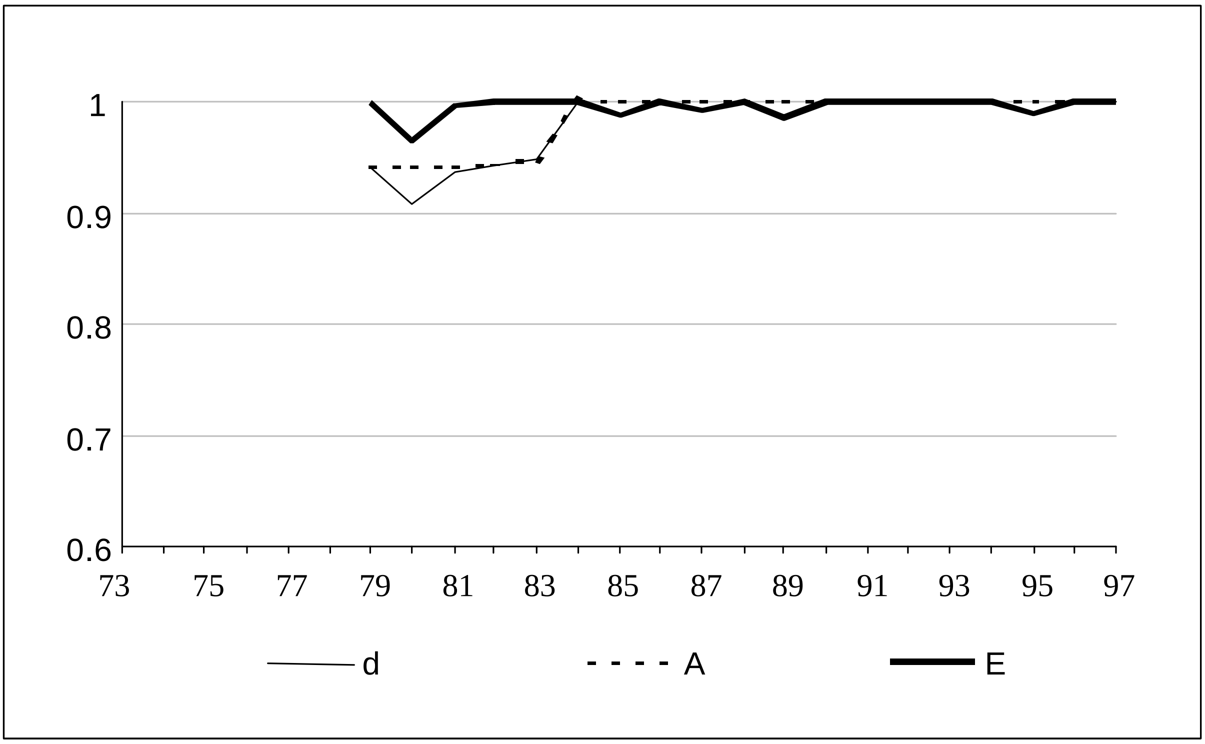
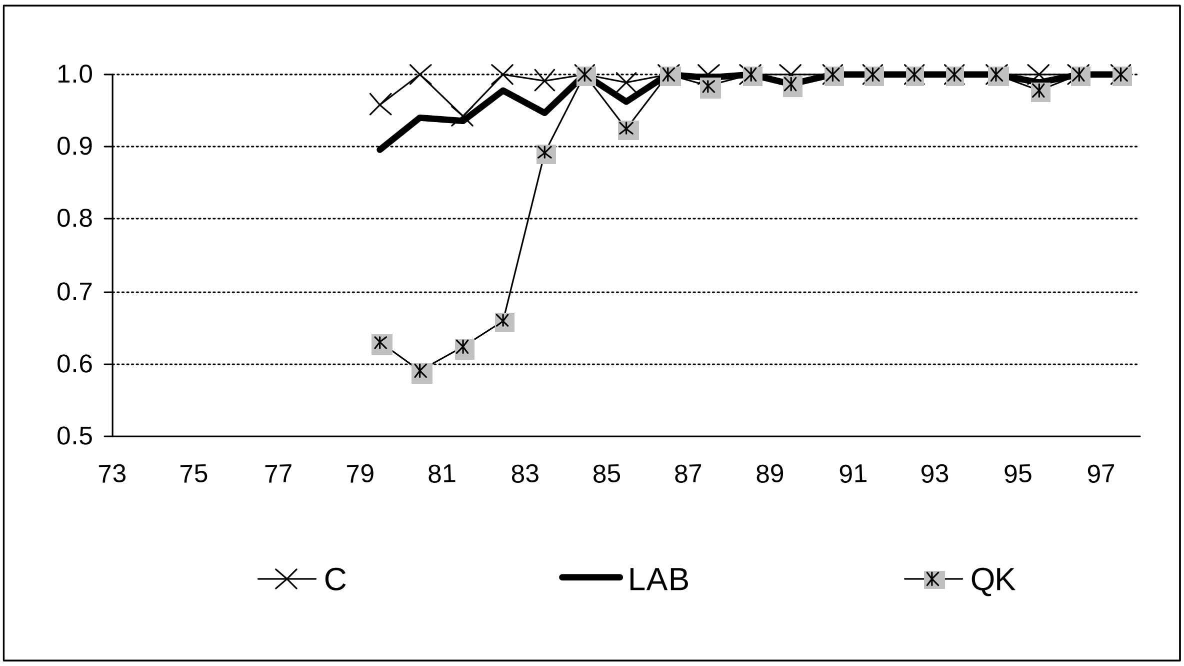
Appendix: Figures for each country: (1) *Productivity (d), technology level (A), radial efficiency (E)*, and (2) *Specific non-radial efficiencies*

A1. Austria

Productivity (d), technology level (A), radial efficiency (E)

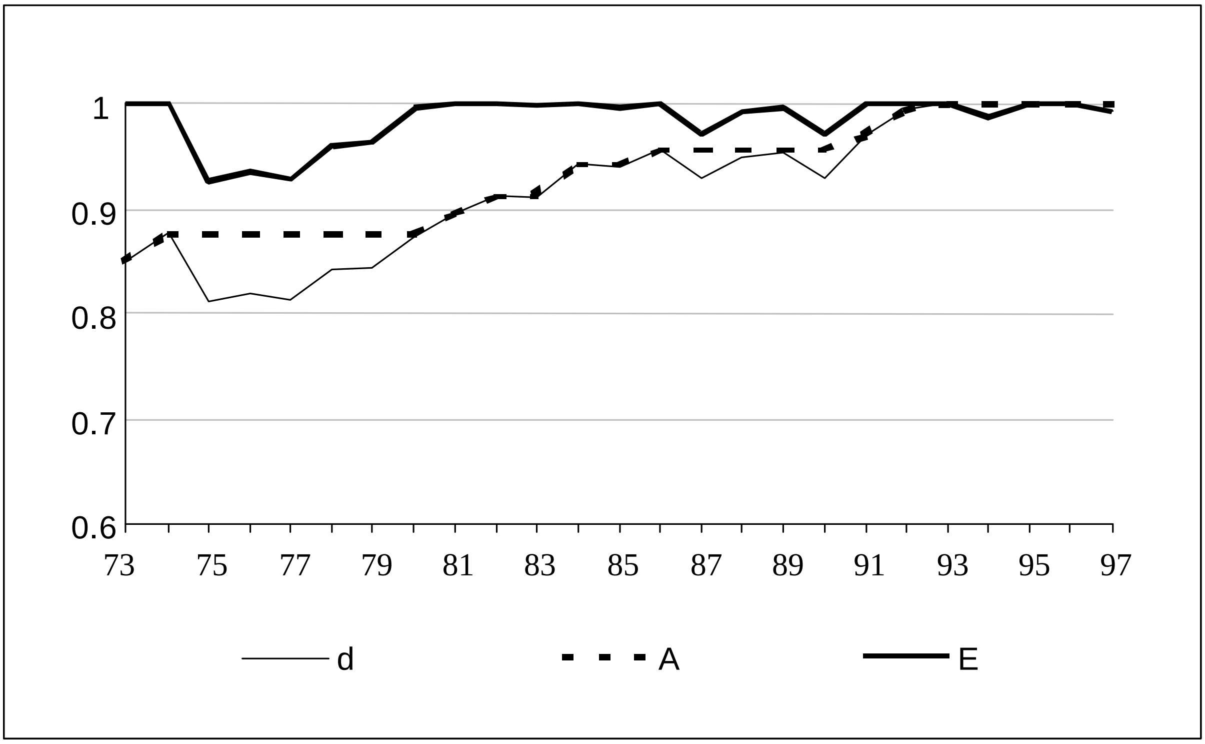


Specific non-radial efficiencies



A2. Belgium

Productivity (d), technology level (A), radial efficiency (E)



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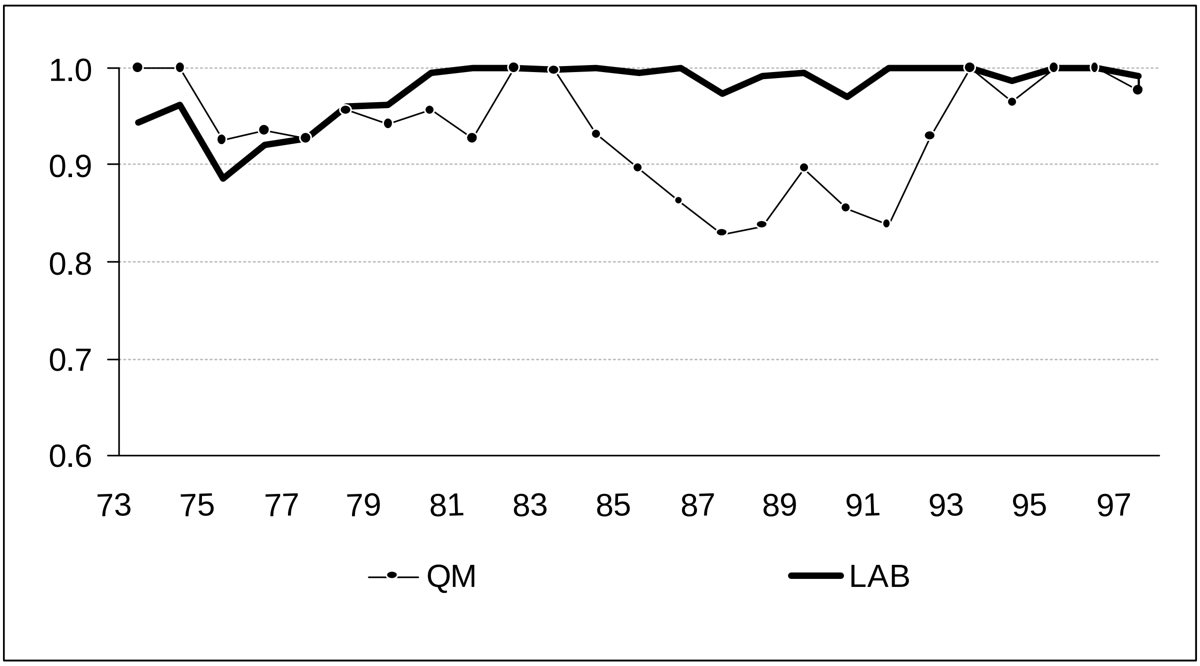
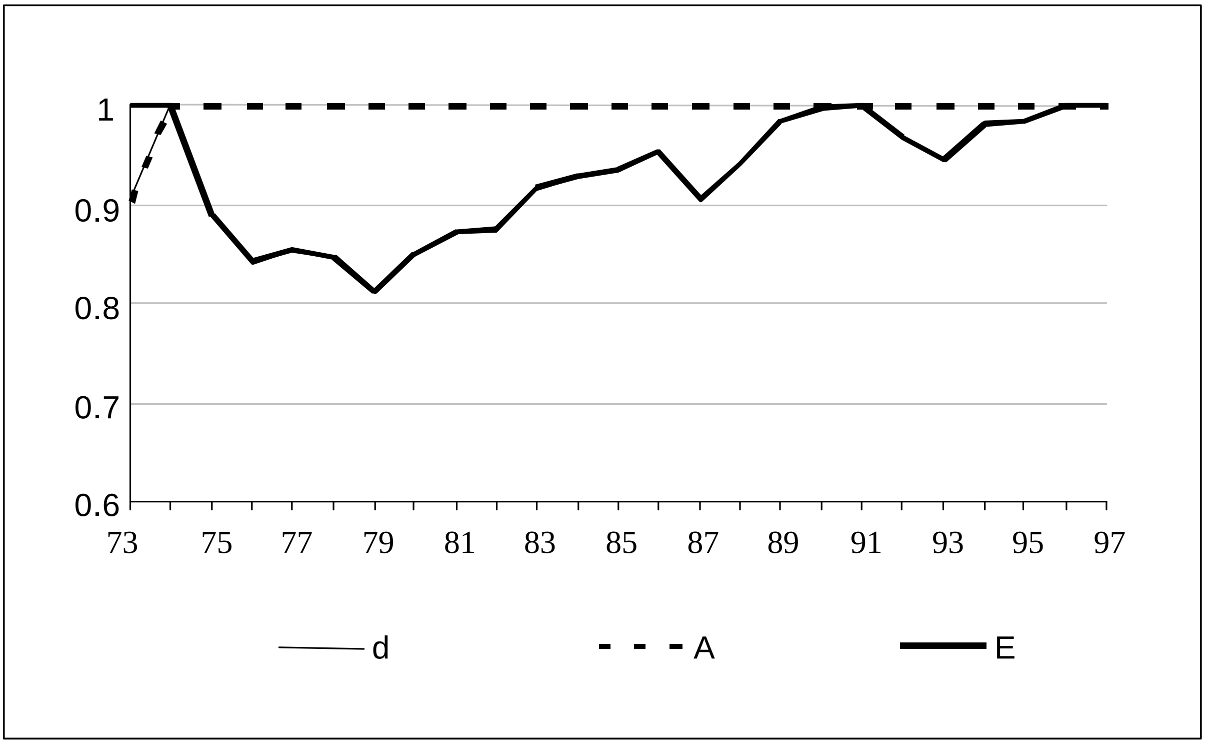
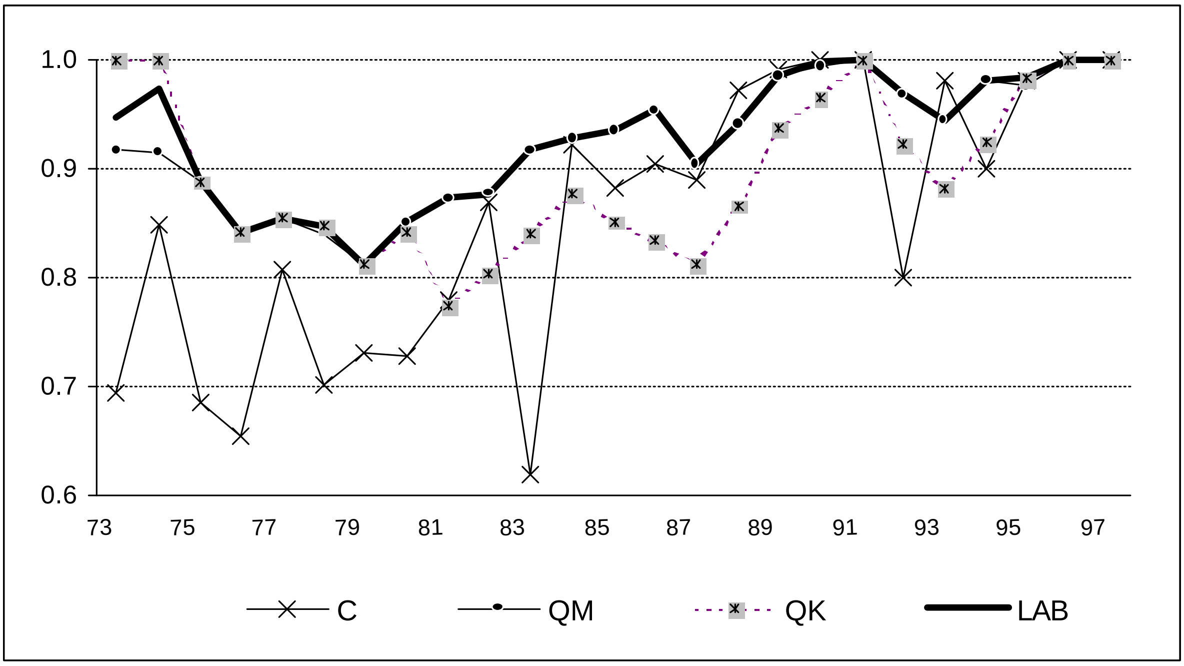


A3. Denmark

Productivity (d), technology level (A), radial efficiency (E)

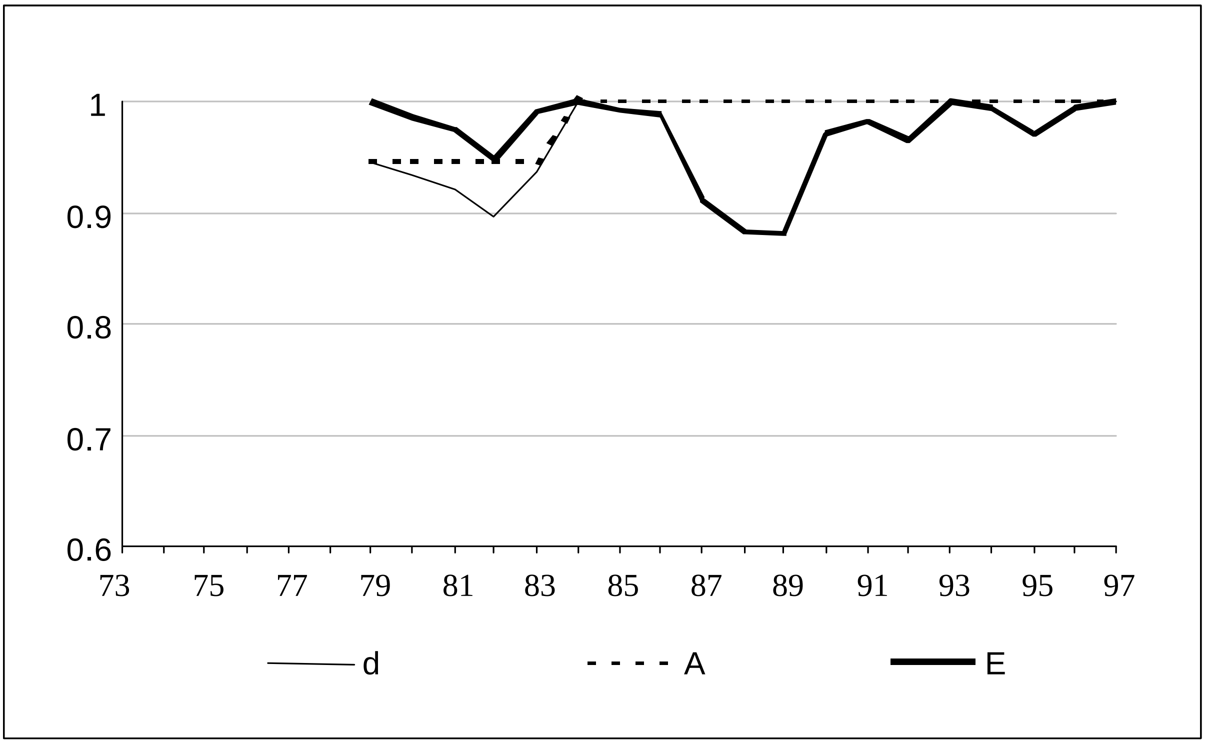


Specific non-radial efficiencies

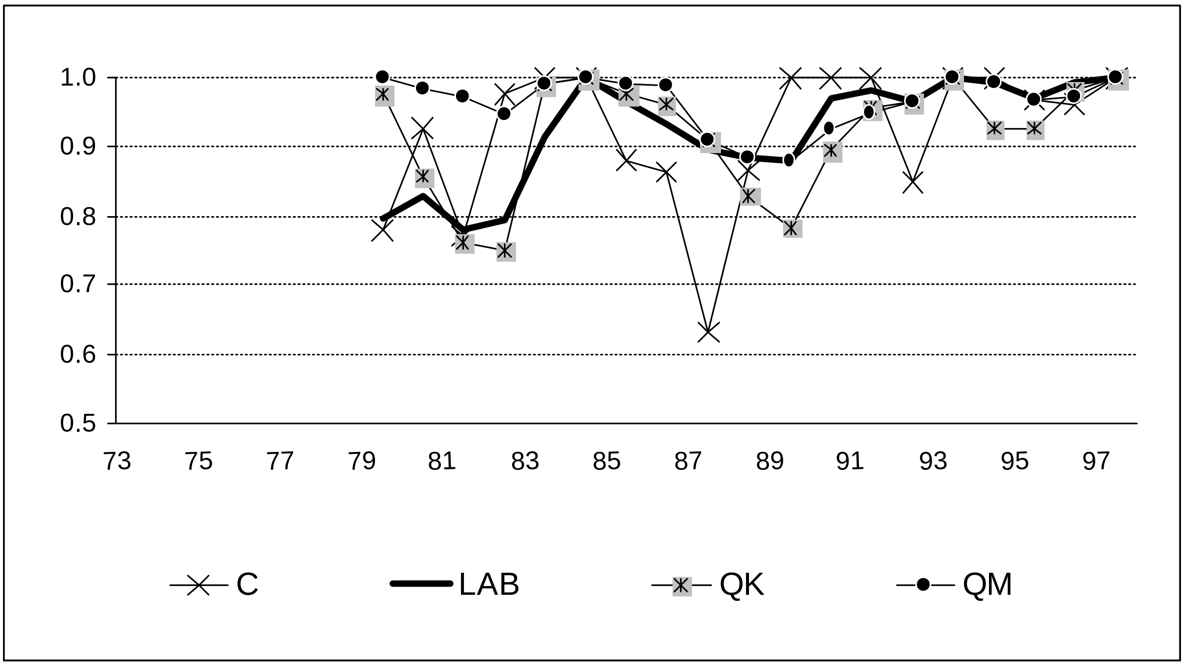


A4. Finland

Productivity (d), technology level (A), radial efficiency (E)

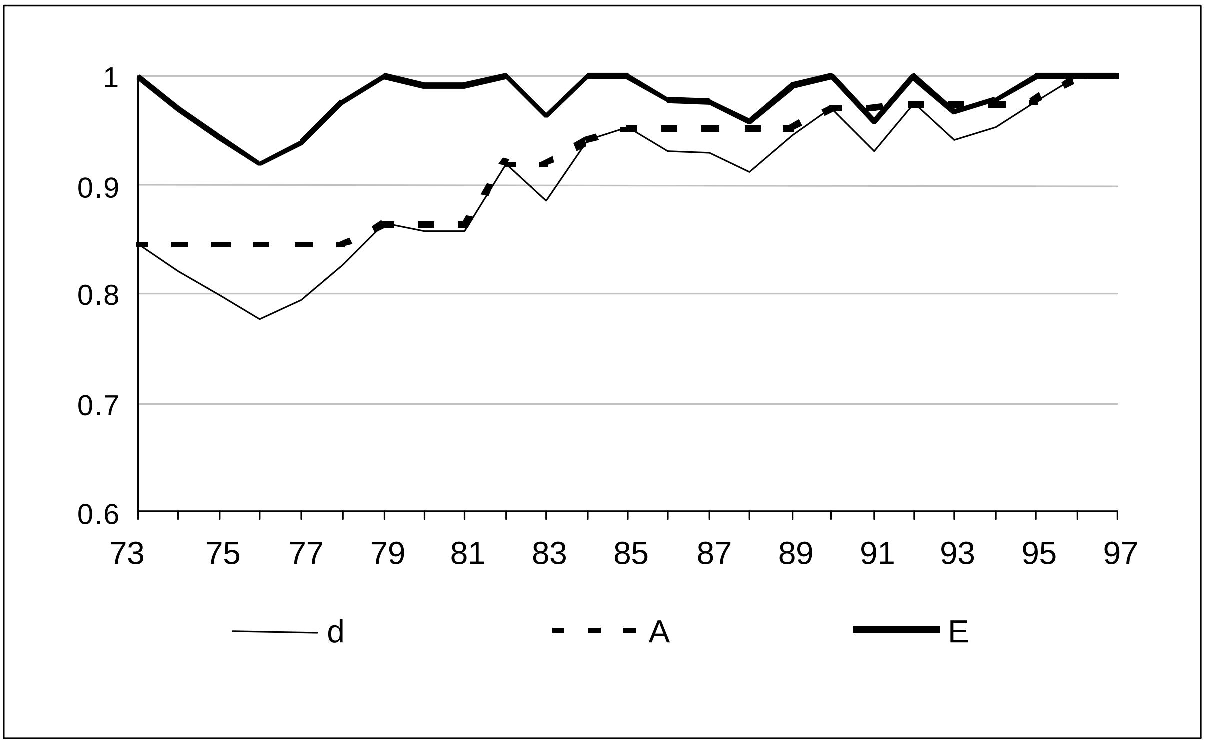


Specific non-radial efficiencies

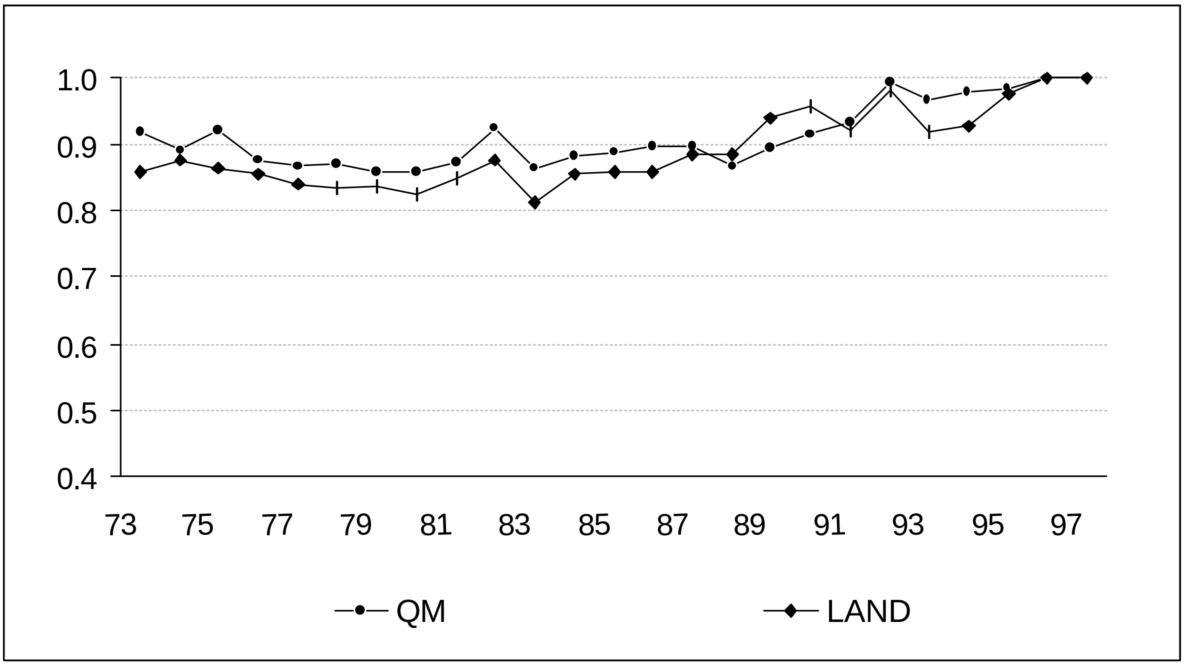


A5. France

Productivity (d), technology level (A), radial efficiency (E)

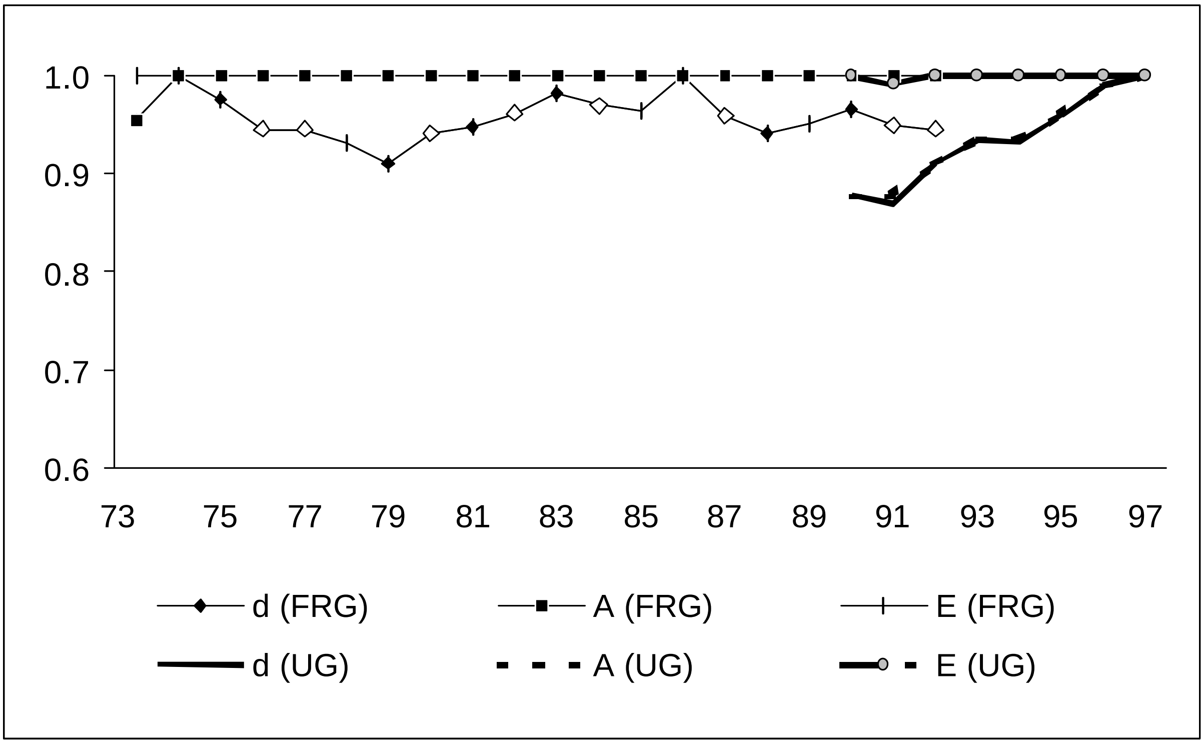


Specific non-radial efficiencies

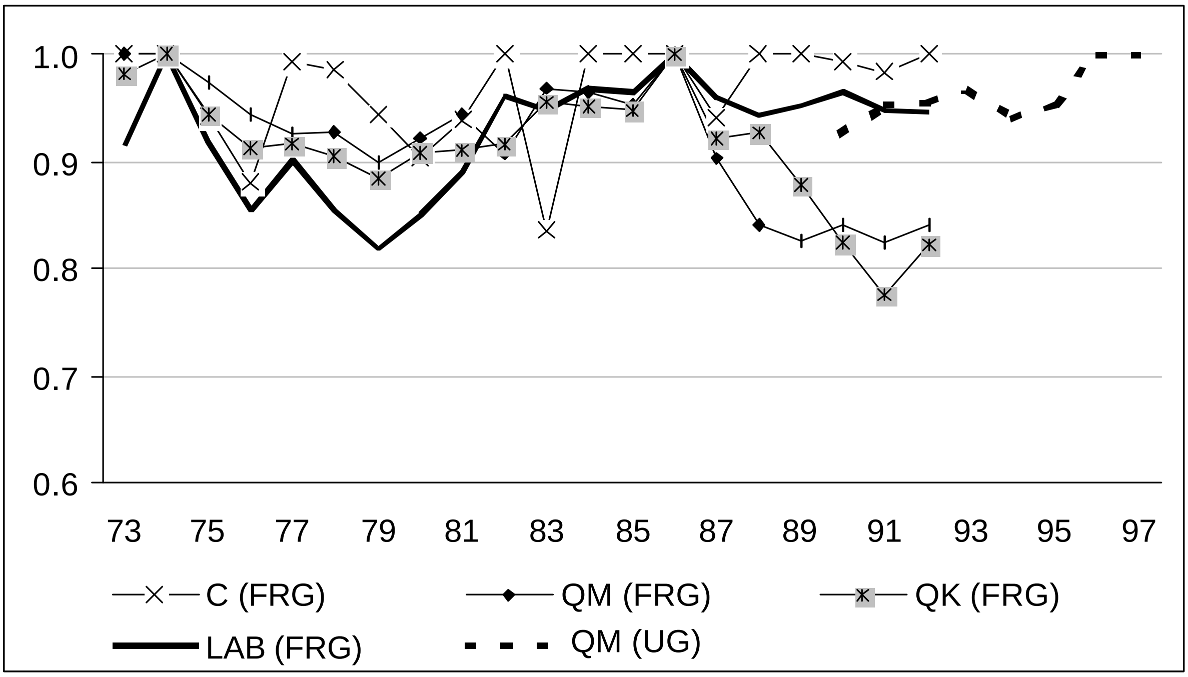


A6. Germany

Productivity (d), technology level (A), radial efficiency (E)

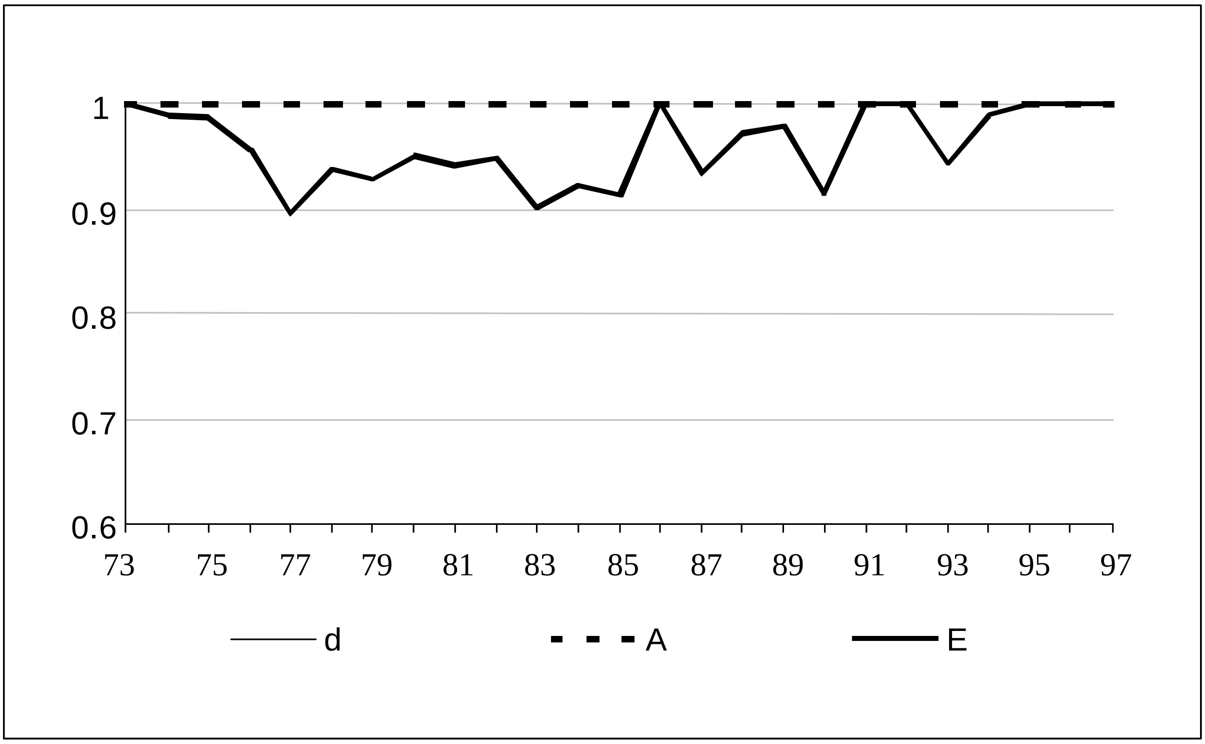


Specific non-radial efficiencies

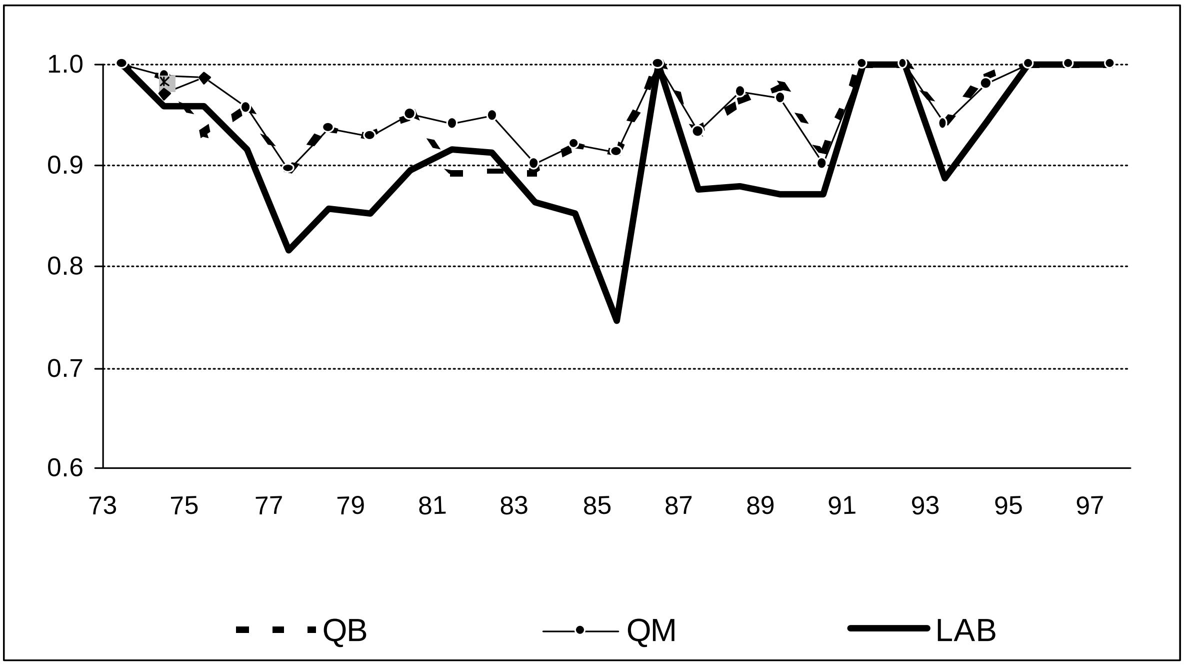


A7. Greece

Productivity (d), technology level (A), radial efficiency (E)

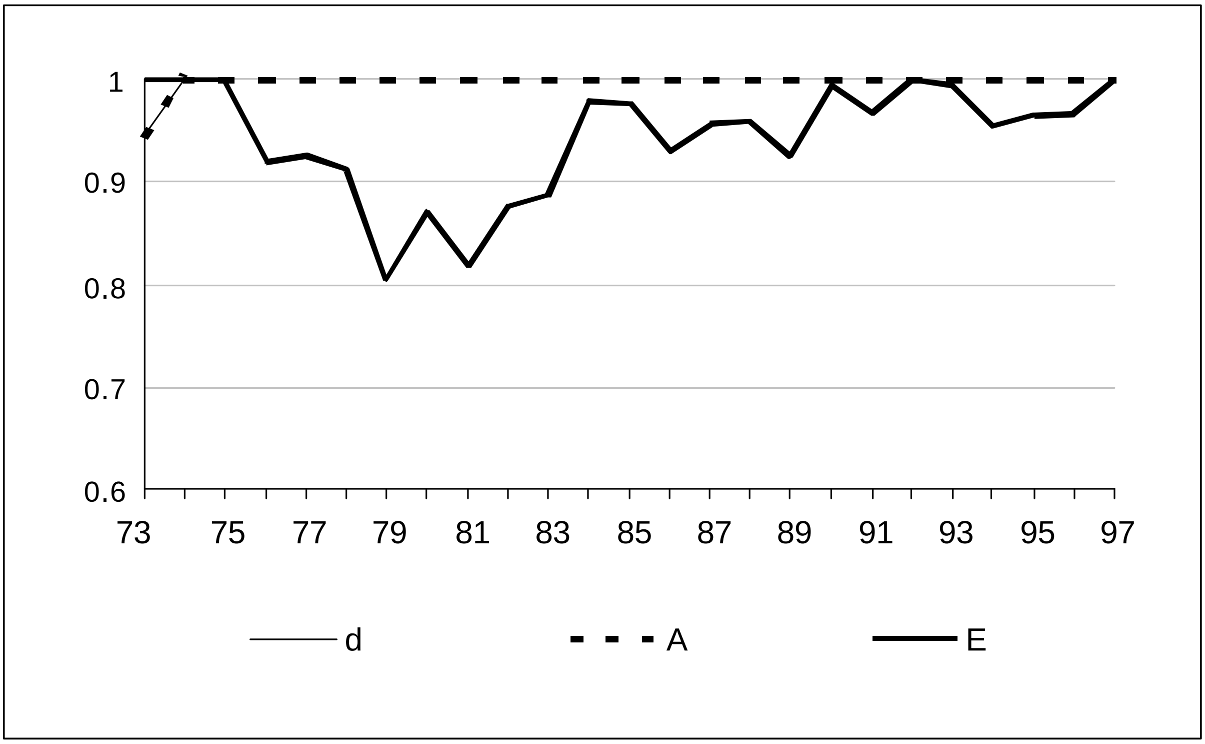


Specific non-radial efficiencies

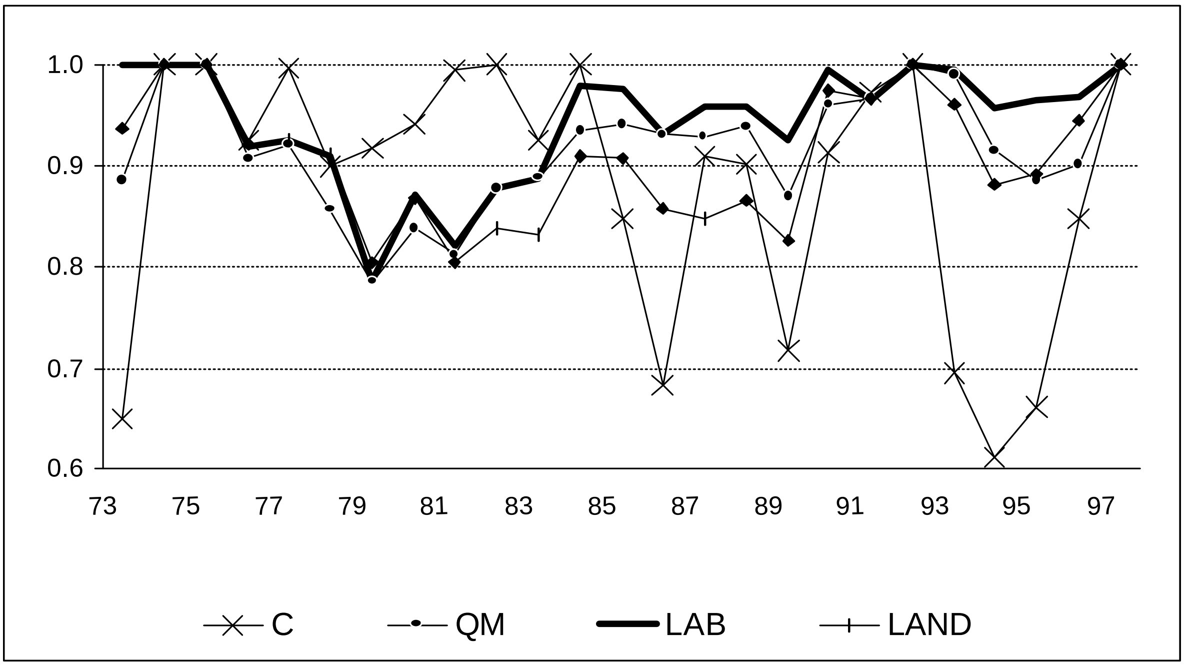


A8. Ireland

Productivity (d), technology level (A), radial efficiency (E)



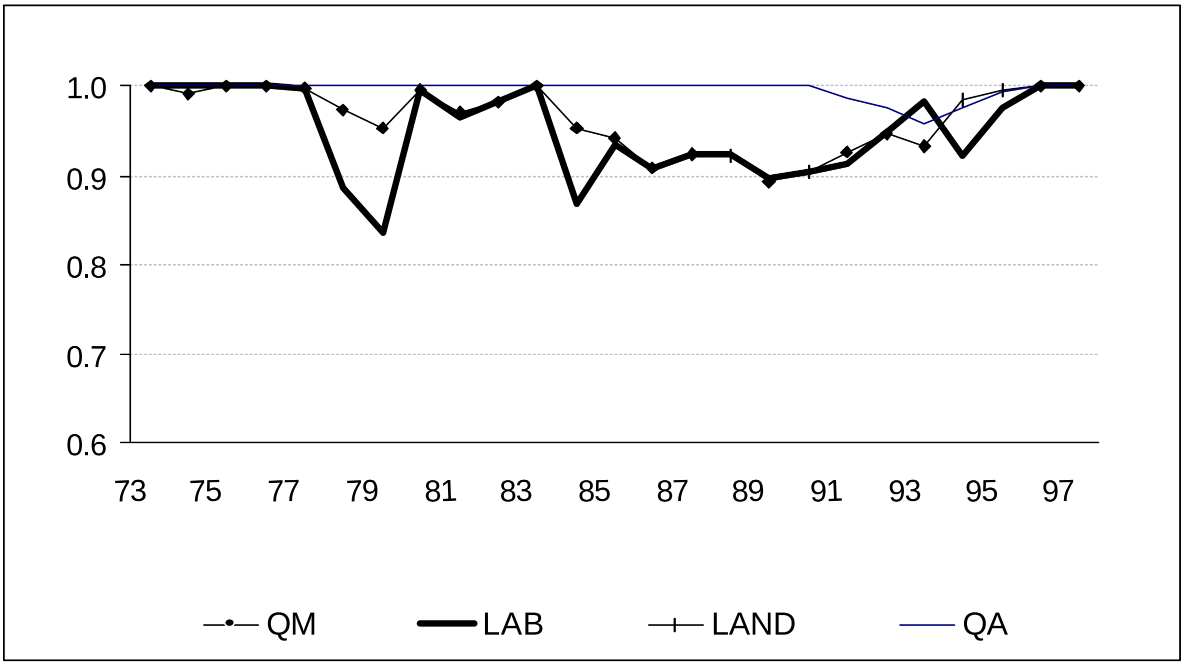
Specific non-radial efficiencies



A9. Italy

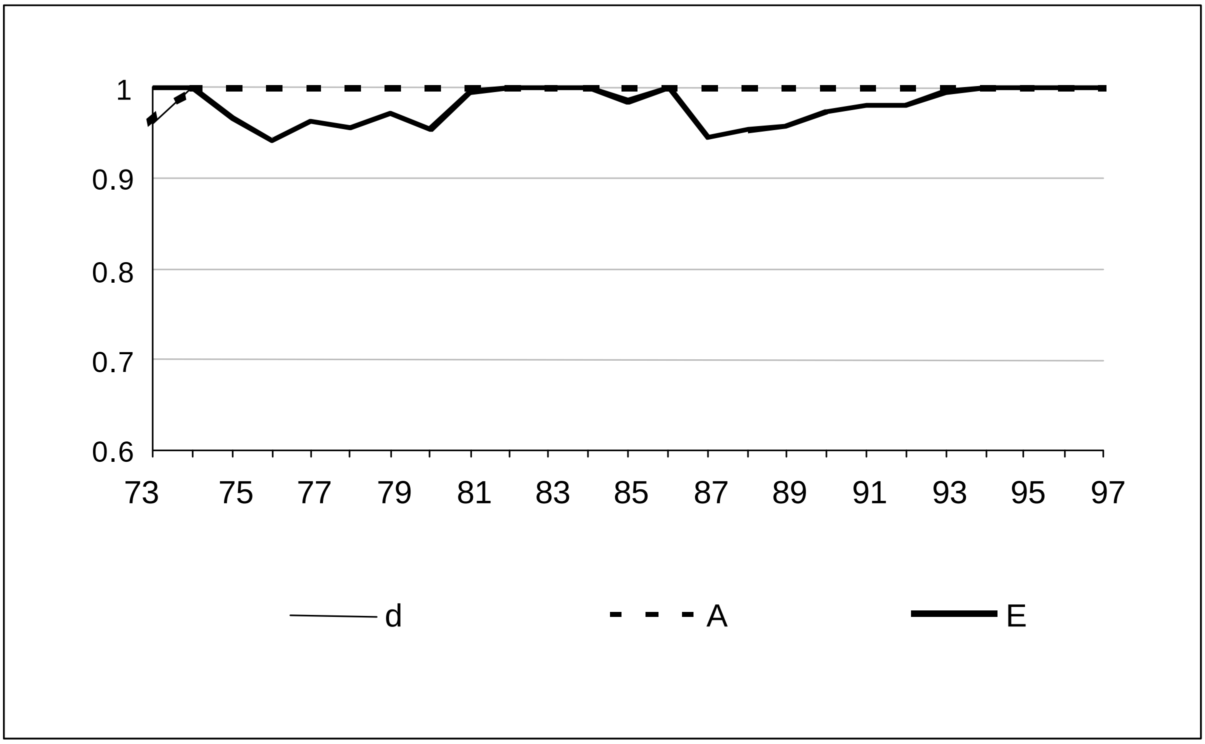
Productivity (d), technology level (A), radial efficiency (E)

Specific non-radial efficiencies

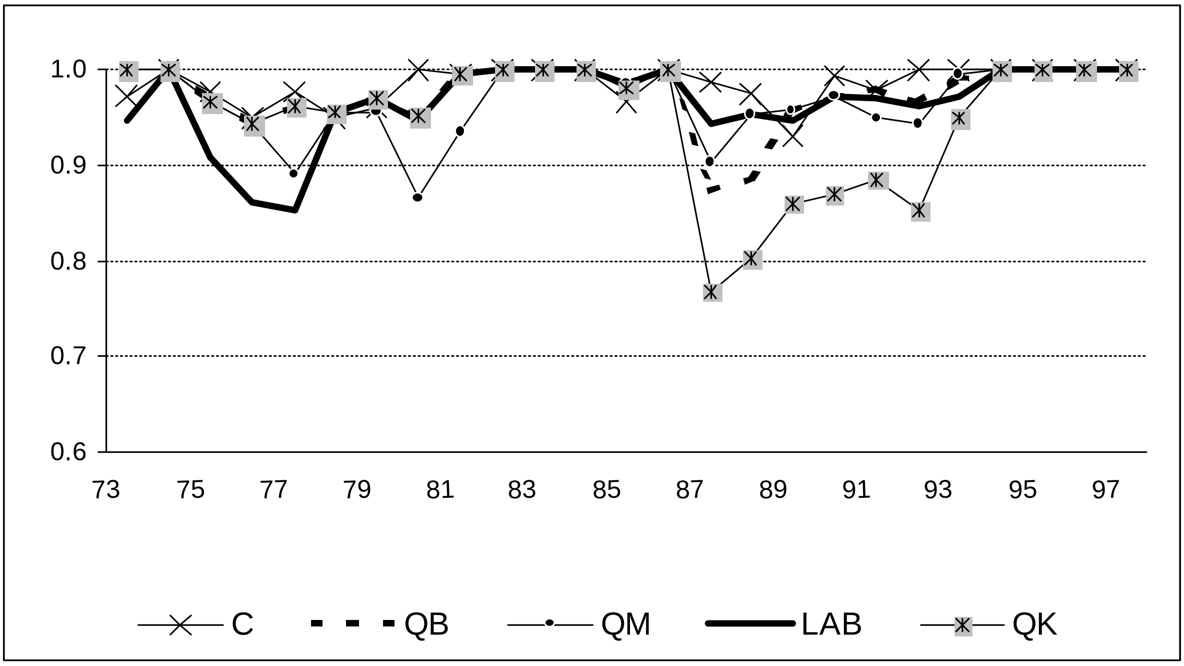


A10. Netherlands

Productivity (d), technology level (A), radial efficiency (E)

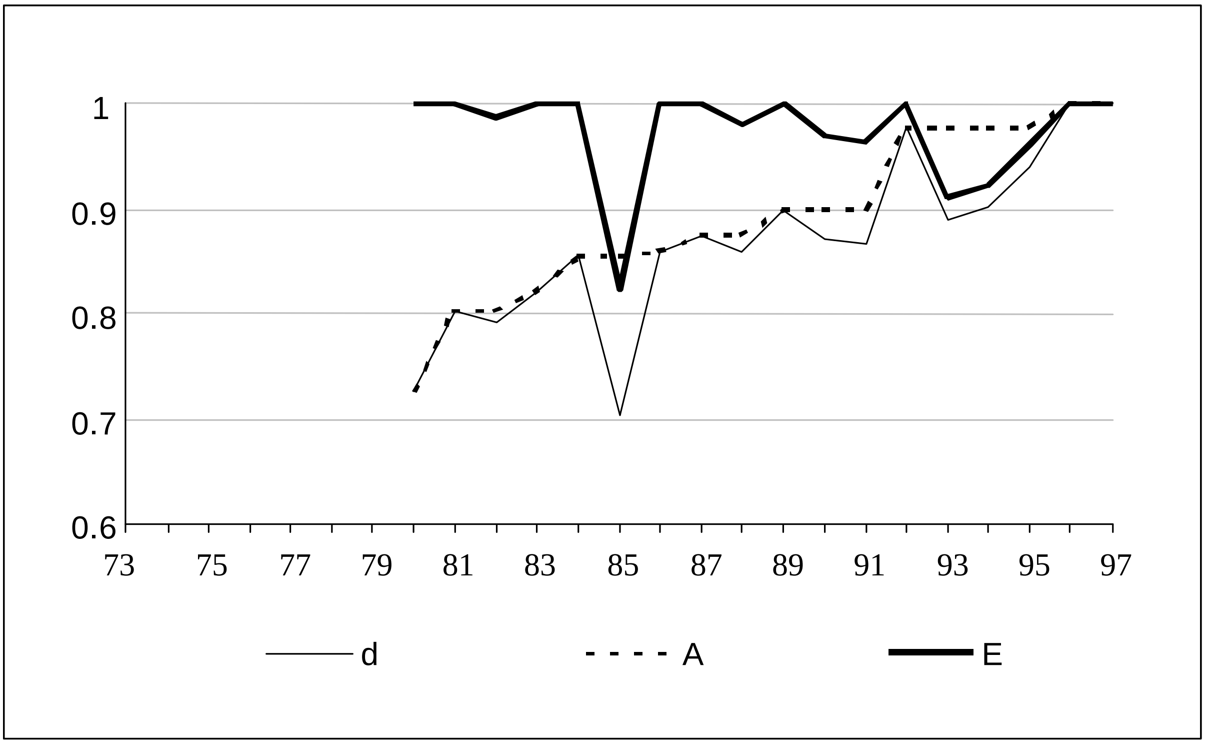


Specific non-radial efficiencies

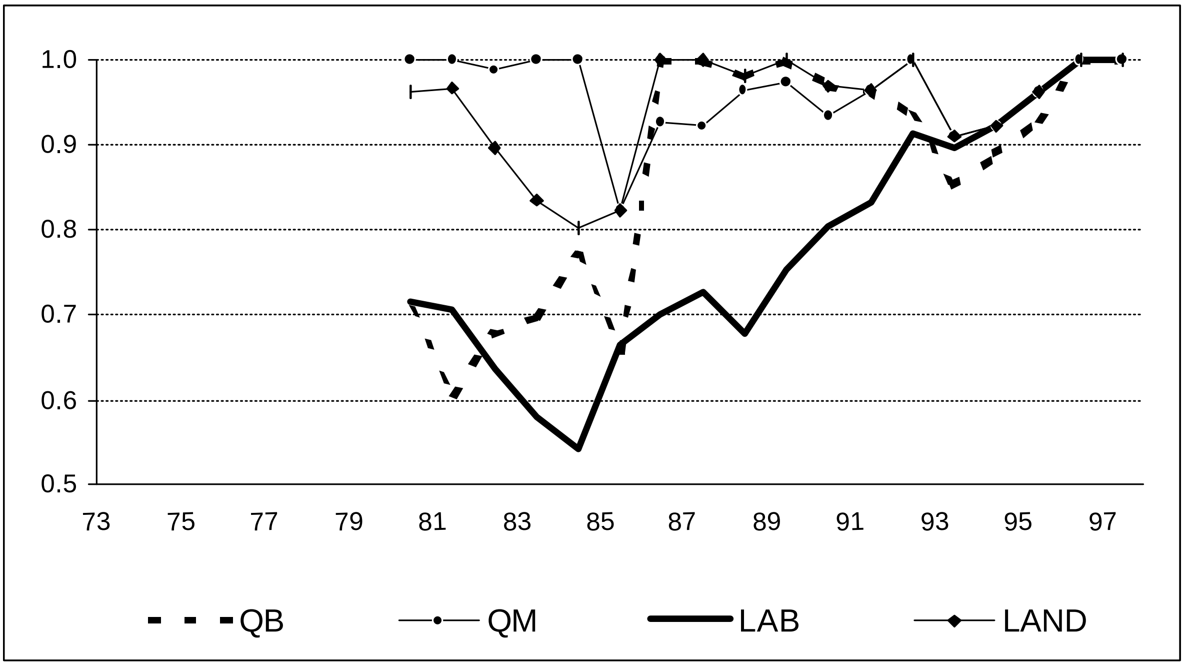


A11. Portugal

Productivity (d), technology level (A), radial efficiency (E)

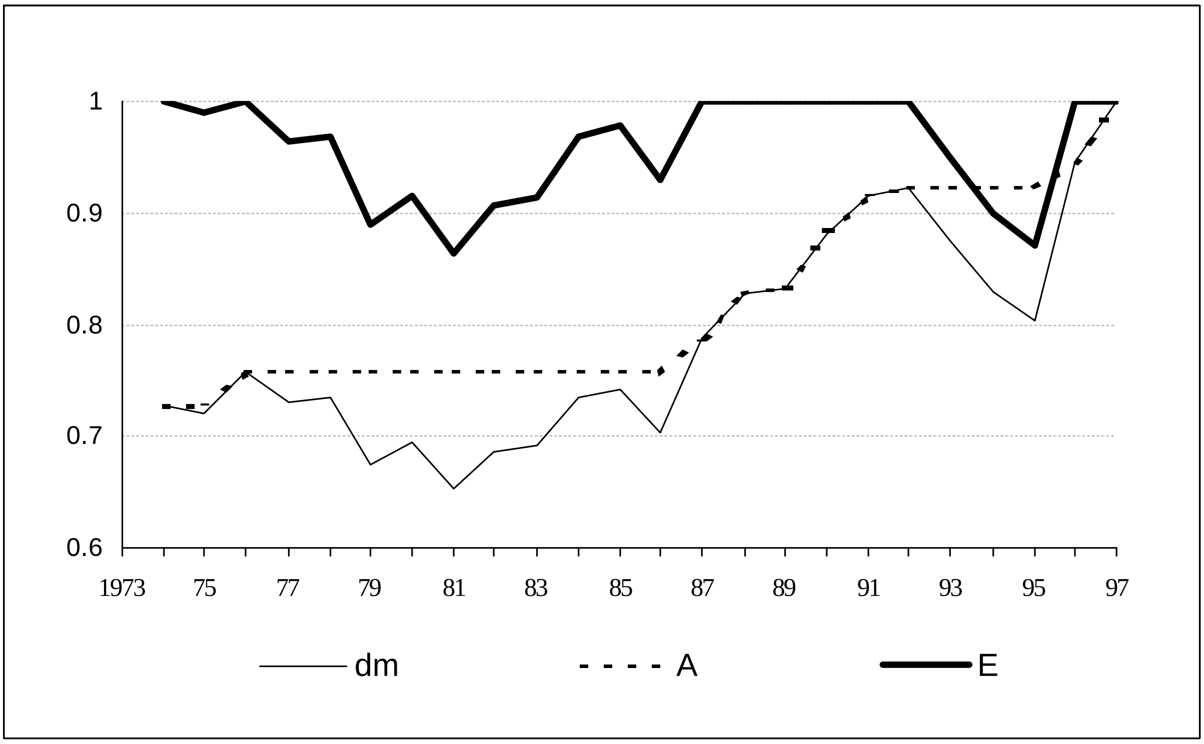


Specific non-radial efficiencies

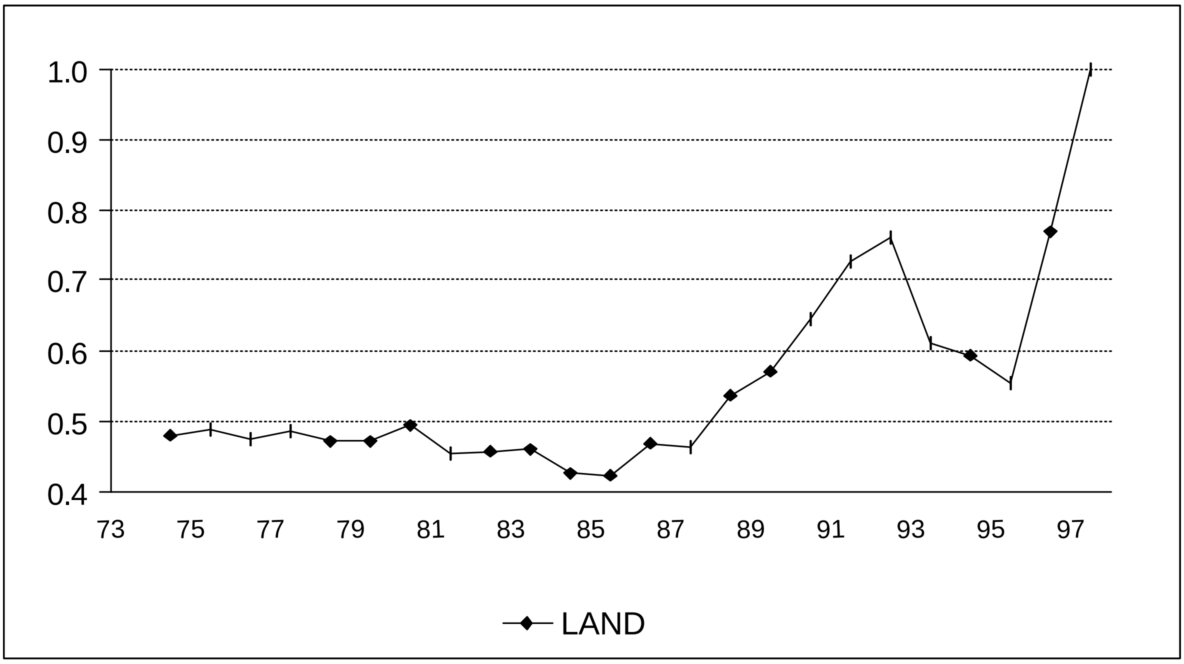


A12. Spain

Productivity (d), technology level (A), radial efficiency (E)

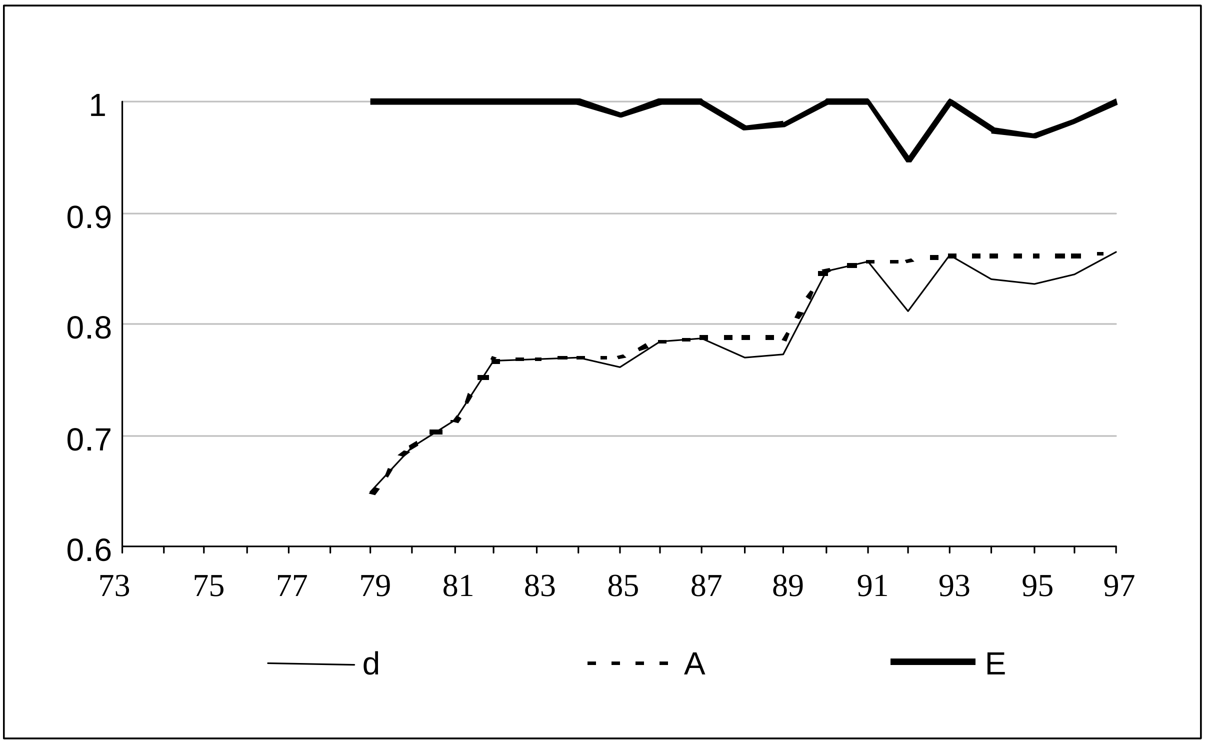


Specific non-radial efficiencies

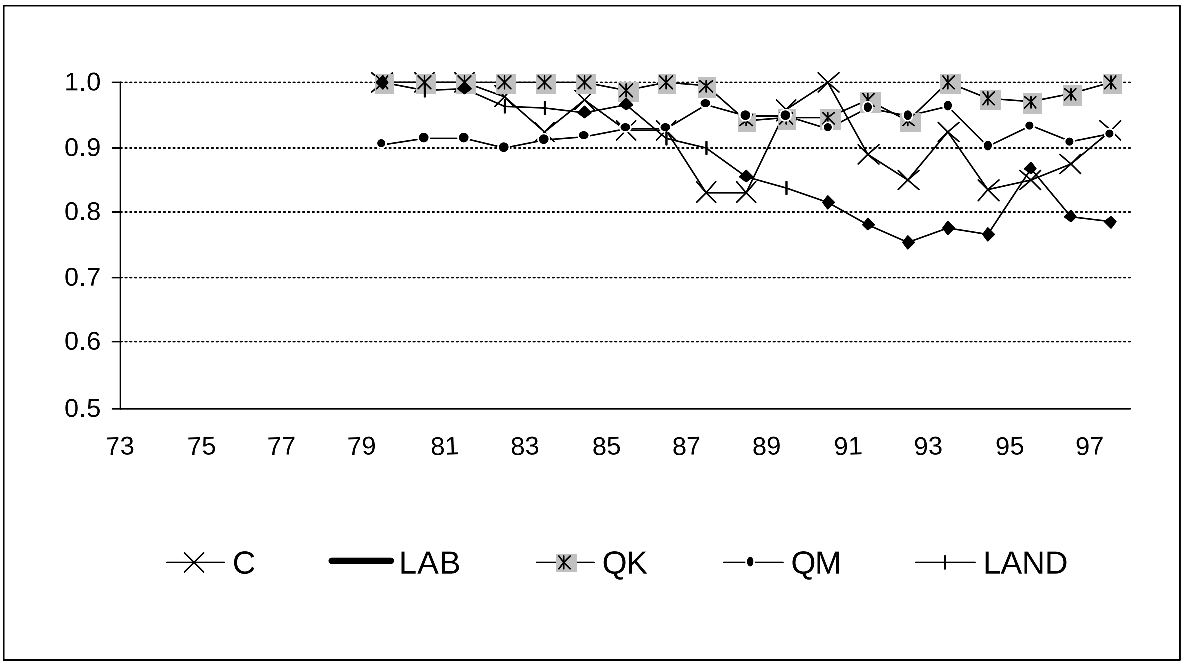


A13. Sweden

Productivity (d), technology level (A), radial efficiency (E)

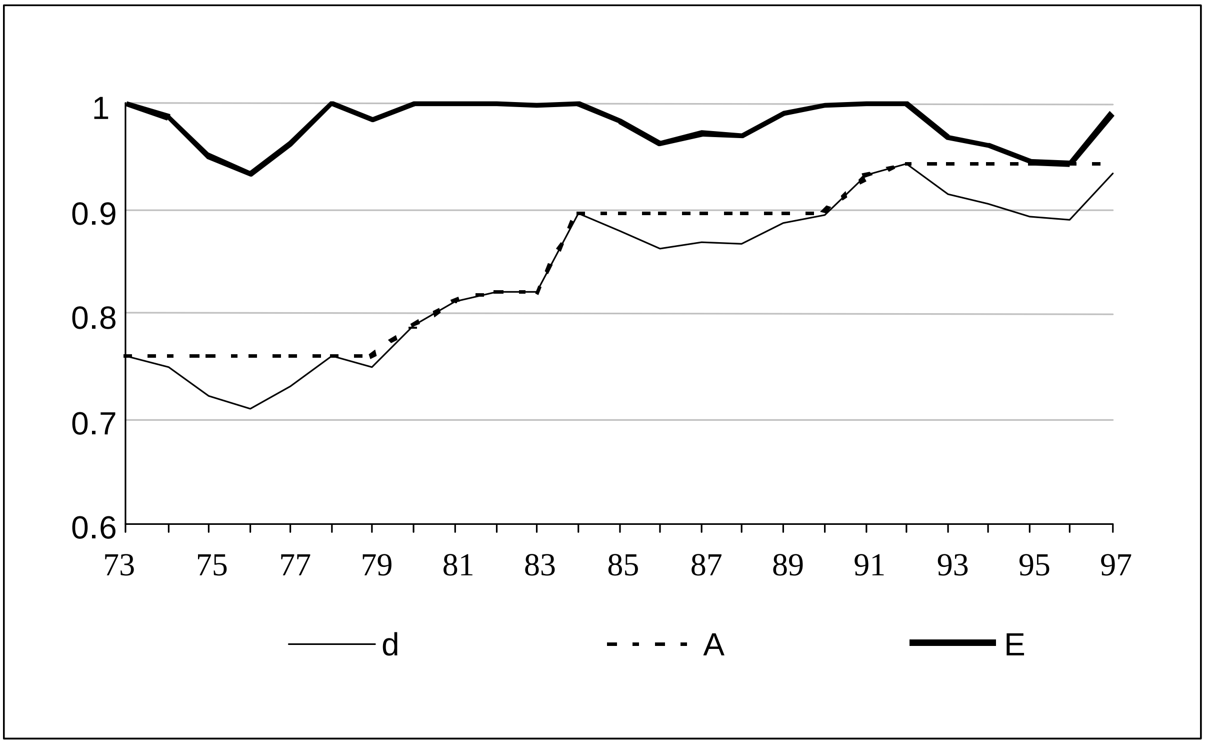


Specific non-radial efficiencies



A14. United Kingdom

Productivity (d), technology level (A), radial efficiency (E)



Specific non-radial efficiencies