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DEA 45

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Abstracts of papers in the DEA45 International Conference.

Please note that these abstracts are provided by the authors, and the organizers have not edited them.

DEA45-003 **Measurement and evaluation of multi-function parallel network hierarchical DEA systems**

Marios Dominikos Kremantzis (University of Bristol)*; Patrick Beullens (University of Southampton); Leonidas S Kyrgiakos (University of Thessaly); Jonathan Klein (University of Southampton)

Many organisations are composed of multiple departments connected either in series or in parallel, which may be further decomposed into a number of functions arranged in a hierarchical structure. Several researchers have successfully used appropriate Data Envelopment Analysis (DEA) modelling techniques to assess complex structures. However, to our knowledge, no one has yet examined the case of measuring and evaluating a parallel network structure combined with a hierarchical one. This paper discusses the development of a multi-function parallel system with embedded hierarchical network structures. A linear additive decomposition DEA model and a non-linear multiplicative aggregation DEA model are proposed as alternatives to evaluate the operating performance of such a structure. The system, the sub-systems, and the efficiencies of their internal units, as well as their relationships, are identified. The system efficiency of the additive model is shown to be greater than or equal to that of the multiplicative model. To verify the applicability of our proposed models, we consider a hypothetical example of the measurement and evaluation of the performances of several Business Schools across a number of universities. Other envisaged areas of application of our structure could include supporting the evaluation of the supply chain management of a firm, or the determination of the most desirable ship design considering maintenance issues.

DEA45-005 **Productivity evaluation of African banking firms: an application of MPI**

Muhammad Auwalu Haruna (Ahmadu Bello University)*

This study intends to evaluate expected changes in total factor productivity (TFP) between 2002 and 2021 in the banking system in Africa. Performance comparative analysis would be carried out between banks that were consolidated and those that were not. The comparison would be within and between countries. the aim is to see how the government-driven banking consolidation across African countries affected banks' productivity. Malmquist Productivity Index (MPI) would be developed using Data Envelopment Analysis (DEA) to conduct the study. It is hoped to discover the TFP growth tendencies at the market average, market category, and individual bank levels despite the fact that the changes are fiat. The outcome is also hoped to show the levels of growth averages at both constant returns to scale (CRS) and variable return to scale (VRS) technologies. This would be a crucial sign that information technology (IT)

and computerization are used consistently throughout the market.

DEA45-009 **R&D Performance Evaluation in the Chinese Food Manufacturing Industry Based on Dynamic DEA in the COVID-19 Era**

Shiping Mao (University of Bristol); Marios Dominikos Kremantzis (University of Bristol); Leonidas S Kyrgiakos (University of Thessaly)*; George Vlontzos (University of Thessaly)

Nowadays, China's food consumption structure is shifting from being survival-oriented to health-oriented. However, the food industry is still facing a research and development (R&D) dilemma. Scientific evaluation of an enterprise's R&D performance can help to reduce the investment risk of R&D and promote economic benefits. This study implements the dynamic data envelopment analysis (DDEA) technique to measure and evaluate the level of R&D performance in the Chinese food manufacturing industry. Twenty-eight listed companies were selected for the study, considering the time period from 2019 to 2021. After constructing a system of inputs, outputs and carry-over indicators, overall and period efficiency scores were obtained. The results reveal that the overall level of R&D in the industry is relatively low (0.332). Average efficiency scores across years were estimated as 0.447, 0.460, 0.430 for 2019, 2020, and 2021, respectively. Lastly, this study considers the actual business situation of the industry and makes suggestions for improvement from the perspective of enterprises and the government; these anticipate aiding the food manufacturing industry to improve the performance management of R&D activities.

DEA45-014 **Agro-climatic environment heterogeneity and productivity convergence**

Barnabe Walheer (Université de Liége)*

This study proposes an alternative approach for studying the role of countries' weather differences on productivity changes. As weather is beyond the control of farmers, we model weather differences by defining time-dependent output-specific agro-climatic environments. These environments condition countries' production process and technology, and indirectly impact their productivity gains. Building on a tailored database for 91 countries, we study productivity changes between 1961 and 2015. This represents a unique opportunity to analyse productivity changes for many countries over a long time period. From a theoretical perspective, we define new output-specific indexes for productivity change and convergence between and within agro-climatic environments, and decompose them into several parts. Another distinguishing feature of our approach is to rely on a non-parametric estimation method. We find that agro-climatic environment heterogeneity has a clear impact on productivity change and convergence, that depends on the outputs and evolves over time. Overall, our results show that productivity change is positive and productivity convergence occurs, both mainly due to technological change. Next, path-dependence is observed for the efficiency convergence but not for technological convergence. Finally, we cannot confirm that productivity

convergence and output growth are related, nor we have arguments for the existence of technology spillovers.

DEA45-015 **Incorporating union metafrontier into the network DEA framework: airline environmental efficiency analysis**

Ming-Miin Yu (National Taiwan Ocean University)*, Kok Fong See (Universiti Sains Malaysia)

There have been several extensions to the network data envelopment analysis (NDEA) model applied in the airline industry. Among these extensions is the metafrontier approach based on the NDEA model. The metafrontier NDEA illustrated that the importance of heterogeneity differs significantly in various subsectors, e.g., the production and service subprocesses of alliance vs. nonalliance groups of airlines, indicating the prevalence of dual heterogeneity. Such heterogeneities can have a significant impact on the accurate measurement of technology gap inefficiencies. Both the technology gap ratio caused by overall production heterogeneity and that caused by process heterogeneity must be less than or equal to 1; no work has yet attempted to provide a way to empirically avoid the contradiction of overall and process TGR greater than unity. This study addresses this significant gap in the literature by developing a union metafrontier NDEA model based on the union-metatechnology production possibilities set. To demonstrate our suggested union metafrontier NDEA model, an empirical analysis using data for 29 airlines was conducted. This study revealed that the union metafrontier NDEA differs from conventional methods for avoiding unreasonable TGRs at the overall and process levels. The analysis also highlighted the union metafrontier NDEA's ability to allow decision makers to determine the relative importance of projection goals and to develop an improvement path that is appropriate for them to reach the group frontier and metafrontier. Some practical implications of the findings in the airline industry are detailed in this study.

DEA45-019 **Markov settings in Data Envelopment Analysis multiple stages – multiple targets**

Andreas C Georgiou (University of Macedonia)*; Emmanuel Thanassoulis (Aston Business School); Georgios Tsaples (University of Macedonia)

This paper addresses contexts such as manpower planning, or the progression of some chronic disease, such as diabetes, through a cohort where over time, the system advances through various states (e.g. employees at each level or persons with mild, severe etc. disease). The aim is to steer the system towards some desired state, or set of states, through interventions made by control variables which are evaluated on their capacity to achieve this goal. The presentation is based on a hybrid modelling framework, which blends Data Envelopment Analysis with Markov Chains in radial and additive models. The Markov process offers difference equations that can be used to describe the movement of the entities (e.g. employees, persons) through time in a hierarchical system (e.g. illness states) and makes possible the investigation of possible

interventions in order to guide the system towards some desired future structure in a single or multiple stages in time. A given set of possible policies (e.g., new treatments used in a health system) are treated as DMUs at each stage., The models provide a means to evaluate the relative efficiency of those policies in achieving given targets in two-stage models. The paper concludes by discussing the advantages and limitations of the models.

The research work was supported by the Hellenic Foundation for Research and Innovation (H.F.R.I.) under the “First Call for H.F.R.I. Research Projects to support Faculty members and Researchers and the procurement of high-cost research equipment grant” (Project Number: 3154).

DEA45-020 **Eco-efficiency approach in sustainable waste management: An uncertainty analysis for Chile**

Maria Molinos-Senante (Pontificia Universidad Catolica de Chile)*; Ramon Sala-Garrido (University of Valencia); Alexandros Maziotis (Pontificia Universidad Catolica de Chile); Manuel Mocholi-Arce (University of Valencia)

Municipalities require eco-efficiency in managing solid waste to enhance sustainability and achieve a circular economy. Despite the relevance of waste statistics, there is high data uncertainty, which limits attempts to benchmark eco-efficiency in this sector. To overcome this limitation, the data envelopment analysis tolerance method was used to evaluate the eco-efficiency of solid waste management for a sample of municipalities in Chile. For each municipality, a composite indicator embracing operational cost, recycled waste rates, and non-valorized waste rate was estimated. Data uncertainty was integrated in the assessment by simulating 729 scenarios for each municipality. Average eco-efficiency of the sample was 0.180, demonstrating the extremely poor performance of the municipalities in sustainable waste management. However, the eco-efficiency scores varied across municipalities, indicating differences in local capacity to develop and implement strategies for promoting circular economy. Large potential to improve eco-efficiency estimated in this study clearly shows that current solid waste management policies are not suitable for achieving circular economy objectives in Chile, thus alternative approaches should be adopted to enhance sustainable waste management.

DEA45-021 **Using DEA to identify Hispanic serving institutions for best practices in Increasing STEM degrees awarded to Hispanics**

Omar S Lopez (Texas State University)*

No single strategy has been shown to contribute exclusively to universities and colleges designated as Hispanic Serving Institutions (HSIs) graduating Hispanics with STEM degrees. Rather, the literature identifies a waterfront of practices researchers suggest are broadly relevant to student academic success. Two problems limit such studies. While they describe what practices HSIs should do, they do not prescribe how HSIs should do them.

Moreover, one cannot determine if the researchers identified the practices in HSIs that efficiently graduate Hispanics with STEM degrees, casting doubt on the efficacy of the practices to transform less efficient HSIs into efficient ones. To solve these problems requires a different type of research, one that is purposeful and built on field-based studies of best practices at institutions that are empirically proven efficient at graduating Hispanics with STEM degrees. Sponsored by the National Science Foundation, this presentation showcases the findings of a two-year study using DEA with data from the Integrated Postsecondary Education Data System (IPEDS) at the National Centre for Education Statistics, to effectively measure the efficiency of HSIs graduating Hispanics with STEM degrees. The guiding research question was: "On what input measures do we select efficient HSIs to serve other institutions as possible benchmarks for program improvement in graduating Hispanics with STEM degrees?" Participants will have the opportunity to comment on the select measures and a framework for investigating and organizing best practices at HSIs for increasing Hispanics earning STEM degrees.

DEA45-028 **Measuring the efficiency of hedge fund's performance: a Data Envelopment Analysis approach**

Huda Ibrahim Aldhahi (University of East Anglia)*

This study seeks to analyse the performance of hedge funds using long-time series data obtained from HFR databases. It uses data envelopment analysis (DEA), where two different DEA models are employed, namely input-oriented (CCR-I) model and (BCC-I) model, to provide accurate ranking results. Thus, it contributes to the existing literature in many aspects: first, to give more insight into hedge fund performance, we use a more extended time series from 1994 to 2020. Second, investigating the instability of various hedge fund strategies using different time horizons provides more information than using a performance of a single period only, where different funds could be efficient across multiple time horizons. Third, we examine the impact of the major economic crisis on the performance of hedge funds. Hence, using this framework assists investors and fund managers identify the underlying reasons behind the fund's poor performance. Moreover, it provides them with a precise evaluation of the fund's performance, ultimately offering investors and fund managers a useful ranking of the fund's performance, accordingly, allowing them to diversify their portfolio with a selection of well-preformed funds across various fund strategies.

DEA45-031 **A generalized DEA approach to performance assessment: case study of Adriatic Sea ports**

Evelin Krmac (Faculty of Maritime Studies and Transport, University of Ljubljana)*; Mozhgan Mansouri Kaleibar (Faculty of Maritime Studies and Transport, University of Ljubljana)

Ports are an important interface between inland and maritime transport. They also play an important role in increasing the country's trade and

economic growth. Therefore, improving the efficiency of ports is crucial as it can boost a country's competitiveness and economy. It also improves a country's access to global markets, leading to growth in trade and consequently higher incomes. Improving the efficiency of ports and the maritime transport system is important for increasing the EU's competitiveness. Cargo volumes in the Adriatic ports of Central and Eastern European countries have increased in recent years. For this reason, the evaluation of ports in the Adriatic region is of particular importance. In the current methods, the evaluation is ignored in case of uncertainties. For this reason, the efficiency scores are not accurate enough to be used for improving port performance, and, in general, they are not useful for port users. Therefore, the main objective of this paper is to evaluate and measure the efficiency of the studied ports over the last two years. In this way, efficient and inefficient ports and the causes of the inefficiency of each port will be identified. The evaluation is based on the operating capacity of the ports, which includes general cargo, vehicles, liquid bulk, containers, and dry bulk. To evaluate the performance, this paper develops a model that considers undesirable inputs and outputs as well as uncertainties and estimates the performance accordingly. In this paper, non-classical generalized DEA models are used in this paper. Therefore, the generalized fuzzy SBM model is used to evaluate the performance of the units. The results of this project will help to improve the performance and efficiency of the studied ports. Policy makers can consider the assessment results when deciding how to improve the European transport network and trade competitiveness.

DEA45-033 **Estimating the causal impact of an intervention on efficiency**

Kristof De Witte (KU Leuven)*

This talk discusses approaches to evaluate the causal impact of a policy change in a multi-input multi-output setting. It combines insights from econometric impact evaluation techniques and efficiency analysis. In particular, we account for endogeneity issues by introducing a quasi-experimental setting within a conditional multi-input multi-output efficiency framework and by decomposing the overall efficiency between 'group-specific' efficiency (i.e., reflecting internal managerial inefficiency) and 'program' efficiency (i.e., explaining the impact of the policy intervention on performance). This framework allows the researcher to interpret the efficiency scores in terms of causality. The practical usefulness of the methodologies is demonstrated through an application to secondary schools in Flanders, Belgium.

DEA45-034 **Effect of global economic shocks on sustainable agrifood security in Ghana; the path analysis method on COVID-19**

Ebenezer Frimpong (Corvinus University of Budapest)*

The global economic crisis of covid-19 pandemic has a deficit in agrifood security in Ghana. This study analyses the effect of Covid-19 on agrifood

security and sustainable and inclusive agrifood value chains in Ghana. A time series analysis technique was used to test the significance of the relationship between Covid-19 and agrifood security in Ghana. A conceptual model was designed to evaluate the effect of Covid-19 on the core elements of sustainable and inclusive agrifood value chains in Ghana. The path analysis method was used. It was evidence the standardized coefficients effect of Covid-19 on agrifood involves agrifood availability-0.74; agrifood accessibility-4.05, and agrifood utilization-11.22. This shows that Covid-19 has a negative effect on agrifood security. Smallholder farmers were affected by Covid-19 hence agrifood production decreases substantially leading to a reduction in yields. It was observed that the higher the Covid-19 cases, the higher agrifood insecurity. Agrifood security and sustainable and inclusive agrifood value chains should be considered in government policies to curb agrifood insecurity during global economic crises for a sustainable agrifood supply chain.

DEA45-035 **Can super-efficiencies improve bias correction? A Bayesian data envelopment analysis approach**

Panagiotis D. Zervopoulos (University of Sharjah)*; Angelos Kanas (University of Piraeus); Ali Emrouznejad (Surrey Business School); Phil Molyneux (University of Leeds)

The validity of data envelopment analysis (DEA) estimates depends on the robustness of the production frontier to measurement errors, specification errors, and the dimension of the input-output space. It has been proven that DEA estimates lying within the (0, 1] interval are overestimated for finite samples, while asymptotically, the bias reduces to zero. Yet, there is no discussion in the literature about the presence of bias in estimates when the efficient units are allowed to exceed unity. Under certain conditions, some super-efficiencies are considered outliers, and their exclusion from the sample is recommended. We prove that both efficiencies and super-efficiencies are biased. Also, a significant inverse relationship between efficiencies and super-efficiencies occurs in the presence of finite samples. However, these two types of efficiencies are asymptotically uncorrelated. We extend the alternative Bayesian DEA approach put forth by Zervopoulos et al. (2022) to correct the bias of efficiencies drawing on the super-efficiency frontier. The proposed method yields statistically significant bias-corrected efficiencies, while the corrections for super-efficiencies are not significant. The novel Bayesian DEA approach is appropriate for small- and medium-size samples as there is no asymptotic relationship between efficiencies and super-efficiencies. Formal proofs, results from real-world data sets, and simulations to justify the performance of the new method's estimates are provided.

DEA45-036 **Economic development, industrialization, and poverty eradication: A benchmarking analysis of developing, emerging, and developed countries**

Diogo Ferreira (Instituto Superior Técnico, University of Lisbon)*

This study is based on the use of benchmarking techniques that allow us

solving the problem of difficulty in monitoring the productivity change over the years concerning the Sustainable Development Goals (SDGs) 1, 8 and 9, which led countries to have great difficulty in interpreting the measures to be taken. In reality, there is a clear connection between economic development, the creation of jobs and wealth, and the eradication of poverty. Those are central objectives in the sustainable development of nations. Monitoring that performance, allowing the construction of a framework to do that, is the main objective of this study. Achieving that goal was possible to solve through the joint use of the Data Envelopment Analysis and the Malmquist productivity indices. These methodologies were applied to 85 countries (2010-2020) belonging to different profile groups of nations (developing, emerging, and developed countries), in view of those SDG indicators. The change in productivity helped to understand how the three profile groups are evolving and the behavior of these groups. It was verified that the three profile groups evolved differently, with emerging countries having the highest productivity evolution, followed by developing countries and, finally, developed countries. It should be noted that the slower evolution of productivity in the developed countries suggests that they are entering stagnation, allowing the convergence of the remaining groups of countries, namely the emerging ones, in terms of the creation and distribution of wealth and the reduction of poverty.

DEA45-037 **Individualized second stage corrections in data envelopment analysis**

Mohsen Afsharian (Leibniz FH, University of Applied Sciences)*; Sara Kamali (Technische Universität Braunschweig); Heinz Ahn (Technische Universität Braunschweig); Peter Bogetoft (Copenhagen Business School)

This paper proposes a two-stage data envelopment analysis (DEA) approach for correcting efficiency scores of decision-making units (DMUs) in the context of incentive regulation. The approach evaluates the impact of contextual variables on individual DMU performance and avoids generating undesirably high/low efficiency scores. It is illustrated with data from the Brazilian electricity transmission sector, for which a DEA-based incentivization mechanism induces transmission service operators to economize their costs. Results demonstrate the effectiveness of the proposed approach in providing a more appropriate evaluation of DMU efficiency. This can help regulatory authorities to make decisions regarding incentivization and performance improvement in regulated industries.

DEA45-038 **Does income diversification affect bank efficiency, effectiveness and performance? Evidence from Indian banking industry**

Mehak Gupta (South Asian University)*; Sunil Kumar (South Asian University)

The banks have been under tremendous pressure recently to improve their performance and financial stability. Diversifying income has been pitched as a potent tool that can help banks improve their performance, particularly when the interest income of the banks is under strain. The present study looks at inter-temporal patterns of income diversification and explores how it affects the efficiency, effectiveness, and performance of Indian banks. In

this study, we conceptualize bank performance as the product of two mutually exclusive components: efficiency and effectiveness. To quantify bank performance and its components, we develop a two-stage performance evaluation model with undesirable output and applied Tone and Tsutsui's (2009) SBM model.

To investigate the linear and non-linear impact of income diversification on efficiency, effectiveness, and performance, we employ the Ridge, Lasso, and Elastic Net linear regression models. We also look into the mediating effects of bank size and ownership structure on the underlined relationship between diversification and performance. To check the robustness of the results, we apply the traditional generalized method of moment (GMM). Our results suggest that asymmetries in performance parameters exist across ownership groups. Public banks outperform their private sector counterparts in all aspects of performance. However, the overall performance of banks is on the lower edge, indicating that there is untapped potential for improvement.

DEA45-039 **Estimating product costs applying DEA and regression trees – insights from an automotive supplier**

Andreas S. Dellnitz (Leibniz FH University of Applied Sciences)*; Andreas Kleine (FernUniversität in Hagen)

Data envelopment analysis (DEA) is a well-established method for measuring the efficiency among a comparable group of decision-making units (DMUs). DMUs mostly comprise profit or non-profit companies which are characterized by their time-related activities -- i.e., their inputs and outputs. Still, the notion decision-making unit is not reserved only for companies, a DMU can also be a project or product. In this paper, we focus on the latter type, using DEA-based efficiency scores to estimate the price for newly developed products to be purchased. DEA-based estimations of such product-related purchasing costs, however, suffer from one fact: DEA only accounts for deterministic input and output relationships and, hence, cannot handle unobservable negotiation behavior. Therefore, we combine DEA with regression trees in order to remedy this deficiency and, ultimately, to improve the estimations of a product's purchase price. To substantiate the superiority of our approach, we study a real-world application stemming from the automotive supplier industry.

DEA45-041 **Evaluation of private interest and public interest in the regional banking business**

Takayoshi Nakaoka (Kindai University)*

The business environment surrounding Japanese regional financial institutions has been highly severe in the last decade because of the ageing and depopulation of society. The vital management goal for regional financial institutions is to contribute to revitalising the regional economy through financial intermediation. From the long-term perspective, regional banks could contribute to the sustainable growth of the regional economy, allowing them to build mutual prosperity relationships with the

economy.

In this paper, using Japanese regional bank data from 2008 to 2017, we apply the data envelopment analysis to evaluate financial intermediation businesses' private and public interests. We find a weak positive correlation between the private and public interest indicators, but it has faded during the massive financial easing policy.

DEA45-043 **Merger dilemma in yardstick competition**

Richard Kalis (University of Economics Bratislava)*; Peter Bogetoft (Copenhagen Business School)

The paper contributes to the literature on mergers in a yardstick competition. The yardstick method is an appealing incentive-based approach; however, it is not immune to potential strategic behaviour concerning horizontal mergers. Because firms in frontier-based regulated industries are evaluated to the most efficient peers, this frontier is prone to inward shifts after mergers. This inward shift can easily overwhelm the expected cost savings of merged firms. The position of the efficient peer being merged is crucial concerning other peers on the frontier. Moreover, compared to the competitive markets, the number of firms outside the merger negatively correlates with industry outcomes after the merger. Our results can serve as a guideline for mergers in yardstick competition similar to one proposed by European Commission for competitive industries.

DEA45-044 **Exploratory benchmarking with DEA and multidimensional scaling – process and reference model**

Steffen Hoffmann (FernUniversität in Hagen)*

Benchmarking is a valuable process to improve strategic as well as operational decisions in profit and nonprofit organizations. An important subprocess of benchmarking relates to measuring performance gaps and uncovering their causes. While Data Envelopment Analysis (DEA) may handle the part of evaluation, Data Mining tasks are appropriate to explore the link of computational results with additional knowledge. Therefore, a new Data Mining process – called Exploratory Benchmarking – is proposed that integrates DEA and Multidimensional Scaling (MDS) as a reference model to structure decision support by applying well-researched methods. The process is exemplified by a real-world application in the field of service operations. However, the approach may be adopted far beyond as a standard process in business analytics and consulting.

DEA45-045 **Accounting for ratio inputs and outputs in DEA models**

Victor Podinovski (Loughborough University)*

Applications of DEA often include inputs and outputs stated in the form of percentages and proportions, collectively referred to as ratio measures. Such measures often represent the socio-economic environment in which the decision making units (DMUs) operate or control for the quality of their inputs and outputs. It has long been realised that ratio measures are

generally inconsistent with the assumptions of the standard variable and constant returns-to-scale (VRS and CRS) DEA models. This includes the assumptions of convexity and (in the case of CRS) scalability of DMUs and possible boundedness of ratio measures. This talk starts by simple examples illustrating the above inconsistencies. It then discusses several approaches to the treatment of ratio measures developed in the literature and outlines unresolved issues and further research avenues.

DEA45-046 **DEA and hyperbolic efficiencies: An extension of application possibilities and the advantage for between-group comparison**

Alexander Öttl (University of Copenhagen)*; Mette Asmild (University of Copenhagen)

Data Envelopment Analysis (DEA) is a widely applied tool to estimate relative efficiencies. Nevertheless, the methodology encounters issues when between-group comparisons with variable returns of scale (VRS) are of interest. In this specification efficiency scores can be undefined as the projection of the efficiency estimation of one group does not have an intersection with the frontier of the other group. To address this issue, a hyperbolic efficiency estimation can be applied. However, it has not yet been possible to include weight restrictions, exogenous variables, and undesirable outputs in the hyperbolic DEA method. Weight restrictions allow for redefining the production possibility set (PPS), while exogenous variables enable adjustments in the model's orientation and inclusion of undesirable outputs. Therefore, it becomes possible to incorporate prior knowledge, substitution effects, and increase discriminatory power. The paper introduces the respective mathematical formulations as well as the practical implementation in statistical software. To facilitate the application of hyperbolic DEA with weight restrictions, exogenous variables, undesirable outputs, and additional functionalities, the estimation methods have been implemented in an R-package called 'hyperbolicDEA'. An empirical example of tilapia and pangas fish farming illustrates the advantages of the introduced methodologies as well as the R-package.

DEA45-048 **A box-uncertainty in DEA: A robust performance measurement framework**

Akram Dehnokhalaji (Aston University)*; Somayeh Khezri (Unicamp); Ali Emrouznejad (Surrey Business School)

The problem of assessment of Decision Making Units (DMUs) by using Data Envelopment Analysis (DEA) may not be straightforward due to the data uncertainty. Several studies have been developed to incorporate uncertainty into input/output values in the DEA literature. On the other hand, while traditional DEA models focus more on crisp data, there exist many applications in which data is reported in form of intervals. This paper considers the box-uncertainty in data which means that each input/output value is selected from a symmetric box. This specific type of uncertainty has been addressed as Interval DEA approaches. Our proposed model deals with efficiency evaluation of DMUs with imprecise data in a robust optimization. We assume that inputs and outputs are reported in the form

of intervals and propose the robust counterpart problem for the envelopment form of the DEA model. Further, we also develop two ranking methods which have more benefits compared to some existing approaches. An illustrative example is provided to show how the proposed approaches work. An application on hospital efficiency in East Virginia is used to show the usefulness of the proposed approaches.

DEA45-049 **A global multi-directional Malmquist Index for addressing infeasibility in variable-specific productivity**

Kwaku Ohene-Asare (University of Ghana)*, Emily Asaa Addison (University of Ghana)

This paper extends the Multi-directional Malmquist productivity change (MM) of Asmild, Baležentis, and Hougaard (2016) by combining the Multi-directional Efficiency Analysis approach and the global Malmquist index of Pastor and Lovell (2005), to develop an index for assessing the global variable-specific productivity index and its four-factor components. The paper shows how infeasibility can occur under both constant and variable returns to scale in the MM and how the proposed index is immune to such LP infeasibility. The index has the attractive feature of incorporating non-radial slacks, non-orientation, and undesirable outputs, it is transitive, it can generate a single pattern of productivity change measure, and it does not average two possibly disparate measurements. A numerical example with results is presented to illustrate the proposed algorithm. For illustration, we apply our methodology to the case of the African Energy Consuming States (AECS).

DEA45-050 **Dealing with uncertainty in healthcare performance assessment: a fuzzy network-DEA approach with undesirable outputs**

Guilherme P Afonso (Civil Engineering Research and Innovation for Sustainability)*; Diogo Ferreira (Instituto Superior Técnico, University of Lisbon); José Rui Figueira (Technical University of Lisbon)

Measuring performance in healthcare is fundamental to guarantee that health facilities operate as efficiently as possible. On top of financial efficiency, considering other variables related to quality (e.g., inpatient time and unexpected readmissions) and access (e.g., waiting times) is essential to evaluate the care provided from a patient perspective correctly. Consequently, this study incorporates several efficiency, quality and access variables on a network-DEA model, one of the most used non-parametric methods, to estimate Portuguese hospitals' performance scores. A four-subdivision framework was designed to represent hospitals' internal structure and interactions. In addition, undesirable outputs, such as postoperative complications, will exist when dealing with healthcare data and should not be maximised. A solution derived from the weak output disposable theory was applied to overcome that problem and minimise unwanted outcomes. Moreover, data retrieved from healthcare units might be imprecise. Therefore, this study suggests an innovative approach to merge network-DEA with fuzzy numbers theory, creating a new fuzzy

network-DEA model capable of dealing with undesirable outputs. Using fuzzy numbers allows one to introduce uncertainty associated with the variables selected. Furthermore, kernel functions were used to define several partial frontiers, which are less sensitive to outliers. Using this methodology to generate various metafrontiers before applying the network-DEA model guarantees that all hospitals in the same metafrontier are comparable. On top of that, using these metafrontiers allows one to incorporate environmental variables, such as population served, regional mortality and elderly percentage, into the model since they act as comparators to build the frontiers. All monthly data used in this study was collected from the Portuguese national health service between 2016 and 2022.

DEA45-052 **Business partnerships in non-homogenous decision making units**

Gholam R Amin (University of New Brunswick)*; Mustapha Ibn-Boamah (University of New Brunswick)

Businesses often lack all the resources they need to meet market demand and thus they require alliances and partnerships with others to enable them to meet their goals. The standard data envelopment analysis (DEA) assumes homogeneity among decision making units (DMUs), however, there are many practical situations where DMUs produce varying amount of outputs. This paper introduces DEA models for optimizing business partnership scenarios between non-homogenous DMUs. These models are important for various non-homogenous business partnerships that seek to enhance efficiency by reallocating input and/or output between partners. An application in banking is used to highlight the findings of this paper.

DEA45-053 **Modelling sub-process non-homogeneity in parallel network Data Envelopment Analysis**

Charles Turkson (University of Dundee)*

Non-homogeneity in DEA exists where decision-making units (DMUs) have different combinations of inputs and outputs. Parallel network models, on the other hand, are used for efficiency assessment of DMUs characterised by concurrent sub-processes with dedicated or shared inputs and outputs. A special case of the non-homogeneity arises where DMUs have differences in the internal structure of the production process for which some inputs and/or outputs must be optimally apportioned. Where such non-homogeneity exists, current approaches for parallel network DEA and resource allocation fail and will result in incorrect efficiency information for existing and non-existing sub-processes. This is because allocation may be made to non-existing sub-processes resulting in artificially low input and output allocation to existing sub-processes. In this paper, we propose two approaches for resource allocation in parallel network DEA models with non-homogenous sub-processes and shared factors. These approaches differ in terms of the restriction placed on the factor prices. An empirical application is conducted using the electricity generation systems of

European states which are characterised by differences in the portfolio of power generation technologies across countries.

DEA45-054 **Role of China's agricultural water policy reforms and production technology heterogeneity on agriculture water usage efficiency and total factor productivity change**

Wasi Ul Hassan Shah (Zhejiang Shuren University)*; Nan ZHU (Southwestern University of Finance and Economics)

China introduced the "agricultural water conversion policy" in 2012 to efficiently utilize agricultural water resources and improve production technology in different regions of the Country to increase sustainable agriculture production. To this end, for Policy impact evaluation, our study employed SBM-DEA, Meta frontier Analysis, and the Malmquist productivity index (MI) to measure the agriculture water usage efficiency (AWUE), agriculture Production technology heterogeneity (TGR), and total factor productivity change in pre- and post-agriculture water policy implementation in different regions of China. Data for 31 provinces and cities were taken for efficiency and total factor productivity (MI) estimation from 2000 to 2020. Results revealed that agriculture water usage efficiency significantly increased after the policy implementation. The average AWUE score for the 2000–2012 pre–policy period is 0.6763, whereas the average AWUE score for the 2013–2020 post–policy period is 0.7522, showing an increase of 11.22%. Further results show that the eastern region maintains superior agriculture production technology compared to the western and central regions, with an average TGR of 0.8941 during the study period. The average MI (total factor productivity change) for the study period is 1.0769. Technological change (TC) is the primary determinant of MI change. There was a slight decline in average MI after policy implementation. Mann-Whitney and Kruskal Wallis test strengthens the study's results by providing statistically significant differences among different periods and regions.

DEA45-057 **Efficiency-driven socio technical system design: a research agenda**

Konstantinos Triantis (Virginia Tech)*

The evolving theory of socio-technical systems is inspired in part by developments in systems thinking and complexity theory. The premise of this research is that in addition to these domains, economic production theory can play a role in this evolving theory when socio-technical systems can be described by the functional, structural, hierarchical, and distinction system relationship, perspective (DSRP) frameworks and/or as complex adaptive systems. An example how a functional system representation along with economic production theory can inform socio-technical system design is provided when computing the workload boundary that is part of the safety envelope of a safety critical infrastructure system. When a structural representation is sought, then dynamic modeling in conjunction with economic production theory can be an appropriate framework. To this end, we revisit the dynamic productive efficiency model (DPEM) and how

this approach can be used to measure dynamic efficiency and capture important system feedback mechanisms. Finally, if we wish to represent socio-technical systems as complex adaptive systems where efficiency is an important system performance dimension, we revisit the complex adaptive productive efficiency model (CAPEM). For each of these research thrusts, open research questions are provided along with modeling challenges. We conclude by addressing how these research thrusts may challenge specific premises of the axiomatic framework of economic production theory.

DEA45-058 **DEA-VIZ: A software for visualization of Data Envelopment Analysis problems**

Shahin Ashkiani (Bank of England)*

Visualizing data envelopment analysis (DEA) problems can be a highly illuminating step for gaining an understanding of the problems and their characteristics. Through the various visualization techniques, the DEA problem and its associated data can be viewed from multiple angles. Doing so would facilitate the identification of potential regularities and patterns, as well as irregularities and anomalies, in the data.

Despite its significance and benefits, visualization is underutilized in DEA applications. Even though there are several suggested methods for DEA visualization in the literature, the majority of studies lack the graphical investigation step, beyond some simple uni or bi-variate plots. It may be because the DEA software packages are severely lacking in high-dimensional visualization capabilities.

This paper introduces DEA-Viz, a new DEA software, developed in R, that focuses primarily on the visualization of DEA problems. The software is a free-to-use cloud-based applet that can shed light on a DEA problem using a variety of visualization techniques and, thus, from multiple perspectives. The intuitive DEA-Viz's graphical user interface enables researchers to generate a variety of plots from their datasets in order to gain insight into problems and enhance quantitative analysis.

DEA45-060 **Francisco – a web tool for the prediction of network services based on the fractal structure of the network traffic by using DEA models**

Francisco Daladier Marques Júnior (IFPB)*; Francisco Iarlyson Santana de Andrade (IFPB)

This year marks the discovery of thirty years of self-similarity in computer networks. To celebrate this date we are launching a computational tool called Fractal Network Cloud Infrastructure Service Comparison and Optimization (Francisco). Francisco is an expert system that compares several computer networks according to the decision variables related to the fractal structure of the network traffic. Francisco employs the super-efficiency model from Data Envelopment Analysis (DEA) as predictors to point out, among the networks listed as decision-making units (DMU), which the network should be chosen to provide services with a greater

quality of experience, throughput, and stability over time to the customers. Other contributions made by Francisco are: performing exploratory analysis of DMUs, compute of several fractal indices to be used as decision variables, customization of decision variables and problems to be solved, importation of data in different formats, generation of DEA efficiency frontiers, export of results with a web interface.

DEA45-061 **Performance evaluation of university faculty members using DEA models with categorical variables**

Tamas Koltai (Budapest University of Technology and Economics)*; Kata Gerákné Krasz (Budapest University of Technology and Economics)

Data Envelopment Analysis is used for efficiency evaluation of decision-making units (DMU) based on input and the output information. DMUs are generally for-profit or non-profit organizational units. It is possible, however, to consider employees as DMUs, and in this case DEA can be used for personal performance evaluation.

This paper shows, how performance of university faculty members can be evaluated with DEA. The output information determined by achievements of faculty members in teaching, research, and service areas. Inputs are determined by the elements of the faculty compensation system. Output-oriented DEA models are used to set objectives for strengthening performance of faculty members in different areas of their work. Input-oriented DEA models are used to explore how the performance and the related compensation of a faculty member correlates. To refine the analysis, categorical variables are applied to distinguish faculties being in different university positions. Non-controllable variables are used to separate variable and fixed elements of the financial compensation system. Finally, weight restrictions are also applied to express different expectations of management in three fundamental areas of performance: teaching, research and service.

The suggested method is illustrated with the case of the School of Social and Management Sciences of the Budapest University of Technology and Economics. The related output and input data are collected from the official performance evaluation system of the school. Faculty members are evaluated with DEA, individual performance and compensation relationship is analysed, and personal and collective improvement possibilities are explored. The conditions of integrating DEA in the performance evaluation system of the school are also discussed.

The presented results show how DEA can support individual performance evaluation and may also open a new area for DEA application.

DEA45-063 **A four stages AHP-DEA based FMCEA method: ranking failure modes of radio frequency identification systems**

Khaoula Chnina (Eastern Mediterranean University)*; Sahand Daneshvar (Eastern Mediterranean University)

FMCEA (Failure Modes Causes and Effect Analysis) is a useful risk

management method that has been used to study and analyze the failure modes of a variety types of products and processes in many fields for a long time. However, this method has some shortages that includes the absence of the cost and time notions in ranking the failures. Additionally, the experts participating in the risk assessment have the same weight, which is not logic. Another concern about the traditional FMCEA is the weights of the risk parameters (occurrence O, severity S and detection D). Moreover, the causes of the failure modes are not considered in the risk priority calculation. In this study, we are going to suggest a four stages method that combines AHP, DEA and FMEA to deal with the mentioned shortages.

In the first stage, Analytic Hierarchy Process as a Multi Criteria Decision Making method will be used to assign weights to the experts participating in the FMCEA. A group decision making approach will be used to compute the pairwise comparison matrices since many decision makers are involved in the expert's weight assignment stage. In parallel, the traditional FMCEA method will be applied and each cause of failure is considered as a Sub-Failure Mode. The cost and time necessary for fixing each failure will be considered as well. In the second stage, DEA (Data Envelopment Analysis) as a data driven and non-parametric method for efficiency measurement will be used to give a weight to each risk factor (O, S and D), then the overall weighted Risk Priority Number will be used to rank the Sub-Failure modes. In a third stage, an aggregation procedure will be performed for each parent failure mode in order to combine the related Sub-Failure modes. The fourth stage will use the outcomes of the previous step as inputs and outputs for the DEA model, in order to compute the efficiency of the Failure Modes. The RFID system will be used as an example to illustrate the details of the method.

DEA45-066 **A gender inequality index under the capability approach: a proposal with Malmquist Index**

Enzo B Mariano (State University of São Paulo (UNESP))*; Vanessa Ferrari (UNESP)

Amartya Sen's Capability approach gave rise to the concept of human development that is the expansion of people's choices, so that they have capacities and opportunities to be what they want to be. However, the disadvantages that women face are an important source of inequality and one of the greatest barriers to progress in human development. Currently, there are few worldwide indices that portray gender inequality in its multiple dimensions, which go beyond income and assess political and social deprivations. Furthermore, it appears that no index portrayed gender inequality from the perspective of social efficiency. It is this gap that the present research sought to fill, aiming to create an index of gender inequality, based on the efficiency of converting income into capacities in different countries of the world (social efficiency). For this, first, through the Data Envelopment Analysis method, two social efficiency indices were generated, one female and one male; these indexes portray the efficiency

in converting income into the Sen's five instrumental freedoms (economic facilities, social opportunities, political freedom, guarantee of transparency and protective security). Then, the female and male efficiency indexes were compared, using the DEA Malmquist method to obtain the social efficiency inequality index, used in an unprecedented way in this work. In addition to a social efficency inequality index, the Malmquist index was also used to construct an index of inequality in human development in general. As a result, it was found that the lowest gender inequality is found in countries with very high human development, mainly European, such as Norway, which had the highest index with 0.46 and the worst index was for Chade 0.13. The work has limitations regarding the variables used, which will be analyzed in future works.

DEA45-067 **A second chance for failed projects using Data Envelopment Analysis based on project attractiveness factors**

Mahmoud Ahmad Ivied (Eastern Mediterranean University); Sahand Daneshvar (Eastern Mediterranean University)*

Many ideas that turn into projects are hard to determine whether or not they are profitable enough to invest and earn money. For this reason, many tools are applied to estimate the project attractiveness for investors. On the other hand, many issues might be raised when the projects are appraised such as the profit in periods that can change by unexpected events, the variables that affect Net Present Value (NPV) may have a great level of uncertainty, the data can be expensive to obtain, the high tendency to avoid bad projects while trying to accept good projects, and the forecast using past records of the project can have a new concept from the suggested one. Project attractiveness is determined by many methods such as NPV, Internal Rate of Return (IRR), and Modified Internal of Return (MIRR), these methods depend on estimated data to value the project which can ignore the benefits of the project or its full potential.

Data Envelopment Analysis (DEA) models are used recently as one of the most powerful nonparametric methods for computing the efficiency of the multiple inputs and outputs of Decision-Making Units (DMU's). Standard DEA models can be developed to reflect the uncertainty in real evaluation problems, also these models can reflect the returns to scale of under-evaluated DMU to determine their efficiency. This article aims at the failed project to attract investors using attractiveness factors, a second chance to be accepted if the inputs\outputs are optimized. First, the attractiveness of the project is calculated using NPV to determine if it is acceptable or not. Then the DEA models are used to give a second chance to failed projects by estimating the returns to scale and maximizing the performance efficiency of these projects based on the given data. A case study where 30 projects are offered to build a road, gives an opportunity to understand the advantages of the proposed procedure.

DEA45-069 **How unequal is school development in India? An application of meta-frontier benefit-of-doubt approach for unveiling spatial gaps**

Sunil Kumar (South Asian University); Rachita Gulati (Indian Institute of Technology Roorkee)*; Anup Kumar Bhandari (Indian Institute of Technology Madras)

This study proposes a nonparametric methodological framework for calculating an all-encompassing school education development index (SEDI) across regional entities. The proposed framework, which we refer to as “meta-RDM-BoD,” combines the range directional measure (RDM) model of Portela et al. (2004) with the meta-frontier analysis suggested by O’Donnell et al. (2008) and the BoD technique first put forth by Melyn and Moesen (1991). The key features of the proposed framework are that i) it handles both desirable and undesirable indicators, as well as indicators with negative and zero values, without compromising the properties of translation and unit invariance, and ii) it adequately accounts for underlined heterogeneity across regional entities. In order to demonstrate how the SEDI can be derived from a set of education indicators, an illustrative example is provided using the most recent data on 36 school education indicators for Indian states and union territories for the year 2021-22. The selected education indicators encompass the five distinct dimensions of school education: “access to school”,” school infrastructure and facilities”, “teacher quality”, “educational outcomes”, and “equity”. The SEDI is also measured at all levels of K-12 education – primary, upper primary, elementary, secondary and overall education – across Indian states. In addition to identifying spatial gaps in school educational development, the final results of the proposed assessment can be used to benchmark, rank, and classify regional entities on school education development at distinct levels.

DEA45-070 **Modelling resource optimisation for supply chains to reduce the impact of a pandemic**

Gokulananda Patel (Birla Institute of Management Technology)*; Chandra Lalwani (University of Hull)

There is limited research on how to identify the stakeholders and the key players who could assist in reconfiguring supply chains to make it possible to get the medical facilities on time for the recovery of patients who have been infected by Covid-19. The purpose of this research is to develop DEA models that would assist in establishing where these resources are needed.

Data for this research have been collected for 21 states of India each with a population of over ten million from authentic published sources. Most suitable DEA models are developed to get the highest values of good outputs, from both discretionary and non-discretionary inputs. Because of a limited number of states, bootstrapping was used which recommended a variable return to scale. The model developed is used to evaluate both contagion control and medical efficiency during the non-vaccination and fully vaccinated periods.

DEA model found that the number of covid tests had little impact on the

efficiency of states. The results from DEA modeling identified efficient and inefficient states during non-vaccinated and vaccinated periods. The results highlighted that there is a need to provide required additional medical and logistics resources to inefficient states even during the vaccination period.

A combined DEA model has been developed in this research to accommodate all discretionary, and non-discretionary inputs and desirable, and undesirable outputs. Results from the models lead to the importance of mapping risk profiles of associated supply chains in minimising the impact of disruptions. Combined DEA models developed can be modified for application to other countries for resource optimisation under similar circumstances.

DEA45-073 **Constant returns-to scale DEA models with ratio inputs and outputs: An application in the context of school education**

Grammatoula Papaioannou (Loughborough University)*; Victor Podinovski (Loughborough University)

DEA applications often include ratio inputs and outputs stated in the form of percentages and proportions. Such measures typically represent socio-economic and quality characteristics of the production process. For example, in an assessment of school efficiency, such measures may represent the socio-economic background of the pupils, their attainment on entry to and exit from the school, proportion of pupils proceeding to higher education or pupils with special needs. It is known that the incorporation of ratio measures generally invalidates the assumptions of convexity of the technology and scalability of data. This implies that the standard convex variable and constant returns-to scale DEA models that make such assumptions should not be used if some inputs and outputs are given in the form of ratios. In this presentation, we discuss a restatement of the constant returns-to-scale models for the case of ratio data and illustrate theory by an application to schools in England.

DEA45-074 **Incorporating production trade-offs in DEA models with ratio inputs and outputs: An application to schools in England**

Junlin Wu (Loughborough University)*; Nikos Argyris (Loughborough University); Victor Podinovski (Loughborough University)

Inputs and outputs represented by ratio data (such as percentages and averages) often appear in efficiency applications along with volume data. As well known, such measures are inconsistent with the basic assumptions (axioms) on which the conventional variable and constant returns-to-scale (VRS and CRS) models of technology are based. The ratio-VRS (R-VRS) and ratio-CRS (R-CRS) models developed by Olesen, Petersen, and Podinovski (2015, 2017) address this issue and allow the incorporation of both volume and ratio inputs and outputs. In this paper, we extend the R-VRS and R-CRS models by accommodating additional production trade-offs between volume inputs and outputs and, similarly, between ratio measures. The specification of production trade-offs provides additional

information about the production process and improves the efficiency discrimination of the resulting R-VRS and R-CRS models. We use an application in the context of school education to demonstrate the usefulness of the suggested methodology.

DEA45-076 **Towards gaining robustness in inverse DEA models**

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The inverse data envelopment analysis (IDEA) approach aims to estimate input and/or output levels when preserving efficiency scores. The input-oriented IDEA version seeks the input level for producing expected output and the output-oriented one estimates the output level under a given input level while the efficiency maintains unchanged. However, in many real-world applications, full and precise information may not be available to guarantee IDEA success. This study presents a novel approach to combat inherent uncertainty, resultantly, enabling us to move towards robustness of IDEA models. We particularly focus on two cases in this research. The first case occurs where the amount of extra input is not certain and almost impossible to be precisely determined due to restricted budget, market volatility, political issues and other external factors. The second case observes in situations where input and/or output data encompasses uncertainty that might be resulting from errors in data measurement, data clearing, vagueness in variables (e.g, customer satisfaction and quality) or other internal factors from organizations.

DEA45-077 **The manufacturing industry in the North American economies, 1984-2018: an estimate of technological gaps through DEA- Metafrontier model**

Odette Delfin-Ortega (Universidad Michoacana de San Nicolás de Hidalgo)*; César Lenin Navarro-Chávez (Universidad Michoacana de San Nicolás de Hidalgo)

This work aims to estimate the efficiency and identify the technological gaps of the 9 manufacturing industry divisions of the North American economies during the period 1984-2018. To estimate efficiency and identify technological gaps, a DEA Metafrontera (MF) model is implemented, where both technical efficiency and the Technology Gap Ratio (TGR) are calculated, which allows for identifying the distances to the potential technology and thus seeking the efficiency in this case study, of the different divisions of the manufacturing industry. Among the main conclusions, it stands out that the North American economies use non-homogeneous technologies and therefore, the technological gaps show the asymmetric situation in which the members of the North American region find themselves.

DEA45-079 **An effective sequence computation scheme for large-scale Data Envelopment Analysis**

Qianwei Zhuang (Osaka University)*; Hiroshi Morita (Osaka University)

Data envelopment analysis (DEA) is a useful tool for efficiency evaluation of a set of homogeneous decision-making units (DMU) with multiple inputs and outputs. However, as the number of DMUs increases, the computation time increases significantly. In this study, we focus on DEA variable returns to scale (VRS) model and propose an effective approach for accelerating the computation when a large number of DMUs are present, which is called a large-scale DEA problem. In fact, only efficient DMUs serve as benchmarks for the less efficient ones and constitute the production frontier in DEA. Thus, a common solution is to determine all efficient DMUs in the 1st stage, and then evaluate the rest with respect to the efficient ones in the 2nd stage. Using statistical information of each DMU's inputs and outputs, we develop an effective method by pre-evaluating DMUs in the 1st stage with respect to a constantly updated temporal frontier. We conduct empirical experiments to verify the effectiveness of our approach on 96 simulated datasets considering different number of DMUs and dimension (total number of inputs and outputs). The results reveal that our approach can make a portion of the less efficient DMUs be evaluated with reference to the complete production frontier in the 1st stage, which can mitigate the computation load of the 2nd stage as a result. They also reveal that the pre-evaluation result of the 1st stage has high consistency (more than 96.5% considering 1e-6 as an error range on all datasets) with the 2nd stage, which means a quick and reliable estimate of DMUs' performance for decision-makers. In addition, our approach achieves 91.78% reduction of computation time on a real dataset (33742 DMUs, 2 inputs and 4 outputs) in comparison with current most effective approach to our best knowledge.

DEA45-081 **A Machine Learning-based approach to estimate efficient frontiers: Efficiency Analysis Trees**

Juan Aparicio (Universidad Miguel Hernández de Elche)*

Free Disposal Hull (FDH) and Data Envelopment Analysis (DEA) present the typical characteristics of a data-driven approach with the specific objective of determining technical efficiency and production frontiers in Engineering and Microeconomics. However, by construction, the frontier estimators generated by FDH and DEA suffer from overfitting problems; something that contrasts with currently accepted models in machine learning. In this regard, FDH and DEA can be seen as statistical descriptive tools that make up of a more complex approach, where the aim is to avoid overfitting in order to conclude something about the underlying Data Generating Process that is behind the generation of the observations in a production process. In this paper, we show how Efficiency Analysis Trees (EAT), which is based on the adaptation of regression trees in Machine Learning, can be a possible solution to overcome the overfitting problem associated with FDH and DEA. Additionally, we illustrate how the new technique may be used as a complement to the standard non-parametric methods through an empirical application based on a PISA (Programme for International Student Assessment) dataset.

DEA45-082 **Primary healthcare efficiency assessment using panel data**

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Objective: An analysis of efficiency in Primary Healthcare Centres (PHC) in a health district of the Valencian Community (Spain)
Methodology: Data envelopment analysis with input orientation and variable returns to scale is used to assess the efficiency using panel data over a 5 year-period (2015 – 2019). Inputs included are rates of: physicians, nurses and pharmacy costs; as outputs the rates of: hospital emergencies, outpatient consultations, referrals, avoidable hospitalizations, avoidable mortality and prescription efficiency; and as exogenous variable: morbidity.
Three models are developed from different approaches: healthcare activity, healthcare outcomes, and both.

Results: Several models are compared, in order to subsequently select the one that allows for the clearest differentiation of PHC efficiency and that considers the results on the health of the population, rather than healthcare activity.
DEA methodology identifies efficient PHCs as a whole. The results show that there are differences in the efficiency scores estimated depending on the variables introduced as output, although it is observed that certain PHCs are always efficient or remain closer to the efficient frontier, while others are always inefficient. Considering healthcare activity outputs generates changes in the scores with an increase in the number of efficient PHCs. It is possible to detect that PHCs experienced, in general, a clear decrease in their efficiency levels throughout the period assessed. This decrease is more pronounced when only activity outputs are included.
Conclusions: Efficiency analysis is useful as a managerial tool in terms of resource allocation, since the DEA allows the analysis of the inefficiencies of the PHCs, although it is necessary to identify the objectives of the PHC, as the perspective of the analyses influences the results.

DEA45-083 **DEA as an audit tool to identify unusual operating results for auditor review and validation**

H David Sherman (Northeastern University)*; Joe Paradi (University of Toronto)

Independent auditors of financial statements are charged with determining if financial reports are prepared in accordance with U.S. Generally Accepted Accounting Standards or International Financial Reporting Standards. Audit procedures include a wide variety of activities ranging from confirming the existence of and valuation of assets to determination of whether a firm will be solvent during the upcoming year.

A common method of auditing accounts has been to sample transactions to determine if they are handled in accordance with the proper accounting

treatment and consistent with the internal control system of the organization. Recently, efforts to expand the audit coverage to review all the transactions, particularly in cases where there is a high volume of substantial transactions, have been an area of study. Methods encompassed by data analytics applied to big data and data mining are techniques that are actively being adapted to expand audit capabilities. The objective is to use such techniques to identify cases where the relationships of some measures to others are unusual. These suspicious relationships would then be evaluated by the auditor to determine if this represents a reasonable exception but it is in accordance with accounting standards. On the other hand the auditor must establish whether it represents an error or some unacceptable treatment of a transaction. If this is the finding, then it could require investigation as to whether it is a one-time or more systemic error.

This study is an exploratory effort to determine if DEA can be applied to accounting data to locate unusual relationships that require auditor follow-up and evaluation. We explore a few different DEA models and apply it to a data base of about 79 retail stores to determine if there are unusual relationships between sales, inventory levels, and operating expenses.

DEA45-084 **Industrial robots and employment change in manufacturing: a combination of index and production-theoretical decomposition analysis**

Bernhard Mahlberg (Institute for Industrial Research)*; Andreas Eder (Institute for Industrial Research); Wolfgang Koller (Institute for Industrial Research)

This paper investigates the contribution of industrial robots to employment change in manufacturing in a sample of 17 European countries and the USA over the period 2004 to 2019. We employ sector-level data for nine manufacturing sectors, including industries with the highest robot exposure such as the transport equipment, electronic as well as the chemical and pharmaceutical industry. To answer our research question, we combine index decomposition analysis (IDA) and production-theoretical decomposition analysis (PDA). In a first step we use IDA to decompose employment change in the manufacturing industry into changes in (aggregate) manufacturing output (output effect), changes in the sectoral structure of the manufacturing industry (output mix effect), and changes in labor intensity (intensity or productivity effect) which is a composite index of labor intensity change within each of the nine sub-sectors of total manufacturing. In a second step we use PDA to further decompose labor intensity change to isolate the contribution of efficiency change, technological change, human capital change, change in non-robot capital intensity and change in robot capital intensity to employment change. Distance functions for the PDA are estimated by Data Envelopment Analysis and the procedure accounts for heterogeneity in production technologies across sectors and time. In almost all of the countries considered, the labor intensity is falling (i.e., increasing labor productivity)

in entire manufacturing, which has a dampening effect on employment. Robotization contributes to this development by reducing labor intensities and employment in all countries and sectors, though to varying degrees. Output, in turn, increases, which increases employment and, in most countries, offsets the dampening effect of declining labor intensities. The structural change within manufacturing has an almost neutral effect in most countries.

DEA45-085 **An empirical data-fitting approach to estimate the production frontier**

Yu Zhao (Tokyo University of Science)*

Estimating production frontiers is crucial for performance benchmarking and productivity analysis. There are currently various methods available for this purpose, including data envelopment analysis (DEA), stochastic nonparametric envelopment of data (StoNED), and stochastic frontier analysis (SFA). This study reviews the existing methods and proposes a nonparametric method for estimating the production frontier based on a data-fitting technique.

The production frontier identifies the maximum producible outputs at a given level of inputs. Our study reveals that the local upper bounds of outputs for each observation can be empirically estimated using a modified ordinary least squares problem. Furthermore, we impose concavity constraints to ensure a concave frontier. The proposed method is nonparametric and stochastic, making it more flexible and applicable to both small and large-scale problems. Additionally, we can adjust the shape of the frontier according to the prior knowledge or level of stochastic noise (if available). We also examine the proposed method using both simulated examples and real-world applications.

DEA45-086 **Not all most preferred solutions are valid in VEA**

Panagiotis Ravanos (University of Macedonia)*; Giannis Karagiannis (University of Macedonia)

In this paper, we explore the implications of using efficient Decision Making Units (DMUs) exhibiting different types of returns-to-scale (increasing, constant, or decreasing) as the Most Preferred Solution (MPS) in Value Efficiency Analysis (VEA) models. More specifically, we show that regardless of the returns-to-scale specification and the orientation chosen for the VEA model, the choice of an efficient DMU exhibiting constant returns to scale as the MPS is valid, in the sense that it does not result in an efficient frontier violating production axioms. On the contrary, in variable-returns-to-scale VEA models an MPS exhibiting increasing or decreasing returns to scale allows for free or unlimited production of output. These results also hold when a combination of efficient DMUs is selected as the MPS, as long as this combination is expressed as an artificially constructed DMU that is included in the sample of existing DMUs. We also show that the nature of the returns-to-scale that is actually exhibited in variable-returns-to-scale VEA models is affected by the choice of the MPS and in essence depends on the range of the interval between

the MPS's right-side and left-side scale elasticities.

DEA45-087 **Learning mobility in European higher education: how has the Union's flagship initiative progressed?**

Miguel A Pereira (INESC TEC)*; Ana Camanho (University of Porto)

In 2010, the European Commission set out the development of an economy based on knowledge and innovation as one of the priorities of its Europe 2020 strategy for smart, sustainable, and inclusive growth. This culminated in the 'Youth on the Move' flagship initiative, aimed at enhancing the performance and international attractiveness of Europe's higher education institutions and raising the Union's overall education and training levels. Such transnational mobility can aspire to enable young people to acquire new knowledge, skills, and competencies, which play a crucial role in their future employability, intercultural awareness, personal development, creativity, and active citizenship. Besides, learning mobility can improve the openness, accessibility, and efficiency of education and training systems. Therefore, it is relevant to assess the performance of the 'Youth on the Move' initiative via the creation of composite indicators (CI) and, ultimately, monitor the progress made by European countries in creating a positive environment supporting learner mobility. For this reason, we make use of the CI-building 'Benefit-of-the-Doubt' approach to exploit the European Commission's Mobility Scoreboard framework of 2016 and 2019. Furthermore, we incorporate the value judgements of experts in the sector to construct utility scales through multi-criteria decision analysis to not only add a layer of knowledgeable reality to the assessment but also convert the framework's ordinal scales into interval ones. In the end, the preliminary results point to heterogeneous performance scores among the European countries, with statistically significant regional differences.

DEA45-091 **Stochastic Data Envelopment Analysis (DEA), principles of Optimal Control Theory (OCT), and inventory management: stochastic and dynamic cost efficiency analysis**

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This research aims to propose a novel Stochastic Data Envelopment Analysis (SDEA) model with principles of Optimal Control Theory (OCT), characteristics from recent dynamical models, as the intermediate measures, and from stochastic models, as uncertainties, because previous SDEA-OCT models did not consider these measures, to stochastically and dynamically evaluate inventory control systems over time. The characteristics of inventory control systems, as the relationship among demand, production or ordered quantities, and inventory variables, can be

incorporated into the development of this kind of SDEA model through principles of OCT. The output (or disturbance) is demand; the input (or control variable) is production or ordered quantity; and the intermediate measures (or state variable) is inventory, representing the dynamic relationship between demand and production (or ordered quantity, for the retail sector). The expected result of this research is a SDEA model with principles of OCT to be applied to control systems of Decision-Making Units (DMUs). As an example, this kind of model can be applied using data from accounting variables of retailing sector and considering the new total cost approach, the model minimizes the inventory and production (or ordered quantities) costs and this result is compared to the observed costs, resulting in the total cost efficiency over time under uncertainties. In summary, the model is relevant to calculate stochastic and dynamic cost efficiency of inventory control systems, considering demand uncertainty while preventing the possibility of finding a projection that ignores the relationship among variables that always occurs in practice in inventory control systems. Thus, this proposed approach avoids over stockage and over production, contributing to more efficient control systems.

DEA45-092 **A Selecting Data Envelopment Analysis approach under an Onion framework to select quality service criteria and evaluate the perception of airport concessionaires' users about Brazilian airports**

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Traditional methods of cost-benefit analysis in business administration usually measure the performance of activities exclusively in monetary terms, though the airport users' perception of quality service is relevant to airlines' operations. This paper aims to present a novel Onion framework for Selecting Data Envelopment Analysis (Selecting DEA) model to select multiple quality service criteria, compare, and evaluate the perception of airport concessionaires' users about Brazilian airports through layers of analysis. This Onion framework consists of running the DEA again, in loop, where each loop is considered an onion layer, and each loop only with the criteria not selected for any of the Decision-Making Units (DMUs) in the previous loop, and to repeat it until all criteria is selected for at least one DMU and there are no more no selected criteria to create another layer. The first step was the compilation of the answers of 31 criteria, collected monthly from the National Civil Aviation Agency (ANAC) in Brazil for the main airports, deemed as Decision-Making Units (DMUs) in this study, from 2014 until 2017 for the empirical application, so, the number of quality service criteria used as measures in the model is relatively larger than the number of DMUs. In the current case, it was necessary to run 14 onion layers of the Selecting DEA and the results showed that the last layer had most of the important quality service criteria. Also, the results showed that

the quality of service is not directly related to the number of boarded passengers, as they do not correlate. The results also demonstrated that 2017 was a year with improved quality perception for many airports, despite the reduced number of passengers (for example, when compared to 2015). It can support and direct decision-makers to select criteria, monitor, and identify management best practices.

DEA45-093 **Reviewing fast DEA procedures**

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Many computational DEA studies have been conducted to accelerate DEA. The common practice in these studies is to examine the performance of the new procedure and provide comparisons with others based solely on execution times. However, there is a neglect of the role of the optimization burden and how it is organized and distributed in the procedure. In this study, we survey the competitive DEA procedures by counting the operations carried out in each of them. The resulting measures are independent of the software and hardware used to implement the procedures and perform the computations.

DEA45-094 **Assessing the progressive and ethical research performance of academic institutions: a case of the Northeast region of the United States**

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Research-based knowledge generation is a critical role in academic institutions. Therefore, there is a great body of studies assessing the research performance of academic institutions. However, most of them tend to focus on desirable outputs of a knowledge production function, ignoring undesirable outputs. To fill the gap in the extant literature, we assess more integrative research performance by incorporating byproducts of the knowledge production function.

Inspired by the philosophy of Imre Lakatos, we coin his progressive and degenerative research to reflect the intended and unintended outputs of the research process. Following the disposability concept proposed by Toshiyuki Sueyoshi, we calculate the research performance scores based on two frontiers: one prioritizing the maximization of intended outputs and another prioritizing the minimization of unintended outputs. The former represents progressive (vs. degenerative) research performance while the latter indicates ethical (vs. unethical) research performance.

As a testbed, we investigate 30 elite academic institutions (classified as R1 research-intensive) in the Northeast region of the U.S., which is composed of 11 states including Massachusetts and New York. First, we assess the progressive and ethical research performance of the 30 institutions. Then, we compare the performance scores across a few institutional characteristics such as Ivy vs. non-Ivy, public vs. private, and three

different groups resulting from latent class analysis based on input and output factors.

We found that Harvard University and Johns Hopkins University outperform in both progressive and ethical research along with a few other institutions excelling in either one. We also found that there is a statistical difference in progressive research performance between public and private institutions and in ethical research performance between Ivy and non-Ivy institutions.

DEA45-095 **Finding different stepwise alternatives based on limited efforts: setting targets and identifying leading benchmarks in intermediate steps**

Xianhua Wu (Shanghai Maritime University)*; Zhiyong Ji (Shanghai Maritime University); Ji Guo (Shanghai Maritime University)

Target setting and peer identification play an important role in benchmarking. Based on this, some authors developed a bi-objective Data Envelopment Analysis (DEA) benchmarking method that both finds the closest target and seeks the appropriate peers. According to the authors, these peers are closest to targets and are known as leading benchmarks that can be emulated to improve performance. However, we often find that there exists a big gap between poor performances and targets (including closest targets), which makes it worthwhile to find more achievable intermediate targets and corresponding leading benchmarks in successive intermediate steps. Moreover, experts and decision-makers (DMs) have different value preferences for different inputs and outputs, which should also be further considered in benchmarking. For these purposes, we further propose a novel stepwise DEA benchmarking approach. The contributions of this approach are as follows: (1) Both intermediate targets and most similar leading benchmarks can be found in every intermediate improvement step; (2) Every target and corresponding leading benchmark conforms to expert opinions on the importance of different inputs and outputs; (3) The upper bound for intermediate improvement efforts can be limited, which makes the gradual paths more feasible. To illustrate the validity of the new approach, a case consisting of 42 Spanish universities was studied.

DEA45-096 **Pareto-Koopmans Efficient Industry Structure in the Long Run and the Short Run: An Application to Retail Pharmacies**

Gokulananda Patel (Birla Institute of Management Technology)*; Subhash C Ray (University of Connecticut)

A firm is considered to be Pareto-Koopmans efficient if (a) there is no room for reducing any input without increasing some other inputs or reducing some outputs and (b) increasing some output without reducing some other outputs or increasing some inputs. In any empirical analysis, one starts with the observed input-output bundle of a firm and then looks for the input-output bundle that yields the optimal slack-based measure of efficiency. In an analogous way, we can also measure the technical efficiency of the input-output bundle of the industry aggregated over all firms. However, one

may consider the possibility of restructuring the industry by changing the number of firms. Any potential improvement beyond removing slack-based inefficiency of the existing firms can be viewed s an indicator of the structural inefficiency of the industry. As shown in Ray (2004) this can be attained by creating an optimal number of identical firms with the same input-output bundle that is endogenously determined. In this paper, we also consider a model where some inputs currently used by the individual firms are not transferable and are considered to be fixed in the short run. Hence, the output targets assigned to individual firms must be producible from the input bundles assigned in conjunction with their existing quantities of the fixed inputs. We develop appropriate DEA models to measure the short-run Pareto-Koopmans efficiency of the industry as a whole and apply the proposed DEA model(s) to measure the Pareto-Koopmans efficiency of a group of retail pharmacies in the National Capital Region in India.

DEA45-097 **Cost-efficiency of renewable district heating systems: the case of Austria**

Andrea Frank-Stocker (Institute for Industrial Research); Wolfgang Koller (Institute for Industrial Research); Bernhard Mahlberg (Institute for Industrial Research)*

Heat generation based on conventional fossil fuels is considered to cause a significant proportion of greenhouse gas emissions. Achieving the climate protection goals therefore requires a change to renewable energy sources such as biomass. Establishing renewable district heating systems is an important element of this transformation. These systems generate heat based on renewable fuels in a centralized location and distribute it through a network of insulated pipes for residential and commercial heating requirements such as space heating and water heating. In contrast to usual district heating systems, the transmission takes place via smaller, rural heating networks over relatively short distances. Another difference to usual district heating plants is that renewable district heating systems mostly obtain their fuel from suppliers in their own region. This study estimates cost efficiency using Data Envelopment Analysis (DEA). A subsequent regression analysis examines how plant-specific technical structural features and the regional environmental conditions of the respective plants influence their performance. Finally, the results of the regression analysis are used to work out the managerial inefficiency purged of the influence of structural peculiarities and operating environment. It is that part of the overall inefficiency that is due to the decisions of the operator and can therefore be reduced by changing the behaviour of the operator. The applicability of the approach developed here is shown empirically using a sample of biomass district heating plants from Austria. The empirical results show that the managerial inefficiency is much lower than the overall inefficiency.

DEA45-098 **Assessing sustainable procurement in the chemical industry: a fuzzy two-stage data envelopment analysis model**

Alka Arya (Indian Institute of Management Kashipur)*; Adel Hatami Marbini (University of Huddersfield)

Sustainable procurement is a key driver to building a sustainable supply chain. Nowadays, in developed countries, customers are more empowered and their attitudes and behavior towards social, economic, and environmental elements of sustainability services are impacted. Therefore, firms are putting an emphasis on sustainable procurement, and they require a strategy to increase their market shares and uphold the standards in sustainable supply chain management (SCM). The conventional Data Envelopment Analysis (DEA) approach assesses the performance of the firms whose structures are black boxes that use a collection of inputs to create a collection of outputs. This paper suggests a product-based, two-stage framework for selecting sustainable suppliers, taking into account various sustainability standards used in the internal operations assessment process. In order to address the vagueness of information that is frequently present during the information-gathering stage, this article exploits the fuzzy sets theory. For determining optimal sustainable suppliers, we develop a two-stage fuzzy DEA method leading to sustainable procurement. The applicability of the proposed method is demonstrated through a case study from the chemical manufacturing sector.

DEA45-099 **Untangling Higher Education Sector: a systematic literature review of DEA and artificial intelligence methods**

Anna Rita Dipierro (LUM Giuseppe Degennaro)*; Kristof De Witte (KU Leuven); Pierluigi Toma (University of Salento)

Higher Education has gained in Europe a prominent recognition being vital in the run for progress, and easing the shift from the triple to the quadruple helix. In essence, civil society has joint the acknowledged three-constellation, i.e. industry-government-university, deriving a new scenario also for European Higher Education Institutions (HEIs) that nowadays embed a wide range of regional stakeholders (i.e. firms, government, and the entire society) by favouring synergies in the name of innovation for territory. It follows an increase echo of the voice of academic in contemporary society. In this perspective, Higher education sector is under constant pressure to increase efficiency. A number of further academic contributions have shed light to the evaluation of the efficiency of HEIs through parametric and non-parametric approaches falling into Operational Research (OR). Amongst the non-parametric approaches towards efficiency evaluation, DEA become a technique of choice, since it handles multiple inputs and outputs without defining the production function. Alongside, over the years, the rapid inroads that Machine Learning (ML) is making in many sectors are also enriching literature surrounding HEI. Nevertheless, in spite of the huge interest of academic research in efficiency evaluation of education sector, few contributions approaching the topic by means of ML techniques. For these specific reasons and bearing these contributions in mind, the research is intended to make a systematic literature review, based on the Preferred Reporting Items for Systematic Review (PRISMA) guidelines over the contributions addressing the Higher

Education sector worldwide by means of efficiency and ML approaches. In so doing, the research seeks to contribute to outline main trends of OR and ML in HEI, the main impacts of past researches as well as the potential of fulfilment of to-be-identified gaps.

DEA45-100 **Revisiting the impact of banking competition with noncovex technology**

Oleg Badunenko (Brunel University London)*; Jérémie Bertrand (IESEG School of Management); Kristiaan HJ Kerstens (IESEG School of Management); Paul-Olivier Klein (IAE)

In this contribution, we build upon recent results obtained by Kerstens and Van de Woestyne (2021) on nonconvex cost functions to investigate the impact of the convexity assumption on the Lerner index, the traditional measure of competition. Obtaining the Lerner index involves estimating marginal costs, which in turn depends on the shape of the cost function. When technology includes only one output and exhibits constant returns to scale (CRS), then convex and nonconvex cost functions coincide. In all other cases the convex or nonconvex cost functions are different. This study devises a way to obtain marginal costs for the convex and nonconvex cost functions alike, offering an updated Lerner Index. We also include a scale analysis conducted under both convexity and nonconvexity assumptions. This allows us to identify banks in three stages of production: (i) those experiencing economies of scale, (ii) those operating at optimal scale, and (iii) those facing diseconomies of scale. We use call reports on a large panel of US commercial banks to demonstrate the effect of convexity on the analysis of competition. We combines our new measure of competition under nonconvex assumptions with the scale analysis to examine the evolution of banking competition in the United States and to highlight potential issues associated with relying solely on studies conducted under convexity assumptions. This offer new insights for policymakers on the extent and impact of banking competition.

DEA45-102 **Efficiency evaluation in the presence of undesirable factors: an inverse DEA approach**

Ali Emrouznejad (Surrey Business School); Maria Michali (University of Bristol)*; Gholam R Amin (University of New Brunswick)

In many cases, the production process involves undesirable inputs and/or outputs, and therefore, many data envelopment analysis (DEA) studies focus on efficiency assessment in the presence of undesirable factors. Undesirable outputs are especially common in environmental efficiency measurement, where waste or by-products such as greenhouse gas emissions are considered. A very common approach to treat undesirable inputs/outputs in the DEA literature is to use their inverse value for each decision making unit (DMU). However, in this case, the resulting DEA model does not correctly reflect the true production process. In this study, we suggest that an alternative, non-linear programming DEA model should be used instead to treat undesirable factors. We also propose a two-stage linear programming relaxation algorithm to solve this model. The new

model is illustrated in real data, assessing the environmental efficiency of European railways, including undesirable inputs and outputs.

DEA45-104 **Are you really better than me? A new method to deal with input and output composition in performance evaluation**

Giovanna D'Inverno (University of Pisa)*; Antonio Peyrache (University of Queensland); Gabriela Sicilia (University of La Laguna)

Efficiency evaluation is increasingly needed to provide policy makers and managers with evidence to learn from best practices and improve performance. In this paper, we propose an extension of the traditional DEA formulation to directly take into account the inputs and outputs distribution of each unit, without resorting to common aggregate measures such as the average or the standard deviation. The suggested framework allows different specifications to model input and/or output composition and to capture heterogeneity across the units under evaluation. Among others, we propose the use of a percentile selection model, to select the most appropriate subset of percentiles that will explain most of the efficiency score. For illustrative purposes, we apply our proposal to an extensive dataset of more than 600 schools in Spain, coming from the international large-scale assessment PISA 2018. This empirical application shows how this tool could support educational policy making assessment while considering the possibility of a heterogeneous working and learning environment. To model potentially different school input composition, we consider the distribution of the student socio-economic characteristics.

DEA45-106 **Impact of the digitalization on productivity**

Mikulas Luptacik (Vienna University of Economics and Business); Eduard Nežinský (University of Economics in Bratislava)*

Digitalization and Industry 4.0 are in the focus of intensive debates and scientific theoretical and empirical research. In order to analyse the impact of digitalization on productivity, we try to answer first the following question: How to measure the level of digitalization and its changes over time? We provide a new composite indicator based on Data Envelopment Analysis (DEA) overcoming the undesirable dependence of final result from the preliminary normalization of sub-indicators (used for the creation of the Digital Economy and Society Index (DESI) and the subjective nature of the weights used for aggregating. Then we try to answer the following research questions: How does the adoption of the elements of the digital economy going beyond automation contribute to the productivity growth? Can be the reduced number of working population in EU countries compensated by digitalization? Using the decomposition based on Henderson – Russell (2004) for the period 2017 – 2022, positive contribution of the change of digitalization to the GDP growth for the sample of 26 European countries can be estimated. Utilizing the indicators of the four areas of digitalization (data from the Report of EC 2017 and 2022) as the inputs (besides of capital and labour) deeper insights into contributions gained by the particular areas of digital performance to the growth of GDP can be

provided. The results based on previous Report of EC 2020 show that significant impact is generated by digital public services, on average by 2%, and by integration of digital technologies for business, on average more than 1% (in Finland more than 6%), which implies higher contribution than change in input labour. In this way, the digitalization offers potential for the compensation of reducing active labour population.

DEA45-107 **Channel efficiency in omni-channel environment: a network DEA Model**

Pankaj Priya (Birla Institute of Management Technology)*; Gokulananda Patel (Birla Institute of Management Technology)

Omni-channel environment entails usage of offline as well as online channels (O-O) for enhanced servicing of end customers. Maximizing reach of the marketer's offerings being the core issue for FMCG sector, implementing an Omni channel strategy is the new contribution to the intensive distribution strategy pursued by these marketers. The consequences are heavy price cutting by different channels to increase their own sales at the cost of channel cannibalisation. So what happens to the net profitability of the marketer as well as those of each channel or channel members. No studies have probed the impact on marketers' profitability, who are the upstream suppliers as well as the brand owners throughout the value chain, while meeting the expectations of myriad segments of customers being served by them. This study will seek to evaluate the efficiency of each channel being utilised by the FMCG companies to serve their customers and benchmark each channel with the one having highest efficiency. The purpose would be to suggest options for concerted focus on better performing channels and improvement or may be elimination of the poor performing channels by FMCG marketers. Data regarding Distribution depth, distribution breadth as inputs) and distribution performance (as outputs) would be considered for this study. A network DEA model measuring the I-O at every stage of distribution for each channel and incorporating the final undesired outputs would be applied. This exercise would ensure better integration of the channels, thus contributing to the business sustainability of the organisation.

DEA45-108 **A generalised additive two-stage network DEA model: the case of an external single constant input**

Giannis Karagiannis (University of Macedonia); Stavros Kourtzidis (University of Dundee)*; Nickolaos Tzeremes (University of Thessaly)

The traditional additive two-stage network DEA model under constant returns to scale has non-increasing decomposition weights (i.e. the weight assigned to the first stage is not less than the weights assigned to the second stage), which also has a direct impact on the stage efficiencies. Previous research has revealed that adding external input/s in the second stage provides the necessary conditions under which there can be a reversal in the decomposition weights for the two stages. In this paper we are investigating the case of an external single constant input in the second stage and its effect on the decomposition weights. The empirical

investigation is undertaken using a dataset of Japanese Regional Banks. Bank of Japan has a long tradition with quantitative easing as a monetary policy instrument that could help boost economic activity, avoid deflation, and overcome the problems of the liquidity trap. Given that quantitative easing provides all banks with liquidity, we model it as a constant input in the second stage of the model. This generalised structure of the model with an external single constant input in the second stage tend to produce results which do not suffer from the issues under investigation.

DEA45-109 **A new class of BoD models accommodating forward and reverse component indicators**

Giannis Karagiannis (University of Macedonia); Stavros Kourtzidis (University of Dundee)*

In this paper we present a new class of Benefit-of-Doubt (BoD) models that can accommodate both forward (desirable) and reverse (undesirable or bad) component indicators proposes by relying on different disposability assumptions, namely, weak, constrained weak and extend strong disposability. We first show that, regardless of the orientation chosen, BoD models with constrained weak and extended strong disposability are equivalent to each other. Then we analyse eight models: the first one is a radial input-oriented model with weak disposability; the second and the third are radial forward-output-oriented models with respectively weak an extended strong disposability; the fourth and the fifth are radial reverse-output-oriented models with respectively weak and extended strong disposability; the sixth is a directional output-oriented model with extended strong disposability; and the last two are hyperbolic output-oriented models with respectively weak and extended strong disposability. These are then compared and contrasted, using the same data set, with two relevant models existing in the literature, namely, a radial input-oriented model with extended strong disposability and a directional output-oriented model with weak disposability.

DEA45-110 **Comparative efficiency analysis of public and private hospitals in Colombia**

Ricardo Losada (Universidad del Politècnica de Valencia)*; David Vivas Consuelo (Universidad Politècnica de Valencia); Javier Gonzalez Rodriguez (Universidad del Rosario)

Colombia's healthcare system operates a public health insurance plan, Entidades Promotoras de Salud (Health Promotion Agencies) (EPS). Healthcare provision is carried out by instituciones prestadoras de salud (healthcare institutions) (IPS). This study compares 61 tertiary level IPS in Colombia, of which 38 are private and 23 public. These IPS serve a population of 48 million inhabitants.

Objective: To analyse the efficiency of public and private hospitals in Colombia and to determine the influential variables.

Methodology: A basic radial data envelopment analysis (DEA) model with input orientation with variable returns to scale was designed. Input

variables included were: the number of hospital beds (non-discretionary variable) and the cost of the general social security system. Outputs were: external consultations; hospital emergencies; hospital discharges and; rate of readmission in less than 15 days (unwanted variable). The source for the data is the Colombian Health Ministry for 2021.

Results: Of the whole sample, 17 (28%) of the IPS were shown to be efficient, with 6 of these being private and 11 public. 5% of the IPS (1 public and 2 private) were very close to the efficient frontier and need to reduce all their inputs by between 7.9% and 14.9% in order to be on the frontier. 24% of the IPS (8 public and 7 private) were close to the efficient frontier, needing to reduce all inputs by between 21.6% and 49.4%. The IPS furthest from the efficient frontier, 43%, need to reduce all their inputs by between 51.5% and 90.2%.

Conclusions: In the data panel set of public and private IPS for 2021, 28% were found to be efficient, the majority of which were public. Comparing the profit margin between public and private IPS, the private have an average profit of 22%, while the public have an average loss of 10%. Key words: Efficiency – DEA – clinics and hospitals – public healthcare.

DEA45-112 **Revenue functions are non-concave in the inputs when the technology is non-convex: the unbearable lightness of convexification**

Oleg Badunenko (Brunel University London); Kristiaan HJ Kerstens (IESEG School of Management)*; Jafar Sadeghi (Kharazmi University)

In this contribution, we analyze revenue functions under the assumption that the technology is nonconvex. More specifically, we show theoretically that the convex revenue functions are larger or equal to the nonconvex revenue functions. However, with one input and constant returns to scale (CRS) technologies both these revenue functions coincide. Including more inputs or varying returns to scale assumption (e.g., variable returns to scale, VRS) results in differences between the convex and nonconvex revenue functions. We use USA state level agricultural data to showcase our theoretical result empirically. We first visualize the revenue functions under constant and variable returns to scale assumptions and demonstrate that the former is identical irrespective of whether technology is convex or nonconvex while the latter revenue functions are different. We further show graphically that the convex or nonconvex revenue functions are different both under CRS and VRS with 4 inputs. Finally, we use statistical tests (equality of densities and stochastic dominance) to show that the convex or nonconvex revenue functions are statistically different.

DEA45-113 **Incentive regulation of electricity distribution and non-convexities: why economists are wrong, and engineers are only half right**

Miguel A Pereira (INESC TEC)*; Kristiaan HJ Kerstens (IESEG School of Management); Ana Camanho (University of Porto)

Incentive regulation in many countries makes use of frontier benchmarking to determine the RPI-X type of formula to be applied to electricity

distributors. Convexity is almost universally imposed on technologies and cost functions modelling electricity distribution by both economists and engineers. However, in the engineering literature, it is well known that the electricity distribution problem is a nonconvex optimization program. To our knowledge, this contribution is the first to investigate to which extent convex and nonconvex cost functions, as specified in the economic literature at the firm level, yield the same cost estimates. We explore the economics and engineering literature. The empirical application analyzes secondary data sets from Finland and Iran. It turns out that, most often, the convexity hypothesis can be significantly rejected. We also spell out the different implications of convex and nonconvex cost estimates for RPI-X cost norms. We hope our contribution makes regulators think twice about the use of the traditional convex cost models to regulate an industry that is intrinsically nonconvex and where the convex models provide a poor approximation of the nonconvex reality.

DEA45-116 **Malmquist Productivity Index from a regulator's perspective**

Laura Carosi (Department of Economics and Management, University of Pisa)*; Giovanna D'Inverno (University of Pisa); Maria Molinos-Senante (Pontificia Universidad Catolica de Chile)

In their monitoring and assessing activities, regulators often have to balance the need for a fair evaluation system, where no one can't complain, with the need for a common framework suitable for comparison and ranking of the evaluated units. In this light, different DEA-like models with a common system of weights have been recently proposed. However, very few papers deal with dynamic performance measurements under a common system of weights (see the recent reviews of Afsharian et al., 2021, and Contreras, 2020).

The current analysis aims at contributing to this strand of literature by proposing a Malmquist Productivity Index with common weights based on Kao and Hung's approach in its Linear Programming formulation proposed by Zohrehbandian et al. (2010). The suggested model is applied to the Chilean water sector.

DEA45-118 **Handling negative inputs and outputs in data envelopment analysis**

Maria Trnovska (Faculty of Mathematics, Physics and Informatics, Comenius University in Bratislava)*

Negative data are encountered in a variety of applications, such as insurance, accounting, and finance. Typically, data envelopment analysis models are designed for non-negative data. The drawback is that only a few standard models have the property of translation invariance. We propose a general framework that permits extension of existing models designed for non-negative data to arbitrary data (i.e., it accommodates the input and output data, for which some or all components are negative). The results are demonstrated in several numerical examples.

DEA45-120 **Are European football clubs overpaying their players? A metafrontier**

analysis of Europe's top leagues

Gabriel Villa (University of Seville); Sebastián Lozano (University of Seville)*

Association football is one of the most money-making sports in the world, and as a result, football teams are ranked among the world's most valuable sports teams. In most cases, the large budget of top teams is due to the large wage bill they pay to the players. Therefore, it would be interesting to determine if the football teams are paying inflated salaries considering the sports results that they obtain each season in both national and international competitions. This study focuses on the top five European football leagues (Italian, Spanish, English, French and German). In this paper we propose a novel non-convex, non-parametric metafrontier analysis approach to determine whether the football clubs are overpaying their players considering their sport performance. Since some of the outputs considered as undesirable, a weak disposability technology is assumed. Each football team is benchmarked first within its own league and then against all five leagues. From this, apart from estimating the payroll efficiency of each team, the average efficiency of each of these five leagues can also be computed. An exhaustive analysis and discussion of the results is presented using data from the 2021/22 season.

DEA45-121 **Regulating multiple interacting externalities using DEA-based approaches**

Mette Asmild (University of Copenhagen)*; Frank Jensen (University of Copenhagen); Rasmus Nielsen (University of Copenhagen)

A lot of economic activity, like food production, generates multiple economic externalities which, in turn, necessitates regulation. The convention, in theory as well as in practice, has, however, largely been to regulate each externality separately.

In this paper we first argue that this fragmented approach to regulating multiple externalities is suboptimal, due to the fact that various externalities interact in different ways. We then provide new theoretical models for the regulation of multiple interacting externalities. Next we show how these theoretical models can, in fact, be operationalized using DEA-related methods. And finally we illustrate the (impact of the) suggested approach using empirical data on aquaculture production.

DEA45-122 **Investment Performance of Taiwan Venture Capital Management Consulting Corporations and Managing Fees**

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The National Development Fund of Republic of China (Taiwan) has entrusted 23 venture capital management consulting corporations (VCMCC) to invest 10 billion of New Taiwanese dollars in small and medium enterprises in Taiwan since 2007. In this paper, we apply data envelopment analysis to evaluate the investment performances of these

VCMCCs. Moreover, we use structural equation modeling to investigate factors determining the performance. In particular, we explore the possibility that the performance is influenced by managing fees paid by the national fund to VCMCCs. The contribution of this study is in investment efficiency literature and government policy.

DEA45-124 **DEA with bootstrap, weight restrictions and negative outputs: shortcomings of the proposal for the Brazilian Distribution Service Operators regulation**

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The Brazilian regulator defined in 2015 the methodology currently used to determine the efficient operating costs of the Brazilian energy distribution service operators (DSOs). It employs an input-oriented NDRS DEA model with weight restrictions, the DSOs' operation and maintenance costs as input, and representative measures of assets, market, and quality measures as outputs. In 2022, the regulator proposed a new model, which is still under discussion. As outputs of the model, ANEEL suggests the use of weighted market segments, network length, transformation capacity, and number of transformers. Additionally, it uses negative outputs (energy service interrupted and non-technical losses) that seek to incorporate the quality of the services provided to the benchmarking model. Data internal to the model are used to calculate the weight restrictions' upper and lower bounds by adapting the Bootstrap methodology. The final result is obtained from 21 average efficiencies that come from different percentiles of the upper and lower bounds. Our analysis of the respective methodology shows that the use of determined weights causes several problems, among them is the loss of the direct identification of peers, one of the advantages of using DEA, and the definition of unattainable targets to the DSOs. Concerning the negative outputs, it is shown that their use in the DEA model produces results contrary to what is expected by the regulator. We demonstrate that there is efficiency gain of companies that have bad quality indices in the supply of electricity, while companies with good quality indices have their scores reduced. This paper aims to evaluate and discuss ANEEL's proposal for methodological updating carried out in the Brazilian model in 2023, regarding the introduction of the Bootstrap methodology to calculate the limits of weight restrictions, the use of 21 models to define the efficiencies of DSOs, and the conflicting results obtained from the use of negative outputs.

DEA45-125 **Second stage analysis of regulatory cost-efficiency of Brazilian transmission system operators**

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In August 2022, the Brazilian Electricity Regulator Agency (ANEEL) opened the Public Hearing No. 14/2022 to gather input on the database to be used in the benchmarking study of regulatory operating costs for transmission agents. ANEEL shared a preliminary dataset of information on assets, operational costs, and environmental variables of the Transmission System Operators (TSOs). The current methodology employs a Data Envelopment Analysis (DEA) model with weight restrictions, followed by a second-stage analysis using environmental variables such as the age of assets, yearly average precipitation, and network density. This second-stage analysis includes three steps: adjusting a multiple linear regression model, calculating an adversity index, and sorting the dataset based on increasing order of the adversity index. For each TSO, the new cost efficiency score is calculated using the DEA model and those TSOs with greater adversity indices, thus creating dynamic clusters of TSOs. The methodology also requires a minimum cluster size of two-thirds of the original database size. Two main shortcomings can be pointed out: i) if only a few TSOs have greater adversity indices than the evaluated TSO, TSOs with lower adversity indices are included in the dynamic cluster; ii) although the proposed methodology yields higher final efficiency scores than the first-stage results, the statistical correlation among efficiency scores and environmental variables still remains. The present paper evaluates alternative methods to adjust efficiency scores using environmental information, such as OLS, Tobit, among others. Results provide conceptually more consistent forms of correction of the TSOs efficiency scores, keeping the regulatory premises intended by ANEEL.

DEA45-126 **Assessing the efficiency and scope economies in the Spanish Courts of Justice**

Pablo Arocena (Universidad Pública de Navarra)*

The operation of a nation's judicial system profoundly influences society, the economy, and the well-being of its citizens. Consequently, ensuring the optimal and equitable functioning of the judiciary necessitates courts of justice operating at the utmost levels of quality, efficiency, and effectiveness. In Spain, as in other European countries, the concern for improving the efficiency and organization of its courts occupies a prominent place in the public debate surrounding pending reforms in the administration of justice. This study focuses on the first level of the judicial system in Spain, which encompasses three primary types of courts. The first type is the courts of first instance solely focused on civil jurisdiction. The second type is the instruction courts, with exclusive competence in criminal jurisdiction, specifically in the investigative phase. The third type is the combined courts of first instance and instruction, which handle cases in both jurisdictions. This article employs a DEA approach to evaluate the efficiency of these three types of courts from 2005 to 2022. Additionally, it examines the presence of specialization (diversification) economies in the configuration of the courts of justice.

DEA45-127 **Cost efficiency under convex and non-convex technologies: does output aggregation matter?**

KH Dakpo (INRA)*; Frederic Ang (WUR); Kristiaan HJ Kerstens (IESEG School of Management)

Convexity is a ubiquitous assumption in economics, especially in performance benchmarking. In data envelopment analysis (DEA), the derivation of shadow prices is an interesting implication of the convexity assumption. Nevertheless, reality may diverge from this assumption for many reasons such as inputs indivisibility. In this work, we assess the impact of imposing convexity when estimating the cost function. The cost function is also estimated using the Free Disposal Hull (FDH) for comparison. In addition, the cost efficiency is computed under different output aggregation possibilities. For illustration, we consider the US agricultural data, which covered the period 1960 to 2004. Four inputs and three outputs are considered at state level. Based on the number of outputs, five output aggregation strategies are conducted. All models are estimated under variable and constant returns to scale. Our preliminary results reveal that, whatever the case, the cost inefficiency is higher when the convexity of the production technology is imposed. Aggregating the outputs yields lower cost efficiency scores. As DEA and FDH are nonparametric approaches, the difference in the efficiency scores can be due to dimensionality. Future work will address this by a sub-sampling method for deriving the sampling distribution of efficiency scores.

DEA45-131 **Sustainable refrigeration system technology selection: A novel DEA-TOPSIS hybrid model**

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Carbon and energy efficient refrigeration technologies plays a critical role in meeting the UK's net-zero policies. Yet, there is a lack of multi-criteria analysis (MCA) framework to evaluate small number of sustainable refrigeration technologies while reflecting stakeholders' subjective judgments. In this paper, we propose a novel hybrid data envelopment analysis (DEA) and TOPSIS model, namely Feasible Super-Efficiency Slack-Based Algorithm (FSESBA), to evaluate competing sustainable refrigeration technologies. We devised various scenarios to overarch the needs of different stakeholders and anticipated changes in the energy and environment markets. Our case study is based on a leading UK supermarket around their present and upcoming refrigeration technologies. We tested both conventional and new models and found that our results and scenarios are robust and suitable for informing policies and decisions. Our findings showed that although HFO-based technologies were prevalent in 2020, two CO2-based technologies lagged behind, but by 2035, this will change. By 2050, CO2-based technologies will be the most attractive due to their lower energy usage and GHG emissions. Our

research also revealed that if we maintain current refrigeration systems, we can achieve international and national targets to decrease F-Gas refrigerant usage, but net-zero targets will remain out of reach. In order to achieve this objective, the existing technologies should be substituted with GHG neutral alternatives or alternatively, supermarkets could adopt carbon capture facilities.

DEA45-133 **Evaluating the sustainability performance of higher education institutions in East and West coastal regions of the United States**

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As anchor institutions in their communities, universities and colleges play an important role in promoting sustainability. While planning and operating their campuses in a sustainable manner, they offer sustainability courses to students and engage community members in the sustainable development process. Despite such diverse dimensions of higher education (HE) sustainability, a great body of studies tends to focus on the operational aspects of campuses (e.g., stressing the reduction of carbon emissions from facilities), which dwarf the significance of other dimensions.

To address this issue, this study evaluates the sustainability performance of HE institutions in a more integrated framework. As a pilot study, we focus on HEIs in east and west coastal regions of the U.S., which include well-performing states (e.g., Massachusetts and California) in terms of sustainability research and practice. For the analysis, we take advantage of data from the Sustainability Tracking, Assessment & Rating System (STARS) of the Association for Advancement of Sustainability in Higher Education (AASHE), which is composed of over 1,100 HEIs. Out of them, we target 73 HEIs in both coastal regions to assess their diverse aspects of sustainability performance, including academic, engagement, operations, planning & administration, and innovation & leadership.

Based on their efficiency scores from ordinary data envelopment analysis (DEA), effectiveness scores from achievement relative to their commitments, and attractiveness scores from context-dependent DEA, we categorize 73 HEIs and compare the result with the AASHE's recognition level such as Reporter, Bronze, Silver, Gold, and Platinum. We found that there are significant differences in efficiency, effectiveness, and attractiveness scores across HEIs depending on their sustainability goals and contextual factors. Also, our study supports the AASHE's rating system by demonstrating relatively consistent results.

DEA45-134 **Fuzzy DEA in group decision-making**

Pegah Khoshnevis (University of Sheffield)*; Adel Hatami-Marbini (University of Huddersfield); Aliasghar Arabmaldar (Technical University of Darmstadt)

Since the emergence of Data Envelopment Analysis (DEA), this analytical decision-making tool has been widely applied to real-world applications to

estimate the relative efficiency of a set of decision-making units (DMUs) with multiple inputs and multiple outputs. The key outcome of the efficiency analysis can be reported by ranking the DMUs based on their relative efficiency. The complexity can be observed when the primary data is collected from several experts, practitioners, or decision-makers to remove bias as a result of group decision-making. The main caveat surrounding group decision-making is how the analyst aggregates individuals' judgements without compromising results. Generally, the judgments' aggregation can be conducted at two levels; before efficiency assessment (data level) and after efficiency assessment (efficiency level). Due to the fact that group decision-making is often associated with intuition and subjective judgements of individuals, linguistic terms such as Very High, High, Medium, Low and Very Low can be utilised to represent imprecision and vagueness inherent in human decision-making. In this paper, linguistic terms used in questionnaires are characterised by fuzzy numbers to model subjective judgements and perceptions of decision-makers. Further, a new fuzzy DEA-based model is proposed to first aggregate the individuals' judgements and then assess the efficiency of DMUs under uncertain environments. An application in risk assessment is presented to illustrate the efficacy and applicability of the proposed approach.

DEA45-135 **An analysis of the Malmquist-DEA productivity index applied to the segment of Electric Power Transmission in Brazil**

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The Malmquist productivity index is used in the segment of Electric Power Transmission in Brazil to adjust the Allowed Annual Revenue (AAR) by reducing the costs of operation and maintenance of tendering companies. The regulator, the National Electric Power Agency (in Portuguese, Agência Nacional de Energia Eletrica-ANEEL), intends to capture productivity gains arising from technological evolution to reduce tariffs. The methodology and parameters to be used in the calculation of productivity gains are defined quinquennially by ANEEL after public discussion. The last discussion occurred in 2021 and the productivity index was established zero in 2022. In the current regulatory model, the Data Envelopment Analysis (DEA) is adopted to calculate the Malmquist distance functions, which are obtained using data from 2013 to 2019. Productivity is segregated between: (i) technical change; and (ii) efficiency change (segregated between scale change and pure technical efficiency change). This methodology also considers the estimation of confidence intervals for technological gains, which are obtained using bootstrap. In this article, we propose to update the information used in Malmquist to verify whether there has been progress in efficiency. We also aim to make a diagnosis of the capture of efficiency gains in transmission tendering concessions in Brazil. Since these concessions have the regulatory revenue determined by the lowest bid offered in the auction, it is important to understand whether the capture

productivity gains are consistent considering the Malmquist interpretation.

DEA45-141 **Prisons service quality: a study of Data Envelopment Analysis Visualisation**

Ane Elixabete Ripoll-Zarraga (Universitat Autònoma de Barcelona)*

Adequate management, supervision and control are essential for the efficient use of public resources and investments, such as prisons, where the success of policies relies on the degree of prisoners' reintegration. The cost of public services is transferred to taxpayers. Hence, governments and regional authorities aim to minimise costs by pleading for larger prisons (Titan prisons) rather than smaller ones without losing security and safety controls (National Audit Office, 2013) or the quality of the service provided. Evidence shows a higher engagement in small-size establishments. However, it does not necessarily mean higher quality service. The prison population is rising worldwide to question the need for an upper limit of inmates assuring the effectiveness of internal policies such as humane incarceration for reintegration. The policies' effectiveness for reintegration depends on internal operations. However, citizens are influenced by their cultural background determining the opportunities to educate themselves before committing a crime. Indeed, reintegration is unlikely without prisoners' engagement understood as their involvement in educational or other activities during the imprisonment (intermediate output) influenced by their background. We apply Data Envelopment Analysis (DEA) for panel data (2018-2022) benchmarking prisons from different counties in the UK, accounting for fixed effects of the prisoners' background, including the regional characteristics of the place of birth and teenage years. We assess if the success of the internal reintegration policies depends on the prison's public resources rather than the convicted background. The expected results are that a more structured family and an economic and social background increase the likelihood of engagement during prison time, hence, their reintegration.

DEA45-144 **On the best practice production function used in economics**

Finn R Førsund (University of Oslo)*

In the efficiency literature in economics it is standard to formulate an efficient production function with a rather limited number of inputs and outputs compared with standard engineering practice. Furthermore, observations are based on actual observations of units, i.e. the engineering concept of various technologies is not used.

Michael James Farrell pioneered the measurement of efficiency in his 1957 article 21 years before Charnes, Cooper and the PhD student Rhodes (1978). Farrell introduced the term best practice production functions and formulated both using a functional form and a nonparametric one both based on estimating a piecewise linear function, both construct obeying constant returns to scale.

The point of departure of my paper is two statements by Farrell in his seminal 1957 article on efficiency measurement introducing his definitions

of efficiency measures; technical efficiency, cost efficiency and overall efficiency:

The method [proposed by Farrell] provides, as a sort of by-product, an estimate of the efficient production function … and he continues:

It will not be surprising if the method of estimation is not the best for any particular use, for it was chosen simply as providing the best measure for technical efficiency.

The economic production function is typically formulated on a much more aggregated level than engineering functions. An engineering function or a blueprint of technology starting from "nuts and bolts" may involve a lot more inputs, intermediate outputs and several relationships than the typical economic production function. Farrell saw two options; using "a theoretical function specified by engineers, and an empirical function based on the best results observed in practice." He chose the last. The engineering approach started with the seminal 1946 article by Hollis Chenery using the transport of gas in pipes had very few variables (neglecting the article by Ragnar Frisch on production of chocolate from 1935).

DEA45-145 **Identifying merger opportunities: the case of air traffic control**

Nicole Adler (The Hebrew University, Business School); Ole B Olesen (University of Southern Denmark)*; Nicola Volta (Cranfield University)

Horizontal mergers and acquisitions offer firms the means to grow. However, forecasting these actions' potential effects on the market is not a simple task. We propose a model that identifies optimal horizontal merger configurations for an industry. The model endogenizes the merger choice by maximizing the overall potential efficiency gain at the level of an industry or firm with multiple branches. We further extend the model to consider mergers that create contiguous firms, should network effects be a consideration. The optimal solution, estimated as a consequence of a change in industry structure, is decomposed into individual learning inefficiencies in addition to harmony and scale effects. The efficiency gains are estimated using a nonradial, directional distance function to facilitate this decomposition. An application of the model to the European air traffic control market suggests that the market ought to be reduced to 4 contiguous firms, replacing the 29 analyzed and the 9 proposed in the Single European Skies initiative. This is likely to lead to overall savings of around e3.3 billion annually, of which approximately 82% is directly attributable to merger synergies. Furthermore, this represents an additional annual saving of euro 1.2 billion over that achieved by the second best: the Single European Skies initiative.

DEA45-152 **Evaluating the efficiency of IoT providers using non-convex technology**

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Saen (Sultan Qaboos University)

The advent of advanced digital technologies, including the Internet of Things (IoT), cloud computing, image processing, and artificial intelligence that are under the umbrella of Industry 4.0, has significantly improved the sustainability and resilience performance of industrial organizations. Despite the increasing use of Industry 4.0 technologies in smart product platforming in industrial organizations, a critical issue remains how to assess the providers/suppliers of such technologies in highly competitive markets in order to fulfil personalized products and services. Following Lancaster's characteristics approach to consumer theory, in this study we contribute to assess digital technologies service providers in the Industry 4.0 era by focusing on theoretical and empirical arguments questioning the convexity of traditional nonparametric frontier estimation techniques. To do so, a non-parametric double frontier estimation of the hedonic price characteristics relation is developed from both the buyer's and seller's perspectives. Moreover, a separable directional distance function-based optimization model is developed for the efficiency estimation. Furthermore, a comparable estimation of the convex and nonconvex hedonic price function is proposed. We also explicitly test the impact of convexity in evaluating the efficiency of IoT service providers. In this study, we also show that the hypothesis of convexity in assessing the efficiency of IoT service providers is rejected using the Li test comparing entire densities.

DEA45-155 **Improving out-of-sample predictive power of benchmark technologies: Recent developments in the electricity distribution regulation in Finland**

Timo Kuosmanen (University of Turku)

Benchmarking is widely used in the incentive regulation of local monopolies such as electricity distribution networks. In the conditional yardstick regulation, the benchmark technology is estimated based on the historical performance of the regulated firms, to define the cost norm for the next regulation period. If the demand or the operating environment of the industry is changing rapidly, the benchmark technology estimated based on historical data may have poor out-of-sample predictive power, which can affect the incentives. In particular, nonparametric methods that impose minimal structure on the benchmark technology are known to be vulnerable to overfitting. In this study we make use of recent advances in the literature of convex regression to alleviate overfitting in order to improve out-of-sample predictive power of benchmarking. The new methodological developments include alternative regularization methods based on the Lipschitz-norm or the L0, L1, or L2-norms. Besides adapting the regularization approaches to the present context, we also consider the weight-restrictions as a more straightforward remedy to overfitting. We assess the out-of-sample predictive power of alternative approaches using panel data of the Finnish electricity distribution firms, dividing the sample to a training set and a test set. Our results demonstrate that overfitting can seriously affect out-of-sample predictive power of benchmarks, which would generally result as a too generous cost norm for the regulated firms.

Imposing weight-restrictions provides a simple but effective remedy, which can be conveniently communicated to the regulator, regulated firms, and other relevant stakeholders.

DEA45-156 **The returns to scale of US airlines according to the selected inputs and outputs**

Sepideh Kaffash (Suffolk University)*; Dariush Khezrimotlagh (Penn State University)

Selecting a reasonable returns-to-scale (RTS) is essential for estimating the production frontier of decision-making units (DMUs) such as airlines. Different selection of inputs and outputs most likely affects the production frontier of DMUs. Thus, one particular RTS may not appropriately represent the corresponding production frontier of the selected inputs and outputs. In this study, we investigate the appropriate RTS that one should consider in measuring the efficiency of U.S. airlines. A dataset including 22 years of quarterly gathered data for eight U.S. airports is used and different selections of inputs and outputs are discussed. It is concluded that a multivariate RTS should be used when number of inputs and outputs are increased.

DEA45-157 **A modified slacks-based measure of efficiency with an adjustable range in the presence of negative data**

Shuguang Lin (Fujian Jiangxia University)*; Paul Rouse (The University of Auckland)

This paper develops a measure that extends the slack-based measure to an adjustable range-denominator slacks-based measure referred to as ARD-SBM, which allows decision makers to adjust the measure by varying a parameter α for negative inputs-outputs to obtain better discriminating power. Compared with existing DEA models capable of dealing with negative data, the measure we propose can be adjusted to satisfy decision makers' preferences for gauging efficiency, and is feasible no matter whether the input-output data is negative or not. We illustrate the model using several numerical examples and an empirical analysis using the data from 30 provinces and municipalities in China. The empirical results show the theorems and proposed model are effective and useful for real-world data.

DEA45-159 **The impact of price on Data Envelopment Analysis with accounting measures**

Claire Cui (The University of Auckland)*; Julie Harrison (The University of Auckland); Fredrick Ng (The University of Auckland); Paul Rouse (The University of Auckland)

This study is motivated by the growing stream of research using accounting measures in Data Envelopment Analysis (FinDEA). There are theoretical concerns about whether accounting measures in FinDEA lead to different results from the conventional DEA, which originates from production economics. Through Monte Carlo simulations, we find that with

moderate price variation and relatively large data, accounting measures in FinDEA tend reliably proxy the physical measures in conventional DEA. However, with high price variation and relatively small sample sizes, accounting measures in FinDEA tend to diverge away from the productivity measured by conventional DEA. We discuss the implementation of the findings for future FinDEA researchers to mitigate potentially biased results.

DEA45-161 **Mapping the research landscape of DEA in higher education: a bibliometric analysis**

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Data Envelopment Analysis (DEA) is the leading non-parametric methodology for measuring the efficiency of homogeneous decision-making units (DMUs). It's seminal paper by Charnes et al. (1978) was applied in education, and the most recent survey on DEA from 1978 to 2021 (Emrouznejad et al, 2022) indicates that the third most common application of DEA is in the field of education, after energy and banking. We conduct a bibliometric analysis to outline the benefits of DEA's ability to boost performance in higher education. We use the PRISMA protocol for systematic reviews, and in the Scopus database, we searched inTitle-Abstracts-Keywords with the following keywords: "(data envelopment analysis and higher education) OR (DEA and higher education)," specifying the document type as solely "articles" and the time period from the database's first article to the date of the search. A total of 545 papers were found, but the final sample for analysis regarding the inclusion phase of the PRISMA protocol consists of 328 papers from the period 1990–August 2022 published in 190 SCOPUS-indexed journals. We use data visualization for descriptive analytics of most influential journals, papers, and most-profiled authors and software VOSviewer to construct co-authorship maps in order to depict the relationship between authors, articles, and countries; text mining and the construction of co-occurrence maps to determine the important keywords by their frequency in different time frames and methodology-related text mining to identify the relevance of different methods and models.

Based on our findings, academics' interest has grown considerably over the past five years (46% of papers have been published). The top relevant journals are Socio-Economic Planning Sciences based on the number of published articles (15) and Economics of Education Review based on citations (849). The observed articles have been written by 635 distinct individual authors. The network visualization maps for keyword co-occurrence in each decade show enlargement not only in the new keywords but also in the methods and models used. Super-efficiency DEA models appear to be the most relevant, followed by the Malmquist index. The advanced dynamic network DEA model was prominent in the last two

years, indicating the frequent application and development of new or improved methods for panel data handling. The multi-stage and multi-frontier DEA models and robustness analysis are still relevant. Those results are in line with the study of the recent DEA methodology development (Emrouznejad, 2022), where the Malmquist index, network DEA, and two-stage DEA are among the six most commonly used types of keywords. Bootstrapping, regression models, and square structural equation modeling are also relevant approaches used together with DEA models. Furthermore, we discovered that artificial intelligence is a relevant term due to the advancement of data science methods and their application in big data handling.

DEA45-162 **Proposal of mixed method in efficiency for best practices on sucroenergetic sector**

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This study aimed to present a proposal of mixed methodology with analysis and integration in efficiency studies, seeking best practices and applications in the sucroenergetic sector through the relationship between productivity and optimization of results. This mixed-method methodology was proposed in i) definition of the theoretical mathematical model, ii) definition of the efficiency model, technique, definition of ranking and respective sampling criteria, and iii) definition of variables that influence this efficiency, that will be bases for research instrument applied at case studies (quanti-quali integration). Notably, this method can develop stakeholders of sugar-energy production chain to achieve and improve their efficiency through best practices generated through production analysis. Although this methodology has been applied in other economic sectors, such as education, banking, healthcare and solid waste, with opportunities for replication in different periods and countries using variables from public or private databases.

DEA45-163 **Technical efficiency of Italian theatrical firms – a bootstrap and conditional DEA approach**

Concetta Castiglione (University of Calabria); Davide Infante (University of Calabria); Marta Zieba (Kemmy Business School, University of Limerick)*

This research applies the most recent extensions of DEA approaches, such as the double-bootstrap (DB) DEA and conditional DEA, to evaluate the effect of subsidies and other efficiency determinants on the output-oriented technical efficiency (TE) of Italian theatrical firms. To that aim, we use balance sheet data for 126 theatrical firms operating in Italy over the period 2006-2014. We account for their diverse production technologies by splitting the sample into three distinct groups of theatres (theatre production companies, permanent theatres and opera houses). The

empirical findings demonstrate that PA firms are considerably inefficient, based on the conventional and bias-corrected bootstrapped DEA models, with the average bias-corrected TE score of 0.28, implying that the investigated firms could increase their artistic output (revenues) by 72 percent. However, accounting for the efficiency determinants in conditional DEA framework, the TE scores increase considerably suggesting that Italian theatres are 82% efficient, and hence implying that subsidies and other firm characteristics influence the frontier detrimentally. Nonetheless, both DB DEA and conditional DEA provide similar findings that public spending increases efficiency of all theatres and of theatre production companies in particular, and that the effect is higher at the higher level of public funding. Moreover, younger theatrical companies, and those organised as corporations are more technically efficient firms. The conditional DEA results also imply that larger companies are more efficient indicating that theatres should better exploit their scale economies. There are also important regional differences in TE scores of theatres with those located in the South of Italy being the least efficient.

DEA45-164 **Impact of water-scarcity on groundwater use efficiency in India: a Data Envelopment Analysis**

Aryama Sarkar (Indian Institute of Technology Madras)*; Sabuj Mandal (Indian Institute of Technology Madras)

Groundwater is the source of irrigation for around 40% of global demand, and India is the world's largest consumer of Groundwater (World Bank 2012). 70% of the total agricultural production in India is based on Groundwater, and it supports almost 50% of the country's total population. A continuous decline in groundwater levels in India calls for sustainable use. Substantial and efficient usage of Groundwater for irrigation purposes can ensure mitigating the adverse impacts of climate change on agricultural production while maintaining the groundwater level for extended periods. This study aims to analyse the efficient water level for India's water-scarce and water-rich states using an Input-oriented Model under Data envelopment Analysis. We have used socio-economic, input-oriented data (ICRISAT-VDSA Meso Data) for seven major Wheat-yielding states in India from 2000-2011, along with Groundwater data for those specified states from the Central Groundwater Board of India (CGWB). The results indicate negative relation between water scarcity and Groundwater use efficiency, both under CRS and VRS methods, establishing the competitive behaviour among farmers in the face of scarcity which can be supported by the idea of Bounded Rationality among individuals. Hence, immediate policy measures along with improved governance should be considered to achieve efficient usage of Groundwater for irrigation while maintaining food security.

DEA45-165 **Performance-based carbon emission allocation for sustainable development**

Li-Hsueh Chen (Department of Applied Economics, Fo Guang University)*; Bo Hsiao (National Yunlin University of Science and Technology); Je-Liang

Liou (Center for Green Economy, Chung-Hua Institution for Economic Research)

The global warming and climate change have become common international issues. In the Paris Agreement in 2015, the parties agree to promote carbon emissions abatement policies and set net zero emissions as the common goal to achieve sustainable development. Net zero emissions are not easily accessible, because economic development requires energy consumption. Carbon emissions to reach a peak is firstly allowed, and then carbon emissions should be gradually reduced after the peak, in order to ultimately achieve net zero emissions. How to allocate the carbon emissions and the amount of carbon emissions abatement among countries will be an important issue in the pursuit of net zero emissions and considering economic development. In this study, a performance-based carbon emissions allocation model based on the data envelopment analysis is established to allocate the carbon emissions among countries for sustainable development. Goal eight in the sustainable development goal: "Decent work and economic growth" as the performance indicator. Under the assumption of maximum performance, the decentralized data envelopment analysis approach is used to allocate carbon emissions. This study will provide the direction of carbon emission planning in pursuit of sustainable development.

DEA45-166 **Assessment of countries' containment performance against COVID-19 using a benefit-of-the-doubt approach**

Roxani Karagiannis (Center of Planning and Economic Research)*; Giannis Karagiannis (University of Macedonia)

During the COVID-19 pandemic, most governments tried to contain the virus transmissions. Many stringent non-pharmaceutical interventions have been established, such as lockdowns, social distancing, cancellation or suspension of public events, international travel restrictions, and online contact tracing. These efforts affect the short-term society and economy, leading to a long-term impact with socioeconomic consequences. Evaluating the containment performance can assist in identifying good policies and optimizing the public system to contain future health shocks, such as pandemics.

Our objective is to assess the containment policies against COVID-19 which are related to the preparedness and capacity of the healthcare systems. We build composite indicators and apply a Benefit-of-the-doubt approach to evaluate the health system's performance against the pandemic. The data are collected from Our World in Data and The Oxford COVID-19 Government Response Tracker (OxCGRT) databases for 180 countries during the pandemic.

DEA45-167 **Environmental performance of coal based thermal generation plants: A two-stage DEA model with undesirable factors**

Shambhavi Mishra (Indian Institute of Technology Kanpur)*; Anoop Singh (Indian Institute of Technology Kanpur); Sufia (Indian Institute of

Technology, Kanpur)

India aims at achieving net-zero emissions by 2070, meeting 50 percent of its energy needs through renewables by 2030 and reducing cumulative emissions by one billion tonnes by 2030, for which it is continuously shifting towards higher Renewable Energy (RE) generation and making efforts towards sustainable development (MNRE, Sept. 2022). As on 31st March 2023, 41.3% (172010 MW) of India's energy generation comes from renewable sources (including large hydro) making it second highest after coal which contributes 49.3% (205235 MW). Even though the proportion of coal-based generation has decreased from 74% in 2018-19 to 50% in 2022-23 and that the overall plant load factor (PLF) has decreased from 83.9% in 2009-10 to 56.63% in 2022-23, we cannot remove coal sector completely as it provides firm base load capacity of the total generation, hence making it more relevant (CEA, 2023). The tariff determination of the generation sector both at centre and states is governed through Section 61, 62, 76, 79, 82 and 86 of the Electricity Act, 2003, Revised Tariff Policy Regulation, 2016 and CERC and SERC's (Terms and Conditions of Tariff) Regulations. The tariff framework has evolved through various stages i.e., from cost of service approach to normative rate of return approach by introducing benchmark norms for various operational parameters.

Using input-oriented data envelopment analysis (DEA), this study evaluates the performance of about 35 coal-based thermal power plants of major electric generation companies for a five-year period from 2012-13 to 2016-17. A model is devised to estimate the performance of coal-based power plants by considering the units generated as the uncontrollable desirable output and suspended particulate matter (SPM), SOx and NOx emissions as the undesirable output. Input variables include unit size, specific coal consumption, specific fuel-oil consumption, auxiliary consumption, and both forced and planned plant outages. This study can help us understand the impact of changing regulations on performance of generation plants and hence assist regulators and stakeholders in developing policies that promote more environment friendly technologies that are efficient and help in flexible operation of thermal power plants in order to integrate a greater proportion of variable renewable energy (VRE).

DEA45-168 **Cost sub-additivity and sources of potential gains from mergers between firms**

Subhash C Ray (University of Connecticut)*

There are various reasons why firms seek a merger. These range from capturing a greater market share or getting access to a source of raw materials to gaining entry into an otherwise restricted market overseas. The primary focus in this paper is on the technological incentives for merger. It is economically more efficient for a number of firms to merge if the production cost of their combined output is lower than the total cost of their respective output bundles produced separately. Such cost economies can be attributed to convexity of the technology and sub-additivity of the (ray) total cost function at the combined output level. In the short run, when

some inputs are fixed, merger also leads to aggregation of the fixed input bundles of the constituent firms. Hence, another potential source of cost economy is the 'capital expansion effect' which simultaneously increases fixed costs but lowers the variable cost. When firms from different industries merge, there are possible economies of scope due to complementarity between outputs. The potential cost economies enjoyed by such vertically integrated firms can be analyzed using a network DEA model.

DEA45-170 **Estimating shadow prices from a Data Envelopment Analysis Model: an illustrative example of banks**

Hirofumi Fukuyama (Fukuoka University)*

The purpose of this paper is to estimate the shadow prices of Japanese banks' inputs and good outputs and undesirable outputs, within a directional linear programming DEA setting. In this paper, we estimate a graph directional distance function which maximizes desirable outputs, such as lendings (loans) and securities investments, and contracts undesirable outputs, such as non-performing loans. Similar to the standard DEA, however, the DEA directional distance function suffers from multiple optimal solutions and tends to provide some zero-valued estimates. We present a way of handling this issue considering the recent developments in the DEA literature.

DEA45-171 **Performance assessment of Turkish banks using a common-weight network DEA approach with weight restrictions**

Ece Ucar Keles (Galatasaray University)*; E. Ertugrul Karasak (Galatasaray University)

Banking systems can be plausibly modelled as network structures including multiple stages. The performance evaluation of multi-stage banking systems cannot be practically represented with conventional data envelopment analysis (DEA) approach as these models neither enable to consider the multi-stage network structure nor provide assessment with common input and output weights for all banks. In this study, a common-weight network DEA approach with weight restrictions is presented to evaluate the performance of two-stage banking systems. The weight restrictions on inputs, intermediate measures and outputs are included in the proposed approach in order to incorporate the preferences of financial managers in performance assessment. Moreover, the proposed common-weight approach overcomes the impractical weight flexibility in DEA, which can lead to unrealistic weighting schemes and overstated efficiency scores. The validity of the proposed modelling scheme is illustrated through a case study assessing the performance of Turkish deposit banks, where a two-stage system including both the production and the profitability stages is considered. The results show that the proposed approach yields complete ranking of banks in stage level as well as for overall performance.

DEA45-173 **DEA as a tool for policy formulation in the public basic education: an**

application in Brazilian schools

Marco Antonio Alves de Souza Junior (University of São Paulo)*; Alexandre Pereira Salgado Júnior (University of São Paulo); Perla Calil Pongeluppe Wadhy Rebehy (University of São Paulo); Yago Silveira Marinzeck Santos (University of São Paulo); Luiz Alberto Frezzatti Negreiros (University of São Paulo); Leonardo Guimarães Medeiros (University of São Paulo)

DEA is often used in performance evaluation research in various sectors, such as healthcare, education, banking, transportation, among others. In education, the use of DEA allows for the evaluation of the efficiency of schools, departments, and educational systems, identifying successful DMU's and others that need improvement. Despite recent progress, Brazil still has an educational deficit, not only compared to developed countries, but also compared to its peers. The scenario becomes even worse when considering only the public education system (BRASIL, 2020). Given the inequality in the country, the importance of school impact evaluations that take into account not only student outcomes but also their access conditions are highlighted (ANDRADE and SOARES, 2008). In turn, Brazilian public education policies are struggling to improve instruction (BAUER; CASSETTARI; DE OLIVEIR, 2017). The cycle of public policy, a theoretical-methodological current, can be considered dynamic and constantly learning. Howlett and Ramesh (1995) divide public policy into agenda building, policy formulation, decision making, policy implementation, and policy evaluation. Based on the assumption that the decision-making process is guided by rationality, certain criteria are used to select the best solution to a given problem when there are alternatives (PARENTE, 2017). In this sense, this study aims to propose the use of DEA as a tool in Public Policies to improve the educational effect of basic public education. Two methodological pillars were used for this study: a literature review of the main research topics and the use of previous works from GREFIC (Efficiency Study Group), such as Grounded Theory.

As a proposal for the use of DEA this study suggests the application of DEA BCC by collecting data and calculating the score of each DMU, as it provides confidence intervals for efficiency scores and allows bias-corrected estimates (MARINZECK-SANTOS, 2021). The results point to DEA (CHARNES, COOPER, & RHODES, 1978; BANKER, CHARNES, & COOPER, 1984) as a useful tool for measuring educational effectiveness (DE WITTE & LÓPEZ-TORRES, 2017). Furthermore, regarding public policy, it is noticed that DEA is an important tool that operates mainly in the first two stages of the public policy cycle: diagnosing needs for the construction of an agenda and assisting the policy formulation process. Applied to the context of school evaluation, the DEA technique allows for the evaluation of a school group, identifying different levels of performance. It is possible to compare both the individual performance of each school in relation to the group (or benchmark) and to verify how much improvement is necessary, as well as the performance of specific groups segmented according to the researcher's interest. The study's result will help school

managers and policymakers to develop programs that effectively enhance educational performance.

DEA45-174 **Network DEA model for measuring the efficiency of national innovation systems**

Milica Jovanović (Faculty of Organizational Sciences, University of Belgrade)*; Gordana I Savić (Faculty of Organizational Sciences, University of Belgrade); Maja Levi-Jakšić (Faculty of Organizational Sciences, University of Belgrade); Milan Martić (Faculty of Organizational Sciences, University of Belgrade)

Policymakers struggle to find new approaches for an efficient and effective decision-making process. DEA has not been sufficiently used by regulatory bodies in this field, although it could be a useful support tool that provides additional information for decision-makers. The paper will present the results of the DEA network model applied to a set of publicly available science, technology, and innovation indicators classified into three pillars: Government, Industry, and University (the Triple Helix model). The model will be applied to a set of 34 OECD countries. Previous research of the authors illustrated the results of the two-phase DEA approach (combined Assurance Region DEA super-efficiency and Benefit-of-Doubt model).

The results showed the great potential of this approach and provided important implications for policymakers but missed capturing the synergistic effect of the collaboration between the institutional pillars. To overcome this issue, this research will apply a network model which, based on the previous application, has more potential in measuring the synergy between the Triple Helix actors. This research is an extension to the previous analysis and it will compare the results to deduce which model is more suitable for quantifying the performance of Triple Helix actors at the national level. Additionally, the results should provide implications for the improvements that would enhance the efficiency of the observed national innovation systems. The presented approach is tested at the national level but is scalable at the regional or local level (with a proper set of indicators). In this way, policymakers would have a scientific-based approach to creating mechanisms and instruments that will support the effective regulatory process.

DEA45-175 **Productivity change and the dynamics of cost competitiveness: an interstate analysis of Indian manufacturing**

Kankana Mukherjee (Babson College)*; Subhash C Ray (University of Connecticut)

Since 1980 the Indian manufacturing sector has stagnated at around 15%-16% of GDP and in the pre pandemic period it increased slightly to about 16%-17% of GDP. The National Manufacturing Policy of the Government of India (2011) aims to increase the share of manufacturing to 25% of GDP by 2025. The focus is on improving the efficiency and competitiveness of firms so that they are at the same standard as other major Asian economies. This paper analyzes the cost competitiveness of the

manufacturing sector across states in India. Following the approach of Ray and Mukherjee (2000) we create a manufacturing cost competitiveness index for a state relative to another. We also decompose this index into three components capturing differences in cost efficiency, input prices, and scale economies. In our empirical analysis, we use state-level data from the Annual Survey of Industries, India for the period 2010–2011 through 2017–2018.

DEA45-176 **Axiomatic modelling of fixed proportion technologies**

Xun Zhou (University of York)*; Timo Kuosmanen (Turku School of Economics, University of Turku)

Understanding substitution (transformation) possibilities of inputs (outputs) is critical for efficient resource allocation and firm strategy. There are several important examples of fixed proportion technologies where some inputs or outputs are non-substitutable or non-transformable. However, there is widespread confusion about the appropriate modeling of fixed proportion technologies in data envelopment analysis. We point out and rectify some misconceptions in the existing literature, and show how the fixed proportion technologies can be correctly incorporated into the axiomatic framework. A Monte Carlo study is performed to demonstrate the proposed solution.

DEA45-177 **Maximizing efficiency and mobility in education funding: a three-stage centralized data envelopment analysis**

Bo Hsiao (National Yunlin University of Science and Technology)*; Kok Fong See (Universiti Sains Malaysia)

Human resources planning is essential for resource allocation and overall performance enhancement. Allocating human resources across firms can be a complex and time-consuming task, particularly when a single entity is responsible for coordinating the activities of a group of DMUs. However, the importance of mobility across firms is always ignored. To address this issue, this paper proposes a three-stage centralized data envelopment analysis method to analyze the efficiency of human resources on the transfer-out and transfer-in of different firms, not only maximizing the efficiency of individual firms but also considering the overall adjustment. The results can provide an essential reference for overall planning of human resources policies, timely adjustment of the organization's operating conditions, and enhancement of the organization's ability to adapt to changes in the human resources environment to improve operational performance and maintain sustainable management.

DEA45-178 **Efficiency decomposition for network production technologies – application to courts of law**

Maria CA Silva (Católica Porto Business School, Porto)

This paper addresses the efficiency measurement of firms composed by multiple components, assessed at different decision levels. In particular we analyse critically existing models on Network DEA and related literature,

and we show recent developments by Peyrache and Silva on the topic regarding models for three levels of decision/production: the subunit (production division/process), the DMU (firm) and the industry (system). The extension of the proposed method to more complex cases is illustrated by the use of courts of law data. Avenues for future research are also proposed and discussed.

DEA45-179 **Is the digitalization changing banks' efficiency? The case of German banks**

Roland von Horn (University of Applied Science Bremen)*; Armin Varmaz (Hochschule Bremen)

As the economically strongest country in Europe, Germany has increasingly weakened banks. For 50 years, German banks have shown an ever-decreasing profitability and return on investment. Banks have not recovered from the banking crisis. Germany is next to Japan the epitome of the bank-based economy (Franklin Allen, & Douglas Gale, 2001). The exogenous factors of an increasing interest rate environment, regulatory requirements, the increasing shift of banking to online and mobile channels and the development of new business models in the context of digitization represent further key challenges and exert a significant influence on traditional banking functions. Therefore, this study examines the impact of digitization on the efficiency of the financial industry using Germany as an example.
In this research, we use Data Envelopment Analysis (DEA) models to show the efficiency of banks considering the effect of digitization . The study is based on the balance sheet data of the 50 largest banks for the years 2010 to 2018 and the degree of digitization of the banks using a defined digitization model. The digitization model is based on the analysis of digitization key words of the evaluated balance sheets, the analysis of the banks' digital product and service offerings and the development of the use of mobile banking compared to the banks' other distribution channels. We use the traditional efficiency models, two-stage production process to measures the efficiency and the Malmquist Index to illustrate the impact of digitalization on firm's performance. The one-step and two-step DEA models show that banks can increase efficiency by investing in digitization. The return on assets (ROA) increases for those banks that digitize compared to those that digitize less. Our study offers a novel approach to measure banks' digitalization effort and efficiency.

DEA45-181 **Regional surgical systems response to COVID-19 pandemic - Preliminary insights through longitudinal DEA analysis**

Sean Shao Wei Lam (SingHealth, Duke NUS Medical School, Singapore Management University)*, Yao Ge (SingHealth), Ashish Kumar (Duke NUS Medical School), Ginny Zhenzhi Chen (SingHealth), Ahmadreza Pourghaderi (Monash University), Ma Wai Wai Zaw (SingHealth), Pierce KH Chow (SingHealth, Duke NUS Medical School), Hiang Khoon Tan (SingHealth, Duke NUS Medical School)

Aim:

We aim to explore the how the various national, local and health system factors affect the productivity of surgical systems across 8 South and Southeast Asian comprising of 10 healthcare institutions.
Methodology:
Data used in this study include institutional level data collected from participating sites which includes hospitals and health systems (HHS) from India, Vietnam, Malaysia, Indonesia, Pakistan, Philippines, Sri Lanka and Singapore. The study timeline is from January 2020 to December 2021. National level data are obtained from the Oxford Government Response Database, World Bank and WHO. Descriptive analysis is used to understand the impact of the pandemic on surgical practice in the different countries and health systems. Surgical systems productivity is compared via surgical specific discharges and total surgery volume. We consider covariates which include the HHS characteristics, available resources, pandemic severity and government restrictions (at the local and national level). Data Envelopment Analysis (DEA) is used to combine various inputs and outputs to measure the various health system efficiency. Malmquist Index (MI) is used to evaluate the productivity changes at the national level over time. Tobit Regression is then used to identify the impact of various policy and managerial level control measures on the productivity changes of health systems with the national MI as the outcome variable.
Result:
Most countries suffered from low factor productivity in the beginning of 2020 when COVID-19 first started. Surgical system efficiencies were improved for most countries after launching a variety of COVID control policies. Total beds capacity, total number of doctors deployed for COVID response and national MI are positively and significantly correlated with productivity improvements. These indicators potentially have a positive effect on the contagion and death control of COVID-19.
Conclusion:
This study provides key insights on the factors that affect the resilience of surgical care against COVID-19 amongst the countries included in the study. Some of the more effective responses were demonstrated in the HHS of Philippines, Singapore and Malaysia. These findings can inform healthcare institutions in their effort preserve healthcare capacity for pandemic response to sustainable provide high-quality surgical services.

DEA45-182 **Benchmarks with uncertain electricity generation efficiency of variable renewable energy power plants: Photovoltaic power plants in Japan**

Yuya Nakamoto (Oita University)*; Shogo Eguchi (Fukuoka University); Hirotaka Takayabu (Kindai University)

Photovoltaic (PV) power generation systems are highly subject to the conditions of such as weather and site and thus the construction project of PV power plants must consider these uncertainty. This study analyzes the electricity generation activities of 249 utility-scale PV power plants in Japan to evaluate electricity generation efficiency. Applying the generic data envelopment analysis framework, benchmark values were identified for power generation from PV power plants. We implemented a Monte Carlo

experiment to analyze the impact of variability in solar irradiance and temperature on power generation efficiency. For our analysis, we consider three inputs—monthly solar irradiance, average monthly temperature, and installed capacity—and monthly electricity generation as the output. The results show that inter-regional gap in efficiency score between the west and north regions is 0.03 and this can be covered by a 0.1 increase in the DC/AC ratio. Additionally, variability in weather conditions affect both the efficiency of a power plant and production possibility frontier, in turn causing the benchmark values for a generic decision making unit to vary. It is crucial to increase the power generation capacity of power plants and operate them more efficiently to expanding renewable energy resource utilization.

DEA45-183 **Measurement and prediction about efficiency of institutions of higher education in India using DEA and ML algorithms**

Preeti Tyagi (SRM University, Delhi NCR Sonepat, Haryana)*

Data Envelopment Analysis (DEA) is useful and reliable technique in operations research to measure the relative efficiency of educational institutes. Machine Learning (ML) Algorithms are very useful in making predictions on efficiency of organizations. In this paper we propose some innovative models with the combinations of DEA and ML algorithms to measure the efficiency of institutions of higher Education in India. Moreover we use cluster analysis to assess performance of these institutes according to their similar virtues to get more relevant measurements. This study provides a structured way to assess the efficiency of institutions of Higher Education and provide some important insights for policy makers.

DEA45-184 **Investigating power generation efficiency of PV power plants focusing on new market entrants: A combined approach of metafrontier DEA and global Malmquist index**

Shogo Eguchi (Fukuoka University)*; Yuya Nakamoto (Oita University); Hirotaka Takayabu (Kindai University)

In Japan, renewable energy sources supplied 21.2% of the total electricity generation in 2020. The Japanese government plans on increasing this ratio to around 36 - 38% by 2030. In this situation, Photovoltaic (PV) power generation will play a significant roll and a large number of new entrants in the market is expected. On the other hand, it is widely known that electricity generation in PV systems fluctuates depending on factors such as weather conditions, seasonality, and location of the power plant. Moreover, in Japan, where the sites for building PV systems are limited, it is essential to improve and stabilize the power generation efficiency of PV systems at plant levels.

In the light of these research backgrounds, by applying a combined research framework of metafrontier Data Envelopment Analysis and global Malmquist index to the data on PV power generation in Japan at plant levels between 2017 and 2020, this study investigates the following three questions: (i) When dividing the whole of Japan into three parts (north, east

and west), is there a significant regional disparity in changes in power generation efficiency? (ii) Which of 'catch-up', 'best practice gap change' and 'technology gap change' effects would mainly affect the changes in power generation efficiency? (iii) How new market entrants would have an impact on power generation efficiency?

During the study period, results of global Malmquist index show that power generation efficiency in the east and north regions is increases by 4.9% and 1.9%, respectively, while that in the west region decreases by 1.3%. Best practice gap change effect is the main driver of the substantial efficiency improvement in the east and north regions, while catch-up effect has negative impact on power generation efficiency in all three regions. Furthermore, new market entrants contribute to increasing the power generation efficiency especially in the west region.

DEA45-186 **Measuring performance of supply chains based on network Data Envelopment Analysis and multi-regional input-output analysis in manufacturing sectors**

Hirotaka Takayabu (Kindai University)*; Shogo Eguchi (Fukuoka University); Yuya Nakamoto (Oita University)

This study developed a novel framework that combined network data envelopment analysis and multi–regional input–output database to investigate the economic and environmental productivity change in the global supply chains associated with manufacturing sectors from 2000 to 2014. Two models are developed; manufacturer model is used to evaluate performance of direct production activity of a sector in countries and supplier model is used to evaluate performance of indirect production activity of upstream suppliers of the sector. The proposed framework enables us to separately analyze the performance of supply chains into direct production activity and indirect production activity of suppliers.

The empirical results show that the environmental productivity of direct production activity of manufacturing sectors was improved by 12.9 percent, while the environmental productivity of the upstream suppliers was improved by only 4.7 percent during 2000–2014 on average. Different patterns of economic and environmental productivity growth were observed between the direct production activity and upstream suppliers in all sectors. The finding suggests that the performance of an entire supply chain should be separately analyzed to consider industry-specific policies. The proposed framework is used to identify countries succeed (failed) to improve economic and environmental performance. Based on the results, this study discusses policies regarding production and supply chain management toward CO2 mitigation.

DEA45-187 **Development of intuitionistic fuzzy revenue efficiency models in DEA: an application to the Indian public sector banks**

Anjali Sonkariya (Indian Institute of Technology Roorkee)*; Shiv Prasad Yadav (Indian Institute of Technology Roorkee)

Data envelopment analysis (DEA) is a non-parametric linear programming (LP) based technique to measure the relative efficiencies of homogeneous decision-making units (DMUs). The classical models of DEA rely on crisp input-output data, which may not always be available in real-life scenarios. Due to the existence of uncertainty and vagueness in real-life data, the concept of intuitionistic fuzzy (IF) has been introduced to handle imprecise data. In this study, the relative efficiencies of DMUs with uncertain data will be determined. Due to this reason, the conventional revenue efficiency models of DEA are extended to the IF environment. Also, the lower and upper revenue efficiency models are developed using α-cut and β-cut approaches. The input-output data and output prices are considered intuitionistic fuzzy numbers (IFNs); particularly, triangular intuitionistic fuzzy numbers (TIFNs). A numerical example is presented to illustrate the practicality of the proposed intuitionistic fuzzy revenue efficiency models (IFREMs). Furthermore, an application to the public sector banks of India is provided. The data of Indian public sector banks is collected from the official website of the Reserve Bank of India (RBI), Govt. of India, India.

DEA45-192 **A stochastic ranking procedure in data envelopment analysis under uncertainty**

Mohammadreza Ghasemi (Hakim Sabzevari University); Joshua Ignatius (Aston Business School)*

Conventional data envelopment analysis (DEA) requires deterministic multiple inputs and outputs for measuring the relative efficiency of a set of decision-making units (DMUs). However, deterministic DEA models are not able to discriminate between efficient DMUs. By applying a standard normal transformation, a stochastic DEA (SDEA) model can be considered as a natural approach for such applications. In this case, the efficiency distribution is more discriminative and informative than the single-valued efficiency. Performance evaluation of DMUs in SDEA naturally calls for ranking procedures that can account for stochastic fluctuations of the input-output data, and hence the efficiency value. Existing methods do not incorporate all the information in the efficiency value distributions for ranking DMUs. To deal with the issue, this paper develops a ranking method for performance evaluation in SDEA by providing a notion for stochastic dominance. The validity of the proposed model has been tested using a numerical example from the literature and we found that our proposed model outperformed the existing methods.

DEA45-194 **Estimating nonparametric conditional frontiers and efficiencies: a new approach**

Camilla Mastromarco (University of Calabria)*; Leopold Simar (Université Catholique de Louvain La Neuve); Ingrid Van Keilegom (KULeuven, Leuven)

In production theory, conditional frontiers and conditional efficiency measures are a flexible and appealing approach to consider the role of environmental variables on the production process. Direct approaches estimate non-parametrically conditional distribution functions requiring

smoothing techniques and the use of selected band-widths. The statistical literature produces way to derive bandwidths of optimal order, by using e.g. least-squares-cross-validation techniques. However, it has been shown that the resulting order may not be optimal when estimating the boundary of the distribution function. As a consequence the direct approaches may suffer from some statistical instability. In this paper we suggest a full nonparametric approach which avoids the problem of estimating these bandwidths, by eliminating in a first step the influence of the environmental factors on the inputs and the outputs. By doing this we produce "pure" inputs and outputs which allow to estimate a "pure" measure of efficiency, more reliable for ranking the firms, since the influence of the external factors have been eliminated. This can be viewed as an extension of the use of location-scale models (implying some semi-parametric structure) to full nonparametric models, based on nonseparable, nonparametric models. We are also able to recover the frontier and efficiencies in original units. We describe the method, its statistical properties and we show in some Monte-Carlo simulations, how our new method dominates the traditional direct approach.

DEA45-195 **Tracking the performance of European skills systems: A re-estimation of the European Skills Index**

Ilias Livanos (European Centre for the Development of Vocational Training); Panagiotis Ravanos (University of Macedonia)*

Skills systems are of outmost importance to stimulate the twin digital and green transitions in Europe. A well-functioning skills system ensures that the skills of the population are developed, activated through employment, and adequately matched to labour market needs. In this paper, we evaluate the performance of national skills systems in 31 European countries over time. To do so, we use data from the European Centre for the Development of Vocational Training (Cedefop's) European Skills Index (ESI), a composite indicator developed for measuring the performance of European skills systems. In particular, we recalculate ESI using a flexible Benefit-of-Doubt weighting method and we examine the changes in ESI over the period from 2016 to 2022 by means of the Malmquist productivity index. The results provide interesting insights on the determinants of overall performance change in the countries' skill systems over time and highlight those countries which could serve as examples to follow when improving poor-functioning systems.

DEA45-196 **Evaluating the efficiency of civil county courts in Greece**

Giannis Karagiannis (University of Macedonia); Panagiotis Ravanos (University of Macedonia)*

In this paper, we assess the performance of a sample of Greek civil county courts, by means of technical and scale efficiency and a comparison between them based on average efficiency, aggregate efficiency, and the performance of the average production unit. The sample consists of 138 courts operating across the entire geographical area of the country for the

year 2018. Our models are output-oriented, with incoming cases, judges, and judicial stuff used as the inputs, and feature two alternative output specifications. In the first specification, the aggregate number of resolved cases is used as a single output, while in the second, three outputs are used, which reflect resolved cases by different modes of disposition. We provide a comparative analysis of the results of these two models to investigate the effect of accounting for different case disposition modes on the courts' efficiency scores, ranking, and peers.

DEA45-197 **Inference in dynamic nonparametric models of production for general technologies**

Leopold Simar (Université Catholique de Louvain)*; Paul W Wilson (Clemson University)

Nonparametric envelopment estimators are often used to estimate the attainable set and its efficient boundary, and to assess efficiency and changes in productivity. Kneip et al. (2015, Econometric Theory; 2016, J. of Business and Economic Statistics) provide asymptotic theory enabling inference about expected efficiency and testing constant versus variable returns to scale using these estimators. In addition, and Kneip et al. (2021, Econometric Theory) and Simar and Wilson (2019, European J. of Operational Research) provide asymptotic results that can be used to make inference about expected changes in productivity measured by Malmquist indices and about the sources of productivity changes. All of these results require convexity of the attainable set, but in a number of situations this assumption is questionable.

Kneip et al. (2016) also provide a test of convexity versus non-convexity of a production set, and convexity is rejected in several recent empirical studies. The results mentioned above have been extended by Kneip et al. (2022) to allow for possibly nonconvex technologies. Kneip et al. (2022) establish properties of a nonparametric envelopment estimator of distance to the boundary of the cone spanned by a possibly non-convex attainable set.

These new results are then extended to make inference about Malmquist indices and their various components in non-convex settings. Simar and Wilson (2019, European J. of Operational Research; 2023, J. Productivity Analysis) illustrate the usefulness of these results in various examples. We propose in our talk an overview of these techniques with an illustration to productivity changes in OECD countries.

DEA45-199 **Comparing the efficiencies of courts in Sweden and Denmark** Mette

Mette Asmild (University of Copenhagen)*; Jonas Månsson (Blekinge Institute of Technology)

The legal systems in many European countries are under pressure, resulting in delayed decisions, which is costly from a societal point of view. As part of the EU COST project "Efficient Justice for All: Improving Court Efficiency through EU Benchmarking" we in this paper estimate the

efficiencies of the first instance courts in both Sweden and Denmark, using Data Envelopment Analysis methods. Furthermore, we compare the efficiencies of the courts in the two countries, in order to identify similarities and differences in the two systems, that are part of the same legal family.

DEA45-200 **Performance measurement to evaluate policy reforms and systems management with Malmquist indices**

Argyro Fourlopoulou (Department of Health Policy, School of Public Health, University of West Attica; Psychiatric Hospital of Attica)*; Nikos Maniadakis (UWA)

Background: Greece has gone through an economic crisis during 2010 and 2020. During this period the health care system went through drastic reforms, which were imposed by the three Economic Adjustment Programs, agreed between the Greek Government, IMF, ECB and EC. These reforms consist the most significant intervention ever to be implemented to a health care system in peaceful times. During this period, Malmquist indices were used to measure and monitor performance of the Greek health care system and hence evaluate policy effectiveness. This study is to show how the objectives of those reforms were evaluated. Methodology: The study employs the Input and the Cost Malmquist Index, and the Group Input and the Group Cost Malmquist Index. The sample consists of 109 Greek public hospitals in the period 2009 to 2021, covering the whole period of the rescue and reform programs. Various models are used.

Results: The study measures Greek NHS hospital performance and shows how Malmquist indices and DEA can be utilized to guide and monitor health policy and health system management and performance improvements.

DEA45-202 **Made in China 2025: identifying spires of excellent manufacturers for Venture Capital Investments in Zhejiang Province**

Arie Y Lewin (Duke University)*; Ziyan Tan (Zhejiang University)

Made in China 2025 national initiative was unveiled in 2013. The stated goal was to upgrade China manufacturing to Global Manufacturing Tier 1. As often is the case national initiatives trigger competition between provinces to undertake their own initiatives to demonstrate their own interpretation of implementing the national initiative. Zhejiang province funded a project at Zhejiang University Business School whose objective was to identify so called “spire of excellence” manufacturers out a total of 28K firms organized in 37 industrial sectors.

This paper reports on a four-stage project. Stage 1 applied Solow 1978 model to identify industry sectors with highest growth due to innovation. In the second stage a DEA application identified the best managed firms within sectors. The analysis also identified provincial cities that stand out for their innovation environment. In stage 3 the paper introduces 21

Venture Capitalists who claimed that they seek to find “seeds” - investment candidates - that they can grow to “giant trees”. In stage 4 the most promising hidden champion companies were identified. Those were the best managed firms (DEA efficiency scores >.8 and above), within industry sectors whose growth reflected the top quartile for industry growth due to innovation. The paper describes the reaction of 21 venture capitalists when presented with “spires of excellence” investment candidates for aggregating the specific industrial sector.

DEA45-203 **Assessing Europe’s circular economy: a stochastic Data Envelopment Analysis approach**

Behrouz Arabi (Heriot-Watt University)*; Mehdi Toloo (Surrey Business School); Ruini Qu (Heriot-Watt University); Bing Xu (Heriot-Watt University)

In response to the urgent need to address global warming, major economies have adopted various strategies, including resource efficiency, production efficiency, energy efficiency, and environmental efficiency. Among these approaches, the reusing and recycling of materials have gained significant attention in both theory and practice. Although the concept of the circular economy was coined four decades ago, its prominence has grown in recent years, particularly in the regulations and practices of European countries. Given circular economy's potential to reduce pollution, emissions, and total material use, European countries are increasingly focused on understanding their actual circular economy performance. This understanding serves two important purposes: firstly, to identify areas where they fall short in terms of circularity, and secondly, to identify the most effective pathways towards enhancing the circularity levels. By addressing the issue of indeterministic variable in circularity performance management, in this paper, we propose a novel approach based on the Stochastic Network Data Envelopment Analysis (SNDEA) methodology. Our models provide realistic benchmarks and offer a range of pathways to guide these countries towards achieving a more realistic circular economy. The findings of this study contribute to the broader efforts of mitigating global warming and promoting sustainable practices in the European context.

DEA45-204 **Research, co-operation, and innovation: unveiling the triple faces of efficiency within Italian universities through two-stage Data Envelopment Analysis**

Angela Rella (Università LUM Giuseppe Degennaro)*; Filippo Vitolla (Università LUM Giuseppe Degennaro)

Research, cooperation, and innovation are the three crucial faces of university efficiency. These faces are fundamental indicators to evaluate the trend of the university's performance. In particular, these aspects allow us to highlight how the university's activities take part in the measurement of performance and which are the factors that determine the efficiency level. This study considers a sample of 62 Italian state-universities in 2021. From this perspective, the aim of the study is two-fold, in fact, firstly, it

seeks to evaluate the efficiency level of Italian universities, in terms of research, cooperation, and innovation through a Data Envelopment Analysis. Secondly, the present study aims to investigate the determinants of the efficiency level of Italian universities through a Truncated regression. The study has some implications for policymakers and public managers. These implications concern the allocation of research funds, the improvement of the networking situation, and the implementation of innovative tools through initiatives and projects, in order to ensure a proper growth environment in the university performance.

DEA45-210 **Future systems and network regulation**

Teresa Romano (Head of Strategic Costs Networks, OFGEM)*

DEA45-211 **On-going cost assessment developments in the UK water and sewerage sectors**

Daniel Mitchell/Asen Velyov (Head of Base Expenditure at PR24)*

DEA45-212 **Cost frontier benchmarking in energy network regulation: a Dutch perspective**

Marcel Vermeulen (Autoriteit Consument & Markt ACM)*

DEA45-213 **Cost frontier benchmarking in energy network regulation: A Norwegian perspective**

Tore Langset (Director, The Norwegian Energy Regulatory Authority)*

DEA45-214 **Common or individual capital costs in regulatory benchmarking: theory and empirics**

Per Agrell (Faculty Dean, Louvain School of Management; Senior Associate Sumicsid Group)*

DEA45-221 **Going beyond hospital-level analysis: leveraging diagnosis-related group (DRG) level data for more accurate hospital efficiency comparisons**

Jiaye Shen (Brandeis University)*

Hospital efficiency comparisons are valuable in identifying areas for improvement and best practices. However, comparing hospitals at the hospital level alone may not account for differences in patient populations and medical conditions. This paper presents the benefits of using Diagnosis-Related Group (DRG) level analysis to compare hospital efficiency.

DRGs group together patients with similar diagnoses, procedures, and clinical characteristics, which allows for a more accurate comparison of hospitals with similar patient populations and medical conditions. Notable innovations in DRGs include the development of All Patients Refined DRGs schemata whereby an individual DRG category is sub-divided by classifying patients into one of four severity categories.

In the United States, the term “safety net” hospital is applied to hospitals

that are typically located in poorer communities with patient populations that include substantial proportions of poor, uninsured, and racial/ethnic minorities. This paper will demonstrate how DRG-level analysis can be used to compare safety-net hospitals (SNHs) to non-safety-net hospitals (non-SNHs). The adoption of DRG level analysis can increase the total sample size and enhance statistical power.

DRG-level efficiency scores will be determined using a production model for DEA with the inputs of the total length of stay and total ancillary cost within each hospital to treat all cases of one specific DRG, and the four outputs being the number of discharges within each of four severity levels of the DRG in each hospital. Focusing on good quality outcomes, the analysis will include cases discharged at home, excluding those discharged to other facilities or who died in the hospital for comparability. The use of input-oriented various return-to-scale models will allow for best practices to vary with the size of the practice. The analysis will control for hospital-level variables such as bed size and DRG-level variables such as the case number of each DRG at each hospital. The paper will show the benefits of using DRG-level analysis to compare hospital efficiency, particularly in comparing SNHs to non-SNHs.

DEA45-222 **Evaluating surgeon performance and learning from outliers**

Richard G Bachu (Harvard Medical School); Kyle A Perry (The Ohio State University); Jon A Chilingerian (Brandeis University); Mitchell Glavin (Stonehill College)*

As an illustration of the utility of using DEA to evaluate efficiency in delivery of clinical care services, this paper will present the findings from two studies that examined the practice patterns within one academic medical center of surgeons performing operations One study focused on the surgical treatment of acute appendicitis while the other study focused on paraesophageal hernia repair in one academic medical center.

The production model for the surgeries evaluated using DEA has two clinical inputs: 1) total length of stay (days in hospital) for all patients, and 2) the total ancillary costs (direct costs for things such as drugs or tests, less per diem cost). In terms of outputs, the production model includes as outputs for the first study: 1) successful discharges for acute appendicitis with generalized peritonitis, and 2) successful discharges for acute appendicitis with localized perotinitis. In terms of outputs, the production model includes as outputs for the second study: 1) successful discharges for elective paraespohageal hernia repairs, and 2) successful discharges for urgent/emergent paraespohageal hernia repairs. This paper will demonstrate how DEA can be used to evaluate scale, technical, and overall efficiency of surgeons' performance.

DEA45-223 **Unlocking physician efficiency at the DRG Level: a Malmquist Productivity Index Approach with insights into the impact of hospital volume on physician efficiency**

Jiaye Shen (Brandeis University)*

This paper will demonstrate measurement of physician efficiency at the DRG level using the Malmquist productivity index (MPI) approach and investigate how a hospital's increase in volume of certain DRGs affects physician efficiency. The Malmquist approach is a beneficial way to calculate physician efficiency as it allows consideration of not only the inputs and outputs used in production but also the technological change that occurs over time.

To measure physician efficiency, the DRG-level efficiency scores will be obtained using the inputs of the total length of stay and total ancillary cost of one physician in one hospital to treat all cases of one specified All Patients Refined DRG, and the four outputs being the number of discharges within each severity level of the specified DRG for each physician. Only cases discharged home will be examined, excluding those discharged to other facilities or who died in the hospital for comparability.

Use of input-oriented various return-to-scale models will allow for best practices to vary with the size of the practice. The MPI approach then provide a means to decompose the efficiency scores into two components: technical efficiency change and technological change. Thus, the sources of efficiency change over time can be analyzed and help to identify the factors that contribute to changes in physician efficiency.

Additionally, the paper will include investigation of how an increase in the volume of certain DRGs within a hospital affects physician efficiency. The research hypothesis is that the increase in volume of certain DRGs will have a positive impact on physician efficiency due to learning-by-doing and economies of scale. This hypothesis will be tested via a panel dataset of physicians from a large hospital in the United States.

The findings of this study have important policy implications for hospital administrators and policymakers. By identifying the sources of efficiency change and the impact of volume increase on physician efficiency, hospital administrators can develop strategies to improve hospital efficiency and quality of care. Policymakers can also use the findings to design policies that promote efficiency and quality of care in the healthcare sector.

DEA45-224 **Use of Data Envelopment Analysis for the measurement of absorptive capacity and technological change in health care**

Jon Chilingerian (Brandeis University); Mitchell Glavin (Stonehill College)*

Studies of knowledge translation reveal wide variations in the ability of organizations to translate scientific research into new practices . Why are some organizations more efficient in discovering, assimilating, and exploiting new practices? The answer may lie in the construct of absorptive capacity (ACAP), an organization’s ability to: (1) identify the value of outside knowledge; (2) assimilate outside knowledge; and (3) learn how to use that knowledge to create outputs.

In this paper, we estimate the absorptive capacity (ACAP) of coronary artery by-pass graft (CABG) programs operating in Pennsylvania between 1994 and 2004[1][1]. We introduce a new way to study knowledge transfer by way of the Malmquist Productivity Index with frontier methodology. The Malmquist index measures productivity by approximately measuring a program's progress or slippages. The objective is to demonstrate how ACAP can be explained by productivity change, technical progress, and relative efficiency of CABG surgeries. By decomposing productivity change in this way, we can directly assess the learning processes of clinical programs in health care. In Pennsylvania, the average hospital's clinical productivity for CABG surgeries grew by more than 30%.

Cardiac surgery is an excellent example of the problems that arise from the assessment, review, and utilization of scientific research in medicine. Over the last 20 years, three dynamic trends have been noted: (1) the substitution of CABGs with percutaneous coronary interventions (PCI) and minimally invasive CABGS; (2) the dramatic increases in the number of cardiac surgery programs; and (3) the development of "fast track" cardiac care that reduce the utilization of services. This study focuses on the third trend, the adoption of fast track cardiac surgeries.

A revolutionary change in cardiac surgery occurred in 1994, when "fast track cardiac surgery" was coined in a paper by Engelman et al., in the Annals of Thoracic Surgery in 1994. Fast tracking described a new care process for cardiac surgery patients that changed the mixture of cardiac anesthetic from heavy narcotic to inhalation agents, thus allowing patients to awaken earlier with extubation < 6 hours versus 12-22 hours. A randomized trial by Cheng et al (1996) found that cardiac teams "able" to adopt "fast tracking" saw 4 advantages: (1) fewer respiratory complications and acquired infections, (2) reduced intensive care costs (by 25%); (3) shorter lengths-of-stay and elective cancellations; and (4) reduced supply cost. In short, fast tracking technology found a quicker route to health for cardiac surgery patients.Herein lies the gap between what is published in the medical literature and what is done in medical practice. In order to become more efficient, cardiac surgery teams develop patterns of behavior and practice routines. Although adopting new clinical technologies can advance the science of medicine, "fast tracking" requires changing behaviors and routines. When traditional patterns of behavior must be disrupted, some cardiac teams will efficiently exploit the new knowledge, while others will experience losses in efficiency.

This paper will present a new way to study knowledge transfer by way of the Malmquist Productivity Index. The Malmquist index measures productivity by approximately measuring a program's progress or slippages. To measure changes in clinical productivity and to accommodate the complexity of hospital technology as a multiple input-output problem, we employ an approach first introduced by Fare et al, (1994). To assess ACAP a DEA approach will be used to analyze the productivity observed from 1994 to 2004 and perform tests of significance.

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