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SAFETY AT WORK IN EUROPE: AN EFFICIENCY ANALYSIS

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Abstract: *Nowadays workplace accidents are more and more recognised as a social problem that has undesirable consequences on both human and organisations. As a result, there has been increasing concern in improving working conditions and in reducing occupational accidents in the European Union. In this context, this paper examines safety performance of fifteen European countries in four economic sectors – manufacturing, construction, distribution trades and transportation – by applying a frontier analysis method, Data Envelopment Analysis (DEA). A linear programming framework is therefore used to construct both constant and variable returns to scale (CRS and VRS, respectively) production frontiers which allow measurement of relative efficiency with respect to the number of workplace accidents.*

Key words: *Workplace accidents, Technical efficiency, Data Envelopment Analysis (DEA), Undesirable outputs*

1. Introduction

Nowadays workplace accidents[3] are more and more recognised as a social problem that has undesirable consequences on both human and organisations. Their prevention is then worthy of heedful regard, since it would enhance the quality of working life and might also contribute to reducing the direct and indirect costs attributable to the production of goods and services (Laflamme, 1990). Occupational accidents, in fact, entail costs that are related to insurance indemnity, safety intervention, security devices and all the other expenditure related (Mazzolini, 2010). Consequently, governments should intervene for reducing injuries at work either on humanitarian or on economic grounds.

In the European context, the improvement of working conditions and the prevention of workplace accidents are amongst the primary objectives to pursue, as stipulated in the Treaty of Rome (article 136) and confirmed by the Framework Directive 89/391. Again at the Lisbon European Council in March 2000, the objective that the European Union set itself was "creating more and better jobs" (Commission of the European Communities, 2002)[4]. Safety and health at work is now one of the most important and most highly developed aspects of the European Union's policy on employment and social affairs.

However, a worrying return to a rising scale of accidents, in certain States and in certain sector, has been evident in the last decade. More than 27 thousands workers die every year due to accidents at work, resulting in a GDP loss of more than 4 percent in the European Union. Occupational safety and health policy is not only a matter of laws and regulations. In order to achieve measurable improvements of working conditions and a reduction of occupational accidents it is necessary to combine them with a variety of other instruments, such as social dialogue, good practices, awareness raising, corporate social responsibility, economic incentives and mainstreaming.

Based on the above considerations, we believe that working towards a safe and healthy occupational environment has to be addressed as part of the general trend in economic activities (Commission of the European Communities, 2002). A safe working environment represent, in fact, a performance factor for national economies, that should be able to balance economic development and social progress with quality of work.

The literature indicates that many disciplines have tried to explain the mechanisms involved in occupational accident genesis. In the past few decades, in fact, several models derived from different schools of thought were developed to study the characteristics of occupational accidents and to identify factors contributing to the occurrence of injurious events in order to guide preventive strategies with useful and efficient insights (Laflamme et al., 1993). Nevertheless, few studies (El-Mashaleh et al., 2009; Liu et al., 2005; Qu et al., 2010) have dealt with the issue of investigating national institutions performance in terms of their ability to maximise macroeconomic objectives while minimising work related accidents.

The motivation of the present study is to provide evidence that proper measurement of performance with respect to work safety is necessary. Hence, we aim to examine the performance of European countries by measuring their technical efficiency with respect to the number of workplace accident in four economical activity sectors – manufacturing, construction, distribution trades and transportation – characterised by a high number of accidents in relation to the number of workers exposed. To this purpose, our analysis is undertaken by applying the non-parametric efficiency measurement technique, Data Envelopment Analysis (DEA), accounting for different returns to scale assumptions, constant and variable. Further, we adapt DEA to the problem at hand, where outputs do not refer only to "goods", but we have also "undesirable" outputs (the number of accidents at work).

The paper is organized as follows. In Section 2 we discuss the DEA method and the efficiency measures applied, in Section 3 we present the data used and list the results obtained, in Section 4 we conclude.

2. Method

Data Envelopment Analysis is a non-parametric method for assessing the relative efficiency of a set of n homogeneous organizational units (or Decision Making Units, DMUs), each consuming different amounts of m inputs to produce s outputs. Rather than explicitly stating the functional form of the best practice frontier, DEA measures efficiency relative to a deterministic frontier using linear programming techniques to envelop observed input/output vectors as tightly as possible. The basic DEA models measure the technical efficiency of a DMU in terms of the maximal radial contraction to its input levels (input orientation) or expansion to its output levels feasible under efficient operation (output orientation). Beside, they can assume different returns to scale (returns to scale of a point on the production frontier are defined as the amount that all the outputs will increase by for a proportionate increase in all inputs): they allow for constant, increasing or decreasing returns to scale.

The first DEA model, proposed by Charnes et al. (1978) and known as CCR, assumes the DMUs to be assessed operate within a technology where efficient production is characterised by constant returns to scale (CRS)[5]. Under input orientation the relative efficiency of a DMU j_0 is obtained from the following linear model:

$$e_0 = \min \theta_0$$

subject to

$$\theta_0 x_{ij0} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0, \qquad i = 1,\dots,m \tag{1}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{rj0}, \qquad r = 1,\dots,s \tag{2}$$

$$\lambda_j \geq 0, \qquad \forall j \tag{3}$$

where x_{ij} is the amount of the i-th input to DMU j, y_{rj} is the amount of the r-th output to DMU j, λ_j are the weights of DMU j and θ_0 is the shrinkage factor for DMU j_0. The linear programming problem must be solved *n* times, once for each unit in the sample, for obtaining a value of θ for each DMU. The value of θ_0 obtained is termed the technical input efficiency of DMU j_0 and it is bounded between 0 and 1: a technical efficient unit, according to Farrell (1957) definition, will have a score of unity, while inefficient ones will have a score less than unity.

Banker et al. (1984) modified this basic model to permit the assessment of the productive efficiency of DMUs where efficient production is characterised by variable returns to scale (VRS). The VRS model, known as BCC, differs from the basic CCR model only in that it includes in the previous formulation the convexity constraint:

$$\sum_{i=1}^{n} \lambda_j = 1 \tag{4}$$

The CCR model yields an evaluation of overall technical efficiency. It must be remembered that the use of CRS specification is only appropriate when all units are operating at an optimal scale, otherwise it will result in technical efficiency measures which are confounded by scale efficiencies. The BCC model, on the other hand, can distinguish between technical and scale inefficiencies by estimating pure technical efficiency at the given scale of operation for each unit.

3. Data and results

We apply the DEA approach for evaluating the performance of 15 European countries for the year 2005 with respect to safety at work issues. The choice of including in the analysis the EU15 countries is due to the homogeneity among economic sectors in this area.

We consider four non-financial business economic sectors, according to NACE (*Nomenclature statistique des activités économiques dans la Communauté européenne*) definition, as they register a high number of accidents in relation to the total number of workers exposed: manufacturing, construction, distribution trades and trasportation. The data required have been obtained from Eurostat, which launched ESAW (European Statistics on accidents at Work) project in nineties.

We define a model characterised by a single input, the number of persons employed, and a single desirable output, the value added (in Euros) for each sector. As mentioned in the introduction, we also include a special kind of output, the number of industrial accidents resulting in three days or more off work, that is considered as undesired output of the productive systems.

In the assessment of comparative performance, this undesirable output or "bad" (Chung et al., 1997; Dyckhoff & Allen, 2001; Seiford e Zhu, 2005) should be minimized. However, it is well known that in standard DEA models decreases in outputs are not allowed and only inputs are allowed to decrease (similarly, increases in inputs are not allowed and only outputs are allowed to increase) (Scheel, 2001). Hence, in order to take into account this undesired variable, we implement a modified DEA model (Coli et al., 2008; Coli et al., 2011): this factor will be included directly into the linear programming problem, just like an input that has to be radially reduced, by adding the following constraint to the general DEA formulations:

$$\theta_0 h_{tj0} - \sum_{j=1}^{n} \lambda_j h_{tj} \geq 0, \qquad t = 1,...,z \tag{5}$$

where h_{tj} is the amount of the t-th input to DMU j and the multiplier θ shrinks both inputs and environmental variables in an equi-proportional manner.

The non-parametric efficiency measures, for each sector analysed, are computed by using the modified input-oriented DEA model under constant and variable returns to scale assumptions. The efficiency ratings, listed in Table 1, have been calculated by means of DEA-Solver, a software developed by Kaoru Tone (Cooper et al., 2000).

Table 1. DEA efficiency scores by European countries for the year 2005

DMU	Manufacturing			Construction			Distribution trades			Transportation		
	CRS score	VRS score	Scale eff.	CRS score	VRS score	Scale eff.	CRS score	VRS score	Scale eff.	CRS score	VRS score	Scale eff.
Belgium	0.4977	0.7436	0.6693	0.5580	0.6155	0.9066	0.9082	1	0.9082	0.7891	0.8380	0.9416
Denmark	0.3989	0.4120	0.9682	0.6417	0.7322	0.8764	0.9241	0.9899	0.9335	0.7583	0.7947	0.9542
Germany	0.3809	1	0.3809	0.3784	0.5461	0.6929	0.7931	1	0.7931	0.5702	0.8278	0.6888
Greece	0.2327	0.2652	0.8775	0.3492	0.4764	0.7330	0.3966	0.4826	0.8218	1	1	1
Spain	0.3060	0.6836	0.4476	0.3527	0.4755	0.7417	0.5609	0.6737	0.8326	0.4497	0.6986	0.6437

France	0.3642	0.8844	0.4118	0.4695	0.6137	0.7650	0.8259	1	0.8259	0.5697	0.8411	0.6773
Ireland	1	1	1	1	1	1	1	1	1	1	1	1
Italy	0.2882	0.6974	0.4132	0.4388	0.4781	0.9178	0.6063	0.7586	0.7992	0.5063	0.7947	0.6371
Luxembourg	0.4576	1	0.4576	0.4461	1	0.4461	1	1	1	0.9548	1	0.9548
Netherlands	0.4773	0.8077	0.5909	0.7147	0.7501	0.9528	0.7880	0.9480	0.8312	0.6361	0.8910	0.7139
Austria	0.4267	0.5569	0.7662	0.5827	0.5972	0.9757	0.7956	0.8651	0.9197	0.8325	0.8628	0.9649
Portugal	0.1355	0.1469	0.9224	0.1885	0.1887	0.9989	0.3441	0.3657	0.9409	0.4168	0.4184	0.9962
Finland	0.4700	0.4763	0.9868	0.5627	0.6080	0.9255	0.9346	0.9690	0.9645	0.4759	0.4777	0.9962
Sweden	0.7378	0.8186	0.9013	1	1	1	0.8842	1	0.8842	0.7702	0.8251	0.9335
United Kingdom	0.7755	1	0.7755	1	1	1	0.7715	1	0.7715	1	1	1

Evaluation of EU15 countries safety performance by means of CRS model shows that Ireland is always on the best practice frontier, in each sector analysed. In both manufacturing and construction sectors only three DMUs (apart from Ireland, Sweden and United Kingdom) are good performers, whilst most countries are operating at a very low level of efficiency. Focusing on distribution trades sector, we observe that units operate at a higher efficiency level: however, only Ireland and Luxembourg are fully efficient. In the transportation sector, three units form the efficiency frontier (Ireland, United Kingdom and Greece) and Luxembourg is very close to it (0.9548).

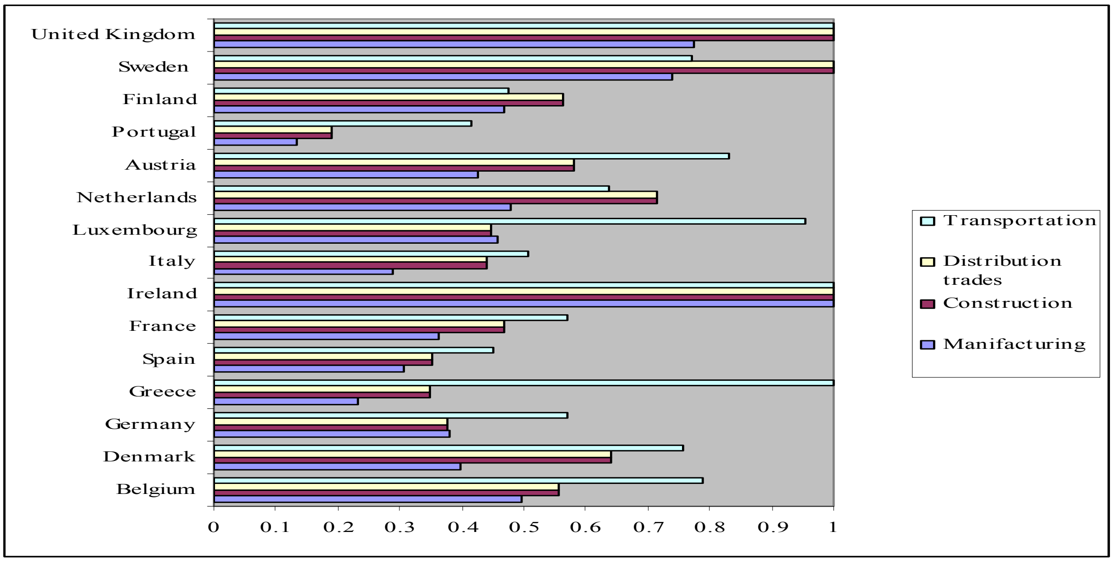

Figure 1. Efficiency ranking from CCR score

With regard to the results provided by VRS model, we observe that in the manufacturing sector four DMUs are BCC-efficient: Germany, Ireland, Luxembourg and United Kingdom. Besides, many countries do not register very high ratings. In the construction sector, we register the entrance between the top performers of one more country, Sweden (in the previous sector it was quite close to the frontier having an efficiency score equal to 0.8186). On the other hand, Germany returns to be inefficient and several of the others DMUs receive low ratings. In the distribution trades sector, we can observe an improvement in the efficiency level in many units: two more countries (Belgium and France) move on the efficient frontier and Germany returns to be efficient. Besides, one country –

Denmark – is very close to the frontier having the efficiency rating of 0.9899. The remaining units are sub-efficient but only two show very low ratings. Finally, in the transportation sector the best performers are Greece, Ireland, Luxembourg and United Kingdom. Besides, many countries become less efficient.

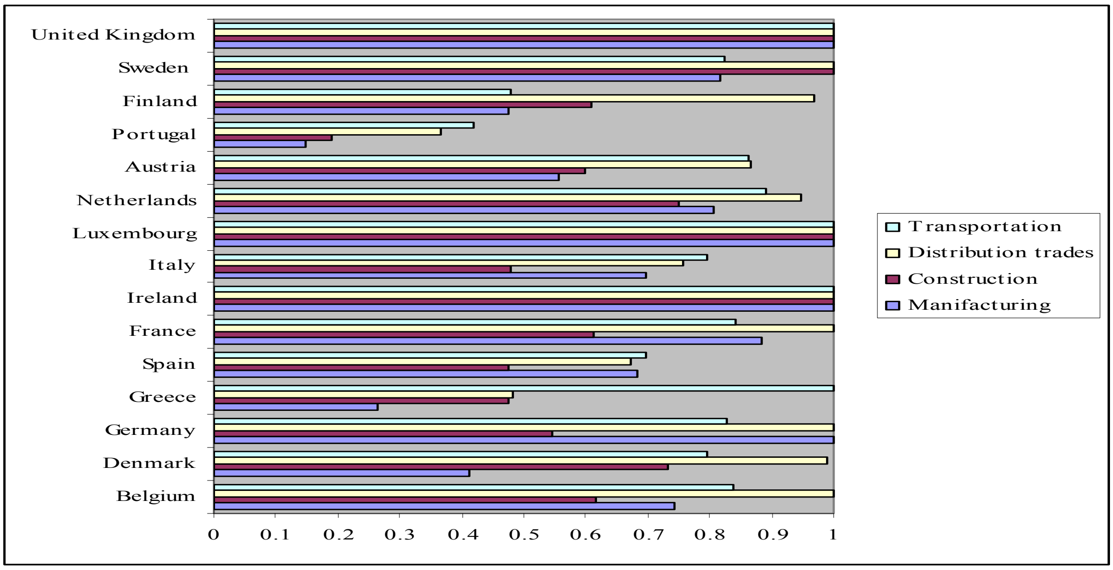

Figure 2. Efficiency ranking from BCC score

Results from CCR and BCC models show that the distribution trades sector register a higher average efficiency score than other sectors in both models and displays less variability in CCR model, whilst the transportation sector displays less variability in BCC model (Table 2). In addition, we can note a substantial difference between Greece ratings: they are very low in manufacturing, construction and distribution trades sectors but are maximum in the transportation sector. Finland shows a similar situation, too, with low scores in manufacturing, construction and transportation sectors but a high score in distribution trades sectors.

Table 2. Summary statistics for DEA efficiency scores

	Manufacturing	Construction	Distribution trades	Transportation
CCR mean	0.4683	0.5789	0.7689	0.7153
CCR minimum	0.1355	0.1885	0.3441	0.4168
CCR maximum	1	1	1	1
CCR standard deviation	0.2161	0.2451	0.1974	0.2055
BCC mean	0.6995	0.6721	0.8702	0.8180
BCC minimum	0.1469	0.1887	0.3657	0.4184
BCC maximum	1	1	1	1
BCC standard deviation	0.2671	0.2338	0.2007	0.1696
Scale eff. mean	0.7046	0.8622	0.8818	0.8735
Scale eff. minimum	0.3809	0.4461	0.7715	0.6371
Scale eff. maximum	1	1	1	1
Scale eff. standard deviation	0.2277	0.1524	0.0738	0.1448

When specifying a VRS frontier the question of the most efficient scale of the units also arises. The divergence between CCR and BCC efficiency scores, in fact, captures the impact of scale size on the performance of the unit concerned. The ratio between CRS and VRS efficiency scores provides a measure of scale efficiency: when it is equal to one, it means that the unit operates at an optimal size (MPSS, most productive scale size); on the contrary, if it is lower than one unit inefficiency also depends on scale factors (Ganley and Cubbin, 1992).

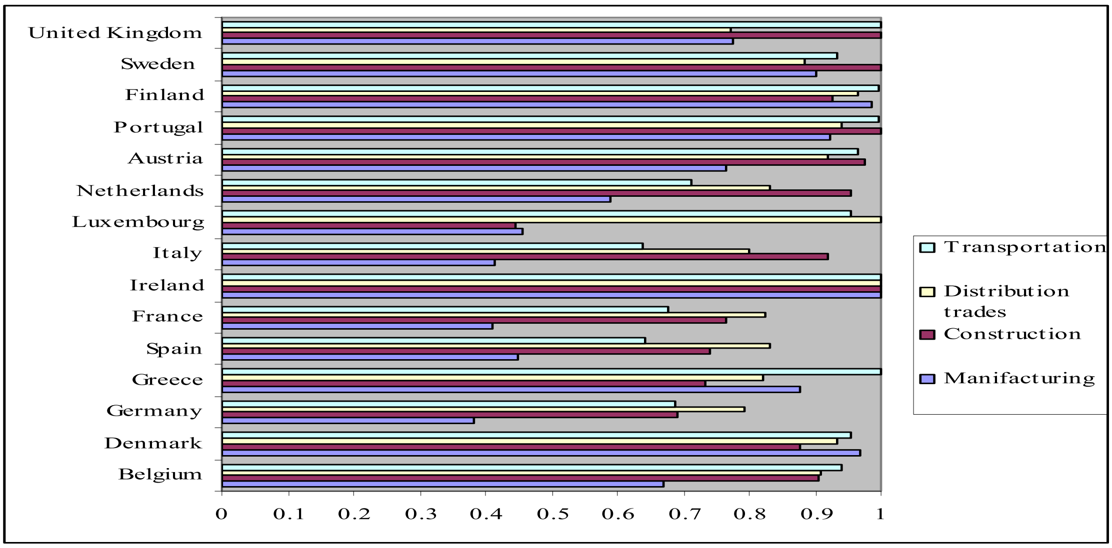

Figure 3. Ranking from scale efficiency

Our findings show that Ireland is always efficient according to scale (Table 1). In construction sector Sweden and United Kingdom are scale efficient, too, in distribution trades sector Luxembourg and in transportation sector Greece and United Kingdom, too. On average, the scale efficiency score is higher than the average score of overall efficiency in all sectors (Table 2), whereas the scores variability is lower, apart from the manufacturing sector. Based on this evidence it seems to say that there are some problems related to inadequate operational dimension.

4. Conclusion

In this work we have investigated the performance of 15 European countries for the year 2005 in four economical activity sectors – manufacturing, construction, distribution trades and transportation – with respect to the number of workplace accidents, which represents a considerable social loss in production and human dignity. In order to obtain technical efficiency measures, we have applied two Data Envelopment Analysis models, CCR and BCC, with one more constraint in order to take into account this undesirable output.
Both CCR and BCC results point out that the distribution trade sector receives the best efficiency ratings. In addition, there is not a substantial difference between manufacturing and construction sectors: DMUs are not operating at a very high level of efficiency and there is room for improvement in several countries. Furthermore, there are countries where performance is better than other, such as Ireland and United Kingdom.

This modified method has helped us to identify benchmarking units so that the best practices can be implemented to become efficient. Hence, this study represents an additional sources of useful information to policy makers for future occupational safety and health policy actions in order to promote a safe and healthy working environment.

Nevertheless, it must be remembered that the efficiency analysis applied in this work can be improved. First of all, further research in this field could perform a comparative evaluation by considering in the analysis the current composition of the European Union – 27 countries –, including all countries that entered in the European Union in 2004 and 2007, too. Second, an additional field of future research could include additional key variables. Finally, we could carry out a performance analysis over time (Sengupta, 2000), when data become available.

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3 An accident at work is defined as an external, sudden, unexpected, unintended and violent event during the execution of work or arising out of it, which causes damage to the health or loss of life of the employee. For qualification as an accident at work to apply, there must be a causal relationship between the violent event and the work. There are many methods of preventing or reducing these accidents, including anticipation of problems by risk assessment, safety training, control banding, personal protective equipment, respiratory equipment, safety guards, mechanisms on machinery, safety barriers, etcetera.

4 The current Community strategy aims to achieve a 25% cut in accidents at work across the EU by 2012.

5 If an activity (x, y) is feasible, then, for every positive scalar t, the activity (tx, ty) is also feasible.