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A Data Envelopment Analysis for the French Machinery Industry

by

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1. Introduction

In the past there has been a continuous interest in the investigation of various sorts of inefficiency in the production process. This kind of analysis has a long tradition in the economics of the public sector where the lack of market forces "produces" inefficiencies.[1] However, research interest has also shifted to the private sector production where inefficient production can also be detected. Traditionally there are two lines of explanation put forward so far. The first one puts main emphasis on presumptive market failures. Here on the one hand the behavioural appoach to business organizations points to the large renegotiating costs among the agents who cooperate in an ongoing enterprise[2]; and on the other hand industrial organization has advanced oligopolistic models which are able to explain the dispersion of competitors' efficiency levels.[3] A second line of research picks up sources of asymmetric productivity levels which do not rely on market failures. Here the main emphasis is on product differentiation[4], spatial market fragmentation[5], or "institutional split"[6].

In this paper we want to take into account another approach stating that the different technological levels of firms are responsible for a diverse industry structure. The main theoretical foundation is laid down by the modern innovation theory. Here firm specific technologies are the outcome of and a determinant for incremental technological progress at the micro level. By the very nature of the underlying technological knowledge being mainly a private good, technological progress shows strong cumulative features. This implies that there exists a variety of technological approaches, i.e. production functions, and that economic determinants are of only secondary importance

1 See for example Bös (1988), Hanusch/Cantner (1991).

2 See for example Crew/Jones-Lee/Rowley (1971), Leibenstein (1976), McCain (1975).

3 For inefficiencies accruing from entry barriers see for example Brandner/Spencer (1985), Mankiw/Whinston (1986). On the effects of excess capacity see Caves/Jarrett/Loucks (1979).

4 See for example Carlsson (1972).

5 See for example Moomaw (1981, 1985).

6 See Caves/Barton (1990).

for further technical advancements. Consequently a variety of technological approaches may prevail within an industry and several technology leaders might be identified.

Based on this view of a technology dependent industry structure, the analytical procedure we employ has to take into account that contrary to traditional frontier-production analysis there may exist more than one best-practice technique. Since the traditional neoclassical econometric approaches to determine frontier production function determine only one best-practice technology - at least at the outset-, these methods are not suitable for our problem. Instead we apply a non-parametric linear programming method originally developed by Farrell (1957) and further elaborated by Charnes/Cooper (1962, 1985). This method has recently been used in empirical studies for the private sector such as in Thore/Kozmetsky/Phillips (1992), Berg/Forsund/Hjalmarsson/Suominen (1993), or Cantner/Hanusch/Westermann (1993).

Applying this method our empirical analysis focusses on the machinery sector in France. For this sector we are able to detect several best-practice technologies as well as a measure for technological inefficiency. Coupled with a traditional cluster analysis technology leaders can be assigned to specific "technology fields".

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.

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 entirely 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.[7] Instead, the modern approach distinguishes between public knowledge on the one hand and private[8], 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.[9] 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[10], they nevertheless differ in their technological approach to produce.

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.[11] This implies (a) that further technological advances are mainly determined and constrained by the technique(s) a firm has been using in the past[12] and

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

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

9 See Dosi (1988).

10 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.

11 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)).

12 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".[13]

A major consequence of this view is that - contrary to standard neoclassical theory - 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.[14] 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

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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.

13 See Atkinson/Stiglitz (1969).

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

techniques - at least in the short-run - to be of zero elasticity of substitution at 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.[15]

(ii) For the medium and long-run one still could assume a strongly localized technological[16] 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.[17] The observation of an increasing mechanisation of the production processes is thus taken into account.[18]

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.[19]

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15 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.

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

17 See David (1975).

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

19 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.

(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 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.[20]

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 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.

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20 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.[21] 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

21 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.[22] Here one can think of a Leontief-type production function.[23] 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.[24]

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, $l \in \{1,\dots,n\}$, out of the sample:

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

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

$$u, v > 0.$$

22 See Chang/Guh (1991) p.217.

23 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.

24 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.[25]

Since we employ linear arithmetic aggregation functions for inputs and outputs, (3) is to be rendered as a problem of linear fractional programming.[26] 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:

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

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.

25 This procedure is also known from activity analysis.

26 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[27] 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:[28]

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

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

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

28 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:

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

NB:

$$\begin{aligned} Y\lambda - s^- &= Y_t \\ \theta X_t - X\lambda - s^+ &= 0 \\ \lambda, s^+, s^- &\geq 0 \end{aligned} \qquad (6)$$

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.[29] Vector e^T contains only elements 1.[30] 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.[31]

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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29 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.

30 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.

31 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

The data set we investigate contains time series data of 142 French machinery firms of different sub-branches. This data set is time consistent in the sense, that we have neither entries nor exits of firms over the whole period of investigation, 1984 to 1991. All firms under consideration are of the legal form "shareholder's company" and employ more than 200 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 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 French machinery industry. "Material" consists of the deflated profit&loss position "raw materials and supplies".

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".

3.2 Procedure of Investigation

Our empirical analysis proceeds in three main steps related (a) to the technological structure, (b) to the dynamics of this structure, and (c) to the aspect of technological variety.

(a) The Technological Structure of the Sector

We start our analysis by investigating the productivity structure of the sample. Here we attempt to detect the efficient firms for each year, the stability of the efficient set over time and the ratio of efficiently produced output. For that we compute ι values as results of year by year considerations. Thus, a efficiency frontier is determined for each year which allows to evaluate the (relative) inefficiencies of the "non-frontier" firms.

(b) The Dynamics of the Technological Structure

In the next step we want to learn something about the dynamics of technologically determined structure. Here we are interested in the "speed" (a) of the movement of the efficiency frontier and (b) of the non-efficient firms (adopting new technologies or improving old ones). So we compute a second kind of ι value comparing all firms over the whole period (1984 - 1991) in order to find an "all time best practice" frontier. The ι values of the formerly efficient firms for each year could now be interpreted as the year by year movement of the frontier towards (or away from) the "all time best practice" frontier. Evaluating additionally the inefficient firms with respect to the "all time best practice" frontier describes the development of the whole sector.

(c) The Variety of Technologies

Another catalogue of computations deals with the questions of differences between the efficiency leaders, the definition of "technology fields" numbers of switches between such fields. In order to deal with these questions, we combined our DEA results with a traditional "cluster analysis" clustering by factors consisting of input ratios.

3.3 Empirical Results

According to our route of investigation in 3.2 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?

(3) How much of the output of a year is produced efficiently?

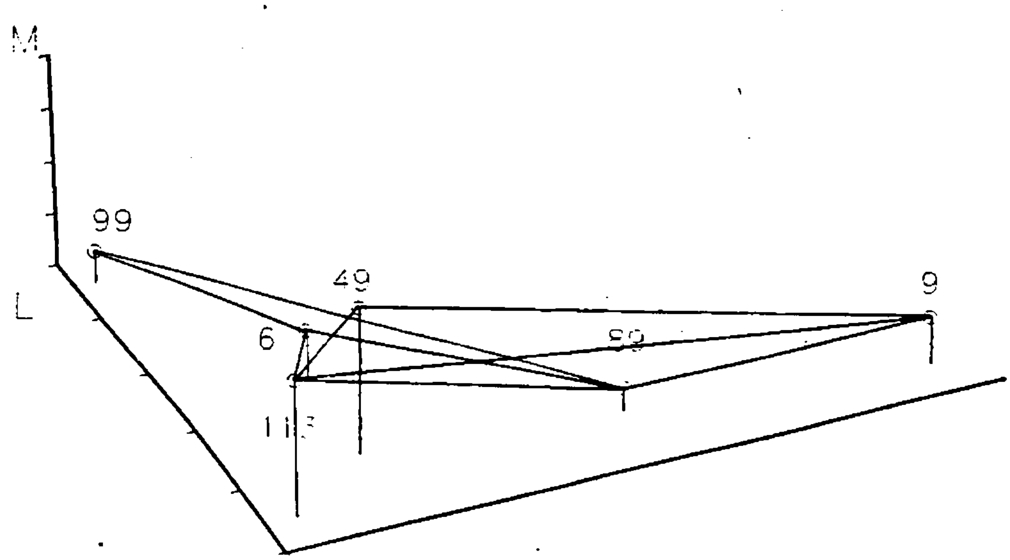

Fig. 1 Efficiency Frontier 1984

Before we start our detailed analysis it might be interesting to visualize the efficiency frontier in the case of the French machinery sector. Figure (1) delivers the graphical representation of the frontier for the year 1984. It is easy to identify the convex envelope with it's facets, built up by the DEA-efficient firms 6, 9, 49, 89, 99 and 113.

Figure (2) shows the DEA-efficient firms in a year by year view and the periods they stay on the frontier. There are four firms that are continously members of the efficient set (# 6, 9, 89, 99). Others improve their efficiency up to 1,0 during the period under consideration (# 21, 105). Firms like #113 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 6 to 9 firms per year with no significant de- or increasing tendency.

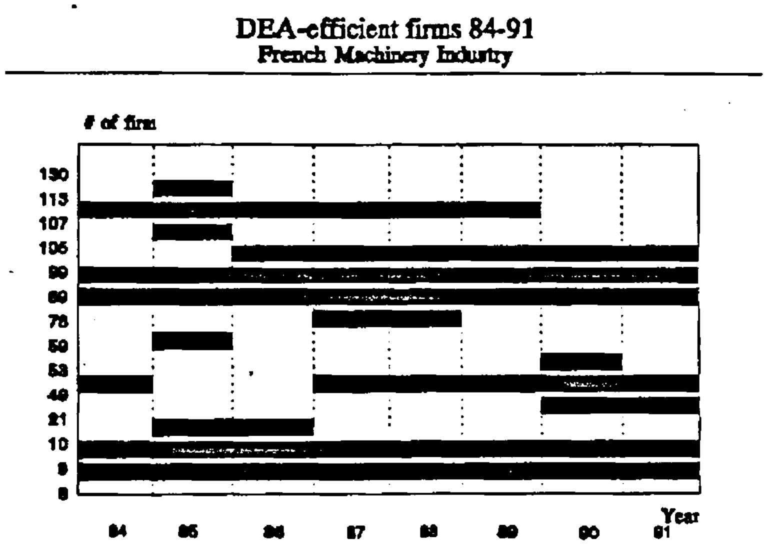

Fig. 2

From this we learn that the structure of the technological frontier changes quite rapidly. One can imagine some of the facets vanishing and others appearing from period to period. We assume that only the technologically best firms stay and stamp the envelope for a longer time. In further studies we will try to find out the reasons for this behaviour (R&D, firm size, etc.).

In order to put the "weight" of the frontier firms in it's proper place, it is necessary to know how much of the sample's output is produced by them. Figure (3) presents the percentage of efficiently produced output and indicates a declining tendency.

This could be interpreted in a way that either the technical efficient firms are loosing market share or the importance of smaller firms for the technological development is increasing. In this context it is important that for the number of efficiently producing firms there is no decreasing tendency (see figure 2).

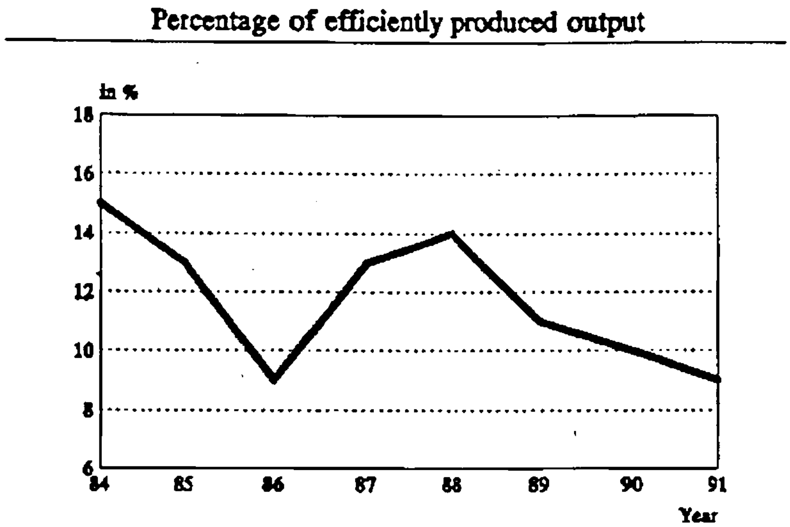

Fig. 3

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

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

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

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

These questions lead to dividing the sample of firms in two sub-groups. One of them including only the efficient firms, the other one consisting of the not efficient firms. Figure (4) shows the average "year by year" ι of the inefficient group (i-ned) together with the average "year by year" ι of the efficient firms (i-ed) (that of course has to be 1,00 by definition). To obtain a measure of the movement of the frontier we compute another average ι for the efficient sub-sample (i-edt) as a comparison with the "all time best practice" frontier.

For the year 1986 figure (4) 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 performed really better, even compensating the shifting of the frontier.

Development of Different Average IOTA Series

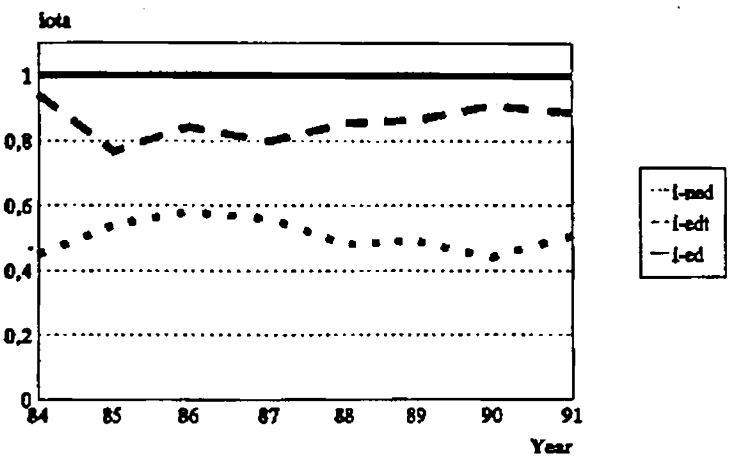

Fig. 4

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 as well an increasing trend from 0.36 (1984) to 0.40 (1990) to 0.37 (1991). Therefore, the whole sector shifts towards more technical efficiency.

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

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

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

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

(10) How strong is the influence of the sub-branches to the definition of the "technology fields"?

In the year 1984 we discovered six firms with an ι of 1,00. The frontier in figure (1) 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 approximated by a Leontief production function as stated in 2.1). Firm #9 and firm #113 for example are the two opposite sides in the usage of "capital". Firm #49 and firm #89 mark the opposite ends of the "material" use continuum. So it is obvious that there exist more than one efficient "technology" in order to produce the same group of goods (here: machinery goods).

The fact that we detected some firms applying extremly differing "technologies" (technicaly) very successfully, brought up the question whether it was 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 applied 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. This delivers four different clusters of input ratios which we label "technology fields". For these fields the DEA assignment is confirmed by 75 percent. Moreover, in two of the four clusters more than one efficient firms join the same "technology field".

Tab 1: Number of firms in each technology field (FL1-FL4)

year	FL1	FL2	FL3	FL4
84	30	1	109	2
85	28	1	111	2
86	33	1	106	2
87	33	4	103	2
88	35	4	101	2
89	30	5	105	2
90	33	6	100	3
91	47	10	83	2

Table 1 gives an account of the number of firms joining the four technology fields. It is evident that the main fields are FL1 and FL3 where the importance of the first is increasing, the one of the latter decreasing over time. The less important fields are characterized by firms using very intensively material (FL4) and capital (FL2) respectively. Figure 1 does show this for the year 1984 with firm #9 (FL2) and firm #49 (FL4).

Tab 2: $\phi\iota$ for each technology field

	FL1	FL2	FL3	FL4
84	0,3157	0,8847	0,3765	0,9243
85	0,3371	0,7443	0,3847	0,9239
86	0,3098	0,8385	0,3935	0,9040
87	0,2994	0,5440	0,3991	0,7580
88	0,3368	0,5852	0,4061	0,7869
89	0,3524	0,5551	0,3895	0,7717
90	0,3416	0,5380	0,4228	0,7621
91	0,3187	0,4437	0,4197	0,7402

The average ι of the technology fields could give an account of the technological level of these fields. 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. Taken this into account, comparing FL1 and FL3 suggests that the (average) technological level of FL3 is higher.

Table 3 shows the number of movements between the fields during the period 84-91. Evidently most of the movements occur between technology fields FL1 and FL3. This again furthers the observation that the technologies in FL2 and FL4 are rather extreme and cannot be easily applied by "outsiders".

Table 4 gives an account of the development of the average ι, table 5 of the total ι of the moving firms. These numbers have to be interpreted carefully. A change into technology field FL1 leads to a worsening of relative technological efficiency.

Tab 3: Movements between technology fields during the period 84-91

	FL1	FL2	FL3	FL4
FL1		2	39	1
FL2	2		3	
FL3	57	12		
FL4			1	

A contrary result is found for a "jump" into FL3. One reason for this is the fact that the gap between the technology leaders and the followers in FL1 is larger compared to FL3. A deeper investigation on why firms nevertheless change to FL1 has to be accomplished in further steps. Economic reasons as well as reason for dynamic efficiency have then to be considered. However, this result does 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.

Tab 4: $\phi\iota$ development of moving firms

	FL1	FL2	FL3	FL4
FL1		0,0511	0,0237	-0,3681
FL2	-0,0314		0,1320	
FL3	-0,0081	-0,0079		
FL4			-0,1601	

Tab 5: Total ι development of moving firms

	FL1	FL2	FL3	FL4
FL1		0,1021	0,9230	-0,3681
FL2	-0,0629		0,3959	
FL3	-0,4592	-0,0947		
FL4			-0,1601	

The final step is to check wether the sub-branches had some relevant influence on the formation of "technology fields". So we look at the efficient firms at a four digit branch level. Here we detect that to each sub-branch at least the two technology fields FL1 and FL3 can be assigned. It is therefore not possible to deduce the technology field from the sole knowledge of the sub-branch.

4. Conclusion

This paper delivers an empirical study on technological performance and diversity within the French machinery sector for the years between 1984 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 sector improves over time and (b) that there are differences among the respective technology fields.

Certainly, our study shows only the structure the machinery sector and its change during time without asking for their determinants. Any analytical results pointing to the suspected driving force of these developments, i.e. technological progress, have not been included yet. Additionally, one has to consider how technical efficiency as determined here is related to economic efficiency, i.e. profitablility. Both aspects will be the topic of our next investigations.

References

Abramovitz M. (1988), Thinking about Growth, Stanford: Standford University Press, 1988.

Ahmad S. (1966), On the Theory of Induced Invention, Economic Journal, vol.76, 1966, pp.344-57.

Atkinson A. and J.E. Stiglitz (1969), A New View of Technological Change, Economic Journal, vol.79, 1969, pp.573-78.

Berg S.A., R.F. Forsund, L. Hjalmarsson and M. Suominen (1993), Banking Efficiency in the Nordic Countries, Journal of Banking and Finance, vol.17(2/3), 1993.

Böhm K.(1978), Lineare Quotienteprogrammierung - Rentabilitätsoptimierung, Frankfurt a.M.: Haag+Herchen Verlag, 1978.

Bös D. (1988), Introduction: recent Theories on Public Enterprise Economics, European Economic Review, vol.32, 1988, pp.409-14.

Brandner J.A. and B.J. Spencer (1985), Tacit Collusion, Free Entry and Welfare, Journal of Industrial Economics, vol.33, 1985, pp.277-94.

Cantner U., H. Hanusch and G. Westermann (1993), Technological Inefficiencies in Asymmetric Industries, SPES-working paper "Comparative Economics of R&D" no.5 , 1993.

Carlsson B. (1972), The Measurement of Efficiency in Production: An Application to Swedish Manufacturing Industries 1968, Swedish Journal of Economics, vol.74, 1972, pp.468-85.

Caves R.E. and D.R. Barton (1990), Efficiency in U.S. Manufacturing Industries, Cambridge: MIT Press, 1990.

Caves R.E., J.P. Jarrett and M.K. Loucks (1979), Competitive Conditions and the Firm's Buffer Stocks: An Exploratory Analysis, Review of Economics and Statistics, vol.61, 1979, pp.485-96.

Chang K.-P. and Y.-Y. Guh (1991), Linear Production Functions and the Data Envelopment Analysis, European Journal of Operations research, vol.52, 1991, pp.215-23.

Charnes A. and W.W. Cooper (1962), Programming with Linear Fractional Functionals, Naval Research Logistics Quarterly, vol.9, 1962, pp.181-86.

Charnes A., W.W. Cooper and R.M. Thrall (1986), Classifying and Characterizing Efficiencies and Inefficiencies in Data Envelopment Analysis, Operations Research Letters, vol.5(3), 1986, pp.105-10.

Crew M.A., J.W. Jones-Lee, and C.K. Rowley (1971), X-Efficiency Theory versus Managerial Discretion Theory, Southern Economic Journal, vol.38, 1971, pp.173-84.

David P. (1975), Technical Choice, Innovation and Economic Growth, Cambridge: Cambridge University Press, 1975.

Dosi G. (1982), Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change, Research Policy, vol.2(3), pp.147-62.

Dosi G. (1984), Technical Change and Industrial Transformation, London: Macmillan, 1984.

Dosi G. (1988), The Nature of the Innovative Process, in: Dosi et al. (1988), pp.221-38.

Dosi G., C. Freeman, R. Nelson, G. Silverberg and L. Soete (1988), Technical Change and Economic Theory, London, New York: Pinter Publishers, 1988.

Dosi G., K. Pavitt and L. Soete, (1990), The Economics of Technical Change and International Trade, New York et al.: Harvester Wheatsheaf, 1990.

Färe R. and W. Hunsaker (1986), Notions of Efficiency and Their Reference Sets, Managment Science, vol.32(2), 1986, pp.237-43.

Farrell M.J. (1957), The Measurement of Productive Efficiency, Journal of the Royal Statistical Society, Series A, vol.120, 1957, pp.253-81.

Fellner W. (1961), Two Propositions in Theory of Induced Innovation, Economic Journal, vol.71, 1961, pp.305-8.

Freeman C. and L. Soete (ed), New Explorations in the Economics of Technological Change, London, New York: Pinter Publishers, 1990.

Green H.A.J. (1964), Aggregation in Economic Analysis, Princeton: Princeton University Press, 1964.

Hanusch H. and U. Cantner (1991), Produktion Öffentlicher Leistungen, Effizienz und Technischer Fortschritt, Jahrbuch für Nationalökonomie und Statistik, Vol.208(4), 1991, pp.369-84.

Hanusch H. and M. Hierl (1992), Productivity, Profitability, and Innovative Behaviour in West German Industries, in: Scherer/Perlman (1992), pp.237-50.

Kendrick J.W. (1956), Productivity Trends: Capital and Labor, Review of Economics and Statistics, Vol.38, 1956, pp.248-57.

Leontief W.W. (1947), Introduction to a Theory of the Internal Structure of Functional Relationships, Econometrica, vol.15, 1947, pp.361-73.

Mankiw N.G. and M.D. Whinston (1986), Free Entry and Social Inefficiency, Rand Journal of Economics, vol.17, 1986, pp.48-58.

McCain R.A. (1975), Competition, Information, Redundancy: X-Efficiency and the Cybernetics of the Firm, Kyklos, vol.28(2), 1975, pp.286-308.

Moomaw R.L. (1981), Production Efficiency and Region, Southern Economic Review, vol.48, 1981, pp.344-57.

Moomaw R.L. (1985), Firm Location and City Size: Reduced Productivity Advantages as a Factor in the Decline of Manufacturing in Urban Areas, Journal of Urban Economics, vol.17, 1985, pp.73-89.

Ott A.E. (1959), Technischer Fortschritt, in. Handwörterbuch der Sozialwissenschaften, Bd.10, Stuttgart, 1959, pp. 302-16.(1959).

Salter W. (1960), Productivity and Technical Change, Cambridge: Cambridge University Press, 1960.

Scherer F.M. and M. Perlman eds. (1992), Entrepreneurship, Technological Innovation, and Economic Growth, Ann Arbor: University of Michigan Press, 1992.

Thore S., G. Kozmetsky and F. Phillips (1992), DEA of Financial Statements Data: the U.S. Computer Industry, Journal of Productivity Analysis, 1992.

Verspagen B. (1990), Localized Technological Change, Factor Substitution and the Productivity Slowdown, in: Freeman/Soete (1990), pp.193-211.

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