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Pushing the DEA research envelope

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ABSTRACT

This brief article first investigates key dimensions underlying the *progress* realized by data envelopment analysis (DEA) methodologies. The resulting perspective is then used to encourage reflection on future paths for the field. Borrowing from the social sciences literature, we distinguish between *problematization* and *gap identification* in suggesting strategies to push the DEA research envelope. Emerging evidence of a declining number of influential methodological (theory)-based publications, and a flattening diffusion of applications imply an unfolding maturity of the field. Such findings suggest that focusing on known limitations of DEA, and/or of its applications, while searching for synergistic partnerships with other methodologies, can create new and fertile grounds for research. Possible future directions might thus include 'DEA in practice', 'opening the black-box of production,' 'rationalizing inefficiency,' and 'the productivity dilemma.' What we are therefore proposing is a strengthening of the methodology's contribution to fields of endeavor both including, and beyond, those considered in the past.

1. Introduction

Recent bibliographic and bibliometric studies suggest that data envelopment analysis (DEA) began to display signs of a maturing theory by the mid-1990s (see [1,2]). While not using the term "maturity," Sun [3] alludes to the same phenomenon by interpreting the post-2004 decline in number of DEA publications as a case of few remaining significant research issues open to investigation. 'Number of publications' suggests that the first peak was reached in the period 1995–1996, followed by a more recent one in 2004 (see Fig. 1 in both [1] and [3]). If DEA has truly entered a phase of maturity, the inherent suggestion is one of a lower probability of further major developments in the methodology and, thus, a smaller number of influential publications. The current study probes evidence on the maturing of DEA, and subsequently suggests new ways researchers might push the field's research envelope.

In this regard, we briefly explore the prevalence of influential DEA publications with a view towards profiling *progress* of the methodology, as well as its diffusion. Section 2 outlines the study's conceptual framework, while Section 3 presents the method and findings. Section 4 concludes the paper with a discussion designed to encourage reflection, and identify new and meaningful directions for future DEA research. In the words of Ormerod ([4], p. 602) on MS/OR publication habits, we aim to "…encourage researchers to consider the nature of their research and how it might contribute to the knowledge base of the subject."

2. Conceptual framework

It is commonly recognized that a theory reaches the mature phase of its development when key underlying assumptions are no longer challenged. Yet, in most cases, including DEA, a typical approach in seeking a new research problem is to identify a small gap in existing theory, or simply to apply accepted theory without modification, but in a novel manner, and/or in a new setting. We refer to this process as *gap identification.* This is akin to expanding the research envelope in small increments. Such cautious scientific inquiry, however, may sometimes perpetuate what might be a questionable foundation theory, or simply undermine further breakthroughs if, for example, the increments are not well thought through. In the current discussion, we make no claim that DEA suffers from such conditions.

A more dramatic and difficult form of investigation is to successfully challenge a foundation theory, or assumptions thereof, or take an undeveloped original idea and present it in a format that can be easily generalized and applied by others. We refer to such a scenario as *problematization,* which generally lays the foundation for more influential work (see [5]). A key objective of the current study is to identify the prevalence of DEA publications that employ

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problematization, and thus attempt to push the field's research envelope in what we define as *substantial ways*.

Our framework for the current study initially borrows from an ongoing discussion within the social sciences. According to Alvesson and Sandberg [6], the dominant view that a theory becomes influential when it receives strong empirical support is conditional upon that theory challenging selected underlying assumptions in existing theories on the subject matter. For example, when discussing problematization, Locke and Golden-Biddle [5] mention three approaches; namely, identifying *incompleteness, inadequacy*, and *incommensurability*. They describe 'incompleteness' as the case where the extant literature is unfinished, while 'inadequacy' arises when such literature does not consider a variety of perspectives on the phenomena being investigated. 'Incommensurability,' on the other hand, implies the existence of misguided extant literature, but is a situation that can be corrected.

At the same time, it is increasingly recognized that established ways of generating research questions rarely involve deliberate or systematic attempts to challenge the underlying assumptions of existing theory [5,6]. An example of this observation can be drawn from research in management where success in producing interesting and relevant theories has lagged behind what would otherwise be expected based on the rigor of research designs found in the extant literature [7]. We thus suggest that DEA researchers reflect on these observations from the social sciences literature when evaluating the *progress* of their field's methodologies.

Further to the above, we acknowledge that some research publications might be difficult to classify into either gap identification or problematization as the lines separating the two may be blurred. In practice, we would expect the two categories to co-exist, with problematization constituting the minority of cases. Sun [3] produces supporting evidence of this condition in his Fig. 1, where plotting the number of theoretical vs. application papers (1996–2006) shows a gradually widening gap, in particular, year 2000 onwards. More significant for the current discussion, this figure indicates a sharp decline in the number of theoretical papers as of 2004, thus suggesting a maturing of the methodology.

Finally, while not directly relevant to the remainder of this paper, we also wish to acknowledge a third category of publications that fits neither problematization, nor gap identification. These are *applications that repeat existing literature*. For example, the technical efficiency analysis of a bank branch network that shows no innovation on research design will, by definition, not push the research envelope. Nevertheless, such a publication may be of interest to practitioners.

3. Method and findings

3.1. Method

As noted in the previous section, we are interested in whether or not selected DEA publications can best be described or categorized as those utilizing *problematization*. We recognize that publications so borne are more likely to be methodology-driven.

Unfortunately, there is no practical way to clearly identify whether a given methodology-based publication derives from problematization or gap identification. We thus employ Cook and Seiford's [8] authoritative summary of methodological developments to help determine if problematization motivates studies of interest to the current effort. We achieve this by identifying original work that *challenges underlying assumptions, or offers a solution to a methodological problem*. For instance, Cook and Seiford suggest that Bessent et al. [9] were the first to introduce constrained facet analysis. We thus accept this publication as an example of problematization. Others that would have improved on Bessent et al. are then treated as publications emerging from gap identification. Similarly, in situations where a small flaw/oversight in an original publication is corrected by a subsequent publication, the latter is also treated as an example of gap identification (e.g., see [10], followed by the correction provided by [11]).

In order to temper the above somewhat subjective approach that utilizes Cook and Seiford [8], we rely on the Web of Science (http://thomsonreuters.com/products_services/scientific/Web_of_Science) to identify citation numbers corresponding to DEA publications short-listed from Cook and Seiford as products of problematization. This more quantitative approach provides insight as to how influential the DEA community, as primary judge, perceives given publications.

Perusing the Web of Science (or Scopus, http://www.scopus.com/scopus/home.url), it becomes obvious that methodology-based publications dominate the field when influence is measured by the number of citations. To provide a clear example of the greater influence of methodology vs. application papers, we refer to the original methodology-based effort by Charnes et al. [12] with 1735 citations, and the first application of DEA to banking by Sherman and Gold [13] with 86 citations (as reported on Web of Science).

We use the *change in numbers of methodology publications associated with problematization* as an indicator of the maturity of DEA. We also accept such numbers as indicators of influential publication output. At the same time, methodology-based publications emanating from gap identification, and application-type publications not addressed by the Cook and Seiford [8] framework, could also be influential, but in a non-theoretical sense. An example of the former is Banker [14], while Charnes et al. [15] is an example of the latter.

3.2. Key findings

Appendix 1 lists the 30 methodology publications mentioned in Cook and Seiford [8] that have been identified in the current study as products of problematization, and their corresponding citation counts. Table 1 organizes the information in Appendix 1 on the basis of six half-decades beginning in 1978. Based on the number of influential methodology publications, the second, third and fourth half-decades (years 1983–1997) emerge as the most prolific, viz., in pushing the DEA envelope, which are followed by a decline.

Judged on the annual average number of citations per half-decade of 20.4, those methodology publications between 1993 and 1997 appear to have been the most influential, where the average is heavily weighted by Färe et al's. [16] monograph (see reference #22 in Appendix 1). The absence of influential methodology publications post-2002 is particularly noticeable. Viewing the number of publication column in Table 1 without the half-decade breakdown, we can envisage an *incubation phase* (1978–1983), a *growth phase* (1984–1995), and a *maturation phase* (post-1996) for the field.

In Appendix 2, we take snapshots of DEA's diffusion at five-year intervals using Scopus subject areas. Overall, the subject areas of *Decision Sciences* and *Social Sciences* occupy the first and second positions, with *Business, Management and Accounting* third. Initially, the growing number of subject areas is an indicator of the successful diffusion of DEA. At the same time, the decreasing growth rate over the study period (see Fig. 1), and the stable number of subject areas in the last five years, could be interpreted as a maturing of the methodology in terms of its applications, which supports the evidence of Table 1. That is to say, the implied maturation in influential methodology publications post-1996 observed in Table 1 can also be seen in the flattening diffusion of DEA as charted in Fig. 1.

Table 1
Summary of influential DEA methodology publications that derive of problematization found in Cook and Seiford [8].

Year	Number of publications (*and total for the half-decade*)	Number of citations per year (*and annual average for the half-decade*)	Year	Number of publications (*and total for the half-decade*)	Number of citations per year (*and annual average for the half-decade*)	Year	Number of publications (*and total for the half-decade*)	Number of citations per year (*and annual average for the half-decade*)
1978	2	66	1988	2	8	1998	1	3
1979	–	–	1989	–	–	1999	1	1
1980	–	–	1990	2	10	2000	1	3
1981	–	–	1991	–	–	2001	2	8
1982	– (*2*)	– (*13.2*)	1992	3 (*7*)	5 (*4.6*)	2002	– (*5*)	– (*3*)
1983	–	–	1993	2	18	2003	–	–
1984	2	51	1994	1	64	2004	–	–
1985	2	16	1995	2	6	2005	–	–
1986	3	18	1996	1	14	2006	–	–
1987	1 (*8*)	n.a. (*17*)	1997	– (*6*)	– (*20.4*)	2007	– (*0*)	– (*0*)

Note: n.a.= not available.

4. Discussion

4.1. Summary

One of the more important indicators of the impact of a methodology/theory is the extent to which it is adopted and adapted by others. In this respect, the original seminal paper by Charnes et al. [12] and the influential paper by Banker et al. [17] have enjoyed great popularity amongst researchers who have applied DEA in a wide variety of settings. Furthermore, some researchers have produced offshoots/extensions of the theory found in these two papers, publishing on such concepts as the additive model, free disposal hull, the slacks-based measure of efficiency, models with restricted multipliers, and a hybrid measure of efficiency [18]. Yet others have looked outside the immediate DEA methodology to borrow concepts from related schools of thought, such as stochastic DEA, which utilizes chance-constrained programming (see, for example [19–21]).

Readers interested in the *theoretical* underpinnings of DEA are referred to Seiford [22], and Førsund and Sarafoglu [23]. More recently, Glover and Sueyoshi ([24], see Fig. 1 on p. 4) offer a broader viewpoint in charting the *statistical evolution* of DEA that stretches as far back as the 18th Century. Also of interest, and used earlier in the current study, is the work of Cook and Seiford [8], who outlined the main methodological developments of DEA for the 30-year period 1978–2007.

In the current effort, we have presented evidence on the *diffusion* of DEA by following participating disciplines over the last 30 years. The rapidity of this process in the first 25 years of the study period, albeit at a declining growth rate, appears to have stalled in the last five years. We offer this finding as further indirect evidence of a methodology that began maturing in the mid-1990s, and which has since been accompanied by a maturing of its applications.

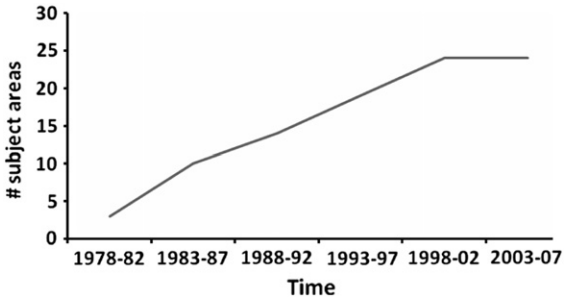

Fig. 1. Diffusion of DEA per Scopus database.

The diffusion of DEA into various subject areas quickly becomes apparent from a search of most appropriate electronic databases. Gattoufi et al. [2], for example, note that, the majority of journals in which DEA-related papers appear, are *not* of an operations research nature; rather, they encompass a wide variety of disciplines and professions such as health care, international trade, and regional planning.

Here, we also note anecdotal evidence that suggests an increasing reluctance on the part of journal editors to accept papers involving simple applications of well-known DEA models. Given the limited 'real estate' available in journal pages, this saturation is not surprising. It could, however, send a signal to authors contemplating yet another DEA application paper that publication is more likely when the submission is seen as otherwise *innovative* and/or *insightful*.

In summary, then, the current study reports further evidence of a maturing DEA methodology involving a dwindling number of *influential* publications, and, possibly, a saturation of methodological applications. In its 30-year life span, DEA researchers appear to have been at their most creative in pushing the research envelope during the period 1983–1997. In this regard, Seiford [22] reported that the early 1990s were characterized by an extensive evolution of DEA practice vs. theory. We suggest he was observing a spike in published applications with some trepidation. Was this an early sign of a methodology reaching its maturity? Evidence unearthed in the current study indicates that the number of publications based on the problematization strategy is in a sharp decline. We leave the ongoing interpretation of this additional evidence to the reader, and move our focus to the methodology's future.

4.2. Directions for future DEA studies

For the benefit of those researchers looking to enhance the progress of DEA going forward, we suggest that future investigations address, in particular, *DEA in practice*. For example, given the popularity of DEA in academic journals, how widespread is its use in existing organizations? Might there be differences in the real-world use of DEA if profit vs. not-for-profit organizations were compared? Also, as a knowledge management tool, could a meta-methodology be developed to help guide the future path(s) of DEA?

In many instances, it is difficult not to observe that DEA publications report findings with a certain complacency. For example, traditional DEA models' primary limitation is treatment of an organizational unit as a black box. That is, DEA analysis points the way to where inefficiencies lie in terms of exogenous inputs and final outputs, but does not identify the underlying interactions at the sub-unit level. Few authors of DEA papers acknowledge this

limitation. Yet, prying open the black box promises further opportunities to push the DEA envelope. In fact, one of the more exciting recent developments is the renewed interest in network DEA (NDEA) based on Färe and Grosskopf [25]. By helping management open the black box of production, NDEA can reveal the underlying diagnostic information in sub-units that would otherwise remain uninvestigated. Nevertheless, we admit that there is nothing stopping the evaluator from comparing the operations of sub-units of benchmark units against that of an inefficient unit. Such a comparison would not necessarily require formulating linkages between intermediate products (a measure that is an output from one sub-unit but becomes an input into another sub-unit) as found in NDEA. For a further discussion of benchmarking and NDEA see Zhu [26] and Avkiran [27], respectively.

Expanding the above discussion, dynamic DEA can be considered as part of NDEA, but these two concepts are not equivalent. What is referred to as 'dynamic DEA' in the literature normally does not explicitly account for sub-DMUs. Similarly, NDEA may not account for temporal relationships, whereas dynamic DEA does. This observation thus points to an additional avenue for future DEA studies; namely, developing sophisticated models that account for dynamic relationships in a multi-period environment with multiple intermediate products. For example, probabilistic models that function in a multi-period setting ought to provide more realistic measures of efficiency reflecting the constantly changing operating environment of the modern firm. Coding conditional dynamics may facilitate, for example, dealing with inventory carry-overs from one period to the next, thus accounting for past experience in an effort to develop future prospects.

Traditional DEA's treatment of the organizational unit as a black box hinders another perspective that could otherwise bring more useful recommendations on efficiency improvements to the business world. For example, the notion of rationalizing inefficiency measured by DEA has not received significant attention (see [28]). That is, from a managerial (rather than a technical) perspective, how useful would it be to target potential improvements suggested by DEA? Might the presence of certain levels of inefficiency be justified on additional grounds of organizational performance? Bogetoft and Hougaard [28] suggest that the rational view of inefficiency can explain the excess usage of resources as essential to producing unaccounted outputs such as a loyal pool of highly qualified or satisfied employees. Put in a more general context, how can one temper potential improvements in order to make DEA's recommendations more meaningful and acceptable to management? These questions can be tackled by further developing the existing literature on *satisficing* models that allow for improvement objectives to be set under uncertainty – typically less than improvements suggested by full efficiency (see [20]). Such less-than-ideal improvement objectives can be further shaped by, for example, assigning probabilities to expected outcomes.

A further limitation in the application (vs. formulation) of DEA that is rarely attended to in the literature – involves what Adler et al. [29] recently discussed under the heading 'productivity dilemma' (also see [30]). That is to say, improving efficiency is usually a short-term activity that may reduce long-term organizational adaptability. While most authors of DEA report potential efficiency improvements (i.e., exploitation of production possibilities), they rarely discuss the impact of such recommendations on organizational adaptability and learning (i.e., exploration of new possibilities). Yet, *exploration* is a key ingredient of organizational innovation essential for survival in the dynamic business environment of the global economy. Indeed, from March ([31], p. 71), "…systems that engage in exploitation to the exclusion of exploration are likely to find themselves trapped in suboptimal stable equilibria." It would certainly improve numerous existing DEA papers if their conclusions were to include a sub-section on *managerial implications* that offered reflections on the productivity dilemma.

DEA's *versatility* as a multi-criteria decision making technique can be furthered by more studies on how to use DEA with ordinal data, or in instances when data are missing. Cooper et al. [32], writing on imprecise DEA, present an excellent starting point on the latter issue. Regarding the use of ordinal data, this can present a problem for DEA because the technique assumes data to have cardinal meaning [33]. Yet, in some DEA applications, where data have been generated by ordinal measurements such as Likert-type scales, researchers have a tendency to overlook this assumption. The potential problem of DEA requiring ratio scale data was acknowledged by Ardehali et al. ([34], p. 500) working with ordinal scale data. While the authors considered converting ordinal scale data to ratio scale in an effort to fulfill this requirement of DEA models, they avoided the question, noting that it was considered outside the scope of their paper.

Finally, DEA has the potential to enter stronger complementary relationships with other methods such as goal programming (which preceded DEA) for the purpose of estimating future performances [35]. While both DEA and goal programming were developed by generalizing the principles observed in successful solutions to real-life problems, they differ on direction (see applications-driven theory strategy for research, as discussed in [36]). That is, DEA is normally used to address problems in the control and evaluation of activities (past performance), whereas goal programming is directed towards planning (future performance). Given that analyzing past performance with a view to forecasting future performance is a key managerial activity, further development of a partnership between DEA and goal programming ought to enjoy wide acceptance both in business and academic circles. Examples of the joint use of DEA and goal programming can be found in Athanassopoulos [37] and Sheth et al. [38].

4.3. Conclusion

The viewpoints suggested in the previous section highlight selected exciting avenues of exploration in future DEA studies. At the same time, they emphasize the need for more critical interpretation of efficiency improvement. As a final note, we hope that the current piece encourages at least a subset of DEA researchers to revisit their approaches to generating research questions, as well as to reflect on their works-in-progress. Methodological maturity does not necessarily imply an end to meaningful research, even if one believes that DEA's mathematical limitations have been reached. Indeed, searching for synergistic partnerships with other methodologies can surely continue to create fertile ground for alternative paths of investigation. In conclusion, the mindset described in this paper can open new horizons, just as it did in 1978, when the then existing knowledge on fractional and goal programming lead to DEA itself.

Acknowledgements

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Appendix 1

Methodology publications (in chronological order) that derive of problematization, and based on Cook and Seiford's [8] assessment of

the field, are listed below. *Total citations* and *citations per year*, based on Web of Science, are in square brackets (rounded to the nearest integer, where annual figures less than 0.5 are shown as 'n.a.').

1. Farrell MJ. The measurement of productive efficiency. Journal of the Royal Statistical Society Series A General 1957; 120 (3): 253–281. [1432; 29]
2. Charnes A, Cooper WW. Programming with linear fractional functionals. Naval Research Logistics Quarterly 1962; 9: 67–88. [379; 8]
3. Färe RS, Lovell CAK. Measuring the technical efficiency of production. Journal of Economic Theory 1978; 19: 150–162. [178; 6]
4. Charnes A, Cooper WW, Rhodes EL. Measuring the efficiency of decision making units. European Journal of Operational Research 1978; 2: 429–444. [1735; 60]
5. Deprins L, Simar L, Tulkens H. Measuring labor efficiency in post offices. In: Marchand M, Pestieau P, Tulkens H. (Eds.), The performance of public enterprises: concepts and measurement. Amsterdam: North Holland, 1984; 243–267. [297; 13]
6. Banker RD, Charnes A, Cooper WW. Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management Science 1984;30:1078–1092. [885; 38]
7. Charnes A, Clarke C, Cooper WW, Golany B. A developmental study of Data Envelopment Analysis in measuring the effect of maintenance units in the U.S. Air Forces. Annals of Operations Research 1985;2:95–112. [115; 5]
8. Charnes A, Cooper WW, Golany B, Seiford LM, Stutz J. Foundations of data envelopment analysis for Pareto–Koopmans efficient empirical production functions. Journal of Econometrics 1985;30:91–107. [238; 11]
9. Sexton TR, Silkman RH, Hogan, AJ. Data envelopment analysis: Critique and extensions. In: Silkman RH. (Ed.), Measuring Efficiency: an assessment of data envelopment analysis, vol. 32. Jossey-Bass, San Francisco, 73–105. 1986. [116; 6]
10. Banker RD, Morey R. Efficiency analysis for exogenously fixed inputs and outputs. Operations Research 1986;34(4):513–521. [155; 7]
11. Banker RD, Morey EC. The use of categorical variables in data envelopment analysis. Management Science 1986;32(12): 1613–1627. [99; 5]
12. Thore S. Chance-constrained activity analysis. European Journal of Operational Research 1987;30:267–269. [2; n.a.]
13. Dyson RG, Thanassoulis E. Reducing weight flexibility in DEA. Journal of the Operational Research Society 1988;39(6):563–576. [127; 7]
14. Bessent A, Bessent W, Elam J, Clark T. Efficiency frontier determination by constrained facet analysis. Journal of the Operational Research Society 1988;36:785–796. [26; 1]
15. Ali AI, Seiford LM. Translation invariance in data envelopment analysis. Operations Research Letters 1990;9:403–405. [41; 2]
16. Charnes A, Cooper WW, Huang ZM, Sun DB. Polyhedral cone-ratio DEA models with an illustrative application to large commercial banks. Journal of Econometrics 1990;46:73–91. [143; 8]
17. Banker RD, Maindiratta A. Maximum likelihood estimation of monotone and concave production frontiers. Journal of Productivity Analysis 1992;3:401–415. [25; 2]
18. Charnes A, Haag S, Jaska P, Semple J. Sensitivity of efficiency classifications in the additive model of data envelopment analysis. International Journal of Systems Science 1992;23: 789–798. [45; 3]
19. Charnes A, Neralic L. Sensitivity analysis in data envelopment analysis. Glasnik Matematicki 1992;27:191–201. [6; n.a.]
20. Andersen P, Petersen NC. A procedure for ranking efficient units in Data Envelopment Analysis. Management Science 1993;39:1261–1264. [224; 16]
21. Cook WD, Kress M, Seiford LM. On the use of ordinal data in data envelopment analysis. Journal of the Operational Research Society 1993;44:133–140. [23; 2]
22. Färe RS, Grosskopf S, Lovell CAK. Production frontiers. New York: Cambridge University Press; 1994. [827; 64]
23. Beasley J. Determining teaching and research efficiencies. Journal of the Operational Research Society 1995;46:441–452. [25; 2]
24. Wilson PW. Detecting influential observations in data envelopment analysis. Journal of Productivity Analysis 1995;6:27–46. [45; 4]
25. Färe R, Grosskopf S. Intertemporal production frontiers: With dynamic DEA. Boston: Kluwer Academic; 1996. [152; 14]
26. Thanassoulis E, Allen R. Simulating weights restrictions in data envelopment analysis by means of unobserved DMUs. Management Science 1998; 44(4):586–594.[29; 3]
27. Frei F, Harker P. Projections onto efficient frontiers: Theoretical and computational extensions to DEA. Journal of Productivity Analysis 1999;11:275–300. [11; 1]
28. Cook WD, Hababou M, Tuenter H. Multi-component efficiency measurement and shared inputs in data envelopment analysis: An application to sales and service performance in bank branches. Journal of Productivity Analysis 2000; 14:209–224. [22; 3]
29. Scheel H. Undesirable outputs in efficiency valuations. European Journal of Operational Research 2001;132:400–410. [13; 2]
30. Tone K. A slacks-based measure of efficiency in data envelopment analysis. European Journal of Operational Research 2001; 130: 498–509. [34; 6]

Appendix 2

We follow DEA's diffusion at five-year intervals by presenting various subject areas ranked on categorization of publications, as per Scopus. In the square brackets next to the dates, the first number represents the total number of categorizations in that five-year period, followed by the number of publications. In fact, for all periods, the number of categorizations is greater than the number of publications. Numbers in round brackets indicate publications that have been categorized into a particular subject area, where a publication could be assigned to more than one subject area.

1978–1982 [5; 3]
1. Business, Management and Accounting (2)
2. Decision Sciences (2)
3. Economics, Econometrics and Finance (1)

1983–1987 [37; 21]
1. Decision Sciences (14)
2. Business, Management and Accounting (6)
3. Social Sciences (3)
4. Earth and Planetary Sciences (2)
5. Engineering (2)
6. Environmental Science (2)
7. Health Professions (2)
8. Mathematics (2)
9. Medicine (2)
10. Nursing (2)

1988–1992 [199; 85]
1. Decision Sciences (41)
2. Social Sciences (35)

3. Mathematics (25)
4. Business, Management and Accounting (21)
5. Engineering (16)
6. Economics, Econometrics and Finance (13)
7. Computer Science (10)
8. Medicine (9)
9. Environmental Science (8)
10. Nursing (6)
11. Health Professions (5)
12. Immunology and Microbiology (4)
13. Biochemistry, Genetics and Molecular Biology (3)
14. Earth and Planetary Sciences (3)

1993–1997 [654; 317]

1. Decision Sciences (169)
2. Social Sciences (110)
3. Business, Management and Accounting (94)
4. Mathematics (77)
5. Economics, Econometrics and Finance (59)
6. Engineering (40)
7. Computer Science (22)
8. Environmental Science (14)
9. Earth and Planetary Sciences (12)
10. Biochemistry, Genetics and Molecular Biology (10)
11. Nursing (10)
12. Medicine (10)
13. Health Professions (9)
14. Immunology and Microbiology (7)
15. Energy (4)
16. Agricultural and Biological Sciences (3)
17. Veterinary (2)
18. Multidisciplinary (1)
19. Materials Science (1)

1998–2002 [1393; 697]

1. Decision Sciences (278)
2. Social Sciences (252)
3. Business, Management and Accounting (218)
4. Economics, Econometrics and Finance (172)
5. Mathematics (161)
6. Engineering (95)
7. Computer Science (59)
8. Medicine (25)
9. Agricultural and Biological Sciences (24)
10. Health Professions (21)
11. Environmental Science (19)
12. Immunology and Microbiology (14)
13. Energy (11)
14. Nursing (11)
15. Biochemistry, Genetics and Molecular Biology (11)
16. Earth and Planetary Sciences (4)
17. Materials Science (4)
18. Psychology (4)
19. Chemical Engineering (3)
20. Physics and Astronomy (3)
21. Dentistry (1)
22. Chemistry (1)
23. Multidisciplinary (1)
24. Neuroscience (1)

2003–2007 [2567; 1466]

1. Decision Sciences (386)
2. Social Sciences (363)
3. Business, Management and Accounting (363)
4. Engineering (302)
5. Mathematics (290)
6. Economics, Econometrics and Finance (290)
7. Computer Science (139)
8. Agricultural and Biological Sciences (94)
9. Environmental Science (73)
10. Medicine (69)
11. Energy (38)
12. Biochemistry, Genetics and Molecular Biology (26)
13. Health Professions (17)
14. Physics and Astronomy (17)
15. Nursing (16)
16. Multidisciplinary (15)
17. Psychology (14)
18. Earth and Planetary Sciences (13)
19. Materials Science (13)
20. Chemical Engineering (13)
21. Immunology and Microbiology (9)
22. Veterinary (5)
23. Dentistry (1)
24. Chemistry (1)

References

[1] Emrouznejad A, Parker BR, Tavares G. Evaluation of research in efficiency and productivity: a survey and analysis of the first 30 years of scholarly literature in DEA. Soc Econ Plann Sci 2008;42:151–7.
[2] Gattoufi S, Oral M, Kumar A, Reisman A. Content analysis of data envelopment analysis literature and its comparison with that of other OR/MS fields. J Oper Res Soc 2004;55:911–35.
[3] Sun S. Research productivity in data envelopment analysis. In: Proceedings of DEA Symposium 2008, Tokyo; 2008. p. 13–22.
[4] Ormerod RJ. An observation on publication habits based on the analysis of MS/OR journals, OMEGA. Int J Manag Sci 1997;25:599–603.
[5] Locke K, Golden-Biddle K. Constructing opportunities for contribution: structuring intertextual coherence and "problematizing" in organizational studies. Acad Manag J 1997;40:1023–62.
[6] Alvesson M, Sandberg J. Generating research questions through problematization. Lund Institute of Economic Research Working Paper Series; 2008. p. 2008–2014.
[7] Bartunek JM, Rynes SL, Ireland RD. What makes management research interesting, and why does it matter? Acad Manag J 2006;49:9–15.
[8] Cook WD, Seiford LM. Data envelopment analysis (DEA) – thirty years on. Eur J Oper Res 2009;192:1–17.
[9] Bessent A, Bessent W, Elam J, Clark T. Efficiency frontier determination by constrained facet analysis. J Oper Res Soc 1988;36:785–96.
[10] Banker RD, Morey EC. The use of categorical variables in data envelopment analysis. Manag Sci 1986;32(12):1613–27.
[11] Kamakura WA. A note on the use of categorical variables in data envelopment analysis. Manag Sci 1988;34:1273–6.
[12] Charnes A, Cooper WW, Rhodes E. Measuring the efficiency of decision making units. Eur J Oper Res 1978;2:429–44.
[13] Sherman HD, Gold F. Bank branch operating efficiency: evaluation with data envelopment analysis. J Bank Finance 1985;9:297–315.
[14] Banker RD. Maximum likelihood, consistency and data envelopment analysis: a statistical foundation. Manag Sci 1993;39:1265–73.
[15] Charnes A, Cooper WW, Rhodes E. Evaluating program and managerial efficiency – an application of data envelopment analysis to program follow through. Manag Sci 1981;27:668–97.
[16] Färe RS, Grosskopf S, Lovell CAK. Production frontiers. New York: Cambridge University Press; 1994.
[17] Banker RD, Charnes A, Cooper WW. Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management Science 1984;30:1078–92.
[18] Cooper WW, Seiford LM, Tone K. Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software. 2nd ed.. New York: Springer; 2007.
[19] Land KC, Lovell CAK, Thore S. Chance-constrained data envelopment analysis. Manag Decis Econ 1993;14:541–54.
[20] Cooper WW, Huang Z, Li S. Satisficing DEA models under chance constraints. Ann Oper Res 1996;66:279–95.
[21] Sengupta JK. Efficiency analysis by stochastic data envelopment analysis. Appl Econ Lett 2000;7(6):379–83.
[22] Seiford LM. Data envelopment analysis: the evolution of the state of the art (1978–1995). J Product Anal 1996;7:99–137.
[23] Førsund F, Sarafoglu N. On the origins of data envelopment analysis. J Product Anal 2002;17:23–40.
[24] Glover F, Sueyoshi T. Contributions of Professor William W. Cooper in operations research and management science. Eur J Oper Res 2009;197:1–16.
[25] Färe R, Grosskopf S. Intertemporal production frontiers: with dynamic DEA. Boston: Kluwer Academic Publishers; 1996.

[26] Zhu J. Quantitative models for performance evaluation and benchmarking: data envelopment analysis with spreadsheets and DEA excel solver. Norwell, MA: Kluwer Academic; 2003.
[27] Avkiran NK. Opening the black box of efficiency analysis: an illustration with UAE banks. OMEGA. Int J Manag Sci 2009;37(4):930–41.
[28] Bogetoft P, Hougaard JL. Rational inefficiencies. J Product Anal 2003;20:243–71.
[29] Adler PS, Benner M, Brunner DJ, MacDuffie JP, Osono E, Staats BR, et al. Perspectives on the productivity dilemma. J Oper Manag 2009;27:99–113.
[30] Abernathy WJ. The productivity dilemma roadblock to innovation in the automobile industry. Baltimore: Johns Hopkins University Press; 1978.
[31] March JG. Exploration and exploitation in organizational learning. Organ Sci 1991;2(1):71–87.
[32] Cooper WW, Park KS, Yu GIDEA. (Imprecise Data Envelopment Analysis) with CMDs (Column Maximum Decision Making Units). J Oper Res Soc 2001;52:176–81.
[33] Cook WD, Zhu J. Rank order data in DEA: a general framework. Eur J Oper Res 2006;174:1021–38.
[34] Ardehali PH, Paradi JC, Asmild M. Assessing financial risk tolerance of portfolio investors using data envelopment analysis. Int J Inform Technol Decision Making 2005;4:491–519.
[35] Cooper WW. Origins, uses of and relations between goal programming and data envelopment analysis. J Multicriteria Decision Anal 2005;13:3–11.
[36] Cooper WW, McAlister L. Can research be basic and applied? You bet. It better be for B-schools!. Socio-Econ Planning Sciences 1999;33:257–76.
[37] Athanassopoulos A. Goal programming and data envelopment analysis (GoDEA) for target-based multi-level planning: allocating central grants to the Greek local authorities. Eur J Oper Res 1995;87:535–50.
[38] Sheth C, Triantis K, Teodorović D. Performance evaluation of bus routes: a provider and passenger perspective. Transp Res E Log Transp Rev 2007;43:453–78.

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