UNIVERSITY OF VAASA

FACULTY OF TECHNOLOGY

INDUSTRIAL MANAGEMENT

Thorsten Frehe

AN EFFICIENCY EVALUATION OF SMALL AND MEDIUM SIZED INDUSTRIES BY DATA ENVELOPMENT ANALYSIS

Master´s Thesis in

Industrial Management

VAASA 2013

TABLE OF CONTENTS

ABBREVIATIONS

BCC	DEA method by Banker, Charnes, Cooper, 1984
CCR	DEA method by Charnes, Cooper, Rhodes, 1978
CRS	Constant Returns on Scale
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DRS	Decreasing Returns on Scale
EF	Efficiency Frontier
FDH	DEA method with Free Disposal Hull
IRS	Increasing Returns on Scale
LP	Linear Programming
OTE	Overall Technical Efficiency
PTE	Pure Technical Efficiency
RAM	DEA method with Range Adjusted Measure
SE	Scale Efficiency
VRS	Variable Returns on Scale

KEYWORDS

Operations Research, Data Envelopment Analysis, Technical Efficiency, Small and Medium-sized Enterprises

TABLE OF FIGURES

UNIVERSITY OF VAASA		
Faculty of Technology		
Author:	Thorsten Frehe	
Topic of the Master´s Thesis:	An efficiency evaluation of small and medium sized industries by Data Envelopment Analysis	
Supervisor:	Professor Josu Takala	
Adviser:	Päivi Helena Haapalainen	
Degree:	Master of Science in Economics and Business Administration	
Major subject:	Industrial Management	
Year of Entering the University:	2009	
Year of Completing the Master´s Thesis:	2013	**Pages: 90**

ABSTRACT

This thesis wants to introduce into the concepts of data envelopment analysis. DEA is a non-parametric tool in the field of Operations Research applying linear programming. Data Envelopment analysis determines the technical efficiencies of decision making units by putting their relevant input and output values in relation and comparing the obtained ratios with each other. Received results support the activities of business performance management. For this research a data envelopment analysis of several industries has been deployed to obtain rankings for their technical efficiencies.

The data of this quantitative study was collected by aid of questionnaires from several small or medium-sized companies from the region North-Ostrobothnia, Finland, of which 6 returned feasible answers.

As a result of this analysis, indicators for potential process improvements are obtained and advices to the decision makers of the evaluated enterprises can be provided. The information should help to determine particular poor and well performing units and the participating companies are then to reallocate resources in order to promote their operational performances.

Due to the limited amount of data which represent the base of this research, a part of this thesis is also focusing onto the significance of achieved results. Thus this thesis tries to find answers to the following questions:

- Under which circumstances results of a data envelopment analysis have the highest degree of validity and quality and thus are most trustworthy?

- Under which circumstances participating companies could benefit most from conducting a data envelopment analysis?

In conclusion it can be said that the unlike business areas of the participating companies and the limited amount of usable data might yield in weak results. Especially a research continuation with an increase of case companies could boost the significance of this evaluation. Thus, before taking actions, companies should pursue a more profound internal research to reinforce arguments for a necessary reorganization and to clarify the optimal way of resource allocation.

1. INTRODUCTION

As has been pointed out by a constantly growing amount of literature small and medium-sized enterprises (SMEs) contribute a vital part to most of the developed economies. As e.g. Luostarinen, Korhonen, Jokinen and Pelkonen 1994 claim the role of SMEs has grown significantly, and the Finnish SMEs have become increasingly globalized during the last decades. According to the latest report of Statistics Finland (Nov. 2012), Small and Medium sized companies represent 99,8 per cent of all enterprises. They account for 51 per cent of the total turnover of the Finnish economy and employ 65 per cent of all personnel. These figures have not changed significantly during the last years. However, in compare to small enterprises (personnel <50), the number of medium-sized enterprises and their personnel increased three times as much over the recent years.

This thesis focuses on the efficiency analysis of some Finnish small and medium- sized enterprises (SMEs) of the manufacturing industry. All companies are located in the region of Northern Ostrobothnia and are engaged in wood processing, sports equipment or factory automation. For data collection the participating companies were asked to fill a questionnaire with questions about certain financial figures of recent years (see Appendix 1).

The small to medium-sized manufacturing enterprise has consistently demonstrated the ability to innovate and bring to the market new technologies and advancement in manufacturing (Ahmad & Qiu 2008: 79–89) SMEs in industrialized nations function as the supplier base for domestic manufacturing. However, as more businesses are going global, SMEs face a new challenge in competing in the competitive global market.

The importance of SME and its relation to globalization can be considered broad and there are many various aspects one can look at (Ahmad 2006: 1106 - 1112). The data collection which is base for this research was trying to evaluate different enterprise data in order to gain insight into company efficiencies and thus their readiness for international markets. The research concentrated on the three areas dynamic capability, innovation capability and competitiveness (Heilbrunn, Rozenes & Vitner 2011). The author believes, that examining those competences will provide information about the SMEs' performances and eventually help them to understand the problems and opportunities confronting their operations.

This thesis wants to highlight the most critical factors on which every SME should concentrate its efforts to improve overall performance and thus increase chances of successful participation in global markets.

However, to what degree, results obtained from a data envelopment analysis can be trusted depends on several factors. A successful DEA evaluation requires, like most other comparing measurement approaches too, an appropriate amount of data. In addition the data envelopment analysis depends highly on the comparability of participating companies. This is due to the fact that the DEA method is a so called "best practice" approach (Charnes, Cooper & Rhodes 1978) which means that, once the best performer is identified, all other DMU´s will be compared to the benchmarking DMU. Should participants be of too different areas, a comparison might lead to wrong results.

Due to above mentioned reasons this paper will therefore also try to provide answers to the question which factors will affect the reliability and significance of results obtained from a data envelopment analysis.

2. METHODS

The Steering Committee for the Review of Commonwealth defines Efficiency like this: *"Efficiency is the success with which an organization uses its resources to produce outputs — that is the degree to which the observed use of resources to produce outputs of a given quality matches the optimal use of resources to produce outputs of a given quality. This can be assessed in terms of technical, allocative and dynamic efficiency."* (1997)

2.1. Evolvement of DEA

Analysts differ between four types of technical efficiency estimations based on their varying assumptions (Coelli, Prasada Rao, O'Donnell & Battese 2005). Those are:

- Data Envelopment Analysis (DEA)
- Stochastic Frontier Approach (SFA)
- Thick Frontier Approach (TFA)
- and Distribution Free Approach (DFA)

"They differ from one another on the basis of the arbitrary assumptions used to disentangle efficiency differences." (Sharma, Raina & Singh 2012) We can separate those approaches into two categories, parametric and non-parametric methods. Of the four mentioned methods, this thesis focuses on the only non-parametric approach, the Data Envelopment Analysis.

Firstly introduced into OR literature by Charnes, Cooper, Rhodes in 1978. Following the initial letters of its inventors the method is called CCR analysis. This first model was build on the assumption of a constant returns on scale for the evaluated technologies, therefore this method is also referred to as CRS method. In what turned out to be a major breakthrough, Bankers, Charnes and

Cooper extended 6 years later the CCR model to accommodate technologies that exhibit variable returns on scale which is named accordingly as BCC analysis or respectively VRS method. In subsequent years, methodological contributions from a large number of researchers accumulated into a significant volume of literature around the CCR/BCC models, and the generic approach or DEA emerged as a valid alternative to regression analysis for efficiency measurement. (Cooper, Seiford & Zhu 2011)

Fig. 1 shows the increasing amount of DEA publications between 1976 and 2006. Especially the introduction of the BCC method in 1984 provided a fertile ground for the constant growth of interest into this research method.

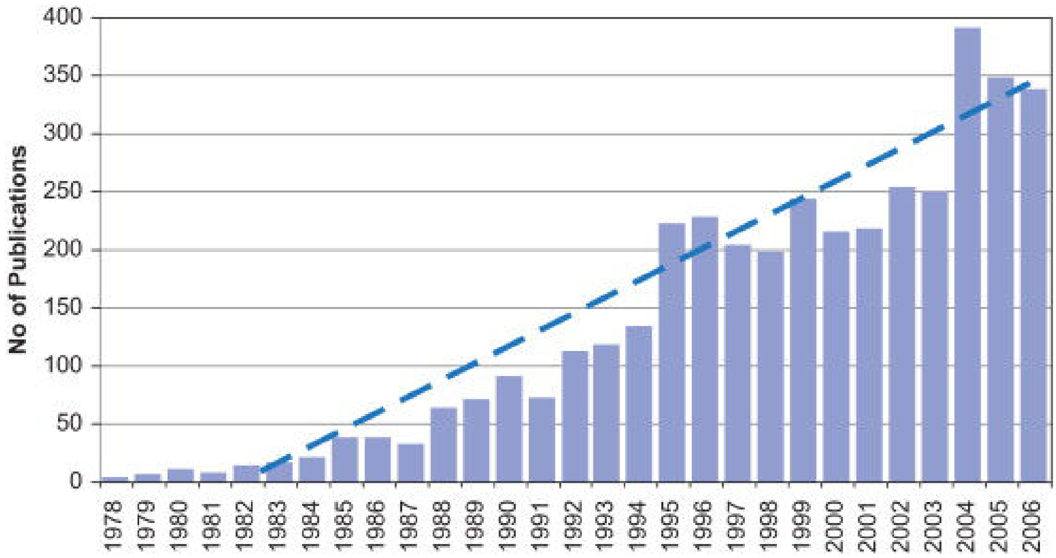


Figure 1. Distribution of DEA publications by year (Emrouznejad, Parker & Tavares 2008)

The extensive literature about this subject has produced many different ways to apply the data envelopment analysis. In order to adapt this method to different circumstances, researchers have introduced in the course of the last 30 years a variety of different method variations. This study will however focus onto the original DEA models introduced by Charnes, Cooper, Rhodes respectively

Bankers, Charnes, Cooper. The following paragraphs want to provide an insight into the mechanisms of a Data Envelopment Analysis.

2.2 Introduction into DEA

One of the biggest advantages of the DEA method is the possibility to process multiple inputs and outputs in the same analysis. For demonstrative purposes the following examples are however based on a simple one input - one output situation. This is due to the limitations of 2-dimensional diagrams. The author strongly believes that the utilization of these models offers a very good opportunity for a quick and easy insight into the subject without trading in too much simplification. Given is a situation where the horizontal axes represents the input and the vertical axes shows the output of 5 different DMU´s.

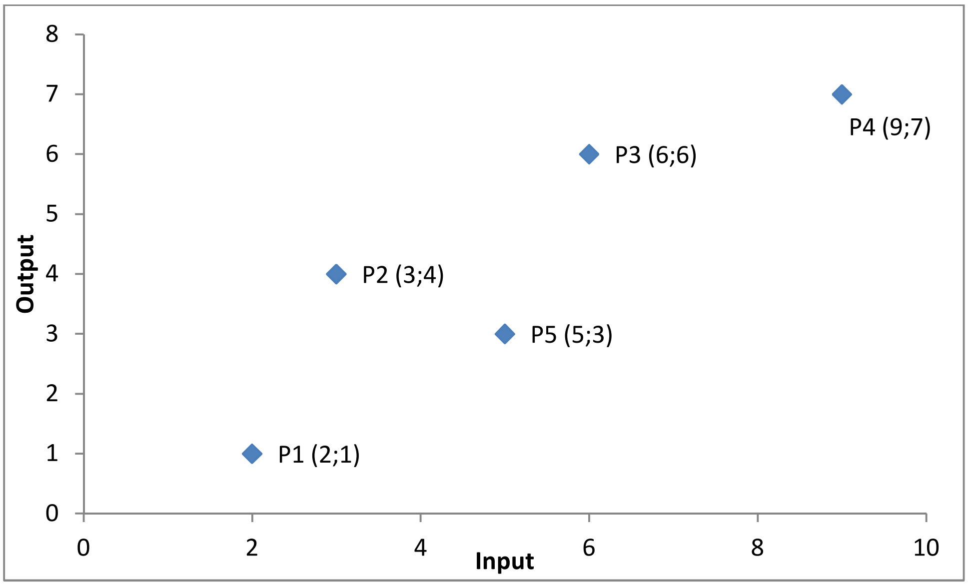


Figure 2. One Input - One Output diagram.

2.3. CCR method

Considering the CCR approach which is engaged with constant returns-on-scale, the efficiency frontier is a straight line intersecting the point of origin and the best performer(s). The best performer is determined by the highest ratio of output to input. In the given example this is P2 (see Fig. 3).

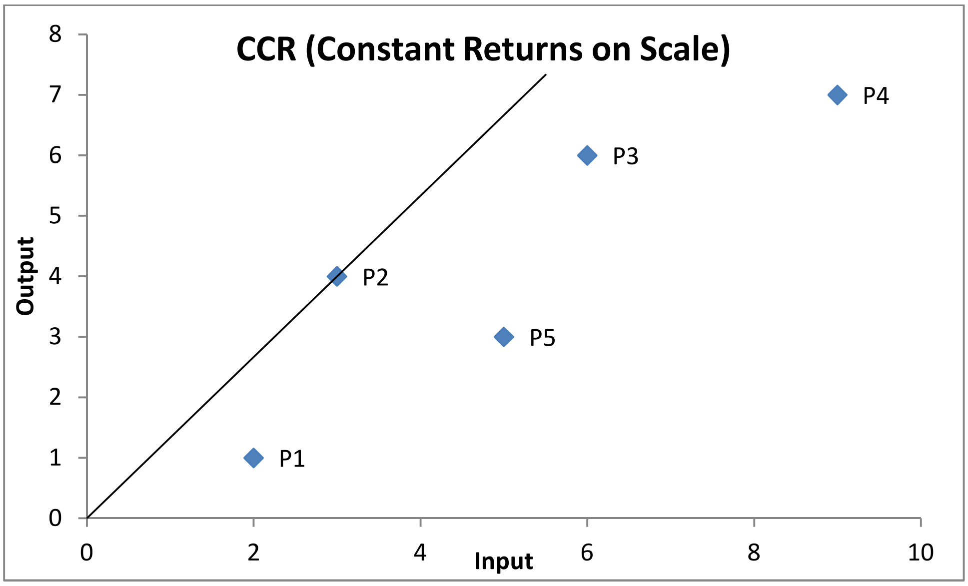


Figure 3. Diagram with CRS line.

The nature of the CCR analysis with its constant returns-on-scale approach leads to the situation that in most cases only one company is considered efficient and all other units are in the area below the efficiency frontier. This area is also referred to as "Production Possibility Set". In the given example the method assumes that, given the same input to P2, as any other DMU, it would outperform the corresponding DMU by higher output. Therefore it is considered as the reference DMU to all other units. The literature commonly agreed on the Greek letter "Theta" for CCR efficiency.

Mathematically the linear programming model is built up like this:

$$\min\left[\theta - \varepsilon\left(\sum_{i=1}^{p} s_i^- + \sum_{u=1}^{q} s_u^+\right)\right] \qquad \textbf{Equation 1.}$$

$$\sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- = \theta x_{i0} \qquad \textbf{Equation 2.}$$

$$\sum_{j=1}^{n} y_{uj}\lambda_j - s_u^+ = y_0 \qquad \textbf{Equation 3.}$$

$$\lambda_j, s_i^-, s_u^+ \geq 0, j = 1,2 \cdots n, i = 1,2 \cdots p, u = 1,2 \cdots q \qquad \textbf{Equation 4.}$$

The above shown formula for the CCR method (Charnes, Cooper & Rhodes 1978) is for the input oriented approach which can be seen from the "min" in equation 1. This method achieves higher efficiencies by minimizing the input. Respectively below the formula for a maximization problem, where better efficiencies are obtained through output maximization (see equation 5).

$$\max\left[\theta + \varepsilon\left(\sum_{i=1}^{p} s_i^- + \sum_{u=1}^{q} s_u^+\right)\right] \qquad \textbf{Equation 5.}$$

$$\sum_{j=1}^{n} y_{ij}\lambda_j + s_i^- = \theta y_{i0} \qquad \textbf{Equation 6.}$$

$$\sum_{j=1}^{n} x_{uj}\lambda_j - s_u^+ = x_{u0} \qquad \textbf{Equation 7.}$$

$$\lambda_j, s_i^-, s_u^+ \geq 0, j = 1,2 \cdots n, i = 1,2 \cdots p, u = 1,2 \cdots q \qquad \textbf{Equation 8.}$$

2.4. BCC method

As mentioned already earlier, the CCR method suffered from its low degree of applicability. Most real processes could not be satisfactorily mapped with the pure constant-returns-to-scale approach. In 1984 Banker, Charnes and Cooper extended the original model by introducing the so called "convexity constraint" which changed the efficiency frontier from being a straight line to a convex hull.

$$\sum_{j=1}^{n} \lambda_j = 1 \qquad \textbf{Equation 9.}$$

This constraint ensures that each composite unit is a combination of its reference units on the convex efficiency hull (Banxia Frontier Analyst 2013). This had two major impacts. Firstly more units could be considered being efficient and secondly inefficient units were now compared to more appropriate peers. The new model was able to deliver results which could be considered closer to realistic situations. Otherwise the mathematical model does not change except that the agreed letter for BCC efficiency is the Greek "Sigma" (Banker, Charnes & Cooper 1984a).

$$\min \left[\sigma - \varepsilon \left(\sum_{i=1}^{p} s_i^- + \sum_{u=1}^{q} s_u^+ \right) \right] \qquad \textbf{Equation 10}$$

$$\sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- = \sigma x_{i0} \qquad \textbf{Equation 11.}$$

$$\sum_{j=1}^{n} y_{uj}\lambda_j - s_u^+ = y_0 \qquad \textbf{Equation 12.}$$

$$\sum_{j=1}^{n} \lambda_j = 1 \qquad \textbf{Equation 13.}$$

$$\lambda_j, s_i^-, s_u^+ \geq 0, j = 1,2 \cdots n, i = 1,2 \cdots p, u = 1,2 \cdots q \qquad \textbf{Equation 14.}$$

The BCC model measures technical efficiency as the convexity constraint ensures that the composite unit is of similar scale size as the unit being measured. The resulting efficiency is always at least equal to the one given by the CCR model, and those DMUs with the lowest input or highest output levels are rated efficient (Ali Emrouznejad´s Data Envelopment Analysis database 2013).

The method by Banker Charnes and Cooper (1984) introduced the possibility to consider also variable returns-on-scale. Coming back to the given example the efficiency frontier is not a straight line but instead a convex hull, defined by several best performers. The efficiency frontier always needs to be convex, therefore any point which would cause an inward bend to the hull must be excluded and therefore be considered inefficient. The efficiency hull is always enveloping the production possibility set. That is from where the name of this analysis method has evolved off because the efficiency hull should always envelope the complete set of possible output/input ratios. The according diagram with the same DMUs as used for the CCR would now look like this:

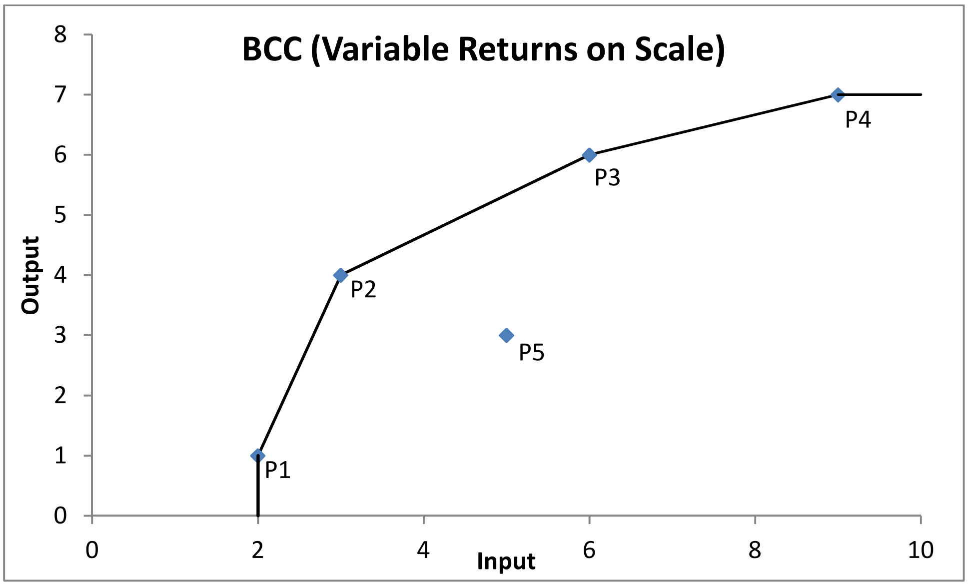


Figure 4. Diagram with VRS line.

In the given example, applying another method leads to a very new result. While the CCR method claims most DMUs as inefficient the BCC method leads to the conclusion that almost all DMU´s are efficient and exposes only DMU 5 as not efficient. This new method is paying more respect to the fact that DMU´s happen to face different production conditions and ergo could also be considered efficient unless a DMU with very similar conditions is indeed performing better.

Depending on the nature of the given input and output data the convex hull can have its origin in different corners of the diagram. This concept can at times be confusing if wrongly interpreted. In some cases the origin could be in the upper right corner which actually suggests that a low input combined with a low output would result in a maximum efficiency. The reader must be aware that the applied values are often ratios where a high input value could actually represent a low amount of invested resources and a low output value could convey the desired result of high output.

2.5. Slacks

In order to make the above mentioned Linear Programming models work, so called "slack values" needed to be introduced. Slacks represent the under-production of output or the over-use of input (Charnes, Cooper, Lewin & Seiford 1994). It represents the improvements needed to make an inefficient unit become efficient. Slack values can be considered as the mathematical "rest" of a division (e.g. 10/3 = 3 + rest 1). An optimal OTE is achieved only if efficiency is one ($\theta^0 = 1$) and the slack values equal at the same time zero ($s_i^{-0} = 0$, $s_u^{+0} = 0$). Only in this case the unit has used its resources optimally for generating output and therefore can be considered as overall efficient. A unit can however still be considered efficient with slack values uneven zero if theta still equals one. These DMU´s are considered as "weakly" efficient (Madrid-Guijarro & Maté-Sánchez-Val 2010).

2.6. Model orientation

2.6.1. Input orientation

When executing a DE Analysis, the user, beside choosing the correct model, also has to decide whether the model should be input or output oriented. In an input oriented approach the inefficient DMU is compared to an imaginary peer DMU with the same output. In other words, a unit is made efficient through the proportional reduction of their inputs while their output proportions are held constant. The corresponding diagram would look like this:

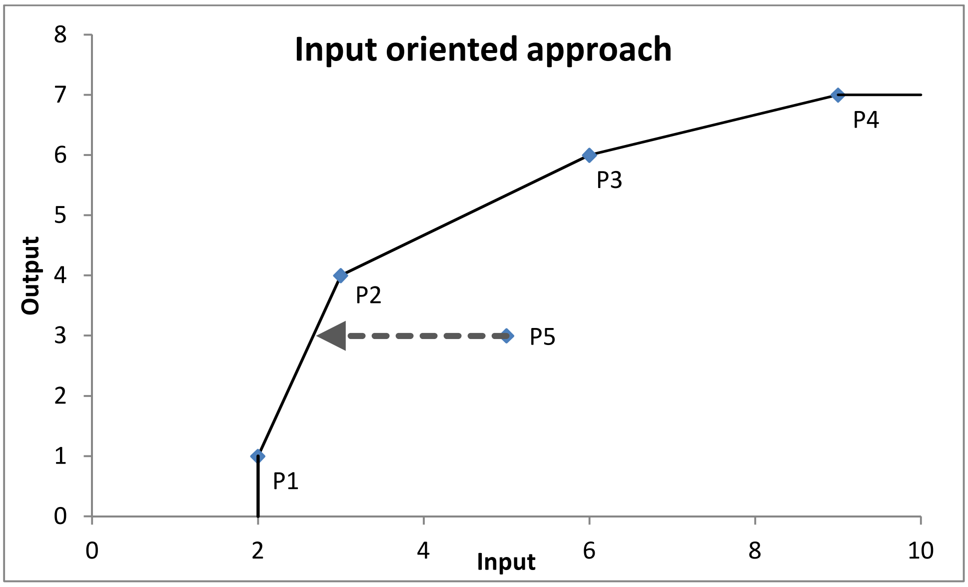


Figure 5. Input minimization approach.

In figure 5. a mix of DMU´s 1 and 2 would constitute the corresponding peer to DMU 5. Output files of DEA solving programs often mention beside the reference set (P1 and P2) also the corresponding portions e.g. 70% and 30%.

2.6.2. Output orientation

If the user chooses to rather maximize the output by keeping the input level constant the output oriented model should be applied. With this approach an inefficient unit is made efficient through the proportional increase of its outputs, while the input proportions remain unchanged. The according diagram would then look like this:

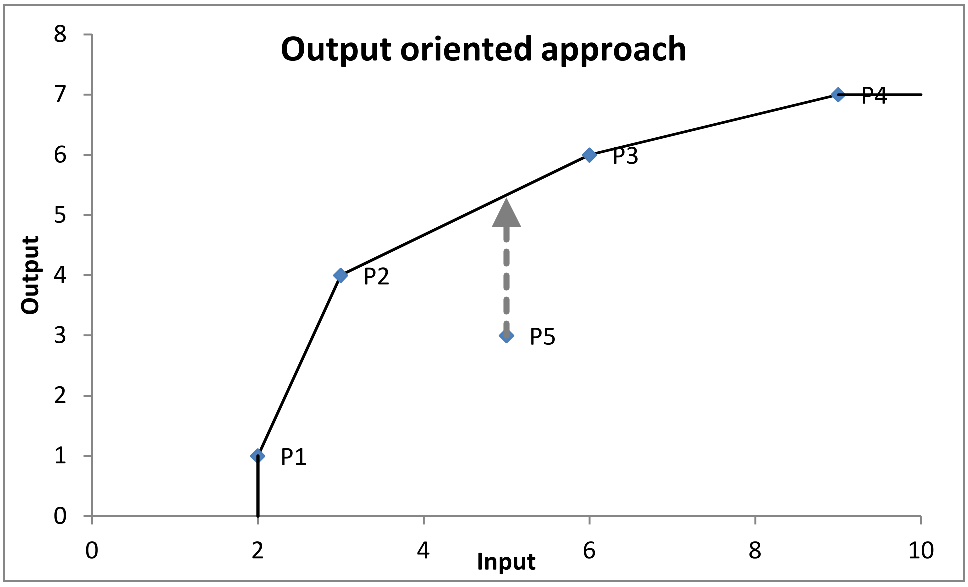


Figure 6. Output maximization approach.

Now the corresponding reference peers would be DMU 2 and DMU 3 which shows that the choice of model orientation has a direct impact onto efficiencies and peering of evaluated DMU´s, even though the actual performances remain unchanged.

It should be noted that making a decision between input and output orientation when choosing to apply the CCR method (constant returns-on-scale) is unnecessary because the efficiency values are same in this case. This is plausible because the ratio between the horizontal and vertical distances (dX/dY) between any point A and a straight line (here the EF for a CRS) stays constant while moving point A in horizontal or vertical direction.

2.7. Super efficiency

Another approach was introduced 1993 by Andersen and Petersen. They suggested the inclusion of a "super-efficiency". This approach claims, the DMUs performance can be considered the better the bigger the radial distance is, between the point itself and the efficiency hull when the particular DMU is left out of the frontier. In Fig. 7 one can see how the super efficiency value for P1 would be determined.

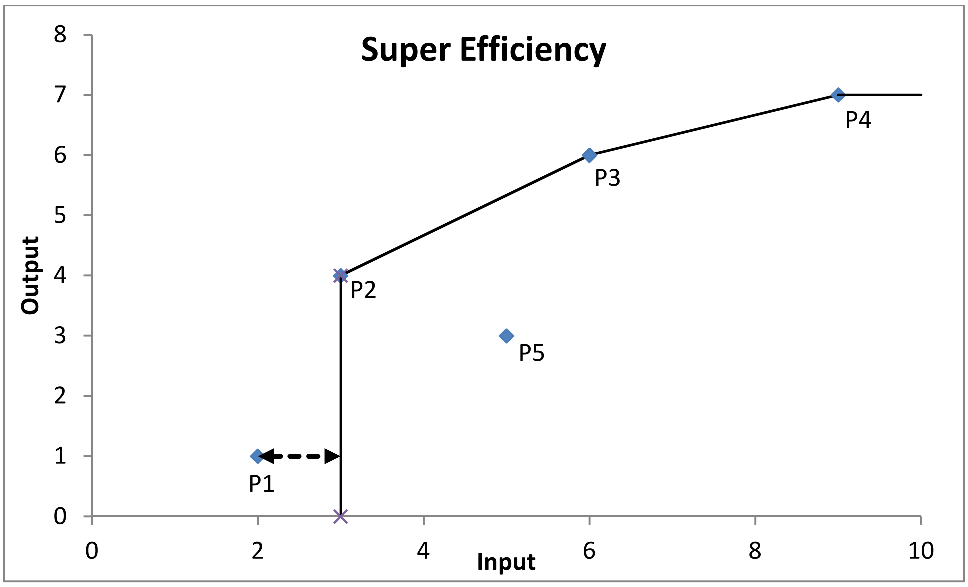


Figure 7. Determination of Super Efficiency of P1.

2.8. Reference peering

From the example above one might notice that the BCC method often defines a gross of the evaluating DMUs as efficient. Therefore there has been a debate that a further differentiation between all the efficient units is required. One approach, which is applied by many DEA solving programs, is the notion, how often one particular DMU is referred to as peer DMU for other inefficient units (e.g. P1 and P2 in Fig. 5). The more often a unit is acting as an efficiency reference for other DMU´s the better its performance is considered (Banker 1984b). As can be noticed from Figs. 5 and 6 the outcome of this analysis strongly depends on the decision between the input and output oriented approach.

2.9. Technical Efficiencies

After clarifying the mechanics of the Date Envelopment Analysis the focus will now be on the actual outcome of such analysis and its interpretations. The efficiency value calculated in CCR is the so called ''overall technical efficiency" (OTE), whereas the efficiency value computed by BCC is the ''pure technical efficiency"(PTE). Those two values are mathematically related via the ''scale efficiency" (SE) (Kumar & Gulati 2008).

A unit is said to be technically efficient if it maximizes output per unit of input used. Technical efficiency is the efficiency of the production or conversion process and is calculated independently of prices and costs (Banxia Frontier Analyst 2013).

Generally can be said that a DMU which obtains overall technical efficiency has also pure technical efficiency. However this is not true vice versa. A pure technical efficiency does not mean that a unit is also overall efficient. If a unit has a PTE of 1, its overall technical efficiency equates the value of scale efficiency complying with the following mathematical correlation.

	$$\frac{OTE}{PTE} = SE$$	**Equation 15.**

The comparison of scale efficiency value and pure technical value sheds light to the main source of inefficiency of DMUs. It is able to reveal if an inefficient DMU has either technical problems associated with the quantity and combination of input and output factors or if the whole operational scale should be changed in order to gain higher efficiencies (Lee 2009). The scale return analysis can identify whether it is in the stage of increasing or decreasing returns to scale so that the production scale can be adjusted accordingly.

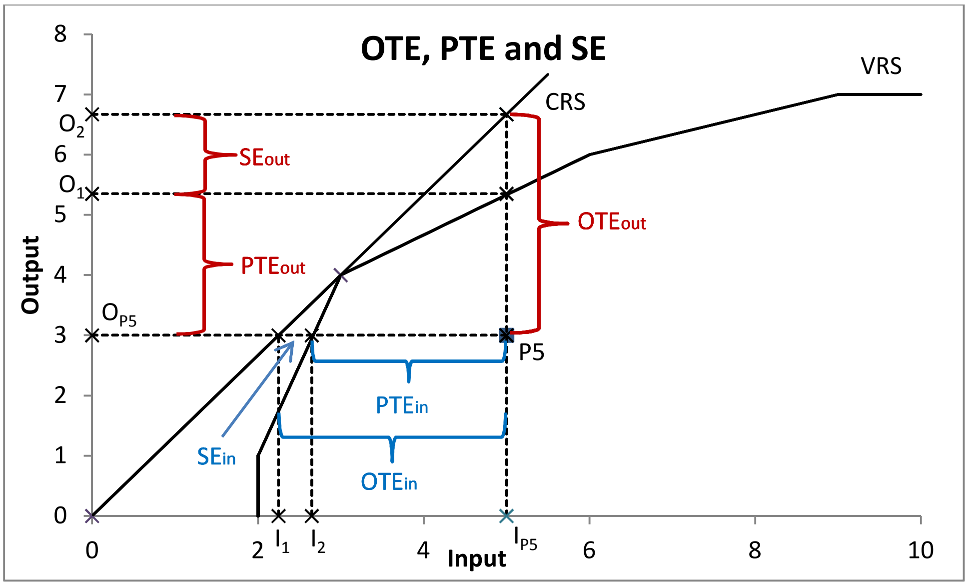


Figure 8. Simplified graphical illustration of OTE, PTE and SE (Sharma & Sharma 2010)

For the one input/one output case the three values could be seen straight from the diagram. Considering the already regarded example one could find the different efficiencies of P5 in Fig. 8. The pure technical efficiency (PTE) of P5 would be defined for an input oriented model by distance I_2-I_{P5}. The overall technical efficiency (OTE) would be defined by I_1-I_{P5}. Accordingly PTE and OTE for the output oriented model would be defined by O_2-O_{P5} respectively O_1-O_{P5}. Considering that the CRS and VRS frontiers both represent the value 1 for OTE and PTE, the diagram is conform with the above given formula. For any DMU on the VRS frontier applies PTE = 1. In this case OTE equals SE. The point where the two frontiers tangent all three values equal 1 and the DMU is fully efficient.

2.10. Returns on scale

It should be goal to every DMU to strive towards overall technical efficiency. Thus it is possible to extract information about the optimal production scale (Seiford & Zhu 1999). Companies situated on the red part of the VRS efficiency frontier (see Fig. 9) are able to gain higher efficiency through an increase of the production scale, thus results of a data envelopment analysis would state increasing returns-to-scale (IRS) for according DMUs. Respectively companies lying on the blue part of the VRS line are suggested to decrease their production scale in order to optimize their efficiency (Banker, Cooper, Seiford & Zhu 2011).

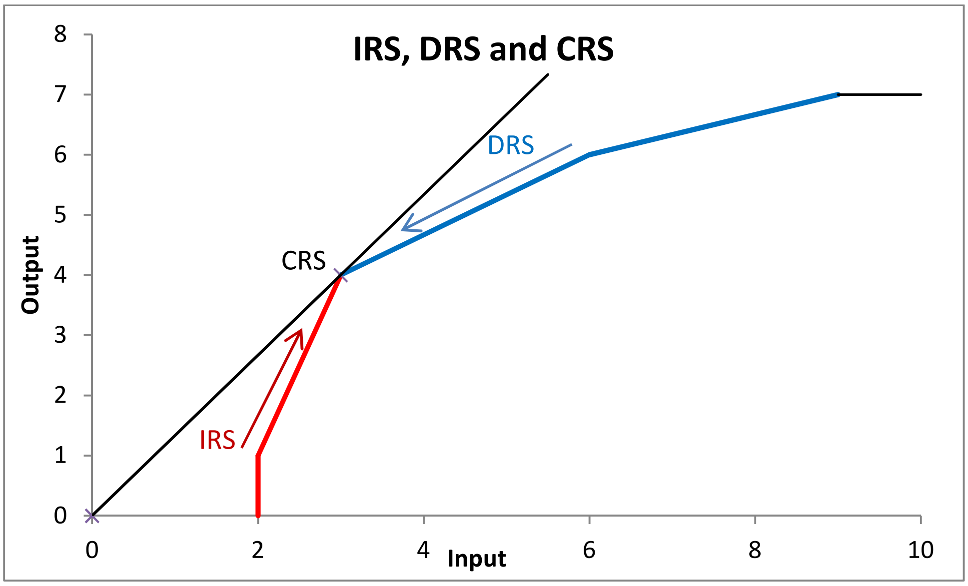


Figure 9. Graphical illustration of IRS and DRS situations.

3. FURTHER DEFINITIONS

3.1. Dual Model

The dual model and the primal (CCR) model provide two ways of looking at the same problem and the efficiency scores calculated are the same with both. Mathematically, the dual model is much faster to solve (although its formulation looks more complex). The difference between the two is that for each unit the dual model (internally) tries to create a hypothetical composite unit, from the existing units, that will out-perform the unit being analyzed. If, within the dual model this composite unit can be created, then the original unit is found to be inefficient, otherwise the unit is efficient (Banxia Frontier Analyst 2013).

3.2. Dual Weights

The dual weights, so called because they are calculated using the dual model and sometimes also called dual multipliers, give an indication of the importance given to a particular unit in determining the input/output mix of the composite unit. In the primal model the weights are associated with the (inputs and outputs in the model). In the dual model the weights are associated with the DMU's (Banxia Frontier Analyst 2013).

3.3. Epsilon

Epsilon is a very small positive constant (which at the time of writing is taken as 1 x 10-6 in Frontier Analyst) which is a non-Archimedean variable. This means that no real number exists by which you could multiply epsilon to get a smaller number. Epsilon is a theoretical-mathematical device to allow us to drive slack variable values to zero, without adding or subtracting any "real" amount to the objective function. In practice this means that inputs and outputs are not "abused as free commodities" and avoids a unit being wrongly classified as efficient (Banxia Frontier Analyst 2013).

3.4. Homogeneous

A DEA study requires a set of homogeneous units. Homogeneity refers to the degree of similarity between units. The operational goals of the units should be similar, as should their operational characteristics (Banxia Frontier Analyst 2013).

3.5. Most productive scale size (MPSS)

The most productive scale size of an efficient unit refers to the point (on the efficient frontier) at which maximum average productivity is achieved for a given input/ output mix. At the MPSS, constant returns to scale are operating. After reaching MPSS, decreasing returns to scale set in (Banxia Frontier Analyst 2013).

3.6. Production function

The production function describes the optimal relationship between inputs and outputs with the aim of maximizing output for the given inputs. In DEA the equivalent of the production function is the efficiency frontier (Banxia Frontier Analyst 2013).

3.7. Uncontrolled inputs and outputs

An uncontrolled or uncontrollable variable (input or output) is one over which the unit's management does not have control and hence cannot alter its level of use or production. An example of an uncontrolled input for a retail outlet would be the number of competitors it had in its area. Uncontrollable variables are also referred to as exogeneously fixed and non-discretionary variables (Banxia Frontier Analyst 2013).

4. RESEARCH GOALS

The focus of this research was to identify inefficiencies of small and medium sized enterprises. By aid of questionnaires data was collected from several companies of the Ostrobothnia region of Finland. 6 companies delivered sufficient data for an Data Envelopment Analysis.

The data was utilized to research three different economical measures

- Dynamic capability
- Innovation capability
- Competitiveness

4.1. Dynamic capability

David J. Teece, Gary Pisano, and Amy Shuen define dynamic capability as "the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments". It is an important aspect of comprehensive performance of enterprises. The rapidly changing business environment sets higher requirements for the environment adaptability, rapid response capability and risk decision-making capacity to enterprises, especially to SMEs. Compared with large enterprises, SMEs have the characteristics of smaller size, simpler organization structure and fewer available resources. Due to these characteristics their risk resistance capacity is weaker and their organizational flexibility is stronger. Therefore, in face of the environmental changes, avoiding risks and adapting to the environment through rapid strategic realignment is the optimal choice of SMEs. Dynamic capability can be considered as one of the most important factors for the survival and development of international operating SMEs (Zhao, Takala, Muhos, Hallikainen, Poikkimäki & Golovko 2012).

4.2. Innovation capability

Alder and Shenhar (1990) defined innovation capability as:

- the ability to develop products to meet the needs of market
- the ability to use existing technology to develop products
- the ability to acquire new technology to create new opportunities.

It is mainly measured by the performance of input-output efficiency in technological innovation. On nowadays global markets with its short life cycles and high competition, innovation capability is undoubtedly very important. Due to small production scales and high labor costs one of the key points for the successful operation of SMEs in industrial countries is a high degree of innovation capability (Guan, Yam, Mok & Ma 2004)

4.3. Competitiveness

Competitiveness pertains to the ability and performance of a firm to sell and supply goods and services to a given market, in relation to the ability and performance of other firms on the same market (*Wikipedia*, Competitiveness 2013). It is mainly measured by the performance of production and capital utilization. Enterprise competitiveness is the ultimate expression of comprehensive performance of enterprises. Through enterprise competitiveness evaluation, the comprehensive performance of enterprises in organization, operation and production can be embodied, thus it is an essential part of SMEs' performance evaluation (Zhao, Takala, Muhos, Hallikainen, Poikkimäki & Golovko 2012).

5. DATA

The possibilities of modern data processing allow the solving of LPs for a Data Envelopment Analysis in an instant. However, the user needs to undertake a profound evaluation of the actual circumstances before making decisions about the set up of the analysis. Indeed most programs will report an error for illogical or not solvable parameter compositions and model combinations but they are not able to detect a lack of relevance or an inadequate degree of comparability between regarded DMUs. Thus the responsibility for the significance of a study lies ultimately by the user (Dohmen & Leyer 2010).

As model parameters were chosen the BCC and CCR Model to obtain the Overall, Technical and Scale Efficiencies. Because no further market evaluations have been executed which could provide evidence for potential market growth or unused market shares, the author embedded this analysis into the assumption of leaving the output at a constant level and increasing efficiency, where applicable, by minimizing the input. Thus the input-minimization approach was chosen.

Due to confidentiality the returned questionnaires could not be included into this thesis. Of 8 participating companies 6 returned sufficiently answered papers. This study is entirely based on those 6 companies. The 2 other companies were not taken into considerations.

The used program to solve the LP problems is the DEA Solver Ver. 04/2009 of University of Hohenheim, Stuttgart. It can be found from:

http://www.dea.uni-hohenheim.de/

On basis of the obtained data from the questionnaires, the figures were included into the calculation of the three evaluated dimensions: dynamic capability, innovation capability and competitiveness as can be seen from the table below.

Table 1. Table of DEA dimensions and their inputs and outputs.

Dimensions	DEA Index System	
	Index types	DEA Indexes
Dynamic capability	Input	The cost of adapting to the change of market
		Response time to the change of market
		The value of resources invested before the change of market
	Output	The rate of sales shifting caused by the change of market
Innovation capability	Input	R&D funds inputs
		Quantity of R&D staff
		Marketing expenditure for new product (per annum)
	Output	The rate of return of new product
		The sales revenue of new product
Competi-tiveness	Input	Total cost of production (per annum)
		Staff quantity
		Marketing expenditure (per annum)
	Output	The product sales revenue(per annum)
		Market Share

6. DISCUSSION AND RESULTS

6.1 Result table

The results from the DEA Solver can be seen from Appendices 3, 4 and 5 and have been summarized in the table below:

Table 2. Results table of Data Envelopment Analysis.

Economical measure	DMU	OTE	PTE	SE	Returns on Scale	Reference peers	Peer count	Super Efficiency	Rank
Dynamic capability	Company A	1,000	1,000	1,000	-		3		1.
	Company B	0,220	0,963	0,229	increasing	A: 95,4%, F: 4,6%			5.
	Company C	0,150	0,945	0,159	increasing	A: 85,6%, D: 7,5%, F: 6,9%			6.
	Company D	0,556	1,000	0,556	increasing		1	1,50	3.
	Company E	0,315	0,926	0,341	increasing	A: 90,7%, F: 9,3%			4.
	Company F	1,000	1,000	1,000	-		3		2.
Innovation capability	Company A	1,000	1,000	1,000	-		1		4
	Company B	1,000	1,000	1,000	-		1	13	3
	Company C	1,000	1,000	1,000	-		2		1
	Company D	0,137	0,138	0,993	increasing	F: 56%, C: 30,5%, A: 13,5%			6
	Company E	0,236	0,245	0,963	increasing	C: 75,5%, F: 22,2%, B: 2,3%			5
	Company F	1,000	1,000	1,000	-		2	1,03	1
Competi-tiveness	Company A	0,966	1,000	0,966	decreasing				5
	Company B	0,608	1,000	0,608	increasing		1	4	4
	Company C	1,000	1,000	1,000	-		1	36,08	1
	Company D	1,000	1,000	1,000	-				3
	Company E	0,491	0,657	0,748	increasing	C: 98,5%, B: 1,5%			6
	Company F	1,000	1,000	1,000	-				2

6.2. Data Interpretation

6.2.1. Company A

Company A has an overall technical efficiency of 100% in the areas of dynamic capability and innovation capability. Furthermore it has a very good overall technical efficiency value for competitiveness (0,966) and a pure technical efficiency of 100%. Because there does not exist a reference peer for this dimension, no graphic is provided. The result of the returns on scale analysis points out that company A can increase its overall technical efficiency for competitiveness by investing less resources into the three inputs: total cost of production, staff quantity and marketing expenditure. For more information please see Appendices 3-5. A further investigation here might reveal where and to what extend investments need to be done in order to obtain further efficiencies. Company A does not have a reference DMU for any of the three dimension, thus no graphical evaluation is available.

Company A is performing exceptionally well in the area of dynamic capability and is here the strongest reference peer for companies B, C and E. With its balanced output and ranks 1., 3. and 4. it belongs to the best performers of this analysis.

6.2.2. Company B

Company B has an overall technical efficiency of 100% in innovation capability, a pure technical efficiency of 100% for competitiveness and poor efficiency values for dynamic capability. The RTS value for the last two values is in increasing state which argues that company B should increase investments into the corresponding inputs: the cost of adapting to the change of market, response time to the change of market, the value of resources invested before the change of market, total cost of production, staff quantity and marketing expenditure. Also here a further investigation must show in what way additional resources should be spent in order to gain higher efficiencies. The following graphic exposes how company B is situated comparing to its reference peers (company A & F) for dynamic capability, broken down to the three inputs and one output. For more information please see Appendices 3-5.

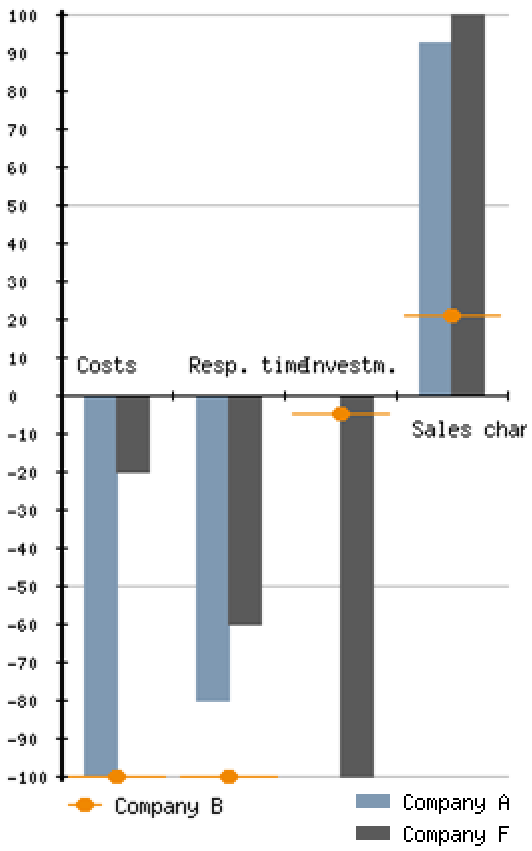


Figure 10. Dynamic capability performance of company B

Company B is twice mentioned as reference peer. In both cases however, the impact is insignificantly small. With ranks 5., 3. and 4. it is one of the worst performers of this analysis.

6.2.3. Company C

Company C has an overall technical efficiency of 100% for innovation capability and competitiveness. Its performance in the field of dynamic capability is particular poor. The RTS state claims that an increase of efforts will result in a higher efficiency here. Thus it should raise investments into the following inputs: the cost of adapting to the change of market, response time to the change of market and the value of resources invested before the change of market. Additional research has to show where and to what extend investments need to be undertaken in order to gain efficiencies. Below the dimension break down for Dynamic Capability for company C. For more information please see Appendices 3-5.

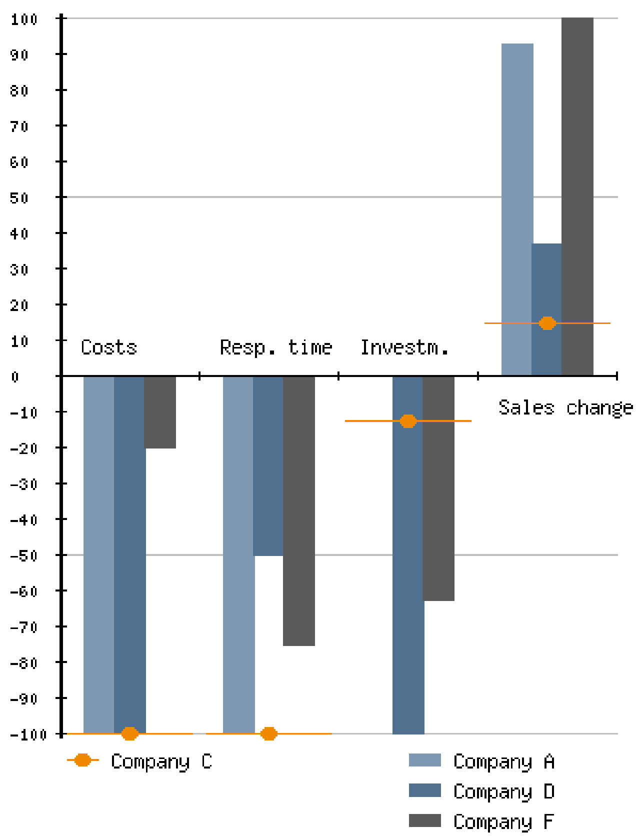


Figure 11. Dynamic capability performance of company C

Company C is performing very well in the areas of innovation capability and competitiveness. It is in both areas the strongest reference peer for other companies and thus ranks first here. Additionally it has a very high super efficiency value for competitiveness. With ranks 6., 1. and 1. it belongs to the best performers of this analysis. If company C manages to improve the performance for dynamic capability it would likely be the best overall performer in later investigations.

6.2.4. Company D

Company D is 100% overall efficient in the area of competitiveness. It has a 100% pure technical efficiency for its dynamic capabilities and overall very poor values for innovation capability. The returns on scale analysis claims that an increase in efforts in: the cost of adapting to the change of market, response time to the change of market, the value of resources invested before the change of market, R&D funds inputs, Quantity of R&D staff and Marketing expenditure for new product could increase the efficiency for those two values. A further investigation must show in what way additional resources should be spent in order to enhance the capacities here.

Here can be seen how company D performs, comparing to its reference peers in innovation capability. For more information please see Appendices 3-5.

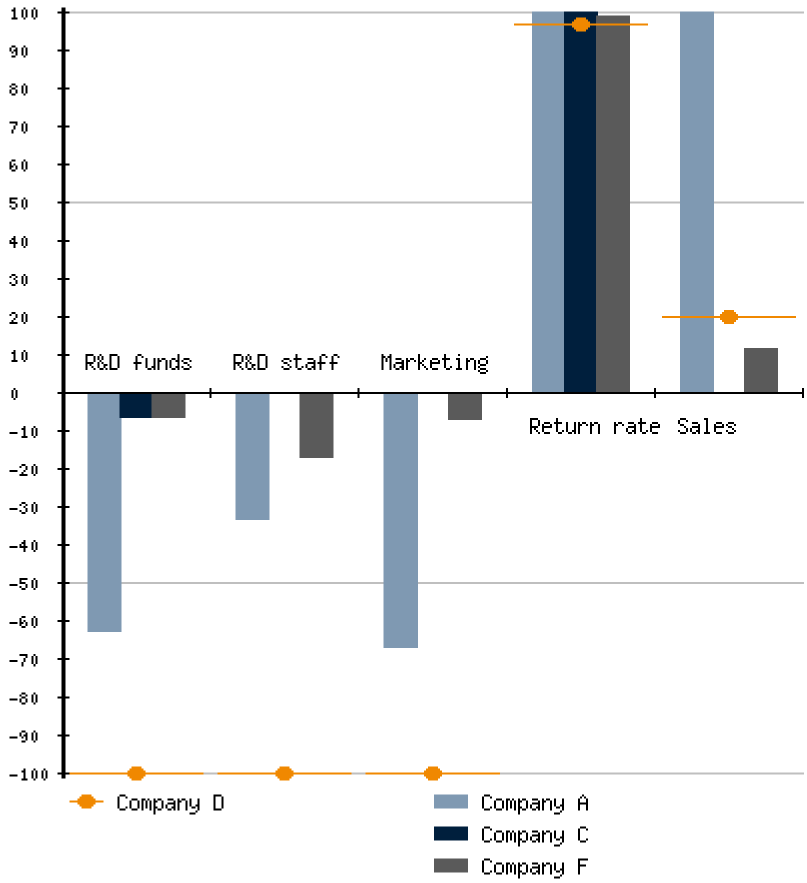


Figure 12. Innovation capability performance of company D

Company D is only once mentioned as reference peer and belongs with its ranks 3., 6. and 3. to the worst performers of this evaluation.

6.2.5. Company E

Company E has neither overall nor pure technical efficiencies of 100%. For all three areas the RTS analysis advises to increase efforts. This company has to undergo a deep analysis about overall structural changes. Making any advises which could increase efficiencies are beyond the scope of this thesis. However, the author strongly recommends that further research should be undertaken. For more information please see Appendices 3-5.

Without even reaching technical efficiency anywhere and with its ranks 4,5 and 6 it is the worst performer in this analysis.

6.2.6. Company F

Company F has 100% overall technical efficiency in all three areas. Furthermore it is mentioned as reference peer for other companies 5 times. Company F is not performing exceptionally well in any of the three areas but performers very good in all of them. Therefore company F is the best performer in this analysis. For more information please see Appendices 3-5.

The author wants to emphasize that this result only testifies a generally efficient performance for the three evaluated areas compared to the other five participants. This should by no means imply that the company could stop striving for further improvements but should rather be regarded as a good foundation for future efforts to increase business volumes on international markets.

7. FINDINGS

Like any empirical technique, DEA has limitations of which practitioners need to be mindful. DEA results provide the maximum benefit when they are interpreted with care. In general, they should be considered as a starting point for assessing the efficiency of the DMU´s within a sample. Indications of possible sources of relative inefficiency can guide further investigation to determine why there are apparent differences in performance. This information can be used to inform the managers of individual service providers, administrators and policy makers (Steering Committee for the Review of Commonwealth 1997).

Within the DEA the benchmarking values are always set by the best performer. While conducting an analysis with constant returns on scale assumption, in most cases only one company emerges as best performer. When, however, applying the variable return on scale assumption, depending on the amount of dimensions evaluated, many DMU´s can reach an efficiency of 100%. Once a company is highlighted as overall efficient the data envelopment method cannot provide useful data for performance improvements for that particular DMU anymore. Examining the results of this study, all DMU´s except Company E are in at least one dimension overall efficient. It is the authors believe that this is not due to a general strong performance of the evaluated companies but rather due to the too small number of participants. Only if the sample size is big enough a data envelopment analysis is able to provide strong and useful information for all companies. Depending of the amount of applied dimensions the amount of examined DMU´s should be at least bigger than fifteen, better would be bigger than twenty. The more DMU´s are included into the research the more significant the results will become (Prusa 2012).

Furthermore the author came to the conclusion that the DEA analysis is only a very strong tool for comparing very similar companies or branches. This analysis is ergo good to compare e.g. state offices or hospital departments but cannot be seen as a very valid evaluation tool to analyze companies from different business areas. This is due to two reasons:

- Firstly is a benchmark set by one company likely not valid for a second company, working in a very different field because different business sectors imply different challenges and market situations, thus some values and ratios achievable in one area might be impossible to reach in other business areas. However, experts say also, while a like-with-like comparison leads to the comparisons being ‘fairer’ and perhaps more readily acceptable to managers, they claim that a diverse range of operating environments may be useful in the study to provide a wider range of ideas and operating styles from which managers could learn (Steering Committee for the Review of Commonwealth 1997).

- Secondly is the ability and willingness of cooperation between the DMU´s of very vital importance in order to assure a maximum benefit for all participants. The DEA method is a very good method to highlight good and bad performers. With obtained results analysts can improve efficiencies of the bad performers by learning about processes, knowledge or technologies from the good performers. Naturally this can be achieved only with delegations from executives. However, a company is very unlikely to give an insight into internal processes to outsiders, least of all to business competitors. Therefore is the successful transformation of DEA results into practice always threatened by the possibility that the participating companies are not willing to cooperate after DEA execution.

The chances for a fail at the step of cooperation are especially higher because in most cases participating companies are either:

- of too different business areas so that processes of good performers are not transferable to the poor performers
- or of too similar business areas so that they are in direct competition and the participants are therefore not willing to share knowledge about their internal processes

Ergo, vice versa can be said that results obtained from a data envelopment analysis have the biggest significance if DMU´s:

- are active in comparable business sectors so that benchmarks set by one DMU can be considered valid also for other DMU´s.
- have to execute similar tasks so that reproducing efficient process structures of peer DMU´s at other DMU´s is an expedient practice.
- have the willingness to cooperate and communicate with each other after the research in order to exchange information and thus ensure maximum benefit to all participants.

A good example for an above mentioned situation would be e.g. an efficiency analysis of all local branches of a bigger bank, initiated by the upper management. Processes are similar and set benchmarks are likely valid for all branches too. Additionally individual branch managers are interested in sharing their knowledge with others because the information would stay within the company and strengthen the competitiveness of the whole company thus also securing his position.

Finally it is important to recognize that, like many other evaluation methods, also applying an efficiency analysis like DEA will inevitably evolve through time (Farrell 1957). While performed measures might occur relatively simple and approximate in the beginning, they will likely become more sophisticated and precise as the evaluating agents gain experience and collect data of higher quality.

Also should participating companies not leave it with a single efficiency evaluation. Only a reiteratively conducted research will result in a permanent improvement of their performance efficiency.

For this study companies of different manufacturing fields have been evaluated. If and to what extend results of this research are valid remains to be seen. If the case companies will follow proposed steps and efficiency scores in later measurements will have increased one could not only have utilized information from theory to practice but also vice versa. If longer term evaluation would proof that a Data Envelopment Analysis of not totally comparable enterprises would still deliver satisfying results, this research would constitute to the wide basement of possible DEA applications.

8. CONCLUSIONS

Goal of this thesis research was an efficiency analysis of 6 manufacturing companies of the North-Ostrobothnia region of Finland. As evaluation method was the data envelopment analysis applied. Parallel to the efficiency analysis this thesis should provide an insight into the mechanics of the DEA method and examine its ability to support decisions in the area of manufacturing strategy.

The investigation covered the determination of three different economical values, dynamic capability, innovation capability and competitiveness. By aid of questionnaires the required data for such evaluation was obtained. Based on the economical environment of the participating companies the design parameters for the analysis were chosen accordingly and the efficiency values extracted from the DEA solving algorithm. On basis of the results of the data envelopment analysis, according recommendations for the different participants were given.

DEA is a method, enabling the analyst to quickly and easily obtain performance measures of different benchmarking members. The fact that the method can transform multiple in- and output values into a single efficiency value offers the analyst an effective tool in the area of performance measurements, provided that the user of the method is choosing the parameters mindfully and interpreting the results advisedly.

According to the calculated efficiency values for the three evaluated economical measures, individual recommendations for all six companies have been given. With according resource allocations, decision makers are able to promote the operational efficiencies and thus increase chances of successful participation in global markets.

While companies A and C have been clarified as good performers and company F as best performer of this evaluation, companies B and D will have to improve their performances even more in order to reach competitive efficiency values. Especially company E could be highlighted as poor performer and need to undergo crucial structural changes if it wants to survive on the international markets.

However, due the small amount of participating DMU´s and their unequal fields of business the robustness of the results of this thesis might be questionable. In order to achieve a higher degree of significance for the results the amount of participating DMU´s has to be higher and the evaluated companies should all be active in similar fields of business.

Once a DEA method is successfully performed, results could unfold their maximum impact if the participants would be willing to cooperate with each other and exchange information about their knowledge, processes and technologies.

9. LIST OF REFERENCES

Ahmad, N. (2006) "*Effectiveness Evaluation Services for Small to Medium-Sized Manufacturing Enterprise*" Service Operations and Logistics, and Informatics, p.1106 - 1112

Ahmad, N. & R. G. Qiu (2008) "*Integrated model of operations effectiveness of small to medium-sized manufacturing enterprises*" Intell Manuf (2009) 20:79–89

Ali Emrouznejad´s Data Envelopment Analysis database <www.deazone.com> [cited January 25th 2013]

Banker, R. D., A. Charnes & W. W. Cooper (1984a) "*Some Models for Estimating Technical and Scale Inefficiencies in DEA.*" Management Science 30(9): 1078-1092

Banker, R. D. (1984b) "*Estimating Most Productive Scale Size using Data Envelopment Analysis.*" European Journal of Operational Research 17(1): 35-44

Banker, R. D., W. W. Cooper, L. M. Seiford & J. Zhu (2011) "*Returns to Scale in DEA*" Handbook on Data Envelopment Analysis

Banxia Frontier Analyst, Data Envelopment Analysis for Professionals <http://www.banxia.com/frontier/resources/glossary> [cited January 25th 2013]

Charnes, A., W. W. Cooper & E. Rhodes (1978) "*Measuring the Efficiency of Decision Making Units.*" European Journal of Operational Research 2(6): 429-444

Charnes, A., W. W. Cooper, A. Y. Lewin & L. M. Seiford (Ed.) (1994) "*Data Envelopment Analysis: Theory, Methodology and Applications.*" Dordrecht: Kluwer Academic Publishers.

Coelli, T. J., D. S. Prasada Rao, C. J. O'Donnell & G. E. Battese (2005) "*An Introduction to Efficiency and Productivity Analysis*" (Second Edition), New York: Springer Science + Business Media

Cooper, W. W., L. M. Seiford & J. Zhu (2011) "*Data Envelopment Analysis: History, Models and Interpretations"* Handbook on Data Envelopment Analysis International Series in Operations Research & Management Science Volume 164, 2011, pp 1-39

Dohmen, A. & M. Leyer (2010) "*Combining Data Envelopment Analysis And Business Process Simulation For Analyzing The Efficiency Of Business Processes*" Proceedings of the International MultiConference of Engineers and Computer Scientists 2010 Vol. 3

Emrouznejad, A., B. R. Parker & G. Tavares (2008) " *Evaluation of research in efficiency and productivity: A survey and analysis of the first 30 years of scholarly literature in DEA*" Socio-Economic Planning Sciences Volume 42, Issue 3, p. 151–157

Farrell, M. J. (1957) *"The Measurement of Productive Efficiency."* Journal of the Royal Statistical Society, Series A, 120 (3): 253-290

Guan, J. C., R. C. M. Yam, C. K. Mok & N. Ma (2004) "*A study of the relationship between competitiveness and technological innovation capability based on DEA models*" European Journal of Operational Research 170 (2006) 971–986

Heilbrunn, S., S. Rozenes & G. Vitner (2011) "*A DEA Based Taxonomy to Map Successful SMEs*" International Journal of Business and Social Science, Vol. 2 No. 2

Kumar, G. & R. Gulati (2008) "*An Examination of Technical, Pure Technical, and Scale Efficiencies in Indian Public Sector Banks using Data Envelopment Analysis*" Eurasian Journal of Business and Economics 2008, 1 (2), 33-69

Lee, C. C. (2009) "*Analysis of overall technical efficiency, pure technical efficiency and scale efficiency in the medium-sized audit firms*" Expert Systems with Applications 36 (2009) 11156–11171

Luostarinen R., H. Korhonen, J. Jokinen & T. Pelkonen (1994). "*Globalisation and SME*" Helsinki: Ministry of Trade and Industry. Studies and Reports p. 59

Madrid-Guijarro, A. & M. L. Maté-Sánchez-Val (2010) "*A spatial efficiency index proposal: An empirical application to SMEs productivity*" Ann Reg Sci (2011) 47:353–371

Prusa, J. (2012) "*The Most Efficient Czech SME Sectors: An Application of Robust Data Envelopment Analysis*" Czech Journal of Economics and Finance, 62, 2012, no. 1

Seiford, L.M. & J. Zhu (1999) *"An Investigation of Returns-to-scale in Data Envelopment Analysis."* Omega 27(1): 1-11

Sharma, S., D. Raina & S. Singh (2012) " *Measurement of Technical Efficiency and Its Sources: An Experience of Indian Banking Sector"* Int. Journal of Economics and Management 6(1): 35 – 57

Sharma, S. & M. Sharma (2010) "*Analyzing the technical and scale efficiency of small industries in India: state-wise cluster study*" Measuring Business Excellence Vol. 14 No. 2 2010, pp. 54-65

Steering Committee for the Review of Commonwealth/State Service Provision (1997) "*Data Envelopment Analysis: A technique for measuring the efficiency of government service delivery"* AGPS, Canberra

Wikipedia, The Free Encyclopedia "*Competitiveness*" <http://en.wikipedia.org/w/index.php?title=Competitiveness&oldid=530980291> [Date of last revision: 2 January 2013; Date retrieved: 25 January 2013]

Zhao S., J. Takala, M. Muhos, H. Hallikainen, J. Poikkimäki & I. Golovko (2012) "*Comparative Study of DEA and CFI Performance Assessment Methods*". The 13th Management International Conference, MIC'2012, Sustainable Economy, November 21-23, 2012, Budapest, Hungary, 18 pages

Appendix 1

Yrityksen kyvykkyyden arviointi –kyselytutkimus, joka perustuu DEA-metodiin

Tutkimuksen lyhyt esittely: Täytä lomake mahdollisimman tarkasti yrityksesi tällä hetkellä voimassa olevalla tiedolla. Tietoa tullaan käyttämään VAIN tieteellisessä tutkimuksessa ja yksittäistä yritystä ei pystytä yhdistämään tutkimustuloksiin tai yksilöimään niistä. **Kiitoksia jo etukäteen vaivannäöstänne!**

<u>Osio 1: Yrityksen kansainvälistymisoperaatioiden kyvykkyys</u>

1. Yrityksen tällä hetkellä ulkomailla työskentelevien työntekijöiden määrä: _____.

2. Vuonna 2011, paljonko keskimäärin maksoi yrityksen kansainvälistymisoperaatiot ja toiminta ulkomailla, ympyröi oikea vaihtoehto;

A: Enemmän kuin 100 000 euroa

B: 50 000 – 100 000 euroa

C: 20 000-50 000 euroa

D: 1000 – 20 000 euroa

E: Vähemmän kuin 1000 euroa

3. Vuoden 2011, kokonaisinvestoinnit ulkomaille:

4. Vuoden 2011, ulkomaiden myynnin netto voitto:

5. Kuinka monessa maassa yrityksellä on tällä hetkellä toimintaa:

6. Vuoden 2011 ulkomaan viennin arvo:

7. Vuoden 2011 ulkomailta tuotujen / ostettujen resurssien määrä (työvoima, raaka-aineet, komponentit…)

Osio 2: Dynaaminen kyvykkyys yrityksen toiminnassa mukautua toimintaympäristön muutoksiin

Tämä osio käsittelee yrityksesi kyvykkyyttä mukautua muutoksiin toimintaympäristössä. Arvioi yrityksesi toimintaa viimeksi tapahtuneen muutoksen valossa.

1. Toimintaympäristössä tapahtuneen muutokseen reagoimisen kustannukset olivat / ovat olleet: (ympäröi oikea vaihtoehto)

(A) Erittäin korkeat **(B)** Korkeat **(C)** Normaalit **(D)**Matalat **(E)**Erittäin matalat

2. Yrityksen reagoimisnopeus markkinoiden muutokseen oli:

(A) Erittäin nopea **(B)** Nopea **(C)** Normaalit **(D)** Hidas **(E)** Erittäin hidas

3. Tuotteiden / palveluiden myynti ennen markkinoiden muutosta oli:

4. Tuotteiden / palveluiden myynti markkinoiden muutoksen jälkeen oli:

5. Paljonko tuotteita toimitettiin ennen toimitettiin yhteensä ennen muutosta:

6. Paljonko tuotteita toimitettiin muutoksen jälkeen:

7. Kuinka suuressa osuudessa oli laatupoikkeamia ennen muutosta:

8. Kuinka suuressa osuudessa oli laatupoikkeamia muutoksen jälkeen:

Osio 3:Yrityksen teknologisten innovaatioiden tuotantokyky

1. Vuoden 2011, tuotekehityspanos:

2. Montako työntekijää toimii tällä hetkellä tuotekehityksessä

3. Montako henkilöstössä työntekijää yrityksessä on kaikkiaan

4. Vuonna 2011, paljonko rahaa käytettiin uusien tuotteiden markkinointiin:

5. Vuonna 2011, paljonko rahaa uudet tuotteet toivat yritykseen (netto)

6. Vuoden 2011 tuotteiden myyntituotto oli:

7. Vuoden 2011 uusien tuotteiden myyntituotto oli:

Osio 4:Yrityksen kilpailukyky

1. Vuonna 2011 yrityksen tuotannon aiheuttamat kustannukset:

2. Vuoden 2011 yrityksen markkinointikustannukset

3. Arvio mikä on tällä hetkellä yrityksen osuus maailmanlaajuisista markkinoista:

Appendix 2

Demografiset tiedot operatiivisten valmistusstrategioiden tutkimukselle

Research Professor Josu Takala

University of Vaasa mailto: jot@uwasa.fi

Dep. of Industrial Management gsm: +358-400-564068

P.O. Box 700 fax: +358-6-3248467

FIN-65101 Vaasa, Finland

Tiedonantajan nimi ja asema yrityksessä:

Yrityksen nimi:

Yrityksen koko:

- Henkilöstömäärä:
- Liikevaihto:
- Viennin osuus liikevaihdosta:

Yrityksen asema toimitusketjussa(järjestelmätoimittaja, komponenttitoimittaja, päähankkija ym.):

Toimiala (Valmistus, teknologiaintensiivinen toimiala.Mikä palvelu?(Tuotanto, ylläpito ym.), palveluliiketoiminta(%/liikevaihto):

Onko yrityksellä toimivaa hallitusta? Kyllä /

Appendix 3

Dimension: Dynamic Capabilities

CCR method, Input oriented

Inefficient DMUs: data table

efficiency	inefficient DMU	activity level (λ)	DMUs used as reference
0.220303	Company B	0.218188 0.010575	Company A Company F
0.150116	Company C	0.127599 0.030023	Company A Company F
0.555967	Company D	0.370645	Company F
0.315464	Company E	0.309155 0.031546	Company A Company F

(*Please note:* This list contains only inefficient or weakly efficient DMUs! The total number of DMUs is 6 of which 2 DMUs are efficient.)

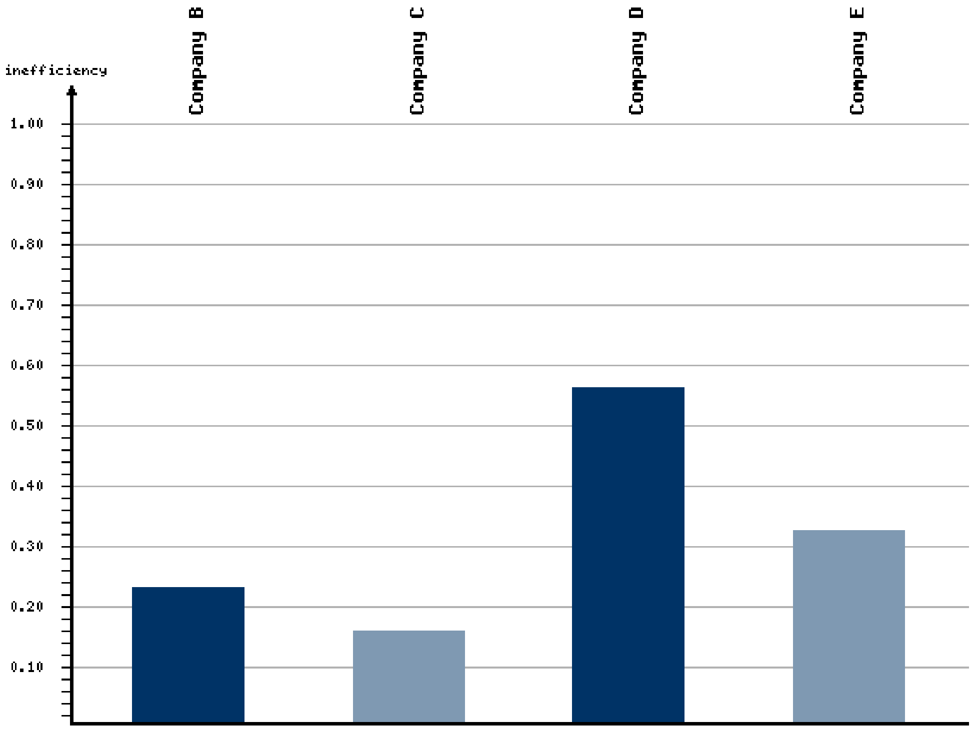
Efficient DMUs: super-efficiency values

Company A	----------
Company F	5.395995

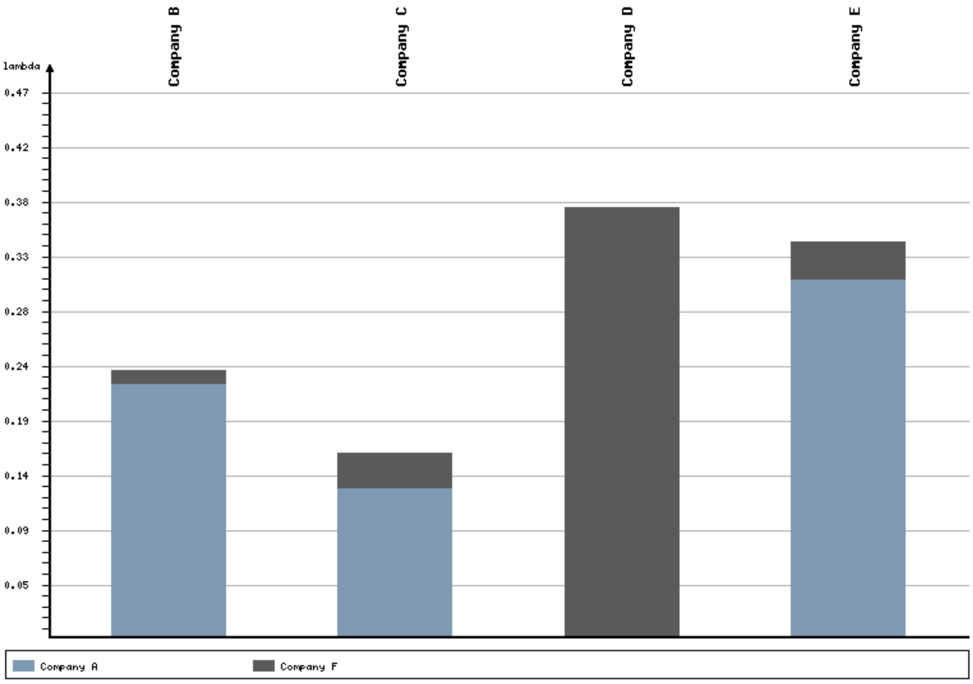
Efficient DMUs: frequency of reference

[+] Company A	3
[+] Company F	4

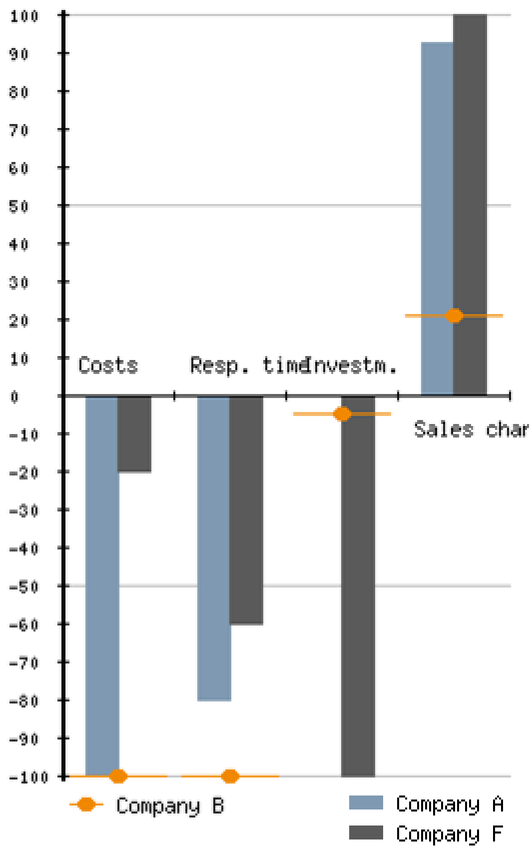
Performance diagram



Combination diagram

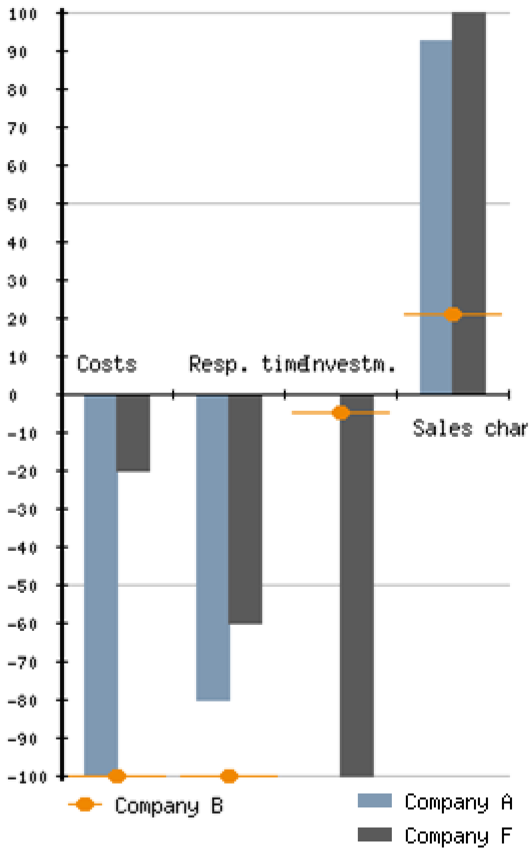


Input/Output	**Company B** (original values / deviation from Composite)		**dual prices** (abs / rel)	
costs	5.000	+353.9%	0.19190100	99.1%
response time	5.000	+452.8%	0.00000000	0.0%
investments	24.000	+353.9%	0.00168700	0.9%
sales change	0.287	-0.0%	0.76760600	100.0%



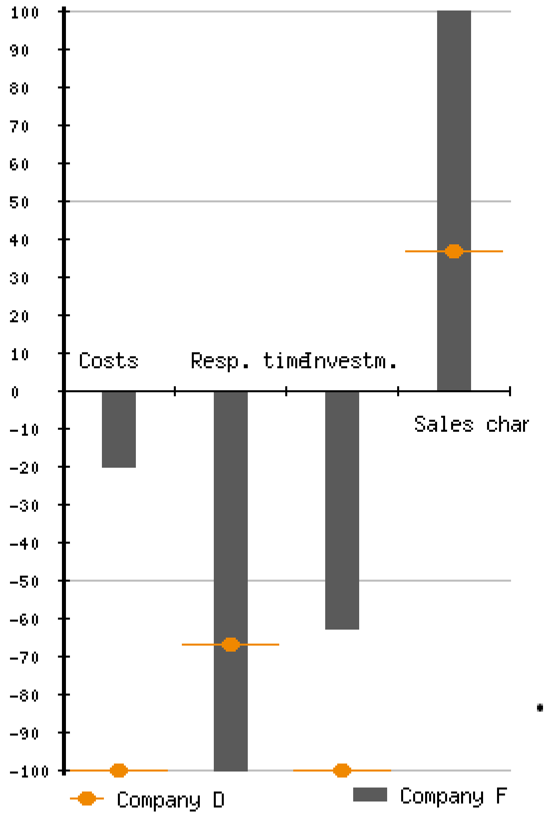
Input/Output	**Composite**			**Company A**			**Company F**
costs	1.102			5.000			1.000
response time	0.904			4.000			3.000
investments	5.288	=	0.21819	0.000	+	0.01058	500.000
sales change	0.287			1.250			1.349

Input/Output	Company C (original values / deviation from Composite)		dual prices (abs / rel)	
costs	5.000	+648.5%	0.00000000	0.0%
response time	4.000	+566.2%	0.23455700	99.7%
investments	100.000	+566.2%	0.00061800	0.3%
sales change	0.200	+0.0%	0.75058200	100.0%



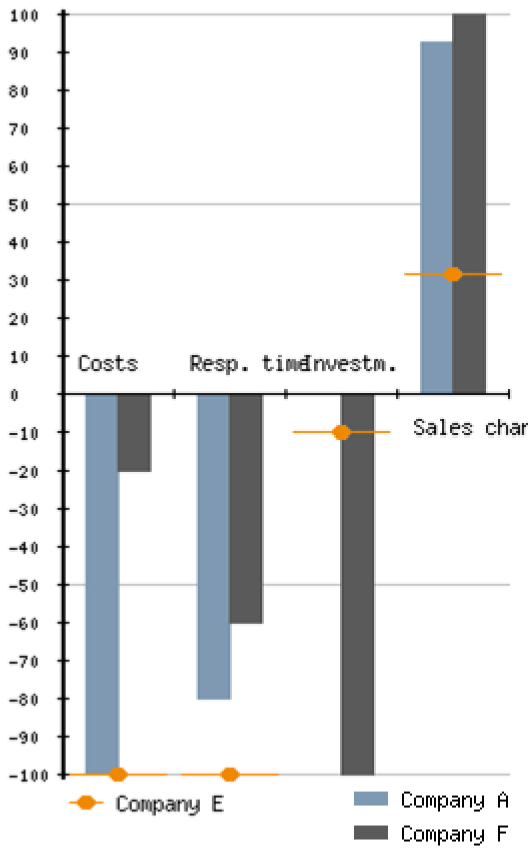
Input/Output	Composite			Company A			Company F
costs	0.668			5.000			1.000
response time	0.600			4.000			3.000
investments	15.012	=	0.12760	0.000	+	0.03002	500.000
sales change	0.200			1.250			1.349

Input/Output	Company D (original values / deviation from Composite)		dual prices (abs / rel)	
costs	5.000	+1,249.0%	0.00000000	0.0%
response time	2.000	+79.9%	0.49999900	100.0%
investments	800.000	+331.7%	0.00000000	0.0%
sales change	0.500	-0.0%	1.11193400	100.0%



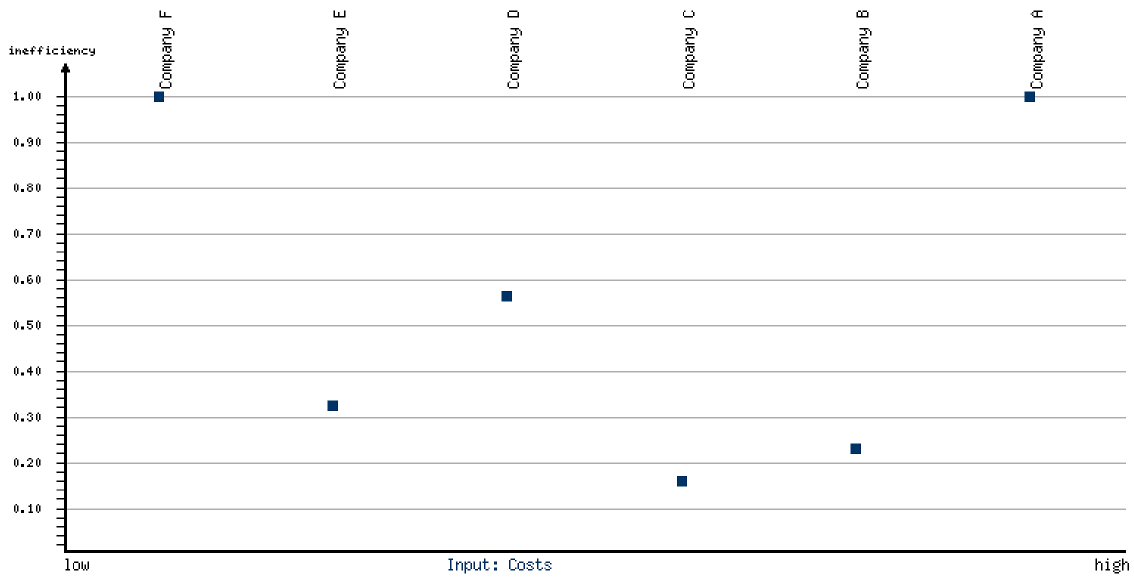
Input/Output	Composite		Company F
costs	0.371		1.000
response time	1.112		3.000
investments	185.323	= 0.37065	500.000
sales change	0.500		1.349

Input/Output	Company E (original values / deviation from Composite)		dual prices (abs / rel)	
costs	5.000	+217.0%	0.18383700	99.1%
response time	5.000	+275.6%	0.00000000	0.0%
investments	50.000	+217.0%	0.00161600	0.9%
sales change	0.429	+0.0%	0.73534800	100.0%

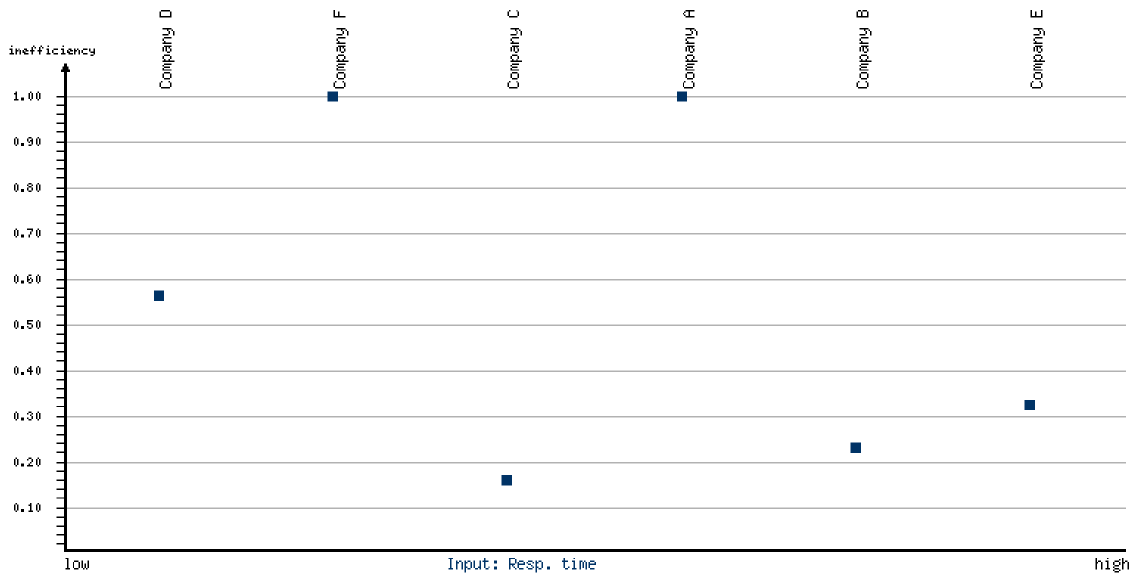


Input/Output	Composite			Company A			Company F
costs	1.577			5.000			1.000
response time	1.331			4.000			3.000
investments	15.773	=	0.30916	0.000	+	0.03155	500.000
sales change	0.429			1.250			1.349

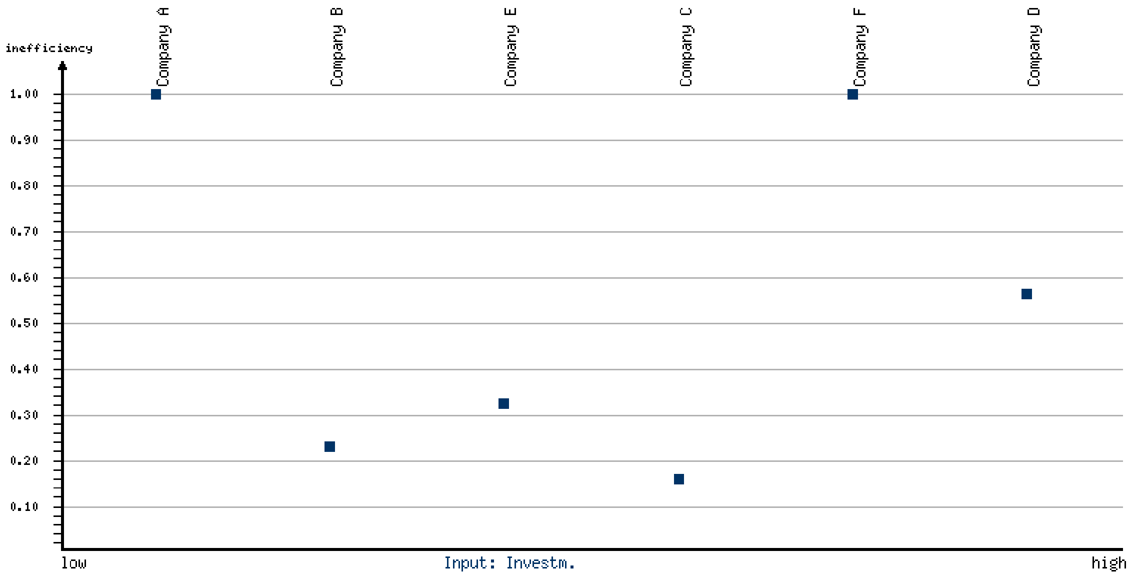
Performance: Cost for market change adaption



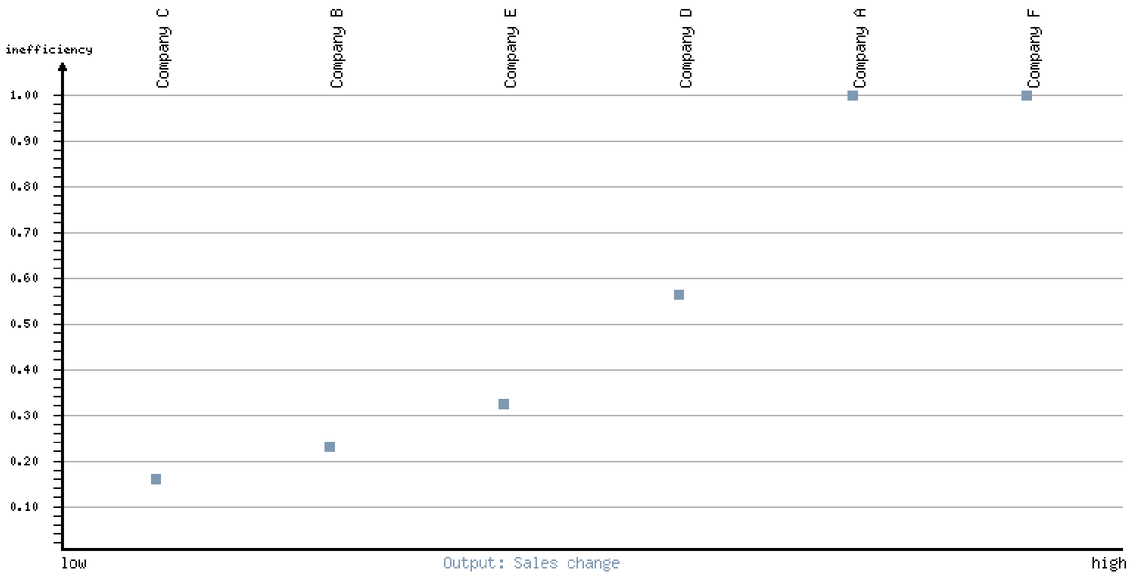
Performance: Market change response time



Performance: Investments before change of market



Performance: Change of sales volume caused by change of market



BCC method, Input oriented

Inefficient DMUs: data table

efficiency	inefficient DMU	activity level (λ)	DMUs used as reference
0.963018	Company B	0.953775 0.046225	Company A Company F
0.945203	Company C	0.856164 0.075342 0.068493	Company A Company D Company F
0.925925	Company E	0.907407 0.092593	Company A Company F

(*Please note:* This list contains only inefficient or weakly efficient DMUs! The total number of DMUs is 6 of which 3 DMUs are efficient.)

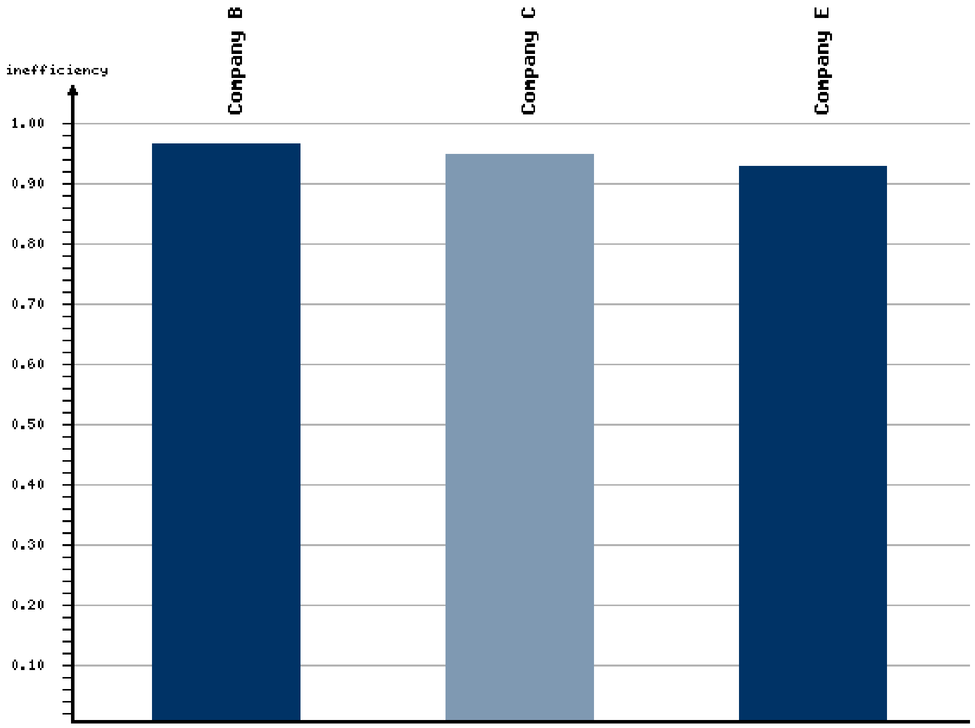
Efficient DMUs: super-efficiency values

Company A	----------
Company D	1.499998
Company F	----------

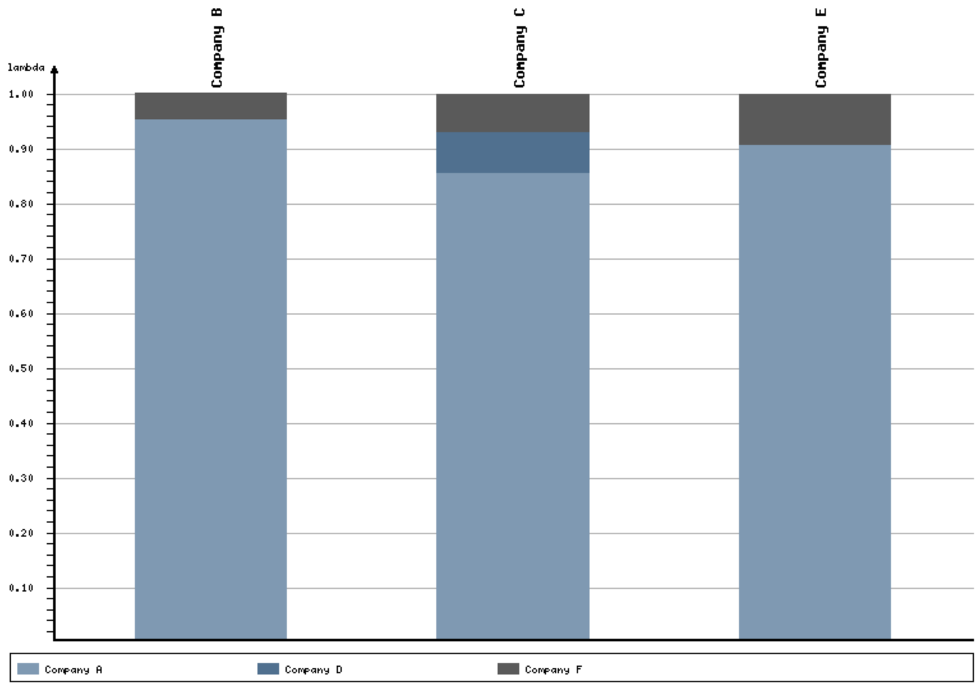
Efficient DMUs: frequency of reference

[+] Company A	3
[+] Company D	1
[+] Company F	3

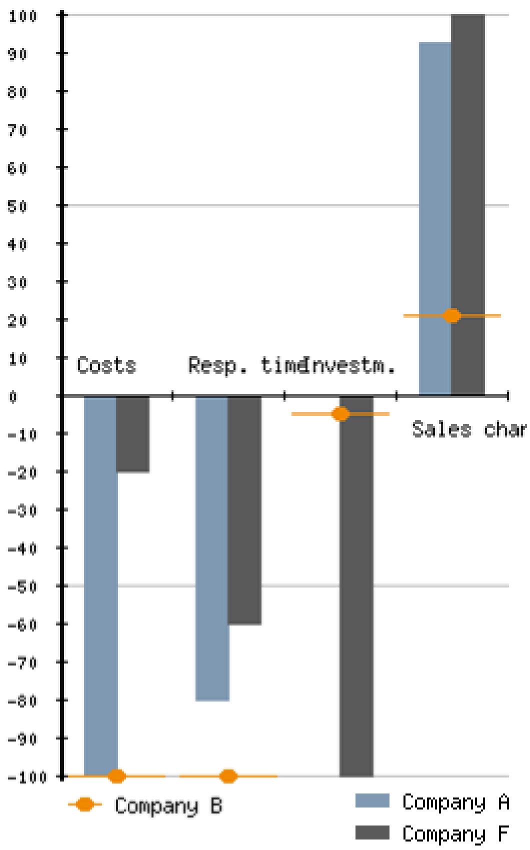
Performance diagram



Combination diagram

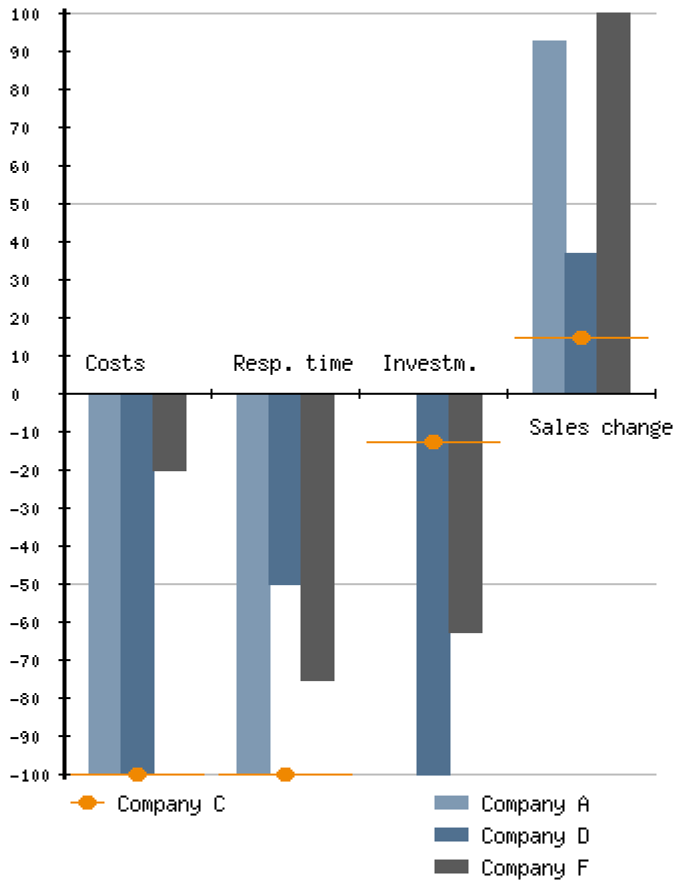


Input/Output	Company B (original values / deviation from Composite)		dual prices (abs / rel)	
costs	5.000	+3.8%	0.19260400	99.2%
response time	5.000	+26.5%	0.00000000	0.0%
investments	24.000	+3.8%	0.00154100	0.8%
sales change	0.287	-77.1%	0.00000200	100.0%



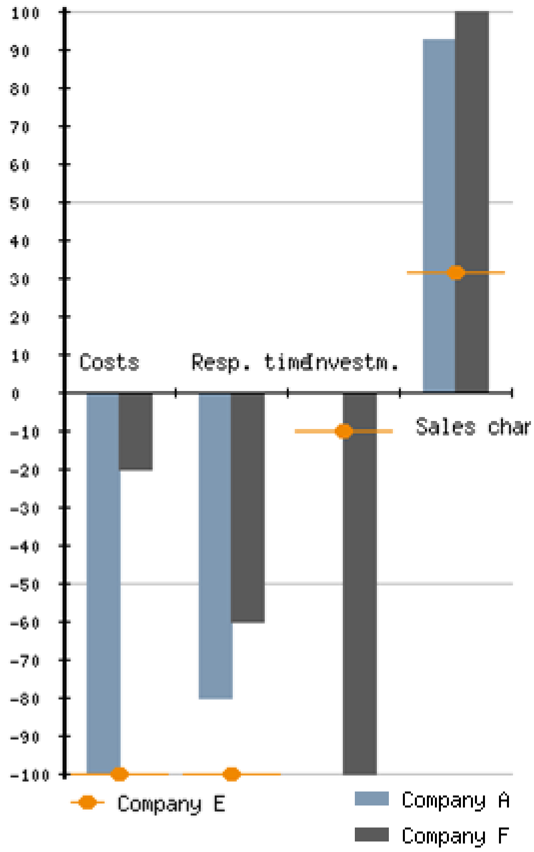
Input/Output	Composite			Company A			Company F
costs	4.815			5.000			1.000
response time	3.954			4.000			3.000
investments	23.113	=	0.95378	0.000	+	0.04623	500.000
sales change	1.255			1.250			1.349

Input/Output	Company C (original values / deviation from Composite)		dual prices (abs / rel)	
costs	5.000	+5.8%	0.01369800	5.9%
response time	4.000	+5.8%	0.21917900	93.9%
investments	100.000	+5.8%	0.00054800	0.2%
sales change	0.200	-83.3%	0.00000300	100.0%



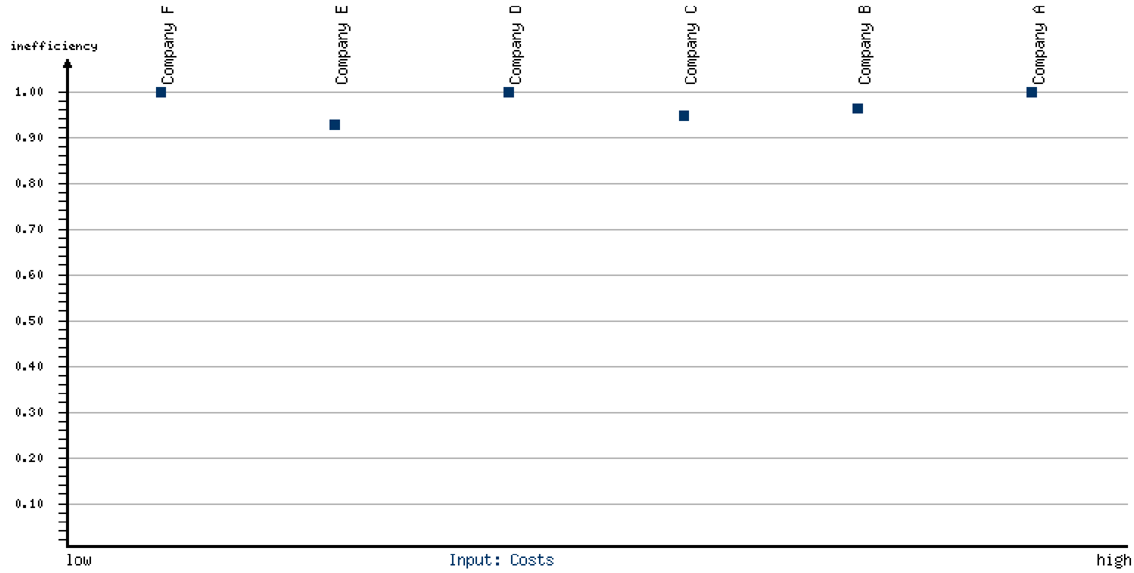
Input/ Output	Composite		Comp. A		Comp. D		Comp. F
costs	4.726		5.000		5.000		1.000
response time	3.781		4.000		2.000		3.000
investments	94.520	=0.85616	0.000	+0.07534	800.000	+0.06849	500.000
sales change	1.200		1.250		0.500		1.349

Input/Output	Company E (original values / deviation from Composite)		dual prices (abs / rel)	
costs	5.000	+8.0%	0.18518500	99.2%
response time	5.000	+28.0%	0.00000000	0.0%
investments	50.000	+8.0%	0.00148100	0.8%
sales change	0.429	-65.9%	0.00000100	100.0%

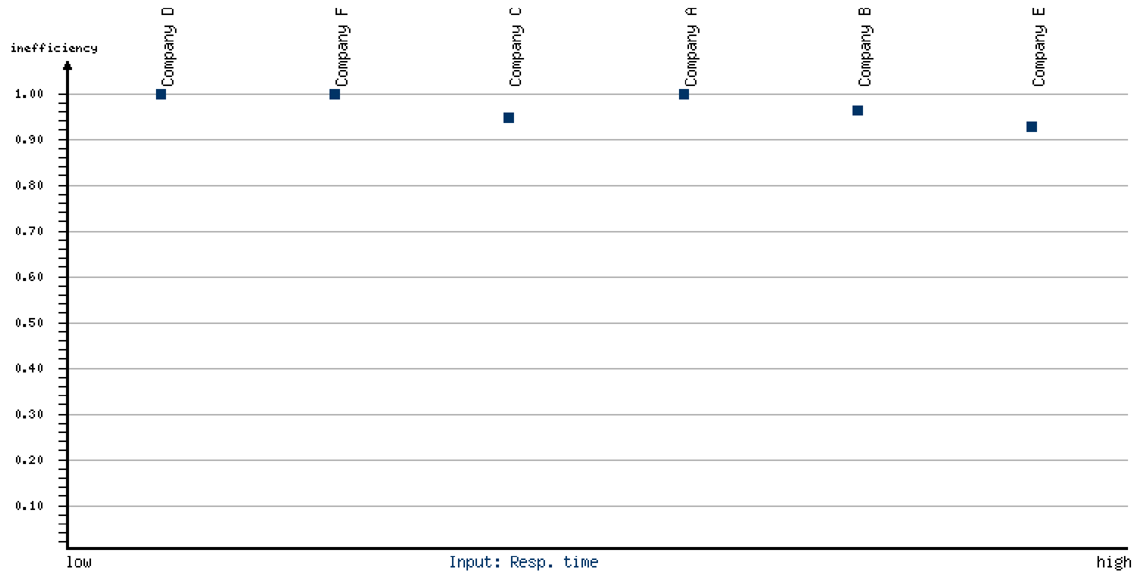


Input/Output	Composite			Company A			Company F
costs	4.630			5.000			1.000
response time	3.907			4.000			3.000
investments	46.297	=	0.90741	0.000	+	0.09259	500.000
sales change	1.259			1.250			1.349

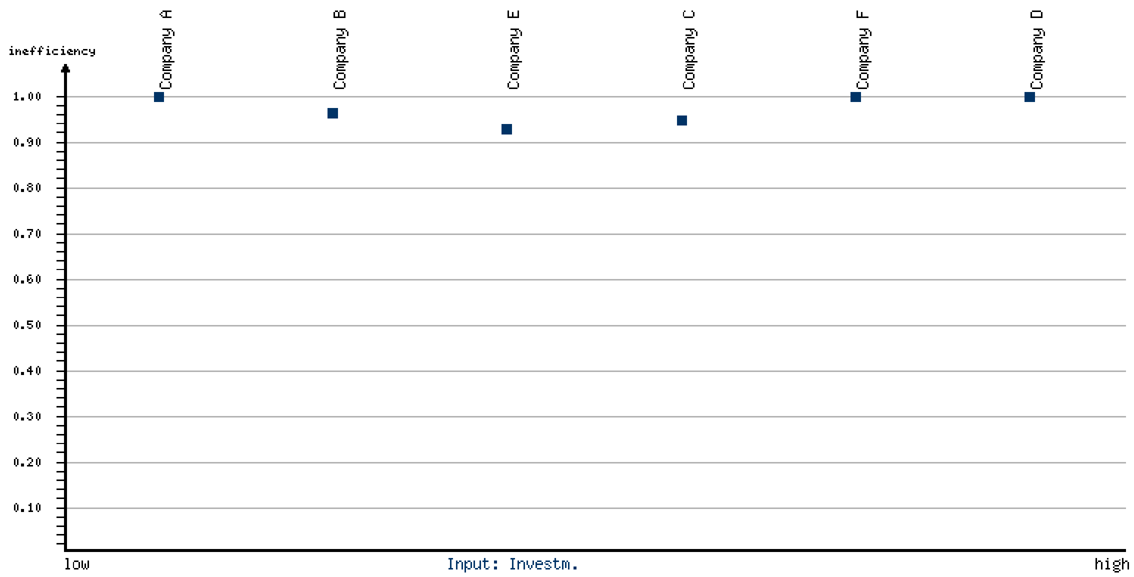
Performance: Cost for market change adaption



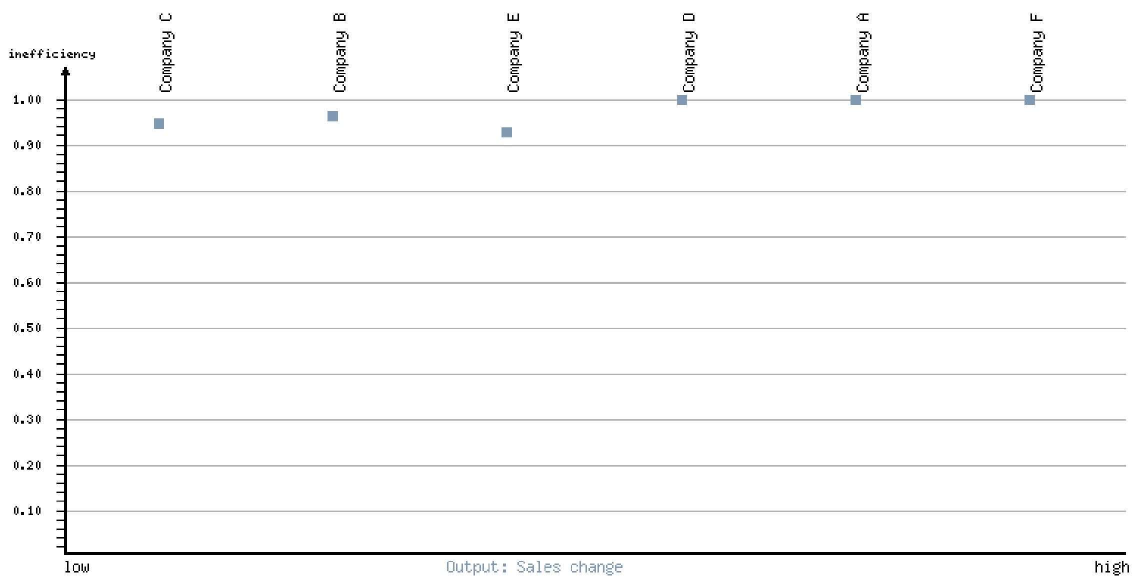
Performance: Market change response time



Performance: Investments before change of market



Performance: Change of sales volume caused by change of market



Appendix 4

Dimension: Innovation Capabilities

CCR method, Input oriented

Inefficient DMUs: data table

inefficiency	inefficient DMU	activity level (λ)	DMUs used as reference
0.862701	Company D	0.135510 0.288905 0.552771	Company A Company C Company F
0.764081	Company E	0.010286 0.717014 0.225632	Company B Company C Company F

(*Please note:* This list contains only inefficient or weakly efficient DMUs! The total number of DMUs is 6 of which 4 DMUs are efficient.)

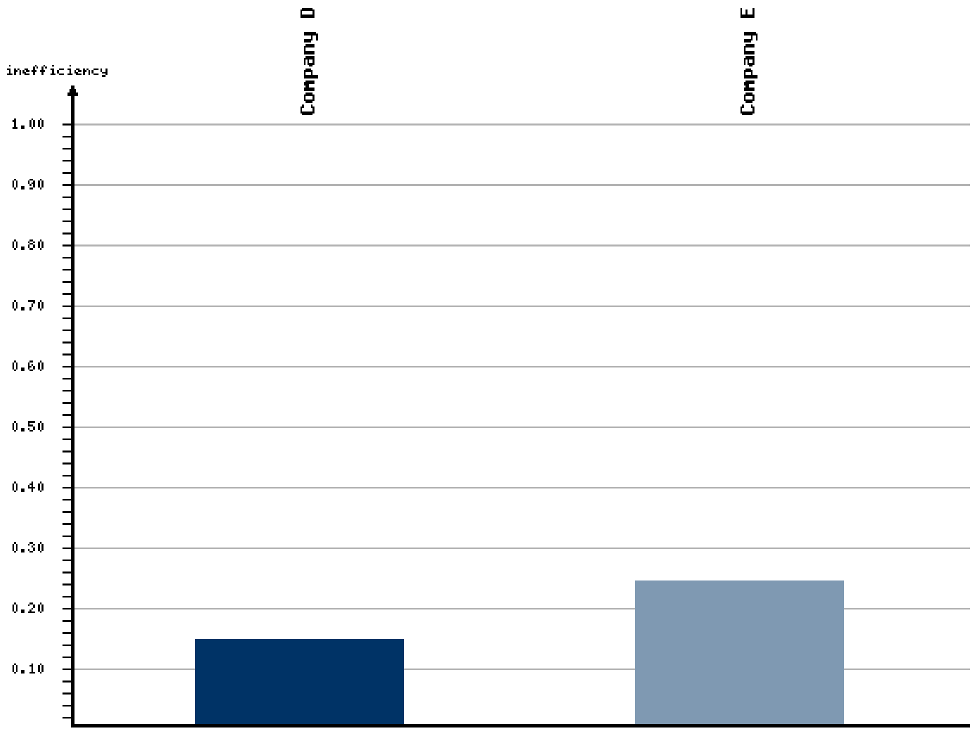
Efficient DMUs: super-efficiency values

Company A	4.285707
Company B	10.037134
Company C	19,999,485,000.000000
Company F	----------

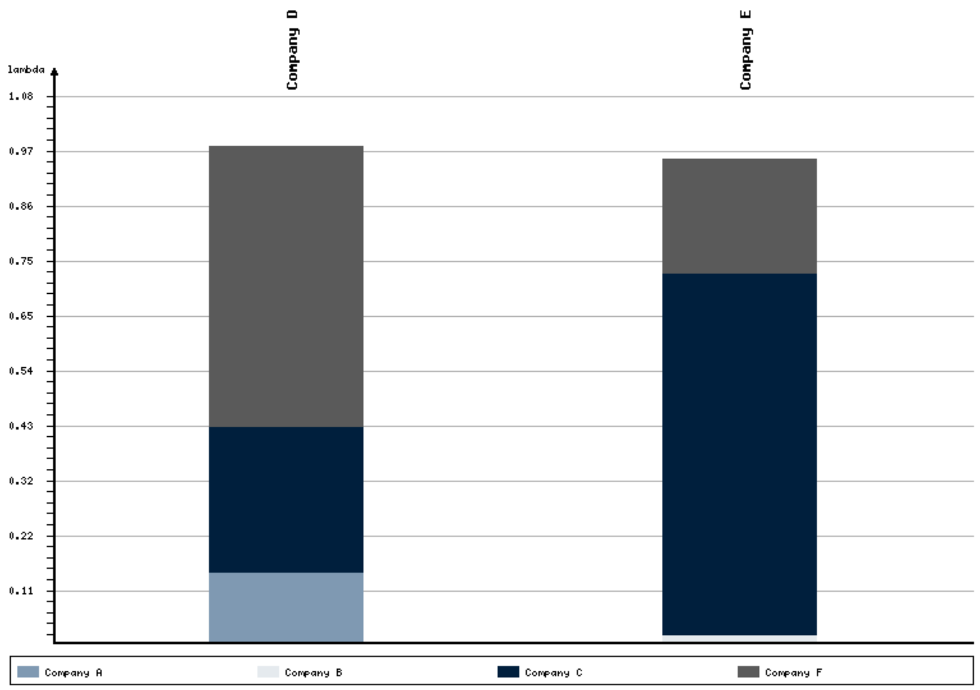
Efficient DMUs: frequency of reference

[+] Company A	1
[+] Company B	1
[+] Company C	2
[+] Company F	2

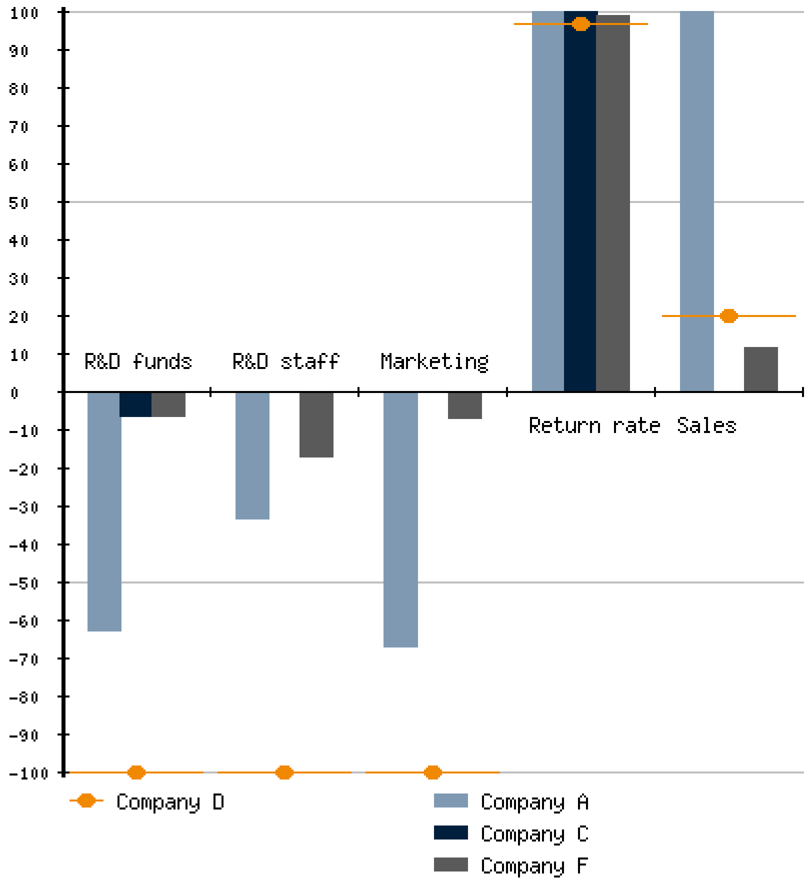
Performance diagram



Combination diagram

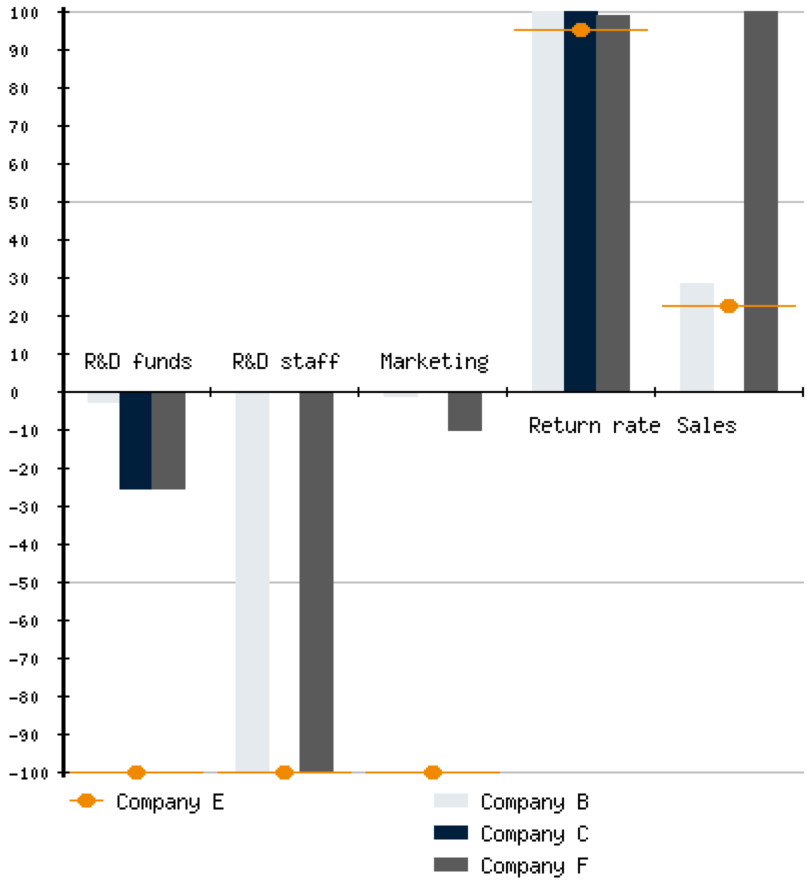


Input/Output	Company D (original values / deviation from Composite)		dual prices (abs / rel)	
R&D funds	800.000	+628.3%	0.00082900	1.5%
R&D staff	6.000	+628.3%	0.05608800	98.5%
marketing	300.000	+686.2%	0.00000000	0.0%
Return rate	0.970	+0.0%	0.04146700	99.6%
Sales	600.000	+0.0%	0.00016200	0.4%



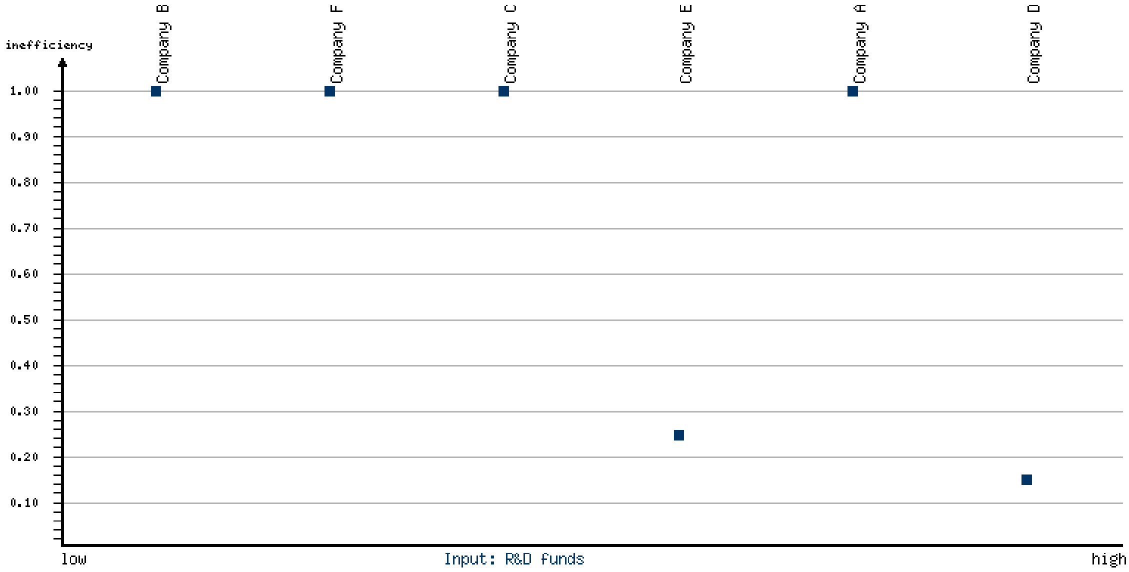
Input/ Output	Composite		Comp. A		Comp. C		Comp. F
R&D funds	109.839		500.000		50.000		50.000
R&D staff	0.824		2.000		0.000		1.000
marketing	38.157	=0.13551	200.000	+0.28891	0.000	+0.55277	20.000
Return rate	0.970		1.000		1.000		0.987
Sales	600.000		3,000.000		0.000		350.000

Input/Output	Company E (original values / deviation from Composite)		dual prices (abs / rel)	
R&D funds	200.000	+323.9%	0.00379900	1.6%
R&D staff	1.000	+323.9%	0.24029500	98.4%
marketing	200.000	+4,311.9%	0.00000000	0.0%
Return rate	0.950	+0.0%	0.18992600	99.6%
Sales	80.000	+0.0%	0.00069400	0.4%

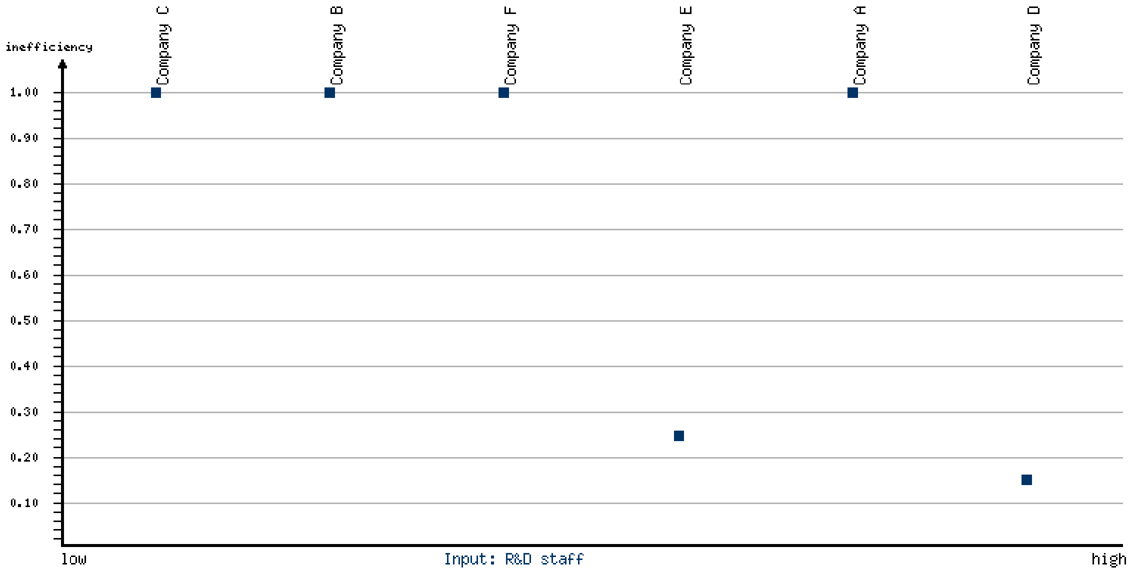


Input/ Output	Composite		Comp. A		Comp. C		Comp. F
R&D funds	47.184		5.000		50.000		50.000
R&D staff	0.236		1.000		0.000		1.000
marketing	4.533	=0.01029	2.000	+0.71701	0.000	+0.22563	20.000
Return rate	0.950		1.000		1.000		0.987
Sales	80.000		100.000		0.000		350.000

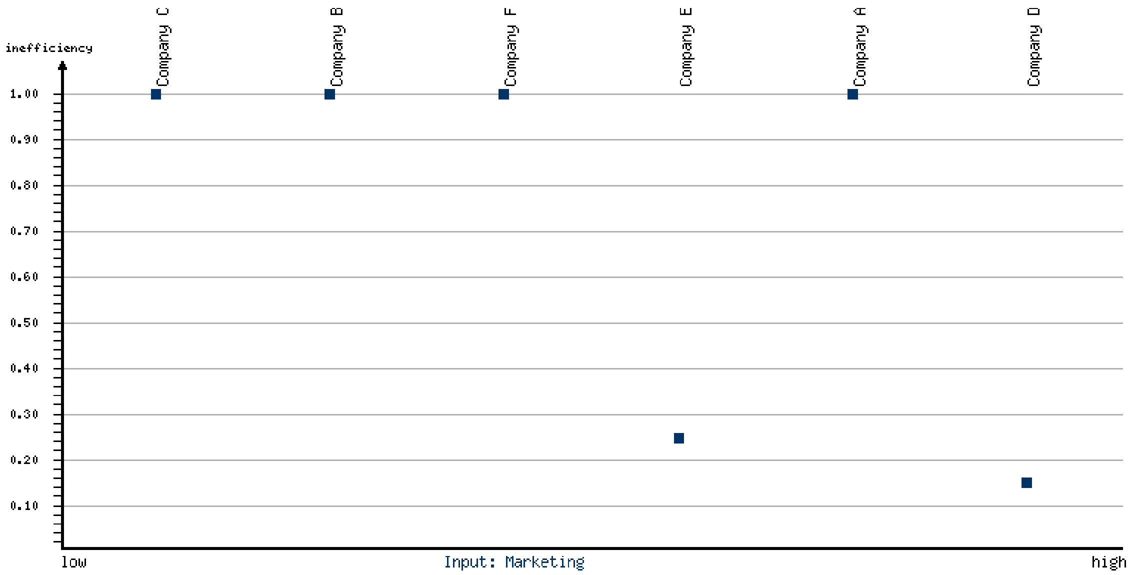
Performance: R&D funds expenditure



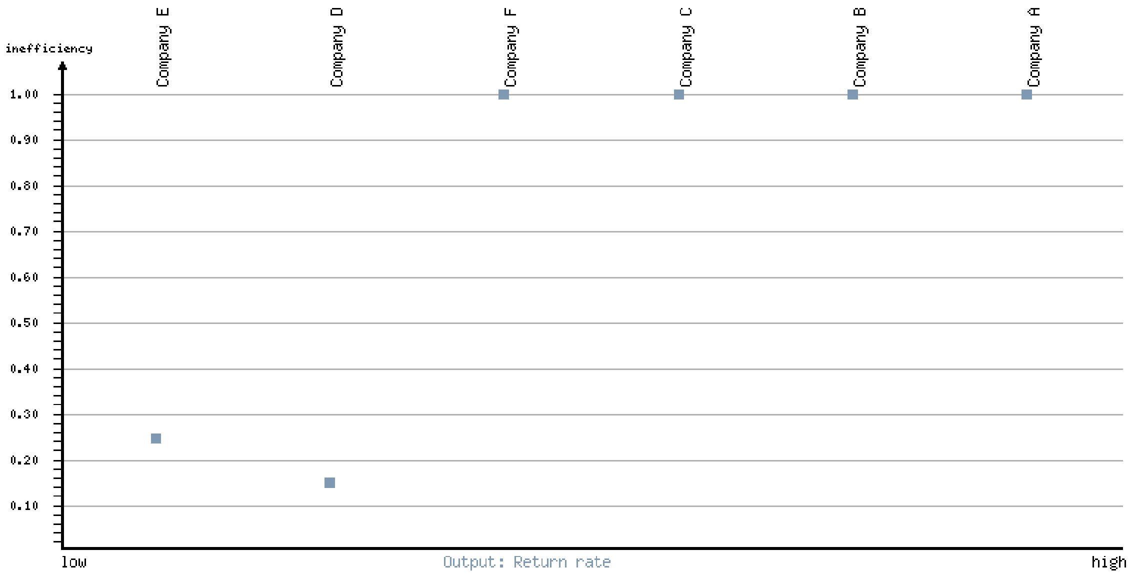
Performance: R&D staff quantity



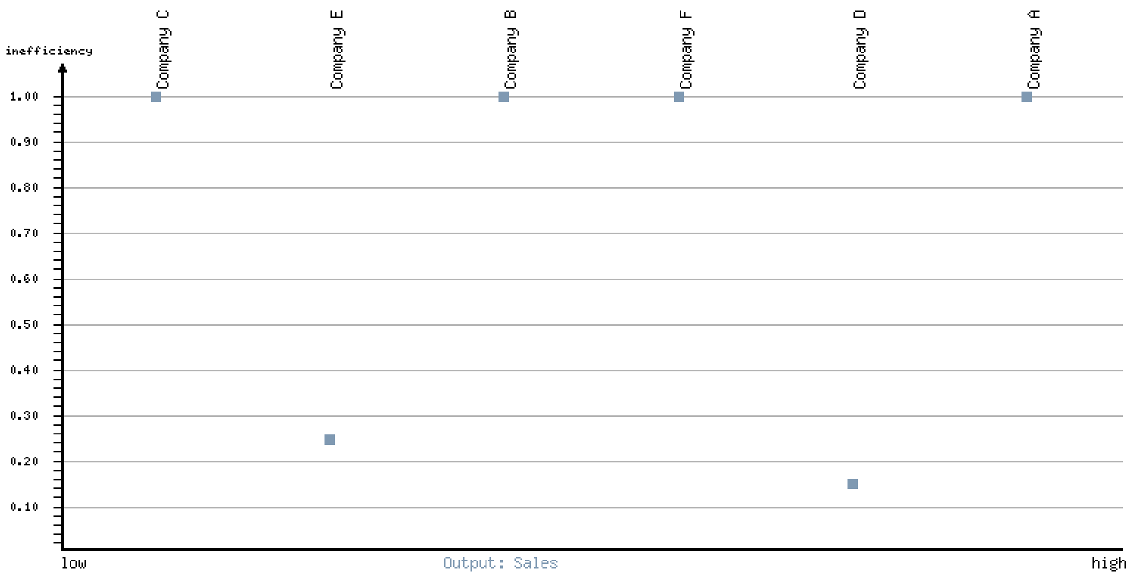
Performance: Marketing expenditure



Performance: Rate of return of new product



Performance: Sales revenue of new product



BCC method, Input oriented

Inefficient DMUs: data table

efficiency	inefficient DMU	activity level (λ)	DMUs used as reference
0.138241	Company D	0.134650 0.305206 0.560144	Company A Company C Company F
0.244867	Company E	0.022814 0.755133 0.222053	Company B Company C Company F

(*Please note:* This list contains only inefficient or weakly efficient DMUs! The total number of DMUs is 6 of which 4 DMUs are efficient.)

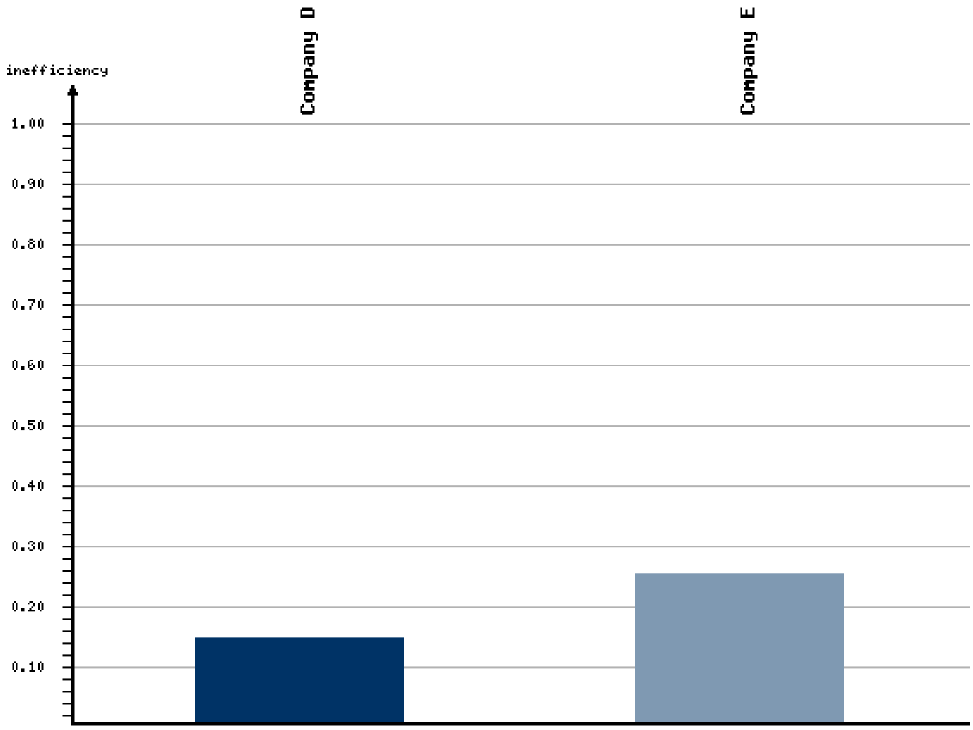
Efficient DMUs: super-efficiency values

Company A	----------
Company B	12.999989
Company C	----------
Company F	1.028125

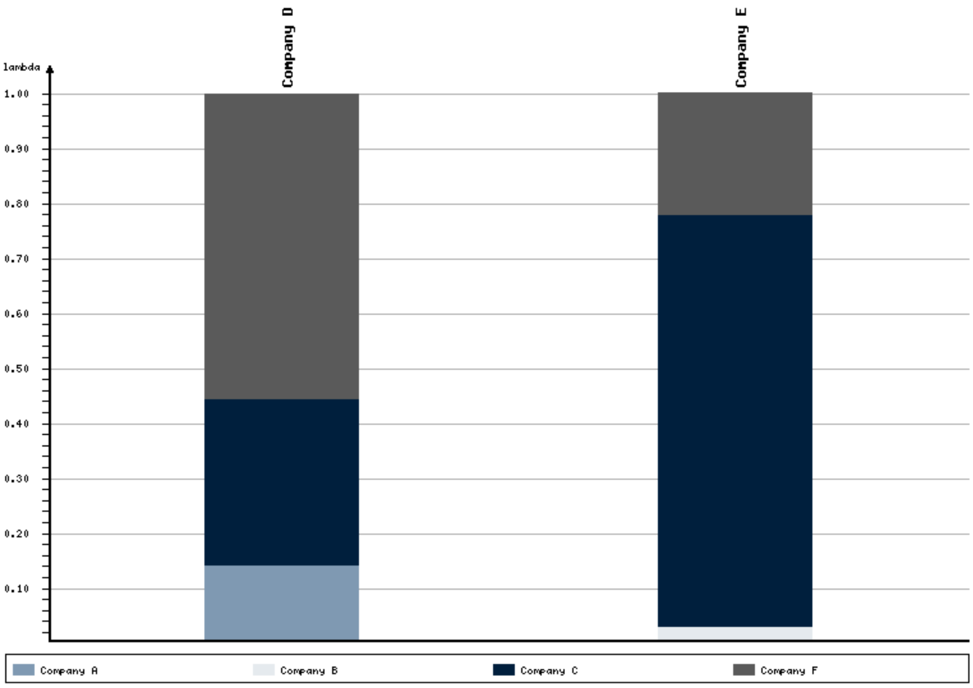
Efficient DMUs: frequency of reference

[+] Company A	1
[+] Company B	1
[+] Company C	2
[+] Company F	2

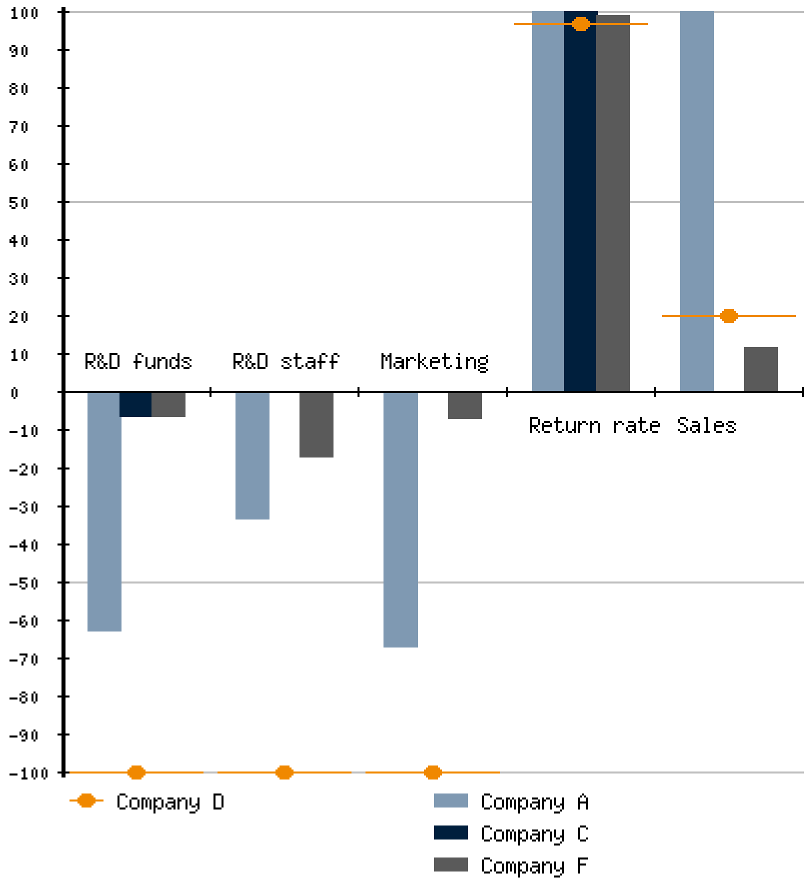
Performance diagram



Combination diagram

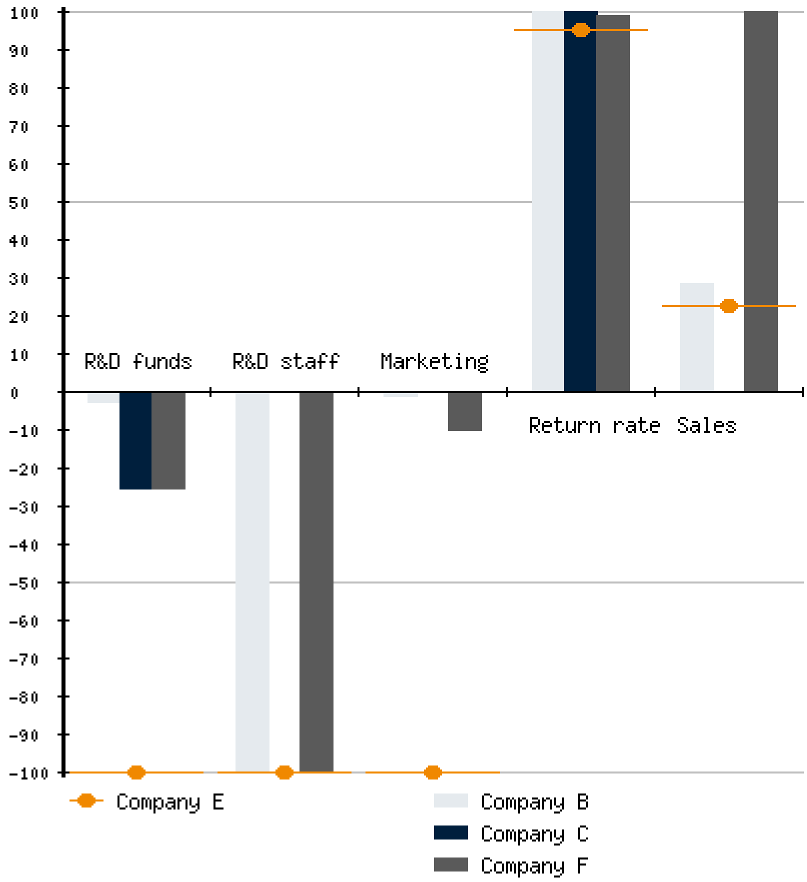


Input/Output	Company D (original values / deviation from Composite)		dual prices (abs / rel)	
R&D funds	800.000	+623.4%	0.00082600	1.4%
R&D staff	6.000	+623.4%	0.05655300	98.6%
marketing	300.000	+686.7%	0.00000000	0.0%
Return rate	0.970	-2.3%	0.00000100	0.6%
Sales	600.000	-0.0%	0.00016200	99.4%



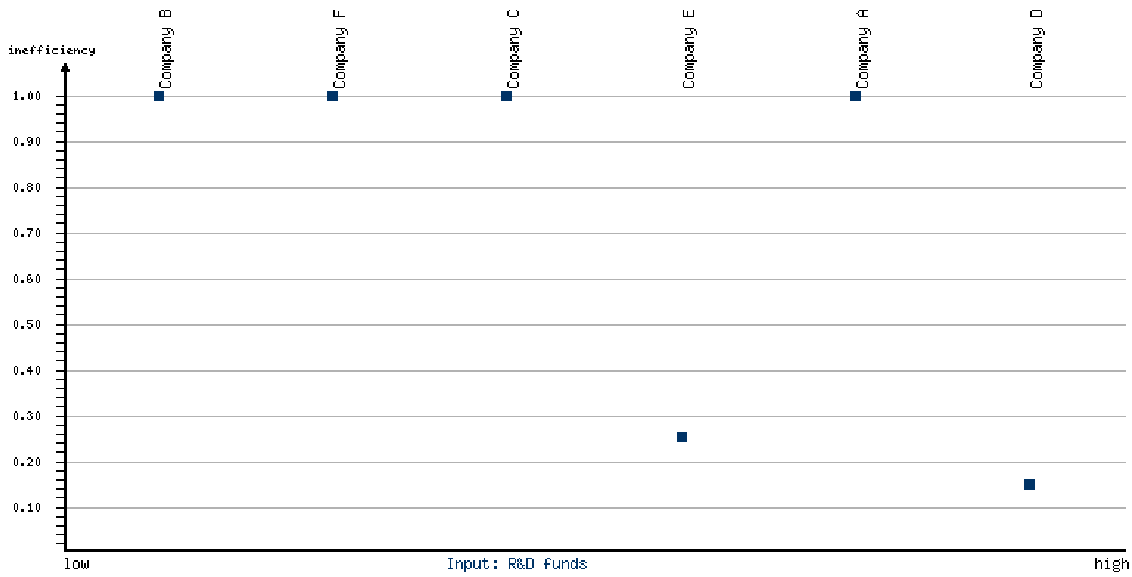
Input/ Output	Composite		Comp. A		Comp. C		Comp. F
R&D funds	110.593		500.000		50.000		50.000
R&D staff	0.829		2.000		0.000		1.000
marketing	38.133	=0.13465	200.000	+0.30521	0.000	+0.56014	20.000
Return rate	0.993		1.000		1.000		0.987
Sales	600.000		3,000.000		0.000		350.000

Input/Output	Company E (original values / deviation from Composite)		dual prices (abs / rel)	
R&D funds	200.000	+308.4%	0.00380200	1.6%
R&D staff	1.000	+308.4%	0.23954400	98.4%
marketing	200.000	+4,357.6%	0.00000000	0.0%
Return rate	0.950	-4.7%	0.00000100	0.1%
Sales	80.000	+0.0%	0.00068400	99.9%

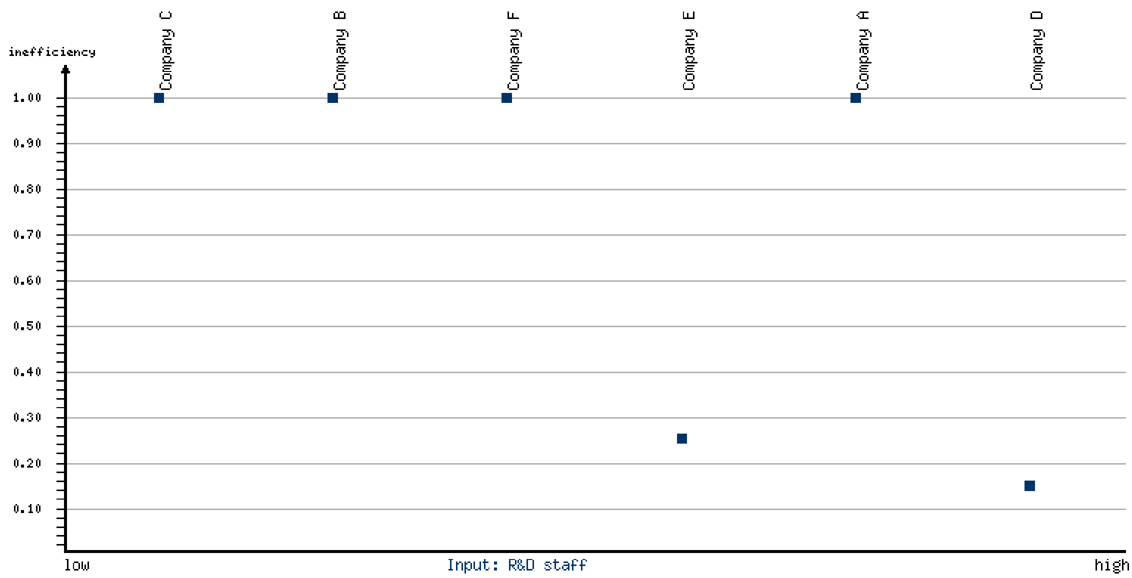


Input/ Output	Composite		Comp. B		Comp. C		Comp. F
R&D funds	48.973		5.000		50.000		50.000
R&D staff	0.245		1.000		0.000		1.000
marketing	4.487	=0.02281	2.000	+0.75513	0.000	+0.22205	20.000
Return rate	0.997		1.000		1.000		0.987
Sales	80.000		100.000		0.000		350.000

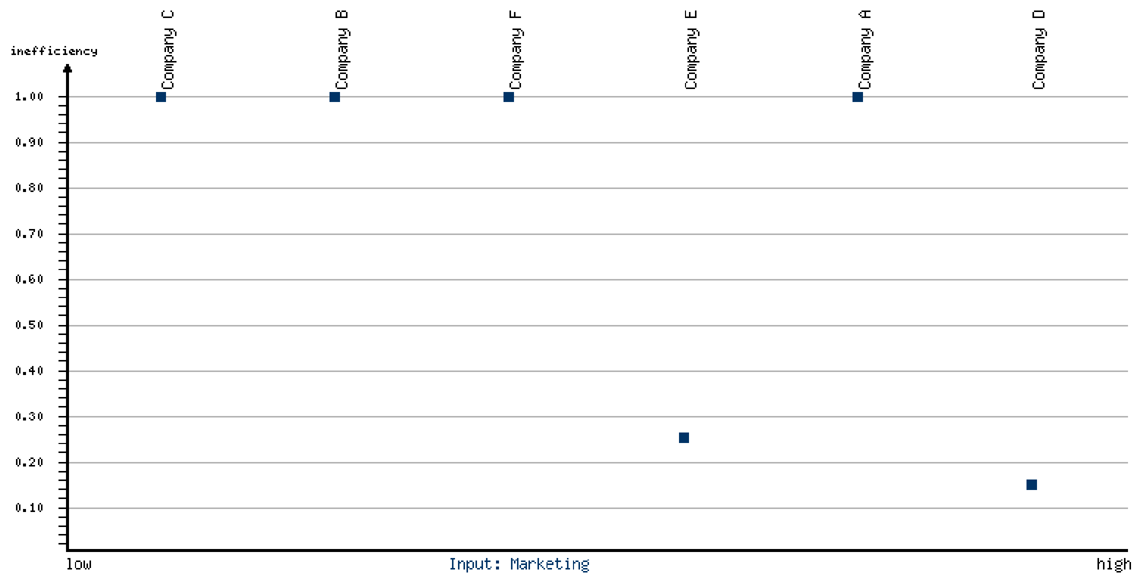
Performance: R&D funds expenditure



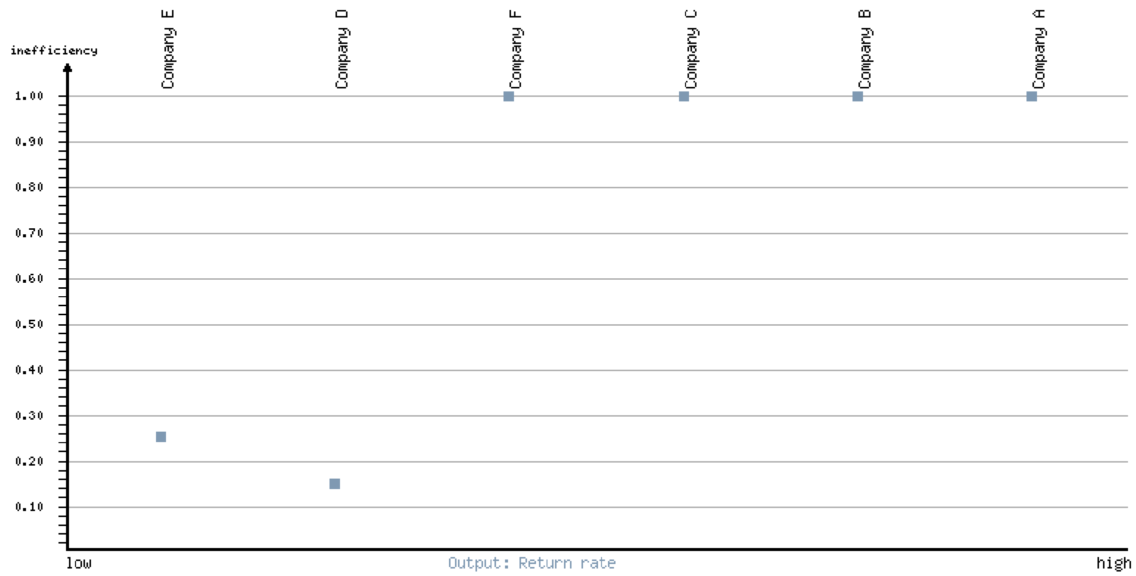
Performance: R&D staff quantity



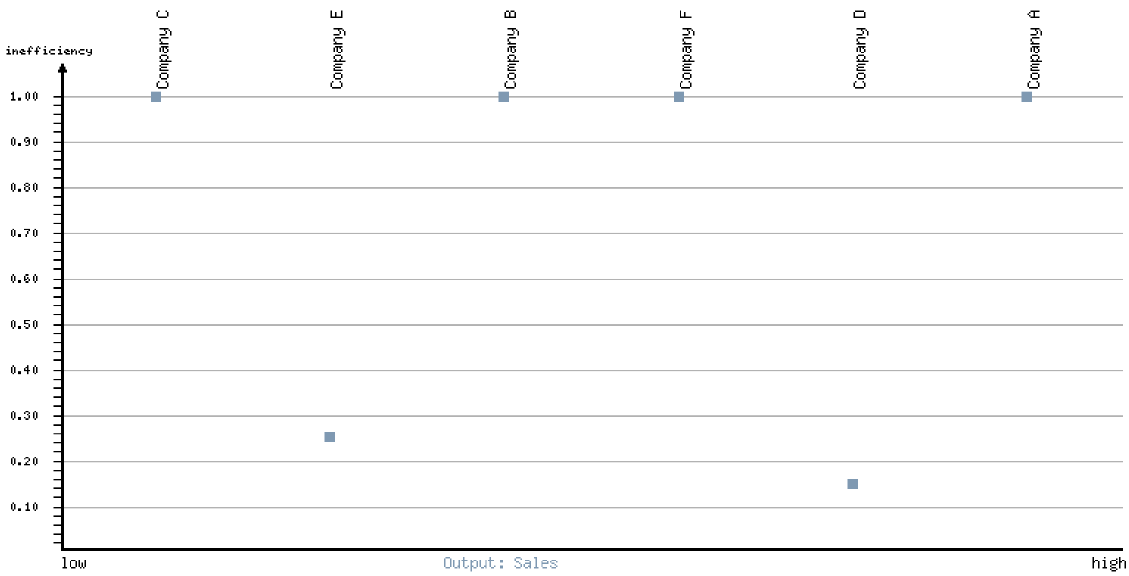
Performance: Marketing expenditure



Performance: Rate of return of new product



Performance: Sales revenue of new product



Appendix 5

Dimension: Competitiveness

CCR method, Input oriented

Inefficient DMUs: data table

efficiency	**inefficient DMU**	**activity level (λ)**	**DMUs used as reference**
0.965971	Company A	1.354167	Company C
0.607675	Company B	0.013927 0.013315	Company C Company D
0.491289	Company E	0.029034 0.013295	Company C Company D

(*Please note:* This list contains only inefficient or weakly efficient DMUs! The total number of DMUs is 6 of which 3 DMUs are efficient.)

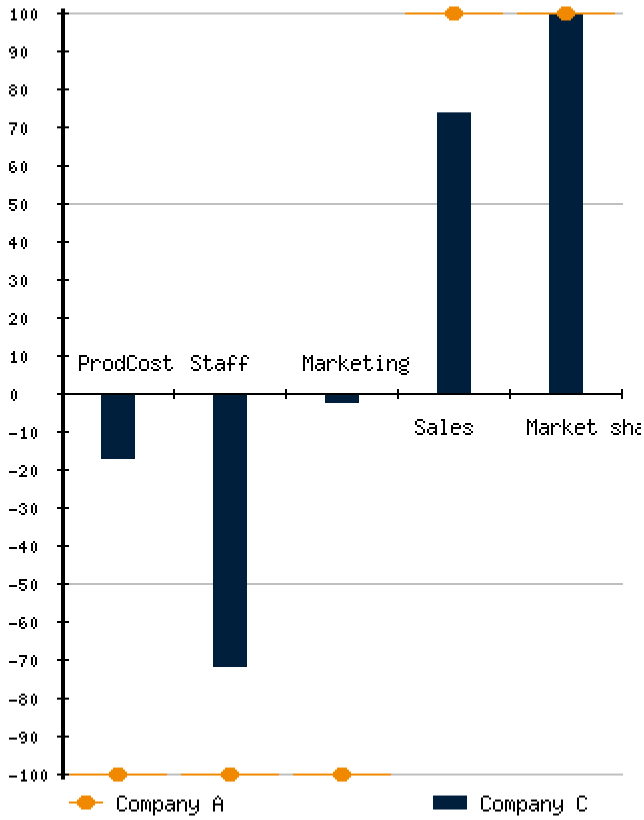
Efficient DMUs: super-efficiency values

Company C	10.322264
Company D	1.080722
Company F	5.124996

Efficient DMUs: frequency of reference

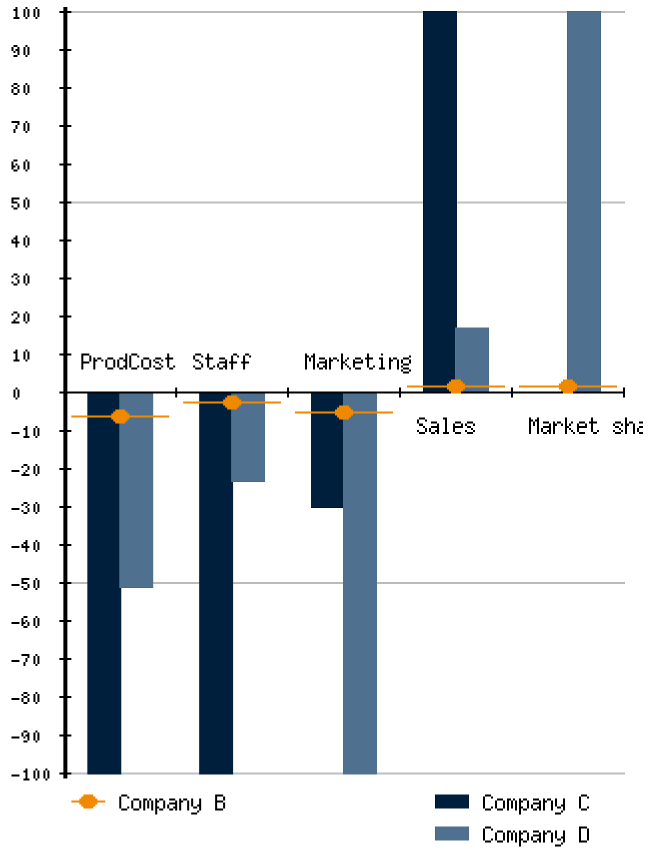
[+] Company C	3
[+] Company D	2
[+] Company F	0

Input/Output	Company A (original values / deviation from Composite)		dual prices (abs / rel)	
ProdCosts	47,000.000	+333.8%	0.00000000	0.0%
Staff	150.000	+3.5%	0.00666700	100.0%
Marketing	1,500.000	+3,592.3%	0.00000000	0.0%
Sales	65,000.000	-0.0%	0.00001500	0.3%
M.Share	0.000	-26.2%	0.00500000	99.7%



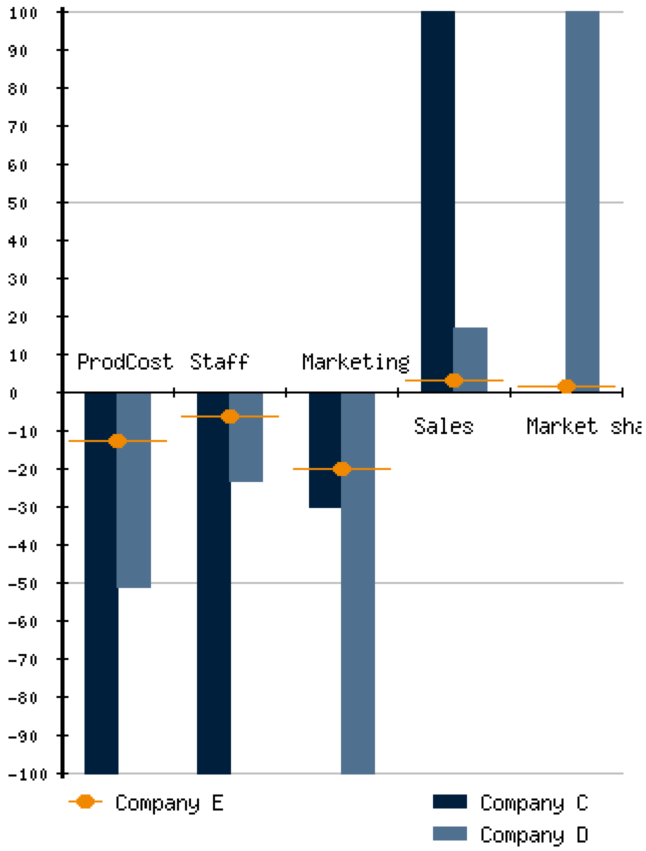
Input/Output	Composite		Company C
ProdCosts	10,833.336		8,000.000
Staff	144.896		107.000
Marketing	40.625	= 1.35417	30.000
Sales	65,000.016		48,000.000
M.Share	0.000		0.000

Input/Output	Company B (original values / deviation from Composite)		dual prices (abs / rel)	
ProdCosts	488.000	+194.0%	0.00000000	0.0%
Staff	3.000	+64.6%	0.33333300	100.0%
Marketing	5.000	+185.8%	0.00000000	0.0%
Sales	775.000	-0.0%	0.00074300	0.0%
M.Share	0.001	-0.0%	31.85906400	100.0%



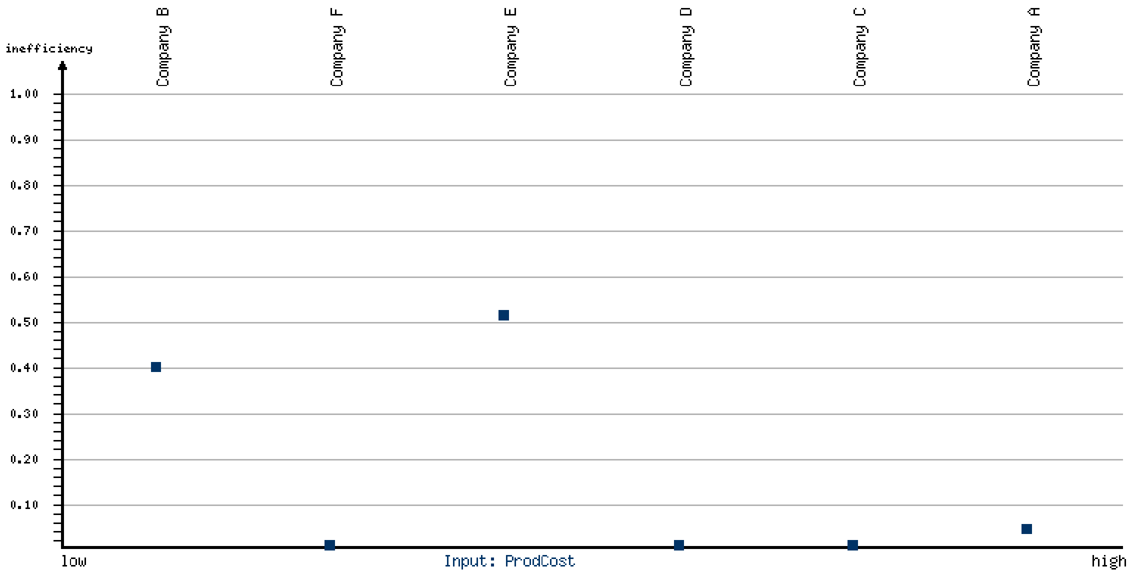
Input/Output	Composite		Company C		Company D
ProdCosts	166.008		8,000.000		4,100.000
Staff	1.823		107.000		25.000
Marketing	1.749	= 0.01393	30.000	+ 0.01332	100.000
Sales	775.016		48,000.000		8,000.000
M.Share	0.001		0.000		0.075

Input/Output	Company E (original values / deviation from Composite)		dual prices (abs / rel)	
ProdCosts	1,000.000	+248.7%	0.00000000	0.0%
Staff	7.000	+103.5%	0.14285700	100.0%
Marketing	20.000	+808.9%	0.00000000	0.0%
Sales	1,500.000	+0.0%	0.00031800	0.0%
M.Share	0.001	-0.0%	13.65386400	100.0%

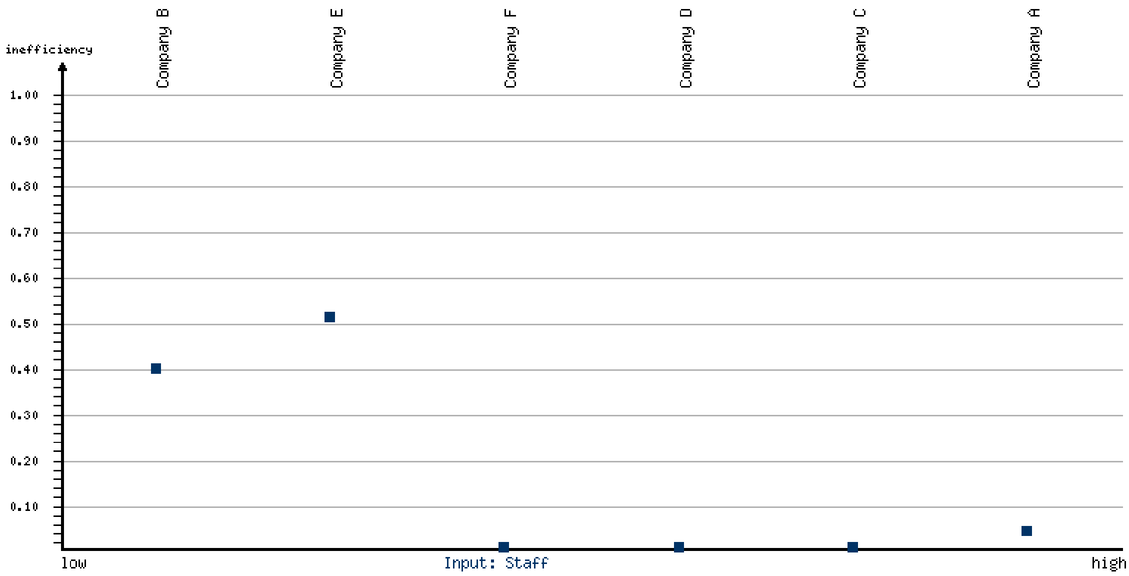


Input/Output	Composite		Company C		Company D
ProdCosts	286.782		8,000.000		4,100.000
Staff	3.439		107.000		25.000
Marketing	2.201	= 0.02903	30.000	+ 0.01330	100.000
Sales	1,499.992		48,000.000		8,000.000
M.Share	0.001		0.000		0.075

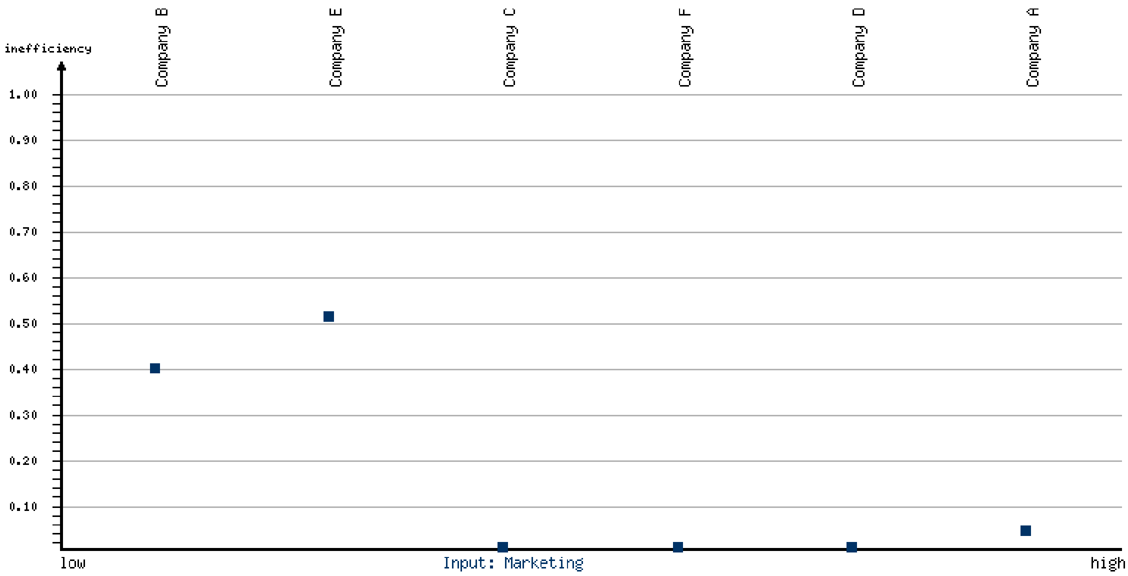
Performace: Production Costs



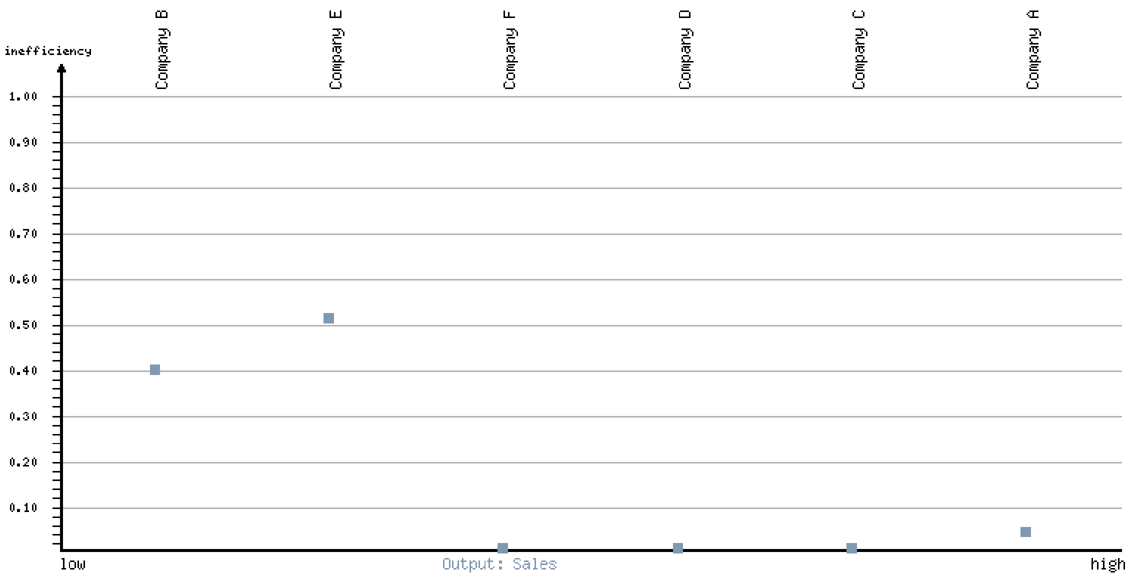
Performace: Staff quantity



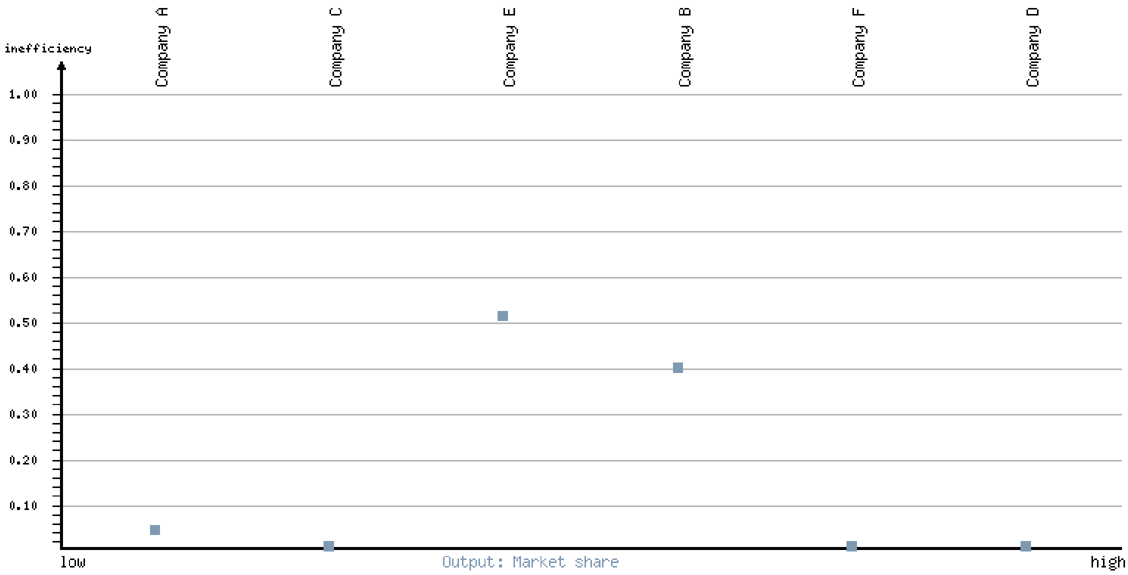
Performace: Marketing expenditure



Performace: Sales revenue



Performace: Market share



BCC method, Input oriented

Inefficient DMUs: data table

efficiency	inefficient DMU	activity level (λ)	DMUs used as reference
0.656821	Company E	0.984490 0.015324 0.000186	Company B Company C Company D

(*Please note:* This list contains only inefficient or weakly efficient DMUs! The total number of DMUs is 6 of which 5 DMUs are efficient.)

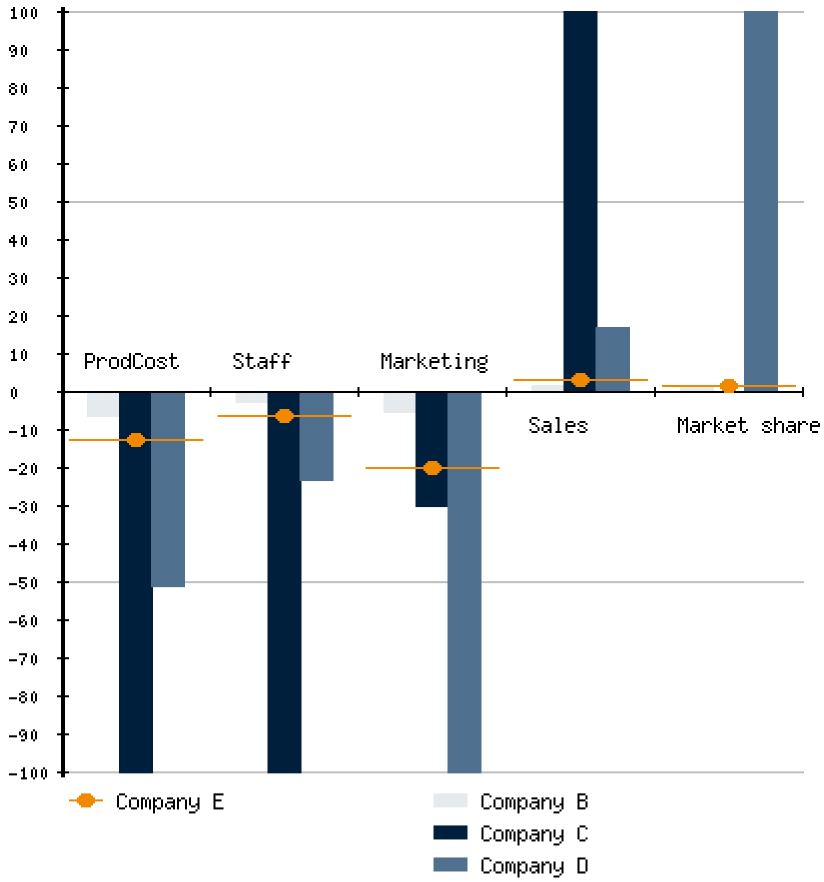
Efficient DMUs: super-efficiency values

Company A	----------
Company B	3.999998
Company C	36.081726
Company D	----------
Company F	5.124996

Efficient DMUs: frequency of reference

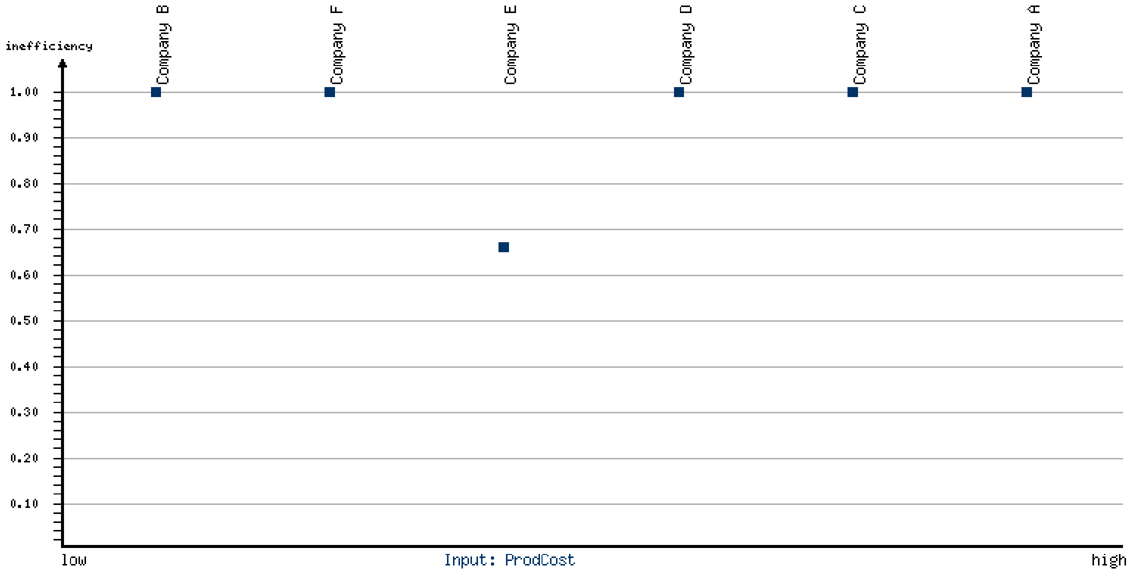
[+] Company A	0
[+] Company B	1
[+] Company C	1
[+] Company D	1
[+] Company F	0

Input/Output	Company E (original values / deviation from Composite)		dual prices (abs / rel)	
ProdCosts	1,000.000	+65.6%	0.00000000	0.0%
Staff	7.000	+52.2%	0.14285700	100.0%
Marketing	20.000	+270.3%	0.00000000	0.0%
Sales	1,500.000	-0.0%	0.00031500	0.0%
M.Share	0.001	+0.0%	11.73290700	100.0%

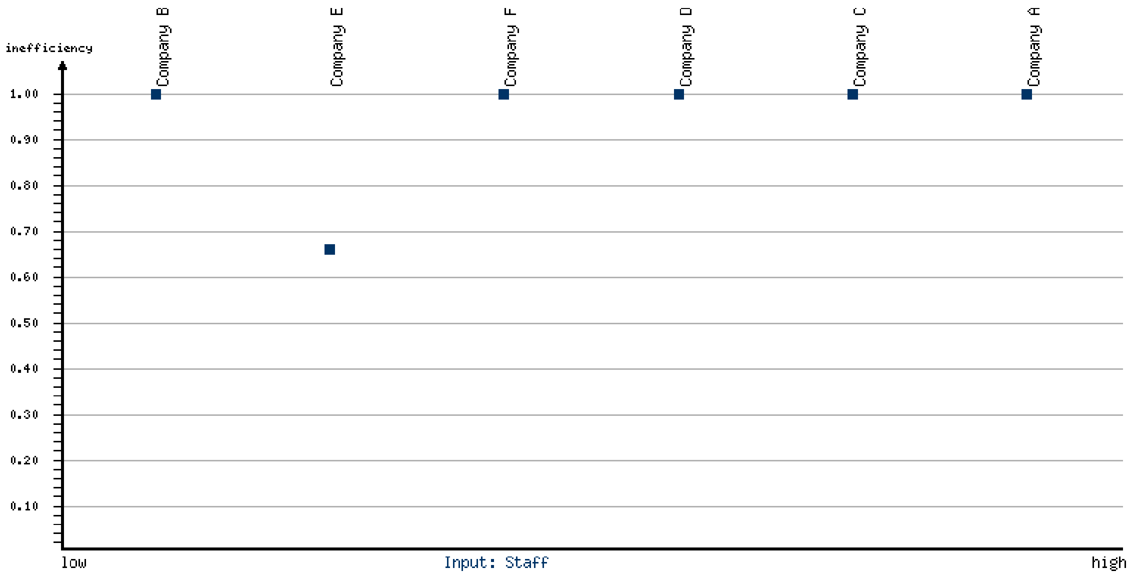


Input/ Output	Composite		Comp. B		Comp. C		Comp. D
ProdCosts	603.786		488.000		8,000.000		4,100.000
Staff	4.598		3.000		107.000		25.000
Marketing	5.401	= 0.98449	5.000	+0.01532	30.000	+0.00019	100.000
Sales	1,500		775.000		48,000.000		8,000.000
M.Share	0.001		0.001		0.000		0.075

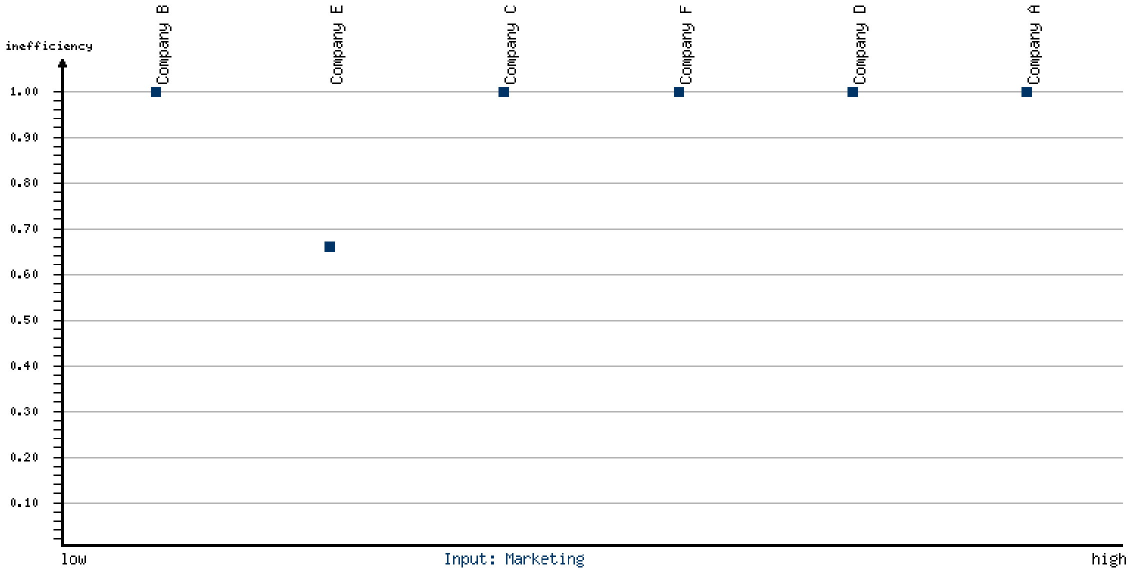
Performace: Production Costs



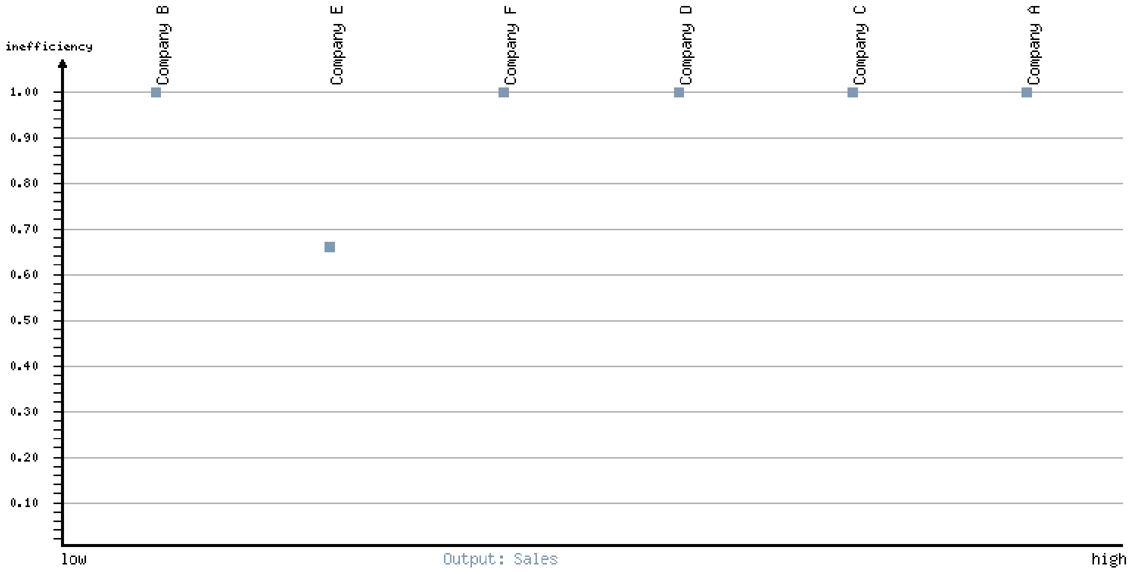
Performace: Staff quantity



Performace: Marketing expenditure



Performace: Sales revenue



Performace: Market share