INSTITUT FÜR VOLKSWIRTSCHAFTSLEHRE

der

UNIVERSITÄT AUGSBURG

Technology and Efficiency Patterns

A Comparative Study on Selected Sectors from the French and German Industry

by

Jean Bernard*, Uwe Cantner, Horst Hanusch und Georg Westermann

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Beitrag Nr. 121

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JEAN BERNARD*, UWE CANTNER**, HORST HANUSCH** AND GEORG WESTERMANN**

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SEPTEMBER 1994

Abstract

The main focus of our paper is concerned with the relationship between total factor productivity growth and technological progress. We pursue this analysis on the micro level using firm data for French and German corporations in the machinery and electronics sectors respectively. Productivity measures are related to certain data used as proxies for the factor "technology". Herewith we attempt to shed some light on the dynamics of productivity development within certain branches characterized by heterogeneous performances of the firms.

Financial Support by the European Commission for the SPES-project "Comparative Economics of R&D: The Case of France and Germany" as well as by the DAAD-programme PROCOPE is gratefully acknowledged.
We are very grateful to the "Stifterverband für die Deutsche Wissenschaft" who made it possible to relate our results on relative firm productivity to German firm specific R&D expenditures. We are especially grateful to Christoph Grenzmann from the "SV-Wissenschaftsstatistik" at Essen who provided the technical assistance as well as the respective computations which are presented in chapter 3.3.
Remaining errors are still our responsibility.

1. Introduction

Investigations into the heterogeneous performances of firms within a certain branch or sector have a long standing tradition.[1] The explanation of such differences as they can be detected for example by comparing firms by total factor productivity measures rely basically on the concept of "market failures" - which is apparent in the concept of X-inefficiency or in several oligopoly models in industrial organization. Inefficiencies measured on the basis of these approaches are mainly referred to as technical (and allocative) inefficiencies stating that a single given best-practice-technology is not used by its full potential throughout a sector.

Recent advances in the economics of technological change, however, increasingly stress that the observed industry structure is also the result of the coexistence and competition of several different technologies.[2] And moreover, this diversity is a major force pushing forward technological progress. Based on this socalled evolutionary approach the heterogenity of technologies in use implies that from a theoretical point of view technological inefficiency (where several different best-practice technologies are compared with each other) has to be distinguished from technical inefficiency (where a specific best-practice technology serves as yard stick).

With these two inefficiency measures in mind, empirical investigation into this field has to take into account technological variety by choosing an appropriate analytical procedure. The traditional (parametric) method of total factor productivity measurement, however, seems not to be well suited for this task because it usually assumes (1) special production functions and (2) certain properties of the underlying theoretical model, i.e. general equilibrium solutions. For an evolutionary approach this procedure is no longer acceptable although to find a better one is by no means an easy task.

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1 See for example Caves/Barton (1990).

2 See for example Nelson/Winter (1982), Dosi (1988).

Therefore we suggest to apply a non-parametric approach, the linear programming approach[3] or the Data-Envelopment-Analysis (DEA)[4], to investigate technological performances and variety which neither needs a special type of production function nor relies on general equilibrium prices. With this procedure it is possible to allow for different production techniques and consequently different technology fields within one sector. Within a panel-analysis, several types of firms can be distinguished and classified according to her "technological behaviour" or her "technological characteristics". One can detect "technology leaders", firms catching up, firms falling behind, and firms changing technology fields.

In Bernard/Cantner/Westermann (1994) and Cantner/Hanusch/Westermann (1993, 1994) this method has been applied to the machinery sector of France and the electronics and machinery sectors in Germany. In this paper we investigate French and German firms within one sample for machinery and electronics respectively.

For this we proceed as follows. Chapter 2 delivers the theoretical foundation of our analysis. Moreover the DEA method is introduced which is well suited to perform an efficiency analysis within the theoretical framework of the modern approach to innovation and new technology. Chapter 3 describes the data base and the results of our analysis. We conclude our paper with a chapter 4 which also presents an outlook on further investigations.

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3 For an overview see Färe/Grosskopf/Lovell (1993).

4 For an overview see Charnes/Cooper/Lewin/Seiford (1994).

2. Theoretical Basis and Analytical Model

2.1 Technological Variety - A Theoretical Foundation

The modern theory of new technology and innovation attempts to explain differences or asymmetries among firms by their respective technological performance. The core of this approach is the emphasis on the fact that opportunities of and advances in technology (tend to) dominate any economic determinants of a firm's choice of technology.

Traditional neoclassical production theory, however, does not share this view as there the path technological progress develops along is mainly determined by changes in relative factor prices where technological possibilities are open to all economic agents. Consequently, assuming a well functioning market mechanism a certain stability of firm heterogenity within a sector is not to be expected. Diversity, nevertheless empirically observable, is then to be explained mainly by market failures.

This neoclassical concept of factor price induced technological progress has been challenged by the well-known Salter (1960) and Fellner (1961) critique. Salter (1960, p.43) notes that "... when labor costs rise, any advance that reduces total costs is welcome and whether this is achieved by saving labor or capital is irrelevant." Moreover, Ahmad (1966, p.345) states that "only technological considerations and not a change in the relative price of the factor may influence the nature of invention, even if there exists the possibility of choosing from different kinds of invention." Modern innovation theory attempts to develop these aspects further.

Here, besides others a major point of criticism focuses on the standard neoclassical assumption that technological knowledge is considered as a public good which - in turn

- implies technological uniformity between firms as core hypothesis.[5] Instead, the modern approach distinguishes between public knowledge on the one hand and private[6], often tacit technological knowledge on the other. It is this private good character of technological know-how which allows firms to develop along a certain technological path often described as cumulative, selective and finalized.[7] Consequently, although different firms belong to the same branch, although they are technologically tied to common - public good - principles and although they are engaged in the production of the same class of goods[8], they nevertheless differ with respect to their specific production technology.

The reason for building up a private stock of technological knowledge leading to technological diversity is found in the conditions by which technological progress is accomplished on the firm level. Here, the technological capability a firm is accumulating is determined by past investment, learning effects as well as own R&D engagements. And just by reverse causation, these capabilities are decisive for further successful technological improvements as well as successful adoption of new techniques developed elsewhere.[9] This implies (a) that further technological advances are mainly determined and constrained by the technique(s) a firm has been using in the past[10] and

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5 As a by-product, the use of a representative agent is justified.

6 One could here also use the terminology of Nelson who uses "latent public" instead of "private".

7 See Dosi (1988).

8 This class of goods may either contain several more or less horizontally or vertically differentiated products, or may represent a homogeneous good produced with different production functions.

9 Technological asymmetries among firms may also be responsible for a sometimes slow diffusion path of capital embodied innovations. "... the process of adoption of innovations is also affected by the technological capabilities, production strategies, expectations, and forms of productive organisation of the users." (Dosi/Pavitt/Soete (1990. p.119)).

10 With respect to the macro-level Abramovitz (1988. p.236) states: "... the capital stock of a country consists of an intricate web of interlocking elements ... built to fit together and it is difficult to replace one part of the complex with more modern and efficient elements without a

(b) that the firm's search for new solutions is characterized by bounded rationality and local learning effects. Technological progress which enhibits strongly cumulative effects is labelled "localized technological progress".[11]

A major consequence of this view is that relative factor prices play only a minor role in the development of new technologies. Employing the standard textbook isoquant only a (small) number of all techniques on an isoquant are practiced, and substitution processes - which are to be considered as resource using search processes - due to changes in relative factor prices are not costless. Therefore, if the technological opportunities of a firm are considerably high, search costs will be devoted to innovation, not to substitution.[12] In this case of local technological advances, the development path of a firm will be characterized by fairly constant factor input ratios independent of the prevailing relative factor prices. And even more, changes in the relative factor prices will not cause the transition to the new technology to be reversable, i.e. technological change is characterized by irreversibilities.

Based on this theoretical background we assume a special form of production structure on the sectoral level which we use for our empirical investigation:

(i) An industry consists of firms which employ different production functions, each one representing the respective firm specific technique. Since these techniques are the outcome of a localized technological progress, we consider the resulting techniques - at least in the short-run - to be of zero elasticity of substitution at

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costly rebuilding of other components". This of course implies that the more capital intensive a production is the more difficult and costly is the switching of techniques.

11 See Atkinson/Stiglitz (1969).

12 In fact such a behaviour is the core of the Salter critique.

the outset. This suggests to assume a Leontief-type production function - at least for the short-run. Firm diversity is then represented by a number of different Leontief-production functions, i.e. different factor input ratios.[13]

(ii) For the medium and long-run one still could assume a strongly localized technological[14] change which would imply the development path to be characterized by a constant factor input ratio. However, we do not need this restrictive assumption but we rather suggest a development path to be constraint within elastic barriers.[15] The observation of an increasing mechanisation of the production processes is thus taken into account.[16]

With this formulation of a sector's production structure it is interesting to compare the firms of the sector with respect to their technological performance. Such an investigation has to take into account the following aspects:

(1) Due to different firm-specific technological approaches there may appear more than one best-practice technique. These techniques cannot necessarily be ranked as being better and worse.[17]

(2) Despite this quite a number of practiced techniques can be ranked as unequivocally better or worse. These differences can be caused on the one hand by

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13 This modelling may take into account the claim put forward by Silverberg (1990) to abandon the traditional neoclassical production function altogether. In this respect the use of short-run fixed production coefficients has been used intensively in the theoretical literature as well as in simulation models.

14 For the distinction between strong and weak localized technological change and its relation to the isoquant see Verspagen (1990).

15 See David (1975).

16 See Dosi/Soete (1983), Dosi/Pavitt/Soete (1990).

17 This aspect is different from the one put forward for example by Dosi/Pavitt/Soete (1990, pp.114) where all techniques can be ranked unequivocally as better or worse.

traditional technical inefficiency where inputs are not used efficiently given a specific technique. On the other hand, this can also be explained by technological inefficiency pointing to the fact that a comparably better technology is practiced elsewhere.

(3) With our assumption of short-run Leontief type production functions allocative (in-)efficiency is only a minor problem because a specific technique is optimal for a considerable range of relative factor prices. In fact, if only one best-practice Leontief-technology is in use, allocative inefficiency does not exist.[18]

Summarizing (1)-(3) our empirical analysis attempts to account (a) for the relative technological performance of firms and (b) for technological variety within a certain sector.

2.2 The Analytical Model

The analytical approach we apply is non-parametric, principally based on a linear programming procedure and known also as the *Data Envelopment Analysis* (DEA). On this basis it is possible to obtain an index for relative technological and technical (in)-efficiency for each firm of the sample. The choice of a non-parametric approach helps to take account of technological variety by allowing for several parametrically different production functions.

[18] In fact, the measure for inefficiency we compute below will consist of technological, technical and allocative inefficiencies. For a very dynamic sector, however, we consider technological inefficiencies as the major source. The other two inefficiencies will gain importance with increasing technological maturity.

Principally DEA relies on index numbers for productivity similar to the one used in traditional productivity analysis. For each firm j ($j=1,\ldots,n$) a productivity index h_j is given by:

$$h_j = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \qquad (1)$$

y_{rj} is used for the r different outputs ($r=1,\ldots,s$) and x_{ij} refers to i different inputs ($i=1,\ldots,m$) of firm j. The parameters u_r and v_i are (variable) aggregation weights. Applying vector notation (1) looks as follows:

$$h_j = \frac{u^T Y_j}{v^T X_j} \qquad (2)$$

Here Y_j is a s-vector of outputs and X_j a m-vector of inputs of firm j. s-vector u and m-vector v contain the aggregation weights u_r and v_i respectively.

h_j in (2) (and (1)) is nothing else than an index for *total factor productivity*. The respective aggregation functions (for inputs and outputs respectively) are of a linear arithmetic type as also employed in the well-known Kendrick-Ott productivity index.[19] There, however, by special assumptions the aggregations weights, u_r and v_i, are given exogenously.

The DEA-method does not rely on such assumptions, especially it is not assumed that all firms of the sample have a common identical production function. The specific

19 See Kendrick (1956) and Ott (1959).

aggregation weights are determined endogenously and can differ from firm to firm. They are the solution of a specific optimization problem (as discussed below), and therefore they are dependent on the empirical data of our sample. Critics often argue that a linear arithmetic aggregation nevertheless predetermines at least a special type of production function.[20] Here one can think of a Leontief-type production function.[21] Since the aggregation weights are determined endogenously and - as we will show below - can be different among firms, at the end there exist a number of different specific production functions although they are of the same principal type.[22]

The basic principle of DEA is to determine the indexes h_j in such a way that they can be interpreted as efficiency parameters. The (relatively) most efficient firms of a sample should be characterized by a h of 1, all less efficient firms by a h of less than 1. The following constrained maximization problem is used to determine such a h-value for a specific firm l, $l \in \{1,\ldots,n\}$, out of the sample:

$$\max\ h_l = \frac{u^T Y_l}{v^T X_l}$$

$$NB: \frac{u^T Y_j}{v^T X_j} \leq 1; \quad j=1,\ldots,n; \tag{3}$$

$$u, v > 0.$$

20 Vgl hierzu auch Chang/Guh (1991) S.217.

21 Leontief (1947) and Green (1964) have shown that a linear aggregation exists for a Leontief-type production function. Instead of a Leontief one could also use a linear production function.

22 Employing parametric methods, e.g. the COLS or the EM-algorithm a specific production function is assumed. The coefficients of this function are estimated using the available data and the resulting production function is used to determine technical (in)-efficiencies of all the fims in the sample. This procedure, however, suggests that there is only one "*best-practice*"-technology (for an empirical investigation on the private sector see for example Green/Mayes (1991), Hanusch/Hierl (1992)). With DEA a number of "*best-practice*"-technologies can be determined.

Problem (3) determines h_l of firm l subject to the constraint that the h_j of all firms of the sample are equal or less to 1. The constraints provide that h is indexed on]0,1]. Moreover the elements of u and v have to be strictly positive. This requirement is to be interpreted that for all inputs used and outputs there exists a positive value.[23]

Since we employ linear arithmetic aggregation functions for inputs and outputs, (3) is to be rendered as a problem of linear fractional programming.[24] To solve such optimizations, there exist a number of methods where the best known is the one by Charnes and Cooper (1962). They suggest to transform (3) into a normal linear programm which then can be solved using the well-known simplex algorithm. This can easily be done, if one provides for the denominator in the objective function of (3) to be constant. By this, the fractional linear program can be dealt with like an (ordinary) linear program which reads as follows:

$$\begin{aligned} &\max \ \mu^T Y_l \\ &NB: \\ &\mu^T Y - \omega^T X \leq 0 \\ &\qquad\quad \omega^T X_l = 1 \\ &\qquad \mu, \omega > 0 \end{aligned} \tag{4}$$

Y_l and X_l are the r- and s-vectors of outputs and inputs respectively of firm l, Y and X are the $s \times j$-matrix of outputs and $m \times j$-matrix of inputs of all firms of the sample. In (4) the vectors μ und ω are the transformed aggregation weights which also have to be (strictly) positive.

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23 This procedure is also known from activity analysis.

24 An overview to linear fractional programming is given in Böhm (1978).

Problem (4) represents a version of efficiency analysis which is known as the "Production"- or "Efficiency Technology"-form: Here, one attempts to maximize the output of firm l where input is normalized, the solution is to be positive, and the efficiency indexes[25] of all firms are restricted to]0,1]. The dual to (4) is known as the "Envelopment"-form since here a frontier function (containing several linear parts) can be determined. This obviously relates our analysis to the one of Farrell (1957). The corresponding dual programme reads then:[26]

$$\begin{aligned} &\min\ \theta_l \\ &NB: \\ &\qquad Y\lambda \geq Y_l \\ &\theta X_l - X\lambda \geq 0 \\ &\lambda \geq 0 \end{aligned} \qquad (5)$$

The parameter θ to be minimized states to which percentage level the inputs of firm l can be reduced proportionally, in order to have this firm producing on the frontier function representing the best practice technologies. With $\theta=1$ the respective firm belongs to the efficient firms on the frontier. The j-vector λ states the weights of all (efficient) firms which serve as reference for firm l. For firm l efficient ($\theta=1$), we obtain $\lambda_l=1$ and $\lambda_j=0$, $j \# l$.

Using the "Envelopment"-form of (5) it is easy to select efficient and inefficient firms directly. Principally, the Pareto-Koopmanns criterum is employed which allows to compare vectors. The linear programming procedure as performed by (5), however, may result in selecting a firm as DEA-efficient although it is clearly dominated by

25 The ratios are stated here as differences which are not allowed to be positive.

26 See Charnes/Cooper/Thrall (1986).

another firm on the frontier. This may happen when the parts of the frontier are parallel to one of the axes. To avoid such results the linear program in (5) has to be modified as follows:

$$\min \theta_l - \epsilon e^T s^+ - \epsilon e^T s^-$$

$$NB:$$

$$\begin{aligned} Y\lambda - s^- &= Y_l \\ \theta X_l - X\lambda - s^+ &= 0 \end{aligned} \qquad (6)$$

$$\lambda, s^+, s^- \geq 0$$

This modification provides that for all firms, which are on the frontier ($\theta=1$) but which are dominated by other firms of the frontier, the respective slacks (s^- for excess inputs and s^+ for output slacks) are taken into account in the objective function.[27] Vector e^T contains only elements 1.[28] ϵ is a positive constant smaller than any other variable of the program. This garantees that slacks are only taken into account when a strictly convex envelope has already been determined.[29]

For efficiency analyses additional to θ one has therefore to take into account remaining slacks. Only then a clear-cut selection of efficient and inefficient firms is possible. For simple qualitative statements this procedure is sufficient.

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27 The variable ϵ has to be smaller than any other measure of the optimization. This implies especially that first the frontier has to be determined and then the slack variables can enter the basic solution.

28 Of course, one should here distinguish two vectors e^T for inputs and output respectively which contain s and i elements respectively. To ease notation we do not take account of this. Further analysis is not affected.

29 This condition is equivalent to the statement that the aggregation weight or prices of the primal programme to be strictly positive.

For a quantitative analysis, however, it would be helpful to combine the proportional reduction θ and the remaining slacks into a single measure. This is done by a method suggested by Färe/Hunsacker (1986). As is known from index numbers for total factor productivity the input factors have to be aggregated in a single number. Applying DEA, the respective weights are given by the marginal productivities of the input factors of the reference firm. These marginal productivities are the solution of the primal program.

The ratio of the marginal productivities obtained here can be interpreted as the slopes of the linear parts of the frontier. Using the marginal productivities of the respective reference firm, one can compute for each firm a virtual input and a virtual slack. The ratio of both delivers the percentage of total slack for firm l. Correcting θ by this ratio delivers an adjustecd aggregate measure of inefficiency, ι, which combines the possible proportional reduction in inputs with the remaining slacks. For our empirical analysis below we rely solely on ι.

3. Data Set, Procedure of Investigation and Empirical Results

3.1 Data Set and Procedure of Investigation

The data set we investigate contains time series data of

(a) 142 French and 78 German machinery firms

(b) 123 French and 39 German electronic firms

of different sub-branches. For each sector German and French data are pooled in one sample - where we used the purchasing power parity of 1985 for converting Franc nominated values.[30] This data set is time consistent in the sense, that we have neither entries nor exits of firms over the whole period of investigation, 1985 to 1991. All firms under consideration are of the legal form "shareholder's company" and employ more than 100 workers.

In order to compute the efficiency score "ι", we define some suitable variables for inputs and output:

As an output measure we construct a "total output" consisting of the sum of "total sales", "inventory changes", and "internal used firm services" from the profit&loss accounts. This output is deflated by a composed price index for French respectively German investment goods.

On the input side we distinguish between "capital", "labour", and "material":
"Capital" is captured by the balance sheet position "fixed assets" (net value at the beginning of the year). Since we have no information about the age structure of capital this measure is not deflated. For "Labour" we compute the effective worker hours per year by multiplying the number of workers of a firm by an index of effective worker hours for the respective industries in both countries. "Material" consists of the deflated profit&loss position "raw materials and supplies".

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30 In Bernard/Cantner/Westermann (1994) and Cantner/Hanusch/Westermann (1993, 1994) an investigation into country specific sectors is provided.

We are certainly aware of the fact that in order to compute a measure for technical efficiency we should have used purely technical variables for the inputs or the output. For "Capital" input an ideal technical measure would be machine hours; for "Material" input we should have gathered data on the used raw materials in tons, pieces, etc.; for output "pieces of produced machines" would be an adequate technical measure.

In some cases these data are not available (machine hours), in others the variables are too heterogenous to be measured technically (output, material). So we have to replace or aggregate the real data by economic weighted values such as "sales" or "raw materials&supplies".

Our empirical analysis proceeds in two main steps:

The first one uses the efficiency scores of DEA and interpretes them with respect to (a) the technological structure of the sector, (b) the dynamics of the technological structure, and (c) the variety of technologies.

In a second step our efficiency indices will be related to firm specific R&D. Here have to reduce the number of firms to 107 (F:42/G:65) in machinery and 98 (F:70/G:28) in electronics which have reported their R&D continously for the whole period under consideration. Consequently, when using these data in our analysis we are forced to reduce our sample because we cannot distinguish whether the firms have not reported R&D expenditures or whether they have not invested in R&D at all.

For both steps our analysis focuses primarily on the question whether there are significant differences between French and German firms.

3.2 Technological/Technical Efficiency

According to our route of investigation the first step of our investigation attempts to answer the following questions on the productivity structure of our sample:

(1) Which are the efficient firms in a certain year?

(2) Is the set of efficient firms stable over time?

Tables 1a and 1b show the DEA-efficient firms in a year by year analysis and the periods they stay on the frontier. For machinery there are four French firms staying continously on the frontier (F6, F9, F89, F99). This "club" is joined by only one German firm in 1986 (D52). Firms like F113 loose their leading position after some years or appear only for a short period on the frontier. The number of efficient firms is varying from 7 to 11 firms per year with no significant de- or increasing tendency.

Table 1a: Efficient firms "year-by-year": machinery

Year / Firm ID	85	86	87	88	89	90	91
D154					X		
D135						X	
D87		X	X				
D52		X	X	X	X	X	X
F130	X						
F113	X	X	X	X	X		
F107	X						
F105		X	X	X			X
F99	X	X	X	X	X	X	X
F89	X	X	X	X	X	X	X
F76			X				
F59	X						
F53						X	
F49			X		X	X	X
F21							X
F10	X	X	X				
F9	X	X	X	X	X	X	X
F6	X	X	X	X	X	X	X
Sum:	9	9	11	7	8	8	8

For electronics the picture changes somewhat compared to machinery. Only German firms are continously members of the efficient frontier (D37 and D100). From the French side F94 jumps onto the frontier in 1986 and F52 rejoins the "club" in 1988. F67 is a previously efficient and then looses considerably. All other firms are only occasionally among the top ones.

From this result we learn that the structure of the technological frontier in each sector is characterized on the one side by some continuity but on the other changes quite rapidly. One can imagine some of the facets on the frontier vanish and others appear from period to period. We assume that only the technologically best firms stay and stamp the envelope for a longer time.

Table 1b: Efficient firms "year-by-year": electronics

Year / Firm ID	85	86	87	88	89	90	91
D203	X				X		
D168		X	X	X			
D138					X	X	X
D100	X	X	X	X	X	X	X
D37	X	X	X	X	X	X	X
F97						X	X
F94		X	X	X	X	X	X
F93							X
F81		X	X	X			
F75				X	X		
F67	X	X	X	X	X		
F56				X			
F52	X	X		X	X	X	X
F42			X				
F33		X	X				
F28					X		
F24				X	X		
F12		X	X				
F11		X					
Sum:	5	10	9	10	10	6	7

With respect to the dynamics of the technological structure we ask the following questions:

(3) Do the inefficient firms get closer to the frontier during time, i.e. is there a catch-up?

(4) Has there been something like technological progress driven by the efficiency leaders?

(5) Compared to the "all time best frontier" does the efficiency of the whole sector increase?

These questions lead to dividing for each sector separtely the sample of firms in two sub-groups. The first one includes only the efficient firms, the other one consists of the not efficient firms. Figures 1a and 1b show the average "year-by-year" ι-value of the inefficient group (i-ned) together with the average "year-by-year" ι-value of the efficient firms (i-ed) (which, of course, has to be 1,0 by definition) for the respective sectors. To obtain a measure of the movement of the frontier we compute another average ιvalue for the efficient sub-sample (i-edt) as a comparison with the "all-time-best-practice" frontier.

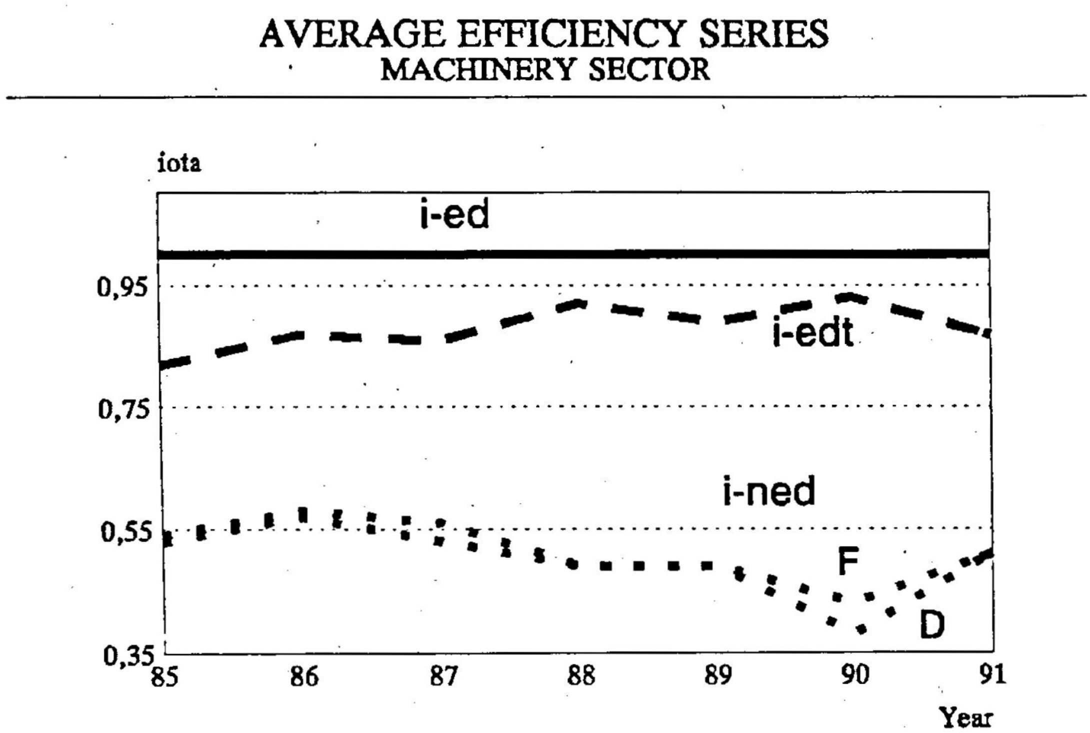

Figure 1a: Machinery

For machinery it is evident that the non-efficient French (i-nedF) and German (i-nedG) firms behave quite similar. Both sets are not able to catch up to the frontier most of the time Only for the year 1986 figure 1a illustrates that the improvement of the non-efficient sample was not the result of a decreasing efficiency of the frontier. In this year the pursuing firms in both countries performed really better, even compensating the shifting of the frontier.

With respect to the "all-time-best-practice" frontier for the efficient firms a slightly but obviously increasing tendency can be noticed. Consequently, the year-by-year efficiency leaders are pushing forward the technological development. The average ι values for the group of inefficient firms (calculated in the same way with reference to the "all time best practice" frontier) show, however, an slightly decreasing trend from 0.44 (1985) to 0.40 (1991). Therefore, although the frontier shifts towards more technical and/or technological efficiency the backward firms become even worse.

For the electronics sector development of the French and German non-efficient firms is as similar than in machinery. Here we notice that starting in 1988 the German subset of inefficient firms overtakes the French one and is even able to catch up to the frontier in 1991. The respective French firms fall even further behind.

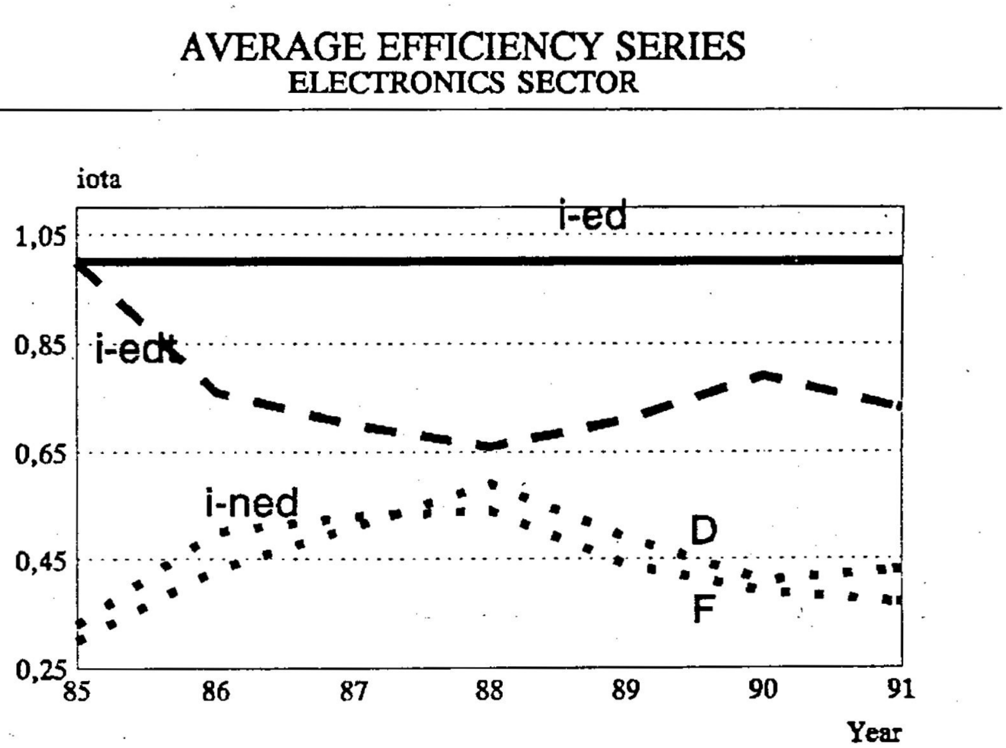

Figure 1b: Electronics

For the impact of technological progress, even if one explains the very good 1985 with business cylce effects, the frontier shows no clear tendency. The non-efficient subsample experiences a decline from 0,292 (1985) to 0,286 (1991). On the average the sector tends to become less efficient.

Finally we want to take account of technological variety. The following four questions are adressed with respect to this issue:

(6) What are the differences between the efficiency leaders?

(7) Do the efficiency leaders define "technology fields" within one branch?

(8) How does the technological efficiency and importance of these "technology fields" develop over time?

As shown above, in both sectors we discover several firms with an ι-value of 1,0. Closer inspection of the input structure of these firms shows clearly that some of them differ extremely in the proportions of the use of the three inputs necessary to produce one unit of output. Such different proportions of inputs will help us to define different "technologies" - each one characterized by a certain input ratio and represented by a Leontief production function as stated in 2.1). So it is obvious that there exist more than one efficient "technology" in order to produce the same group of goods (here: machinery or electronic goods).

The fact that we detect some firms applying extremly differing "technologies" (technicaly) very successfully, leads to the question whether it is possible to define them as the protagonists of different "technology fields". This seems adequate because the DEA method evaluates the non-efficient firms using the facets of the frontier built by linear combinations of the efficient ones. So we apply the λ values (see page 11) delivered by DEA to group the inefficient firms around the technology leaders. To verify this assignment defined by the DEA method, we additionaly ran a traditional cluster analysis using input ratios as factors. For both sectors this delivers six different clusters of input ratios which we label "technology fields", FL1 to FL6. For these fields the DEA assignment is confirmed by 71% in machinery and only by 53% in electronics.

Tables 2a and 2b give an account of the number of firms joining the six technology fields in each sector. It is evident that the main fields are FL1 and FL5 in machinery and FL1, FL3 and FL4 in electronics. Investigating the development within each technology field during 1985 to 1991 one has to recognise that there are fields which increase their importance while others loose. In machinery, for example, in FL1 continously more and more firms are found, whereas the number in FL5 decreases. This result applies to both the French and German side as well as to the whole sample.

Table 2a: Number of firms in each technology field (FL1-FL6) machinery

Field	FL1		FL2		FL3		FL4		FL5		FL6	
Country	G	F	G	F	G	F	G	F	G	F	G	F
85	4	33		2		1			74	106		
86	5	40		2		1			72	99	1	
87	11	49		2		1			66	90	1	
88	11	58	1	2		1	1		65	81		
89	12	65	2	2	1	1			63	74		
90	16	67	1	2	1	1	1		59	72		
91	20	84	1	1		1	2		55	56		

Table 2b: Number of firms in each technology field (FL1-FL6) electronics

Field	FL1		FL2		FL3		FL4		FL5		FL6	
Country	G	F	G	F	G	F	G	F	G	F	G	F
85	1	15	1		10	17	24	88	1	2	2	1
86		21	3	2	12	14	21	82	1	4	2	
87		32	2	2	13	15	21	71	1	3	2	
88	1	42	3	4	14	17	18	55	1	5	2	
89	2	42	2	3	19	20	12	51	1	7	3	
90	3	47	1	4	19	23	11	39	1	10	4	
91	5	52	4	5	16	14	9	40	2	12	3	

For electronics the development is more "complicated". For both countries FL3 and FL4 show a contrary development where the former tends to gain and the latter clearly looses importance. This applies to both countries. FL1 is a special case. In early periods French firms are already engaged here and their number increases drastically. German companies, however, "detect" FL1 only in 1988/89 with an increasing tendency.

Computing the average ι-value of the technology fields could give an account of the technological level of these fields.[31] Tables 3a and 3b deliver these measures for each

[31] For this measure Forsund/Hjalmarrson (1987), Carlsson (1972).

field and each year. Here, however, one has to be very cautious as (in a cross section comparision) this value tends to be higher for a lower number of firms. This explains why technology fields like FL2 in machinery or FL6 in electronics perform quite well.

Table 3a: ϕ_ι for each technology field: machinery

Field	FL1		FL2		FL3		FL4		FL5		FL6	
Country	G	F	G	F	G	F	G	F	G	F	G	F
85	0.360	0.377		0.938		0.831			0.460	0.462		
86	0.341	0.376		0.923		0.933			0.476	0.465	1.000	
87	0.382	0.363		0.804		0.879			0.459	0.480	0.959	
88	0.362	0.382	1.000	0.833		0.932	0.261		0.464	0.508		
89	0.398	0.386	0.557	0.787	0.097	0.967			0.472	0.500		
90	0.398	0.357	0.958	0.839	0.345	1.000	0.145		0.485	0.470		
91	0.390	0.353	0.956	0.722		1.000	0.178		0.492	0.497		

Interesting is FL1 in electronics. Here the German companies started quite late. However, they were successful in improving their performance continously and the decline in average efficiency of the French firms in 1990 is explained by the fact that german firms took over technology leadership - which is additionally documented by their higher value in 1991.

Table 3b: ϕ_ι for each technology field: electronics

Field	FL1		FL2		FL3		FL4		FL5		FL6	
Country	G	F	G	F	G	F	G	F	G	F	G	F
85	0.183	0.299	0.506		0.338	0.331	0.265	0.308	0.143	0.328	0.996	0.438
86		0.275	0.553	0.350	0.314	0.353	0.223	0.315	0.280	0.280	0.892	
87		0.271	0.624	0.405	0.339	0.330	0.229	0.314	0.292	0.190	0.883	
88	0.153	0.261	0.639	0.383	0.316	0.323	0.241	0.306	0.304	0.277	0.790	
89	0.176	0.275	0.557	0.373	0.302	0.318	0.249	0.298	0.313	0.284	0.825	
90	0.224	0.250	0.447	0.417	0.290	0.353	0.235	0.308	0.294	0.349	0.803	
91	0.328	0.262	0.420	0.435	0.309	0.350	0.251	0.284	0.217	0.315	0.895	

Also interesting are tables 4a and 4b which show the number of movements between the fields during the period 85-91. These figures give an account of the respective fields "attractiveness".

In machinery evidently most of the movements occur between technology fields FL1 and FL5. This furthers the observation that the other technologies are to be considered as rather extreme and cannot be easily applied by "outsiders".

Table 4a: Movements between technology fields during the period 85-91: machinery

Field	FL1		FL2		FL3		FL4		FL5		FL6	
Country	G	F	G	F	G	F	G	F	G	F	G	F
FL1			1						9	16	1	
FL2	1									1		
FL3							2					
FL4					1							
FL5	26	67	1		1							
FL6							1					

In electronics the relations are not so clear-cut. FL2 and FL6 seem to be "outsiders" for both countries. For the other fields country differences become evident. FL5 and FL1 seem to be rather "attractive" for French firms. German firms, however, seem to "jump" mainly between FL3 and FL4.

Table 4b: Movements between technology fields during the period 85-91: electronics

Field	FL1		FL2		FL3		FL4		FL5		FL6	
Country	G	F	G	F	G	F	G	F	G	F	G	F
FL1					2	4		10		11		
FL2					1	2					2	
FL3	3	17	4	4			8	17	1			
FL4	3	44	1	2	19	29						
FL5		1		1								
FL6			1							1		

Table 5a and 5b give an account of the development of the average ι-value of the moving firms. These numbers, however, have to be interpreted carefully. In principle they should give us account of a firm's change in technological position or gap towards the respective technology leader.

For machinery most interesting are the "jumps" between FL1 and FL5. A move from FL1 to FL5 leads on the average to to closening the gap towards the frontier. On the contrary, from FL5 to FL1 the average efficiency declines.

In electronics French firms move quite often into FL1 and FL5 which results in a widening respectively closening of the gap towards the frontier. An equivalent outcome is found for switches between FL3 and FL4 by both countries, where the choice of FL3 (FL4) provides for an improvement (worsening).

Tab 5a: ϕ_t development of moving firms: machinery

Field	FL1		FL2		FL3		FL4		FL5		FL6	
Country	G	F	G	F	G	F	G	F	G	F	G	F
FL1			-0.312						0.063	0.152	0.562	
FL2	0.063									-0.036		
FL3							-0.055					
FL4					-0.164							
FL5	-0.004	-0.043	0.000		-0.018							
FL6							-0.698					

Tab 5b: ϕ_t development of moving firms: electronics

Field	FL1		FL2		FL3		FL4		FL5		FL6	
Country	G	F	G	F	G	F	G	F	G	F	G	F
FL1					0.028	0.012		0.046		0.001		
FL2					0.270	-0.046					0.092	
FL3	-0.059	-0.031	0.002	0.083			-0.078	-0.004	-0.229			
FL4	-0.013	-0.027	-0.123	0.150	0.047	0.020						
FL5		0.009		0.340								
FL6			-0.235							-0.282		

As explanation for this result economic reasons as well as reasons for dynamic efficiency have to be considered. However, this outcome does partly fit into the concept of "elastic barriers" (David (1975)) where a switch into a considerable different technology is accompanyied by technical (as well as economic) inefficiencies.

3.3 Technological/Technical (In)efficiency and Technological Progress

In this chapter we focus on the relationship between the inefficiency measures obtained in the previous paragraph and proxy variables for the firm specific technological progress. Is the relative efficiency position of firms - at least partly - determined by its technological performance?

To make the latter concept operational for empirical analyses one can distinguish between technology input measures such as R&D expenditures and technology output indicators such as patents. Here we will use only R&D expenditures since we yet do not have an account of the respective firms' patenting.[32]

In order to relate our ι-measures to R&D-expenditures we have to reduce the number of firms in the sample. For this analysis we use traditional OLS where ι is the dependent variable and the R&D capital stock and other measures are independent. Some qualifications towards these measures have to be made.

The first one is related to ι when it is used in regression analyses in the following form:

$$\iota = Z\beta + \epsilon \tag{7}$$

Z is the matrix of independent variables and β is the vector of regression coefficients and ϵ is the vector of error terms.

Since the efficiency scores are restricted on $]0,1]$ the error term ϵ is dependent on Z and thus biased and inconsistent estimates for β are to be expected. A proof of this is found in Holvad/Hougaard (1993).

32 For using patent data in this context see Cantner/Hanusch/Westermann (1994).

In order to correct for this one has to look for a procedure transforming ι onto an unrestricted range. Holvad/Hougaard (1993) suggest the following:

$$\ln\left(\frac{1-\iota}{\iota}\right) \tag{8}$$

Consequently the dependent variable is unrestricted and OLS can be applied. For interpreting the regression results, however, one has to keep in mind that the sign of the estimates for the β values is related to the transformed and not the original ι, where the sign is just opposite.

In our estimation we related different independent variables with our efficiency measure. One of these is the R&D capital stock, RDS_t, which we use instead of yearly R&D expenditures, RD_t, for the following reasons:

(a) R&D expenditures cannot be expected to improve productivity at once but only after a certain lapse of time;

(b) technological progress is considered as a cumulative activity.

We suggest therefore that the technological level of a firm which is supposed to have a positive impact of productivity can be approximated by the accumulated R&D expenditures of the past. For this reason we calculate this stock for each firm by the perpetual inventory method where we apply degressive depreciation by a rate of 15%:[33]

$$RDS_t = RDS_{t-1} * 0{,}85 + RD_t \ . \tag{9}$$

The measured relative inefficiency of firms naturally has more than one determinant. Among others one should take into account measures of competitive conditions, product differentiation, geographical specifities, organizational influences and others

33 This is a rate very often used in empirical investigations where R&D capitals stocks are used. See for example Meyer-Krahmer/Wessels (1989) for the German manufacturing industry.

more.[34] In the context of our analysis we are mainly interested in whether technological factors can be attributed to determine the relative position of firms. The following OLS results are therefore to be taken as to test the sign of the investigated relations rather than an estimate of a complete theoretical model. Therefore, we include RDS/L as the R&D capital stock per labour; K/L, the capital/labour ratio takes into account the effects of an increasing mechanisation of the production process; RD/Y is the R&D intensity; the time variable ETP should cover not specified trend effects such as exogenous technical progress; finally in certain runs we include dummy variables DCL for the respective technology fields in order to catch technology specific fixed effects.

For RDS/L, ETP we expect a negative coefficient because R&D and exogenous technical progress should improve the relative position of a firm with respect to the all-time best-practice frontier. RD/Y is expected to have a positive sign because the R&D expenditures in year t are assumed to increase productivity only in later years. The coefficient of K/L can have either sign, however, whenever process innovations are embodied in investment the sign should be negative.[35] For the respective technology fields we include dummy variables DCL.

Tables 6a and 6b show our results for the coefficients, the t-values (in parenthesis) and the R^2 measures for two model variants. The first one does not take into account the technology fields identified above, whereas the second one does.

Considering the variants 1 and 2 for both sectors and the full sample it is evident that the consideration of technology fields improves the estimation. Splitting into respective country subsets additionally shows that technology fields are more important in the case of Germany. Below the results for the technology fields the ranking of the fields with respect to their efficiency level is reported. For electronics this ranking is quite similar for both countries. In machinery, however, the less important fields FL4 and FL3 dominate in the case of Germany.

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34 For a discussion of these aspects see for example Caves/Barton (1990).

35 It would be interesting to include here investment data in order to take into account vintage effects. As yet, our data do not allow to take this into account.

Table 6a: Regression Results for the Machinery Sector

variant	const.	RDS/L	K/L	RD/Y	ETP	DCL	R^2
full sample with French and German firms							
1	6,9599 (80,704)	-0,0044 (-4,961)	0,000001 (1,619)	0,0013 (0,352)	0,0223 (1,166)	-	0,04
2	-	-0,0040 (-4,159)	0,000007 (2,914)	-0,0002 (-0,045)	-0,0124 (-0,692)	5 of 6 sign. 3>1>5>4>2	0,22
only French firms							
1	6,419 (35,775)	-0,0512 (-5,809)	0,00003 (6,459)	15,367 (3,628)	-0,0191 (-0,532)	-	0,20
2	-	-0,0485 (-4,776)	0,00003 (4,298)	14,341 (3,079)	-0,0201 (-0,557)	3 of 3 sign. 1>5>2	0,20
only German firms							
1	7,027 (75,298)	-0,0033 (-4,238)	0,000001 (0,052)	0,0013 (0,401)	0,0140 (0,672)	-	0,06
2	-	-0,0044 (-5,770)	0,000003 (1,200)	-0,0007 (-0,267)	-0,0126 (-0,719)	5 of 6 sign. 4>3>1>5>2	0,38
specific fields with French and German firms							
FL1 n=230	7,358 (33,392)	-0,0072 (-2,602)	-0,000001 (-0,162)	-0,0006 (-0,175)	0,0281 (0,912)	-	0,03
FL2 n=12	5,316 (2,085)	-0,098 (-1,336)	0,0001 (2,966)	28,876 (0,537)	0,0017 (0,007)	-	0,46
FL5 n=499	6,171 (50,476)	-0,0046 (-4,624)	0,00005 (9,680)	-0,0017 (-0,189)	-0,0436 (-2,208)		0,21

Investigating the signs of the different variables, we find that in most equations the signs of RDS/L and K/L are both significant but of different sign. The negative coefficient of RDS/L implies that a higher R&D capital stock per unit of labour leads to a higher relative efficiency score. Contrariwise, a higher degree of mechanisation implies a lower relative efficiency. The signs of RD/Y are as expected but in most cases they are not sigificant. For ETP a conclusive result is not obtainable.

Table 6b: Regression Results for the Electronics Sector

	const.	RDS/L	K/L	RD/Y	ETP	DCL	R^2
full sample with French and German firms							
1	7,651 (91,663)	-0,0004 (-2,855)	0,000002 (1,833)	0,2817 (2,520)	0,0016 (0,085)	-	0,02
2	-	-0,0004 (-3,217)	0,00001 (3,128)	0,2241 (2,363)	0,0067 (0,417)	6 of 6 sign. 4>1>3>2>5>6	0,29*
only French firms							
1	7,546 (79,745)	-0,0023 (-2,535)	0,000003 (2,121)	1,5287 (3,024)	0,0074 (0,371)	-	0,03
2	-	-0,0020 (-2,230)	0,0001 (2,985)	1,3663 (2,690)	-0,0035 (-0,168)	6 of 6 sign. 4>1>3>2>6>5	0,07
only German firms							
1	7,648 (39,192)	-0,0004 (-2,129)	0,000005 (1,326)	0,2342 (1,658)	0,0068 (0,166)	-	0,03
2	-	-0,0004 (-4,764)	0,00001 (1,622)	0,2138 (2,990)	0,0334 (1,547)	6 of 6 sign. 1>4>3>5>2>6	0,76
specific fields with French and German firms							
FL1 n=183	7,775 (37,500)	-0,0004 (-3,762)	0,000003 (0,926)	0,2016 (2,605)	-0,0025 (-0,097)	-	0,08
FL2 n=22	6,973 (37,071)	-0,0021 (-1,065)	-0,00001 (-0,491)	3,984 (0,738)	0,0628 (1,690)	-	0,18
FL3 n=149	7,396 (52,694)	-0,0010 (-1,584)	0,00001 (2,698)	0,7717 (1,818)	-0,0091 (-0,476)	-	0,07
FL4 n=284	7,996 (60,894)	-0,0056 (-3,024)	-0,00002 (-2,848)	2,1009 (2,590)	0,0563 (2,523)	-	0,07
FL5 n=40	7,292 (4,634)	0,0006 (0,150)	0,000005 (0,479)	2,2304 (0,895)	-0,1132 (-0,679)	-	0,12
FL6 n=8	3,727 (0,568)	-0,0774 (-0,323)	-0,0006 (-0,854)	393,16 (0,996)	1,3861 (3,058)	-	0,58

Additional runs specific to the technology fields repeat these results only partly. The signs of the coefficients are again as expected, their significance as well as the R^2, however, lower. Only for less "populated" technologies the estimation fit improves which, however, is combined with mostly insignificant coefficients.

Summarizing, we can conclude that the accumulated R&D capital stock has a considerable positive impact on the firms relative position towards the all-time best-practice frontier.[36] Moreover, the various technology fields have a specific (fixed) effect.

4. Conclusion

This paper delivers an empirical study on technological performance and diversity within the French and German machinery and electronics sector for the years between 1985 and 1991. Based on concepts from modern innovation theory we employ a non-parametric linear programming procedure, DEA, which allows (a) to compute an index for the relative technological and technical inefficiency of firms and (b) to determine certain technology fields differing by their relative use of input factors.

Our study shows that it is possible (a) to find a structure of technological inefficiencies characterized by several technological leaders and (b) to detect several technoloy fields which takes into account technological diversity. A dynamic analysis delivers

(a) that the total efficiency of the machinery sector improves over time whereas in electronics there is a declining tendency;

(b) that there are differences among the respective technology fields.

It is also shown that the R&D-capital stock influences the technological position of a firm. Moreover, in this respect the various technology fields show up significant.

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[36] Comparing also the magnitude of the respective coefficients does not lead to additional insights because the efficiency scores are a relative concept applicable only on a intrasectoral basis.

Comparing the French and German firms it becomes evident that a number of differences exist, e.g. the most "attractive technology fields", catch-up behaviour, technology specific development of efficiency, significance of technology for the efficiency of R&D, etc.

Although our results do very much confirm the notion that technological progress is an important determinant of firm performance in both countries and both sectors some qualifications necessarily have to be made. First, all what we know about the technology of a firm is deduced by a very rough procedure, e.g. technologies are distinguished by their factor input ratios. An analysis related to more technical aspects would be very much appreciated here. For future work we consider to use more information on the production structure as well as qualitative innovation data to improve our results. Second, quite crucial for our results is obviously how the factor "capital" is defined. Vintage effects, capacity utilisation, technical life cycle, etc. are not considered yet. Some improvement on this is expected whenever longer time series data completed with more reliable investment figures are available. Last but not least, the analysis of efficiency scores has to be worked on in order to distinguish between the top firms which are as yet not comparable ($\iota=1$). Those improved measures might then help - in a longer times series analysis - to compare different technology fields and their comparative development directly.

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Beiträge in der Volkswirtschaftlichen Diskussionsreihe seit 1991

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