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Productivity and Efficiency Analysis Software: An Exploratory Bibliographical Survey of the Options

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Abstract:
The software available to implement and carry out efficiency analysis is crucial for the diffusion of efficiency frontier techniques among applied researchers and policy makers. The implementation of up-to-date productivity and efficiency analysis is indeed important to advance our knowledge in many fields, ranging from the public and regulated sectors to the private ones. This contribution fills a gap in the existing literature and surveys the currently available options to estimate a variety of frontier methodologies using either general or dedicated programs. We present a conceptual mapping of the key terms associated to the surveyed software and outline directions for future research.

Keywords: frontier models, productivity, efficiency, review, software

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Introduction

The availability of software and codes to perform rigorous empirical analysis is important for applied researchers and the wider scientific community. It is also increasingly important given the need to exploit data resources and the availability of big data. This need is particularly felt in the so-called frontier literature on Productivity and Efficiency Analysis (PEA) that has boomed over the last decades, since these extremum estimators tend to be rather computationally intensive. There is a wide variety of methodological surveys available on this PEA frontier literature (examples include Bogetoft and Otto (2011), Del Gatto, Di Liberto and Petraglia (2011), Murillo-Zamorano (2004), and Parmeter and Kumbhakar (2014), among others). Equally so, the enormous amounts of empirical applications of these PEA frontier methods have been capably summarised in a series of surveys per sector. Examples include agriculture (Bravo Ureta et al. (2007)), banking (Aiello and Bonanno (2016)), health care (Rosko and Mutter (2011)), ports (Odeck and Bråthen (2012)), and water and sanitation (Worthington (2014)), among others.

While on occasion a review of some PEA frontier software has appeared in the literature (e.g., Barr (2004) or Hollingsworth (1999)), and some comparative review of available statistical tools and packages covers the gap of econometric software surveys (Korösi et al. 1993), to the best of our knowledge no systematic and recent review of PEA software options is currently available. Therefore, the main research question that we address in this paper is: What software options exist to carry out frontier-based PEA? How many studies have analysed the existing software options? That is, what is the state of the art about the "implementation" of techniques to produce (generate) empirical evidence on productivity and efficiency? And related to this question, how many options are already available to researchers interested in the implementation of frontier models? In the existing literature, there is a lack of a unifying view on the different options available in terms of software implementation. We fill this gap by making a state of the art survey of the available software options. We also report the outcome of a clustering and a cognitive map based on the keywords of the identified relevant documents. We open a perspective to further research (outside the scope of this paper) on the field including:
-a large scale evaluation and comparative assessment of the performance/validity of the existing software;
-need of standard to check the quality of the available software and to create an open repository for their storage and maintenance.
The method applied to carry out the survey is based on a *systematic review*, taking into account the specificities of the objective of the study and the limitations of the technique.

The paper is organized as follows. The next section introduces the approach followed to carry out the systematic review. The subsequent section reports the main outcome of the paper that is the state of the art of the existing options of software for PEA and outlines a comparative analysis carried out on them. The next section reports the cluster and density maps produced by the main keywords of the relevant documents identified, while the final section concludes the paper and outlines directions for further research. In the Appendix additional information on the queries carried out on Scopus and Google Scholar are reported, together with the flow diagrams of the systematic search and additional detailed information on the study carried out.

Methodology of the Survey

According to Petticrew and Roberts (2006, p. 19) a "*systematic* (literature) *review* is a review that strives to comprehensively identify, appraise and synthesize all the relevant studies on a given topic. Systematic reviews are often used to test just a single hypothesis, or a series of related hypotheses." In sum, it tries:

1. to collect *all existing evidence* that fits some pre-specified *eligibility criteria* in order to answer a *specific research question.*
2. It uses explicit, *systematic methods* (adopting a replicable, scientific and transparent process) that are selected with the purpose of minimizing the inherent bias, and hence, enhancing the reliability of the findings.

The principal characteristics of this approach are:

- a clearly stated *objective* with pre-defined *eligibility criteria* for inclusion of the relevant materials;
- an explicit, reproducible *methodology*;
- a *systematic search* that attempts to identify all studies and relevant materials that would meet the eligibility criteria;
- a *systematic presentation* and *synthesis* of the features of the included relevant studies and documents.

This approach has been developed initially in medical science to summarize and make sense of an often contradictory mass of empirical evidence available that is difficult to synthesise (see, e.g., the reference in this field by Higgins and Green 2011). The limitations of the approach have been described in many works, including Petticrew and Roberts (2006) who discuss the specific features of the approach for application in the social sciences. Tranfield et al. (2003) highlight the limits of the approach in the managerial field and propose a "lighter" use of the approach to provide an "evidence informed" or "evidence aware" answer to the research question (objective) of the systematic review, instead of a stronger "evidence based" information. We follow this latter approach given the specific questions we wish to address.

In Box 1, we summarize the main choices we have made in our analysis pertaining to the main objective, the eligibility criteria, explicit methodology, systematic search, and systematic presentation and synthesis.

Main objective (our research question)	How many and what software exist to carry out PEA? How many studies have analysed the existing software options?
Eligibility criteria	We include only those programs or software that are diffused as a package or a toolbox and for which there is sufficient English language documentation for the user.
Explicit methodology	Systematic review on two databases with

	a different coverage: Scopus and Google Scholar, integrated by expert knowledge and a "light" application of the systematic review approach for social sciences.
Systematic search	All details about the queries run on the two databases are described in the paper and reported in Appendix (Table 1A).
Systematic presentation and synthesis	The outcome of the survey is reported in a summary way in Table 4 and in a more detailed way in Appendix (Table 3A). A mapping and clustering illustration of the main keywords is reported in Figures 1 and 2.

Box 1. Choices made in the systematic review

In the selection carried out on the identified papers in the English language solely (see more details below) we avoid that articles mentioning the simple application of an existing software were considered as relevant (e.g., "our results were computed in GAMS", "we used FEAR", etc.). Equally so, articles that simply mention the availability of computer code or contain snippets of such code without a written documentation are ignored. Moreover, we distinguish between frontier software and articles describing conceptual or real decision support systems involving some use of frontier estimation. The latter type of articles are excluded in this survey: examples include Fernández-Montes et al. (2012), Johnson et al. (2010), Johnson and McGinnis (2011), Lai et al. (2011), Pasupathy and Medina-Borja (2008), Samoilenko and Osei-Bryson (2013), Wang (2005), Yousefi and Hadi-Vencheh (2010).

Our survey is entirely bibliographical and is limited to sources in English. In particular, we have made no attempt to make an inventory of software that is undocumented.[i] For instance, these can be programs that do not contain any documents or user guides, ignoring any eventual minimal installation instructions. Or, it concerns code in software that is related to a specific article or working paper, often made available on repositories or researcher's web pages.[ii] The key summary tables of the study (i.e., Table 4 and Table 3A) contain first and foremost references to the documents. The main reason to limit our survey to a bibliographical approach is that the methodology of doing a bibliographical search is rather well established. By contrast, the methodology to assemble all sources of software code is far less standardized.

Synthesizing the evidence, from the inspection of these summary tables it emerges that there has been an increase in the number of free open toolboxes proposed in the last years, denoting an increasing interest for the field and ability/willingness to share codes and programs. This leaves open the issue on how to control the quality of these existing packages (which one can be used for which purpose). We return to this issue in the concluding section when outlining directions for further research.

Let us now describe the main steps in our systematic search. The systematic survey on PEA software literature initiates with a list of 34 documents identified as relevant by expert knowledge (i.e., the authors). In this list (see Table 1), there are 9 books, 17 articles, 2 reports and 6 user Guides. We collect the keywords of these documents

(when present) to run the first broad query in the two scientific literature databases considered in our analysis, namely Scopus and Google Scholar. Books, manuals, reports, user guides and many types of documentation do not provide keywords associated. For those cases, the most repeated words in the title, abstract or introduction are taken as keywords to compose a complete repository of terms associated with (and to track the) software options. An overview on the process followed in the search on these two databases (Scopus and Google Scholar) is shown in Figure 1A.

The systematic search on Scopus was conducted with eight specifications described by the scripts reported in the top panel of Table 1A. The search was carried out on December 1st, 2016, from 14h08m (UTC+01:00) to 17h20m. The query Q1 (see Table 1A), was run over all the disciplinary fields in the Scopus search engine. We obtained a dataset of 7814 documents that includes research papers, articles in press, books, reports, technical notes, letters, reviews and conference proceedings distributed among the main areas of life science, health science, physical science, social science and humanities, from the year 1988 to 2016. After this first step, the query Q1 was rewritten in terms of Q2 to remove case studies that are not relevant for the purpose of this survey. A total of 3266 documents in 160 subject categories resulted from this specification, ranging from 21 to 1492 occurrences per subject category.

Thereafter, we introduced further refinements on subject classes to exclude general and irrelevant documents. This process leads us to the queries Q3 and Q4 (see Table 1A). These refinements resulted in a total of 627 potentially relevant documents. Subsequently, the queries Q5 and Q6 (see Table 1A) were run to limit the obtained documents to the specific knowledge area related to PEA software reviews. As an outcome, we obtained 395 potential relevant documents. Lastly, from this set of 395 potential relevant documents, a title based selection lead us to consider 29 documents for a deeper exploration based on the documents' abstract and body. The reading of the 29 documents obtained lead us to consider 1 relevant document. The left side flow diagram of Figure 1A reports a graphical representation of this process run on Scopus.

The systematic literature search on Google Scholar followed a similar reasoning, but with a difference in the specifications concerning refinements and re-refinements (since the Google Scholar engine limits queries to 256 characters). The Google Scholar systematic search was carried out on December 2, 2016, at 13h21m and ended at 16h38m (UTC+01:00). It consists in six specifications: from the broadest to the more specific ones (see Figure 1A right side flow diagram). The general terms in Q7 and Q8 are the same as Q1 and Q2 carried out in Scopus, but with a different syntax. These queries lead to a wider set of results due to Google Scholar's extensive capacity to find out documents throughout internet servers and a wider variety of document sources and types. The attempt to increase the precision of results for geographic regions, general terms and unrelated areas considerations lead us to 719 thousand occurrences. Further refinements and specifications (see queries Q9, Q10 and Q11 in Table 1A) lead us to a title inspection on a total of 296 potentially relevant documents.

As an outcome of this title inspection, 82 documents were selected as potentially relevant documents and thereafter 33 final documents were retained for abstract reading (one of which was already included in the outcome from the Scopus database). Since in total 16 out of these 33 potentially relevant documents also belong to the initial expert documents list, a number of 17 documents was added to the original list from the

systematic search and 16 documents are added from additional sources. The right side flow diagram of Figure 1A summarizes this selection process.

Tables 1, 2 and 3 present the 3 lists of relevant documents obtained as well as some additional information retrieved from Google Scholar. The first column of the tables reports the id number of the document; the second column reports the reference of the document; the third column indicates the nature of the document; and the fourth column mentions the number of versions of the document available in Google Scholar.

The documents are classified into books (including book chapters), articles in scientific journals, proceedings (conference papers and reviews), reports (working papers, white papers, press releases, erratum, essays, and sales or marketing documents with a report structure), and manuals (user guides, letters, notes on software or any relevant documents with a manual structure).

The number of versions available of each document merits some discussion. In Google Scholar each document may have different versions when the document is found with different years in different repositories or different editions of the same book. Also, different digital extension formats (such as .doc, .docx, .pdf), proceedings papers that are later published as journal articles, and different language sources, or author name abbreviations may lead to different versions of the same document.

Table 1: 34 Original Relevant Documents (expert-based). Descriptive Information from Google Scholar (Last updated: Feb 9, 2017)

N.	Reference	Document Type	Google Scholar Versions
[1]	Akçay et al. (2012)	Article	7
[2]	Álvarez et al. (2016)	Report	3
[3]	Arickx et al. (1997)	Article	1
[4]	Barr (2004)	Book	10
[5]	Bogetoft (2013)	Book	4
[6]	Bogetoft and Otto (2010)	Book	10
[7]	Chang and Sueyoshi (1991)	Article	4
[8]	Cheng and Qian (2011)	Manual	1
[9]	Coelli (1996)	Manual	4
[10]	Coelli (1996b)	Manual	3
[11]	Coelli (1997)	Manual	1
[12]	Cooper et al. (2006)	Book	3
[13]	Emrouznejad (2005)	Article	11
[14]	Ferris and Voelker (2002)	Article	18
[15]	Green (1996)	Article	9
[16]	Greene (2007)	Manual	1
[17]	Griffin (2007)	Article	30
[18]	Herrero and Pascoe (2002)	Article	1
[19]	Hollingsworth (1997)	Article	2
[20]	Hollingsworth (1999)	Article	2
[21]	Hollingsworth (2004)	Article	12
[22]	Hussain and Jones (2001)	Report	6

[23]	Ji and Lee (2010)	Article	12
[24]	Kumbhakar and Wang (2015)	Book	8
[25]	Kumbhakar et al. (2015)	Book	6
[26]	Ley (1996)	Book	2
[27]	Meza et al. (2005)	Article	8
[28]	Olesen and Petersen (1996)	Article	6
[29]	Sena (1999)	Article	4
[30]	Scheel (2000)	Manual	7
[31]	Tauchmann (2012)	Article	8
[32]	Thanassoulis (2001)	Book	11
[33]	Wilson (2008)	Article	15
[34]	Zhu (2014)	Book	12

Table 2: 17 Relevant Documents added after the systematic search on Scopus and Google Scholar. Descriptive Information from Google Scholar (Last updated: Feb 9, 2017)

Order	Reference	Document Type	Versions
[35]	Argyrioy and Sifaleras (2013)	Proceedings	6
[36]	Barr and Durchholz (1992)	Proceedings	1
[37]	Ceyhan and Benneyan (2010)	Proceedings	1
[38]	Charnes et al. (1994)	Book	1
[39]	Chatzigeorgiou and Stiakakis (2011)	Article	20
[40]	Coelli et al. (2005)	Book	10
[41]	Coelli and Henningsen (2015)	Manual	210
[42]	Daouia and Laurent (2015)	Manual	329
[43]	Diaz-Martinez et al. (2008)	Manual	3
[44]	Emrouznejad and Thanassoulis (2009)	Proceedings	2
[45]	Iliyasu et al. (2015)	Article	3
[46]	Jablonsky (2014)	Article	4
[47]	Li et al. (2016)	Article	3
[48]	Meza et al. (2004)	Proceedings	4
[49]	Morgunov (2005)	Report	3
[50]	O'Donnell (2010)	Report	5
[51]	Straub (2015)	Manual	117

Table 3: 15 Relevant Documents Added from Additional Sources coming from free search on the web. Descriptive Information from Google Scholar (Last updated: Aug 8, 2017)

Order	Reference	Document Type	Versions
[52]	Badunenko and Mozharovskyi (2016)	Article	8
[53]	Badunenko et al. (2017)	Manual	-
[54]	Belotti and Ilardi (2013)	Article	9
[55]	Bogetoft and Otto (2015)*	Manual	163
[56]	Dakpo et al. (2016)	Manual	-
[57]	Ferrara and Vidoli (2015)	Manual	43
[58]	Fusco and Vidoli (2015)	Manual	32
[59]	Kalvelagen (2002)	Report	7
[60]	Lim and Anderson (2012)	Proceedings	4

[61]	Oh and Suh (2013)	Manual	179
[62]	Pavlyuk (2016)	Manual	77
[63]	Ramanathan (2003)	Book	2
[64]	Shott and Lim (2015)	Manual	-
[65]	Sickles and Zelenyuk (2017)	Book	-
[66]	Soteriades, A.D. (2017).	Article	-
[67]	Wilson (2014)*	Manual	2

Notes: *: This is a document/user manual of a package already described in at least a document reported in Table 1.

It has to be noted that the additional documents reported in Table 3 were added on the basis of expert knowledge because their keywords did not match with our initial keyword specification. This is really an area of further research since combining expert knowledge and other kinds of systematic source searches (e.g., web sites of PEA scholars) may bring valuable information on existing software options.

Comparative Analysis of the Available Options

In this section, we summarize the main characteristics of each PEA software and packages inventoried by our systematic review. The main result of this paper is the content of Table 4. Table 4 summarizes -to the best of our knowledge- the available software for PEA based on the systematic review described above. Table 5 describes seven main dimensions (based on Barr (2004)) for which the comparative assessment on the existing software for PEA is carried out, namely, Frontier Models, System Requirement, Variable and Constraints Limitation, User interface, Reports' Structure, Cost and User Support. More details can be found in the Appendix Table 3A.

Table 4: Overview of the Software Tools available for PEA (Last updated: February 20, 2017)

Software	**Type**	**Reference and/or Web Pages**
AMPL	DEA	Green (1996)
GAMS	DEA	http://www.gams.com/latest/gamslib_ml/libhtml/gamslib_dea.html Ferris and Voelker (2002); Olesen and Petersen (1996)
Mathematica	DEA	Ley (1996)
Matlab	DEA	DEA Toobox (Álvarez et al. 2016); http://www.deatoolbox.com/
R	DEA & Stoch. Fr.	R Packages (available on https://cran.r-project.org/web/packages, except when otherwise indicated): - additiveDEA (Soteriades 2017); - Benchmarking (Bogetoft and Otto 2010); - FEAR (Wilson 2014); www.clemson.edu/economics/faculty/wilson/Software/FEAR/fear.html) - Frontier (Coelli and Henningsen 2015) - Frontiles (Daouia and Laurent 2015); - Nonparaeff (Oh and Suh 2013); - npsf (Badunenko et al. 2017); - Productivity (Dakpo et al. 2016); - semsfa (Ferrara and Vidoli 2015); - SFA (Straub 2015); - spfrontier (Pavlyuk 2016) - SSFA (Fusco and Vidoli 2015). - TFDEA (Shott and Dong-Joon 2015)
SAS	DEA & Stoch. Fr.	proc qlim Emrouznejad (2005)
STATA	DEA &	frontier, xtfrontier

	Stoch. Fr.	Kumbhakar and Wang (2015) Tauchmann (2012) Stata Packages: - DEAS (Ji and Lee 2010); https://sourceforge.net/projects/deas/ - SFA (Kumbhakar et al. 2015) https://sites.google.com/site/sfbook2014/home/data-and-programs - sfcross (Belotti and Ilardi 2013) http://www.econometrics.it/?p=286 - sfpanel (Belotti and Ilardi 2013) http://www.econometrics.it/?p=286" - tenonradial, teradial, teradialbc, nptestind, and nptestrts (Badunenko and Mozharovskyi 2016) www.stata.com/meeting/germany16/slides/de16_badunenko.pdf
Program		**Author(s) and/or Web Pages**
BSFM	Stoch. Fr.	Arickx et al. (1997)
DEA-Excel	DEA	Jablonský (2014); http://nb.vse.cz/~jablon/dea.htm
DEAFrontier	DEA	Zhu (2014); www.deafrontier.com/deasolver.html
DEAQual	DEA	http://wak2.web.rice.edu/
DEAP	DEA	Coelli (1996); www.uq.edu.au/economics/cepa/deap.php
DEA-Solver-Pro	DEA	Cooper, Seiford and Tone (2007); www.saitech-inc.com/Products/Prod-DSP.asp
DPIN	DEA	O'Donnell (2010); www.uq.edu.au/economics/cepa/dpin.php
EMS	DEA	Scheel (2000); http://www.holger-scheel.de/ems/
Frontier	Stoch. Fr.	Coelli (1996); www.uq.edu.au/economics/cepa/frontier.php
Frontier Analyst	DEA	Hussain and Jones (2001); http://banxia.com/frontier/
Inverse DEA	DEA	http://maxdea.com/InverseDEA.htm
LIMDEP	DEA & Stoch. Fr.	Greene (1995); www.limdep.com/
MaxDEA	DEA	Cheng (2014); www.maxdea.cn/
NLOGIT	DEA & Stoch. Fr.	Greene (2002); http://www.limdep.com/products/nlogit/
OnFront	DEA	http://onfront.software.informer.com/
Open Source DEA	DEA	www.opensourcedea.org/
PIM-DEAsoft	DEA	Thanassoulis (2001); www.deasoftware.co.uk/
ISYDS (SIAD)	DEA	Meza et al. (2005); www.uff.br/decisao/
SmartDEA	DEA	Akçay, Ertek and Büyüközkan (2012)
TFPIP	DEA	Coelli (1997); www.uq.edu.au/economics/cepa/tfpip.php
WinBUGS	Stoch. Fr.	Griffin and Steel (2007); Thanassoulis and Emrouznejad (1996); www2.warwick.ac.uk/fac/sci/statistics/staff/academic/steel/steel_homepage/software
Online Program		**Web Pages**
DEAOS	DEA	www.deaos.com/
DEA Solver Online	DEA	www.dea.fernuni-hagen.de
WebdeA	DEA	https://sites.google.com/site/dsslabunipi/tools

The programs present in Table 3A are divided in two categories: General purpose software (econometric programing languages) and Dedicated software, which also includes web-based programs. The programing languages are able to feature any DEA or SFA approach with proper knowledge of the algorithm design and specific characteristics of the tool. Our comparative analysis also lists a set of specific libraries each program grants the usage. By way of example, Benchmarking and FEAR are libraries that can be attached to the general-purpose statistical package R to enable

access to up-to-date advances in DEA and SFA analysis. The web-based programs bring benefits of interoperability among different operating systems and save hardware capacity and resources. They require web browsers to perform the analysis. For instance, Opensource DEA aims to provide a free open platform and code that can be used and modified by anyone.

The information considered for the first dimension is summarized as FDH, DEA and SFA models, parametric or non-parametric approaches, in the Appendix Table 3A. The choice of the most appropriate Frontier Model is a source of discussions in surveys of core methods for productivity measurement (Del Gatto et al. 2011; Murillo-Zamorano 2004), which mostly depends on the decision maker goals, data set and characteristics of the empirical area of assessment. A wide range of DEA models are considered by each package, from the traditional constant and variable returns to scale DEA models (Charnes Cooper and Rhodes 1978; Banker et al. 1984), additive slack-based (Charnes et al. 1985; Tone 2001), extensions of Andersen and Petersen (1993) Super-efficiency and Malmquist (1953) productivity indexes to more recent and specific models such as the O'Donnell (2008) decomposition of the Hicks-Moorsteen Total Factor Productivity index, Podinovski (2004) model of trade-offs, or Tone and Tsutsui (2010) dynamic slack-based model.

Most of these models are available for both input-oriented and output-oriented cases. A total of 41 instances of DEA models were inventoried: readers are advised to check the relevant documentation to see which package can perform which specific model. Some packages such as DEA-Solver-Pro, DEAFrontier and MaxDEA permit the implementation of recent advances on network DEA models: e.g., network variable returns to scale (Chen and Zhu 2004), network slack-based (Tone and Tsutsui 2009), and dynamic slack-based (Tone and Tsutsui 2014) models. The inverse DEA model of Wei et al. (2000) has a unique package designed exclusively to perform this particular model. Finally, FDH refers to the Free Disposal Hull nonparametric estimators (Deprins, Simar and Tulkens 1984).

Table 5: Summary Table on the Comparative Analysis carried out on the software options.

Options	Dimensions	Definition
Libraries, Solvers and Language-Based Algorithms	Frontier Models	DEA and/or SFA models included in the package/software
General Purpose DEA/SFA Software	System requirements	Hardware and Operating Systems requirements to run the program
Web-server Programs	Variable and constraints limitations	Problem size of the linear programming model which the package can execute
	User Interface	Command Line, Graphical User Interface or Interface from other Applications
	Report Structure	Main features and capabilities of the software results
	Cost	Academic and Commercial license prices retrieved between Nov. 2016 and Jan. 2017
	User Support	Provision of technical support, documents and

orientation to users.

With regard to SFA, the most relevant models inventoried are the time invariant model (Battese et al. 1989), the generalized production frontier (Battese and Coelli 1988), the Pitt and Lee (1981) model of technical inefficiency, the conventional Aigner et al. (1977) cross-sectional estimation of SFA, Stevenson (1980) likelihood function model for cross-sectional data, and the Reifschneider and Stevenson (1991) reformulation of traditional two-stage approaches. Readers are advised to consult the references to verify which models and stochastic error distribution are assumed in each instance of SFA software.

The system requirement dimension in Table 3A looks at the different operating systems and processor requirements in which the programs can operate. The dimension "Variable and Constraints Limitation" refers to the problem size, i.e., the number of decision making units and input/output variables which the program can handle without additional data scaling or adjustments. This information is retrieved from manuals, online documentations, reports and case study applications to present a synthetic content of the packages.[iii]

The user's interface considers three types of usage platforms: DOS command line (CLI) or specific integrated developer environments (IDE) (e.g., the R command line prompt), particular graphical user interfaces (GUI) designed by the developers and outsourced graphical user interfaces (e.g., MS Excel in which the software borrows the environment and graphical resources to perform and report the assessment). The report structure presents the main features of the software results (such as the efficiency projection, individual scores, graphs, scripts, weights, lambdas (intensity), peers, slacks, and summary statistics (when statistical tools[iv] are included). Some of the simplest software options generate only a single text file with main results.

The costs listed in the seventh column relate to standalone commercial licences for a single computer during the period of one year, and are separated into academic users (university students and faculty) and business users (public[v] and private companies). Many packages require additional solvers, packages or programs to analyse the Frontier Models described in the second column. This information is added after the main prices, relating the specific solver/program in parenthesis, to obtain an accurate picture of the total costs for interested readers. Some programs offer customized prices depending on the problem size (i.e., number of DMUs, constraints and resource items), or grant discounts for a second year renewal. Readers are invited to consult the references and websites for more details. Finally, the user support dimension relates to the provision of technical support, user guides, documentation, manuals, FAQ, training courses, and other forms of contact and support for clients (with pricing information when applicable).

On the one hand, the necessity of empirical application against the background of a rapid development of many DEA models and ways to estimate the SFA frontiers with different assumptions for different purposes gives a lead to the usage of standard programing languages (e.g., R, Matlab[vi], Gams and AMPL[vii]) instead of dedicated programs. Dedicated or specific software products are designed for a limited number of features, tools and specific properties, without the possibility to explore new approaches or assumptions that may contribute to advance theory. Programing languages make it

easier to follow the frontier of scientific knowledge by allowing for improvements in conventional models and by providing the tools to bring forth recent considerations. On the other hand, the inconvenience for the user to learn the syntax of a mathematical programing language and the additional work to perform simple statistical analysis may lead some researchers to opt for easier specific DEA and SFA programs.

There are few considerations that must be stated. All DEA software products in this comparative assessment are able to perform both constant (CRS) and variable (VRS) returns to scale models, and most can also handle the non-decreasing and non-increasing returns to scale variations. For instance, PIM-DEAsoft is a much customized product with different price specifications depending on license quantity, number of DMUs, license expiration time (with an option for a permanent license) and additional models. The price information in Table 3A regards a single license for 1 year to evaluate up to 50 units including all additional packages. DPIN 3.1 and TFPIP 1.0 use DEA variants of the CRS model for both output and input oriented cases to estimate the production frontier and compute productivity indexes and determinants of efficiency change. Thus, DPIN focuses on the estimation of production technology and levels of efficiency change into Hicks-Moorsteen indices of Total Factor Productivity (TFP), whereas TFPIP approaches the Törnqvist (1936) and Fisher (1922) index number methods of TFP.

LIMDEP and NLOGIT are the only specific software products available that perform both efficiency evaluation in terms of DEA modelling and for SFA, and that can also consider partial or environmental effects on data. Readers might find prior versions of DEAFrontier referred in some textbooks and papers as Excel DEA Solver, with the same basic DEA models and tools.

Mapping and Linking Keywords Related to the Available PEA Software

In this section, we summarize the outcome of a mapping exercise carried out on the keywords of the relevant documents considered in this survey. The objective is to present some cognitive and proximity maps among concepts linked with the software and packages options available for PEA.

The network cluster illustrated in Figure 1 and the density map reported in Figure 2 summarize the results of this exercise. The set of keywords co-occurrence metrics needed to generate the two figures were created with the resources of the software tool VOSviewer (Van Eck and Waltman 2010, 2014). The relationships illustrated in the Figures are generated by the information provided in Table 2A, namely the item occurrences (see column 2) and the link strength of the keywords (see column 3) extracted from each document. Each keyword is designed as a circle node where the number of occurrences defines the size of its label, and the strength of a link defines the network relation and position. When there is a link between two keywords, the strength of the link gets a positive number equal to one; it equals zero otherwise.

Some generic keywords were eliminated to avoid double counting the related concept/approach. Thus, both Figures 1 and 2 relate to a refined set of keywords without the expressions ‘Data Envelopment Analysis (DEA)’, and ‘Efficiency and Productivity Analysis’. The figures 1 and 2 are obtained based on 154 connected nodes

(items) and 6 isolated terms from a network of 160 relevant keywords. Note that these map projections are created based on the keywords of the relevant documentation reported by Tables 1 and 2 (i.e., the additional sources of bibliometric data are not taken into consideration).

In Figure 1, three main clusters can be observed. The red cluster which aggregates data envelopment software and packages items, the green cluster for parametric and nonparametric models and methods, and the Blue cluster in which some general efficiency analysis expressions and R packages are included. The density of co-occurrences reported in Figure 2 expresses an intensity of the evaluated keywords' relevance according to the number of neighbouring (or adjacent) keywords in the specific document, and their importance in terms of connections with other documents. This yields a considerable importance to identify the most relevant areas and expressions for a systematic survey (Van Eck and Waltman, 2010) and to support additional systematic searches for future updates in software products. The isolated keywords clusters of interactive benchmarking (efficiency analysis) and cross-sectional items, for instance, has weak relevance as red-density words, with some less intense connection (and related documental terms) as outcome of the general queries.

Some adjustments had to be made on a few specific keywords provided by the authors or extracted from the documentation that contained spelling typos or presented several forms to designate the same expression, such as 'orderm' and 'order-m', 'nonparametric' and 'non-parametric', 'measurament' instead of 'measurement' or 'algebric' instead of 'algebraic'. The main structure of the scientific mapping did not present a significant change with this sort of items aggregation. The main result, which appears from this mapping exercise, is a kind of unified view (a compact presentation) of the different frontier models and their program implementation. It seems to support a trend towards a *convergence* of the parametric and nonparametric approaches in PEA (see also Daraio and Simar 2007, Figure 2.1 p. 27).

Figure 1: Clusters of Key Terms and Expressions related to Table 1 and 2 documents

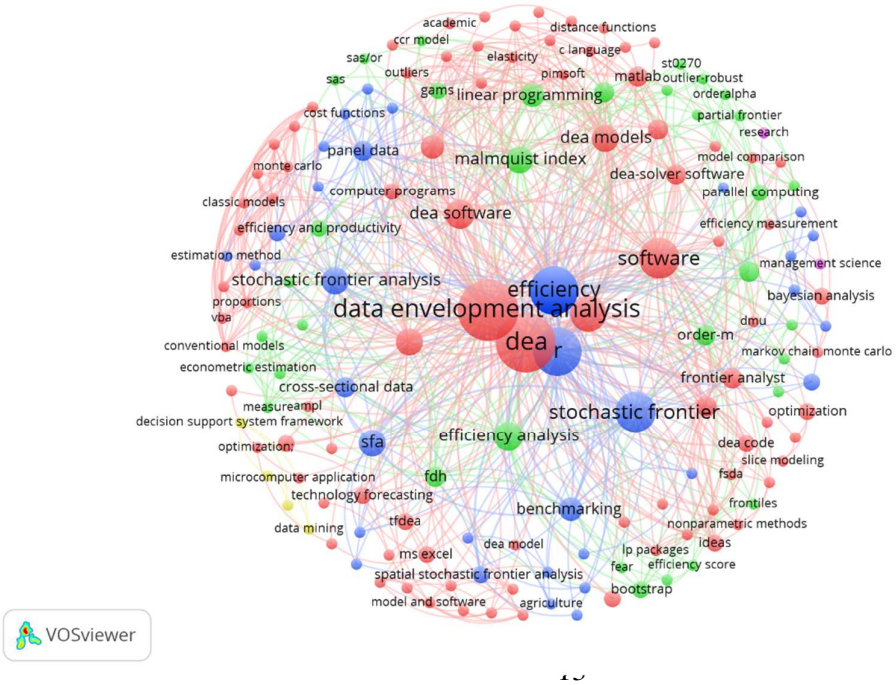
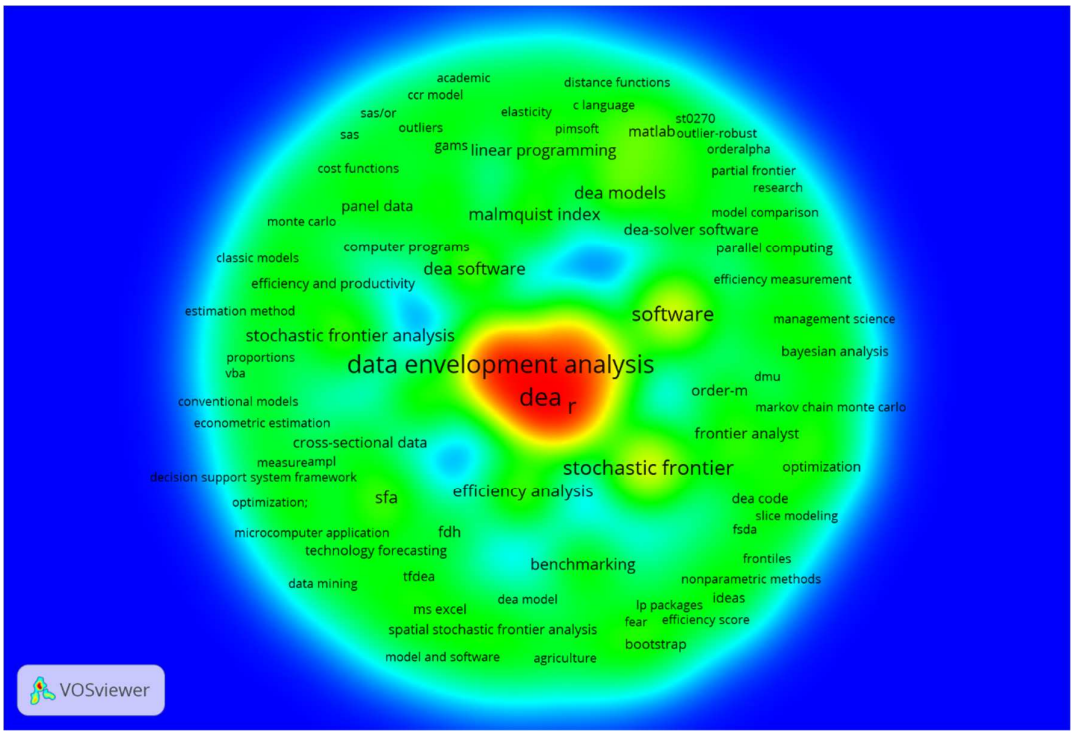


Figure 2: Density Map of Key Terms and Expressions related to Tables 1 and 2 documents



Conclusions and Future Research

In this paper we have presented a state of the art review of the existing software options available to carry out frontier estimation and PEA analysis. The information provided is probably particularly suited for applied economists interested in the interdisciplinary field of PEA, as well as to researchers and policy makers interested in the state of the art on the tools available for frontier models implementation.

The survey has been limited to searching for the software and its related documentation. In a second step we provide a summary comparative analysis on the relevant software/documents found on the basis of the self-declared information on the web site and/or reported in the documentation. This means that a systematic comparison and or assessment of the performance of the surveyed software is out of the scope this review. This could be an interesting avenue for further research. To perform such an in-depth evaluation of the software options there are several possibilities. For instance, one can contact all software distributors, develop an exhaustive classification scheme, and perform some benchmark tests. Alternatively, one can focus on the commercial publishers and ask their collaboration to define some minimal scheme of features, or one can analyse only open source or free software.

The survey carried out in this paper highlights an increasing availability of open source toolboxes and software for the implementation of many alternative or coincident efficiency models. Another interesting avenue for further research could be to foster the development of open sources available. Von Krogh and Von Hippel (2006) analysing the research on Open Source software identify different areas of its development, including *motivations of contributors* and including also *the process of innovation in*

open source software projects. In addition, they consider also the *competitive dynamics enforced by open source software.* This latter option is, perhaps, the most important motivation for our analysis. The availability of new open software for carrying out productivity and efficiency analysis indeed can lead to improve the available tools at the benefit of the communities of users and interested policy makers at hand.

A crucial unanswered question posed by the evidence reported in this paper is the following: what is the "quality" of these existing and available software tools? This is a relevant question to further address in future research. It is not an easy topic. For instance, Stamelos et al. (2002) propose three main steps for an open source code quality analysis, namely:

1) the definition of a set of "standard" software rules,
2) a source code analysis to assess the code developed and verify conformance to the selected rules
3) using the results of the assessment in the new release of the software.

The answer to this question would be important for the eventual development of an *Open Source Dynamic Digital Repository* of software for running PEA whose main features of the software and the respective maintenance could be made available to the community of practitioners and policy makers.

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[i] Toolboxes in progress but not yet released (e.g., Badin, Daraio and Simar, 2013) are not included.

[ii] Obviously, we know that a lot of researchers in the PEA area offer snippets of computer code in various languages on their web pages. Examples of such web pages include: O. Badunenko (https://sites.google.com/site/obadunenko), R. Sickles (http://rsickles.rice.edu/efficiency-software/, Sickles and Zelenyuk (2017)), H.-J. Wang (http://homepage.ntu.edu.tw/~wangh/#professional), among others. However, we believe that to systematically collect all such web sites and report results in a meaningful way is promising work for the future.

[iii] This is coherent with the main aim of this survey: i.e., to present the state of the art of the existing software options, without entering into a full scale analysis of their performance.

[iv] E.g., regression modelling, hypothesis tests, resampling simulations that support confidence intervals and the estimator's consistency, among others.
[v] LIMDEP and NLOGIT have separate prices for government and non-profit organizations. NLOGIT includes all features of LIMDEP plus an estimation component for multinomial choice modelling.
[vi] An open source version is available: Octave.
[vii] AMPL code can be run in some open source MP solvers: see http://ampl.com/products/solvers/open-source/.

Appendix

Table 1A: Query Scripts Used to Perform the Systematic Literature Survey

	Acronym	Mention
SCOPUS	(Q1)	(DEA OR Data Envelopment Analysis OR SFA OR Stochastic Frontier OR Efficiency) AND (Software OR Package OR Program OR Library) AND (Review OR Survey OR Evaluation OR Manual OR Guide OR Report)
	(Q2)	(DEA OR Data Envelopment Analysis OR SFA OR Stochastic Frontier OR Efficiency) AND (Software OR Package OR Program OR Library) AND (Review OR Survey OR Evaluation OR Manual OR Guide OR Report) AND NOT (Case Study)
	(Q3)	(Q2) AND (EXCLUDE (Human, United States, Humans, China, Energy Efficiency, Priority Journal, Eurasia, Europe, Sustainable Development, Investments, Education, Organization and Management, Ranking , Energy Utilization, Societies and Institutions, Empirical Analysis, Health Care Quality, Banking, Carbon Dioxide, Health Care, Innovation, Nonhuman, Quality Control, Environmental Management, Management Science, Controlled Study, Industrial Engineering, Information Management, Marketing, Project Management, Spain, Commerce, Environmental Impact, Health Care Cost, Management, Manufacture, Economic And Social Effects, Hospitals, Industrial Management, Strategic Planning, Agriculture, Higher Education, Logistics, Numerical Example, Brazil, Hospital, Decision Makers, Health Services Research, Industrial Economics, Telecommunication Industry, European Union, Finance, Planning, Principal Component Analysis, United Kingdom , Animals, Artificial Intelligence, Asia, Numerical Methods, Airport, Public Policy, Turkey, Air Transportation, Analytic Hierarchy Process, Empirical Studies, Health Care Delivery, Supply Chains, Economic Development, Energy Policy, Environmental Efficiency.))*
	(Q4)	(Q3) AND (EXCLUDE (Decision Making , Data Reduction, Data Handling, Operations Research, Fuzzy Sets, Regression Analysis, Economics, Industry, Competition, Neural Networks, Cluster Analysis, Data Mining, Cost Benefit Analysis, Genetic Algorithms, Set Theory, Interval Data, Constraint Theory, Elasticity, Random Processes, Banks, Forecasting, Fuzzy Data Envelopment Analysis, Numerical Model, Input-output, Uncertainty Analysis, Competitiveness, Complex Networks, Effectiveness, Electric Power Distribution, Employment, Environment, Functions, Manufacturing, Port Operation, Productivity Growth, Rough Set Theory, Australia, Design, India, Local Government, Methodology, Transportation, Agricultural Production, Bank Efficiency, Cybernetics))*
	(Q5)	(Q4) LIMITED TO Economics, Econometrics and Finance, Mathematics, Computer Science, Engineering, Multidisciplinary, Undefined
	(Q6)	(Q3) AND (EXCLUDE (Social Sciences, Decision Sciences, Agricultural and Biological Sciences, Multidisciplinary, Environmental Science, Energy, Earth and Planetary Sciences, Arts and Humanities, Physics and Astronomy, Materials Science, Chemical Engineering, Medicine, Biochemistry, Genetics and Molecular Biology, Chemistry, Health Professions))*
Google Scholar	(Q7)	(DEA OR "Data Envelopment Analysis" OR SFA OR "Stochastic Frontier" OR Efficiency) (Software OR Package OR Program OR Library) (Review OR Survey OR Evaluation OR Manual OR Guide OR Report)
	(Q8)	(DEA OR "Data Envelopment Analysis" OR SFA OR "Stochastic Frontier" OR Efficiency) (Software OR Package OR Program OR Library) (Review OR Survey OR Evaluation OR Manual OR Guide OR Report) -"Case Study"
	(Q9)	(DEA OR "Data Envelopment Analysis" OR SFA OR "Stochastic Frontier" OR Efficiency) (Software OR Package OR Program OR Library) (Review OR Survey OR Evaluation OR Manual OR Guide OR Report) -"Case Study" -Human -"United States" -China -energy -education
	(Q10)	(DEA OR "Data Envelopment" OR SFA OR "Stochastic Frontier" OR Efficiency) (Software OR Program OR Package) (Review OR Survey OR Manual OR Guide OR Report) -"Case Study" -humanities -energy -education -social -management -health -biology -art
	(Q11)	allintitle: (DEA OR "Data Envelopment" OR SFA OR "Stochastic Frontier" OR Efficiency) (Software OR Program OR Package) (Review OR Survey OR Manual OR Guide OR Report) -"Case Study"

* The specification requires that the reserved expression '(EXCLUDE (EXACTKEYWORD , "…") OR EXCLUDE (EXACTKEYWORD , "…") OR …' be inserted among the refined subject keywords.

Figure 1A: Flow Diagrams Representation of the information through the different phases of the systematic review (according to the PRISMA scheme, see Moher et al. 2009)

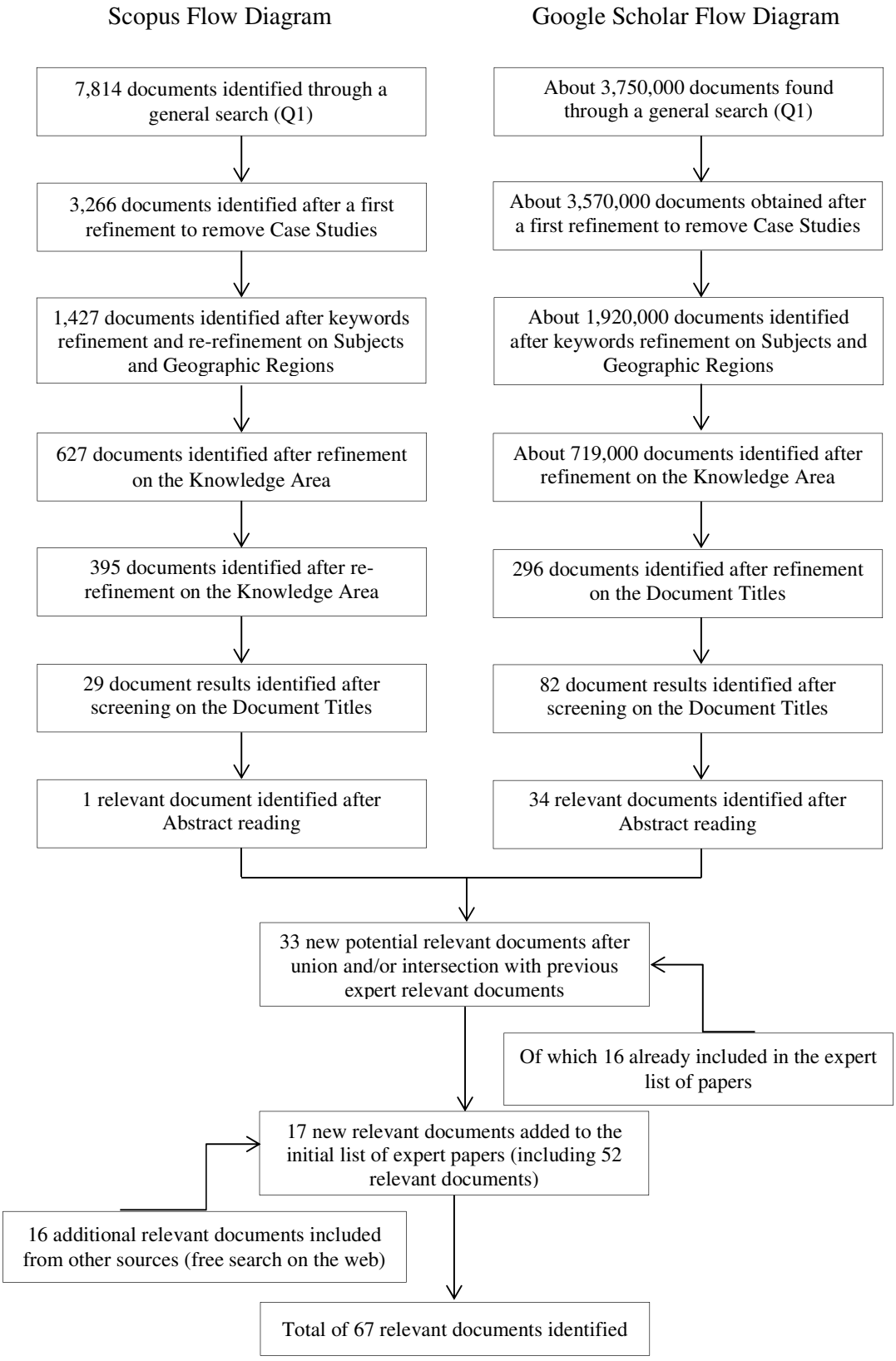

Table 2A: Keywords Occurrences and Link Strength in the Documentation Network

Keyword	Occurrences	Total Link Strength
dea	24	122
data envelopment analysis	25	119
r	16	79
software	11	74
efficiency	14	72
packages	9	67
dea software	6	45
stochastic frontier	11	43
efficiency analysis	6	40
performance measurement	5	39
malmquist index	5	38
dea models	5	29
decision-making units	3	29
stochastic frontier analysis	5	29
fdh	3	25
warwick-dea	3	25
dea-solver software	3	23
technical efficiency	4	23
computer programs	2	22
order-m	3	22
deap	3	21
sfa	5	21
panel data	3	20
benchmarking	4	19
linear programming	4	19
nonparametric	3	19
frontier analyst	3	18
efficiency and productivity	2	17
ideas	2	16
elasticity	1	15
input and output	1	15
matlab	3	15
outliers	1	15
pimsoft	1	15
returns to scale	1	15
super efficiency	1	15
bootstrap	2	14
classic models	1	13
conventional models	1	13
dea code	2	13
estimated rates	1	13
model inputs	1	13
monte carlo	1	13
monte carlo methods	1	13
performance measurements	1	13
proportions	1	13
special purpose software	1	13
spreadsheet software	1	13
spreadsheets	1	13
vba	1	13

econometric estimation	1	12
efficiency and productivity analysis	1	12
measure	1	12
measurement methods	1	12
methods for efficiency	1	12
frontier	2	11
c language	1	10
data envelopment analysis (dea)	3	10
fortran	1	10
software development	1	10
byudea dea	1	9
cross-sectional data	3	9
lp packages	1	9
onfront	1	9
parallel computing	2	9
pioneer	1	9
cost functions	1	8
dea-based performance measurement	1	8
exogenous input	1	8
free disposal hull	1	8
gams	2	8
maximum likelihood estimation	1	8
missing data	1	8
model and software	1	8
model specification	1	8
ms excel	2	8
orderalpha	1	8
outlier-robust	1	8
partial frontier	1	8
reallocation decision	1	8
salle university	1	8
stochastic frontier production	1	8
technology forecasting	2	8
tfdea	2	8
time-varying efficiency	1	8
undesirable output	1	8
alpha-quantile	1	7
efficiency score	1	7
fear	1	7
frontiles	1	7
nonparametric methods	1	7
software reviews	1	7
spatial stochastic frontier analysis	2	7
bayesian analysis	2	6
stochastic frontier analyses	1	6
agriculture	1	5
decomposition	1	5
dmu	1	5
generalized additive model	1	5
markov chain monte carlo	1	5
mathematical programming	1	5
model comparison	1	5
nonparaeff	1	5
nonparametric efficiency meseurement	2	5

optimization	2	5
ratio dea models	1	5
regularity	1	5
sas	1	5
sas/or	1	5
stoned	1	5
sustainable value	1	5
academic	1	4
algebraic modeling language	2	4
ampl	1	4
ccr model	1	4
commercial	1	4
data mining	1	4
decision support	1	4
decision support system framework	1	4
dpin	1	4
fsda	1	4
information visualization	1	4
input and output-oriented technical efficiency	1	4
interactive benchmarking	1	4
manual	2	4
maximum likelihood	1	4
object-oriented design	1	4
optimization software	1	4
production function	1	4
productivity	1	4
productivity index numbers	1	4
review models	1	4
smartdea	1	4
software metrics	1	4
software packages	1	4
truncated distributions	1	4
distance functions	1	3
estimation method	1	3
frontier models	1	3
modeling systems	1	3
multiple criteria decision making	1	3
nonparametric models	1	3
npsf	1	3
optimization;	1	3
slice modeling	1	3
spfrontier	1	3
stata	1	3
dea model	1	2
dea packages	1	2
efficiency measurement	1	2
efficiency measurement system	1	2
efficiency/inefficiency analysis	1	2
features	1	2
integrated system for decision support	1	2
maxdea pro	1	2
microcomputer application	1	2
management science	1	1

research	1	1

Table 3A: Comparative Analysis based on available documentation

General purpose software	Dimensions						
	Frontier models	System requirement	Variable and Constraints Limitation	User interface	Reports' structure	Cost	User support
AMPL (Green, 1996)	DEA models	Windows (32 or 64 bit); Linux (32 or 64 bit); MacOS; NEOS Webserver	300 DMUs, up to 90000 constraints, 300 input/output variables	Java; Matlab; C++; Visual Studio; AMPL Studio	Text file; Scripts; Graphs; Projections; Brief Summary of Detailed Results; Specific Results; Tables; Report on compilation errors	US$400 + US$300 (MINUS) for academics / US$4000 + US$9500 (CPLEX) + US$3000 (MINUS) for business	Free online Book and Reports
GAMS - dea.gms - (Kalvelagen, 2002)	DEA models	Windows Vista or newer (32 or 64 bit); Linux; MacOS X; Solaris (i86pc or SPARC 64 bit); IBM AIX	300 DMUs and constraints, 300 input/output variables, 50 discrete variables, 2000 linear non-zeros, and 1000 non-linear non-zeros	GAMS IDE or external APIs (Excel; VBA; C; Visual Basic; Java; PHP, GIS; Matlab; Gnuplot; Web Server and others)	Text file; Scripts; Graphs; Projections; Maps; Summary Tables; Codes; Brief Detailed Results; Specific Results; Compilation Errors	US$640 for academics / US$3200 for business	Free online documentation; User's Guide (US$13.22); Solver Manuals (US$13.22)
Mathematica - DEA.m - Ley (1996)	DEA models	Windows 7, 8, 8.1 and 10 (32 or 64 bit); Mac OS X 10.9, 10.10, 10.11 and 10.12; Ubuntu 12.04–16.04, RHEL and CentOS 6–7, Debian 7–8, openSUSE 12.1–13.2, Leap 42.1 and Fedora 14–24; and Webserver (Browser or Mobile App)	Unlimited constraints and variables*	Graphical User Interface	Text file; Scripts; Graphs; Projections; Plots; Tables; Maps Sounds; Codes; General Scores, Specific Results; Charts; Statistics	US$1150 for academics / US$2360 for NPO (government) / US$2620 for business	Online Wolfram Language Documentation; Email and Phone technical support; Online FAQ; Video Tutorials and Training Classes;
Matlab - DEA Toobox –	DEA models	Windows Server 2003, XP, Vista, 7, 8, 8.1 and	Unlimited constraints and variables*	GUI	Text file; Scripts; Graphs; Projections;	Free (requires the Optimization	White Paper; Online FAQ

(Álvarez et al. 2016)		10; Mac OS X 10.9.5 and 10.10; Linux Ubuntu 16.04, SUSE 12, Red Hat 6 and 7 and Debian 7 and 8			Plots; Tables; Codes; General Scores, Specific Results; Statistics, indexes; Weights, Lambdas	Toolbox - €200 for academics and €1150 for business - and Statistics and Machine Learning Toolbox (optional for bootstrapping analysis) - €200 for academics and €1000 for business)	
Matlab (Sickles and Zelenyuk, 2017)	DEA/SFA models	Ibidem	Unlimited constraints and variables*	GUI	Text file; Scripts; Graphs; Projections; Tables; General Scores, Panel Data Estimators; Specific Results; Statistics, indexes	Free (for academic uses only)	Email and Phone technical support
R - additiveDEA - (Soteriades, 2017)	Additive DEA Models	Windows NT, Server, XP, Vista, 7, 8, 8.1 and 10; Mac OS X 10.6 or newer; Linux Ubuntu OpenSuse, Debian, Redhat and Ubuntu	Unlimited constraints and variables*	R Command-Line Prompt, RStudio, JGR, R Commander, RKWard, Deducer, Rattle, Red-R	Text file; Scripts; Graphs; Projections; Plots; Tables; Codes; General Scores, Specific Results; Partial Prices; Statistics, indexes; Weights, Lambdas; Peers and Slacks	Free (requires lpSolveAPI)	User's Guide; Reference Book; Email Support
R - Benchmarking - (Bogetoft and Otto, 2015)	FDH/DEA Models	Ibidem	Ibidem	Ibidem	Ibidem	Free (requires lpSolveAPI and ucminf packages)	User's Guide; Reference Book; Email Support
R - FEAR - (Wilson, 2008)	FDH/DEA other robust Nonparametric Models	Ibidem	Ibidem	Ibidem	Ibidem	Free for academics (requires KernSmooth package)	Introductory White paper; User's Guide; Email Support

R - Frontier - (Coelli and Henningsen, 2015)	SFA Models	Ibidem	Ibidem	Ibidem	Ibidem	Free (requires additional free packages)	User's Guide; Email Support
R - Frontiles - (Daouia and Laurent, 2015)	Robust Nonparametric Eff. Models	Ibidem	Ibidem	Ibidem	Ibidem	Ibidem	User's Guide; Email Support
R - Nonparaeff - (Oh and Suh, 2015)	FDH/DEA Models	Ibidem	Ibidem	Ibidem	Ibidem	Ibidem	User's Guide; Email Support
R - npsf - (Badunenko et al., 2017)	nonparametric and parametric efficiency Models	Ibidem	Ibidem	Ibidem	Ibidem	Ibidem	User's Guide; Email Support
R - Productivity - (Dakpo et al., 2016)	DEA Models	Ibidem	Ibidem	Ibidem	Ibidem	Ibidem	User's Guide; Email Support
R - semsfa - (Ferrara and Vidoli, 2015)	Semiparametric models	Ibidem	Ibidem	Ibidem	Ibidem	Ibidem	User's Guide; Email Support
R - SFA - (Straub, 2015)	SFA Models	Ibidem	Ibidem	Ibidem	Ibidem	Ibidem	User's Guide; Email Support
R - spfrontier - (Pavlyuk, 2016)	Spatial SFA	Ibidem	Ibidem	Ibidem	Ibidem	Ibidem	User's Guide; Email Support
R - SSFA - (Fusco and Vidoli, 2015)	Spatial SFA	Ibidem	Ibidem	Ibidem	Ibidem	Ibidem	User's Guide; Email Support
R - TFDEA -	DEA Models	Ibidem	Ibidem	Ibidem	Ibidem	Ibidem	User's Guide; Email Support

(Shott and Dong-Joon, 2015)							
SAS/ETS proc qlim	SFA Models	Windows Server 2008 and 2012, 7, 8, 8.1 and 10; Linux Oracle 6.1, Red Hat 6 and 7 and SUSE 12 or later	Unlimited constraints and variables*	Multiple SAS/ACCESS Interfaces	Text file; Scripts; Graphs; Projections; Plots; Tables; Codes; Statistics, indexes; General Scores, Specific Results	Unavailable (on demand)	Free online documentation; User's Guide; Free online Tutorials, Forums, Online assistance, Email and phone technical support
SAS/OR (Emrouznejad, 2005)	DEA Models	Ibidem	Ibidem *	Ibidem	Ibidem	Ibidem	Ibidem
STATA frontier, xtfrontier	SFA Models	Windows Server 2003, 2008 and 2012, 7, 8, and 10; ; Mac OS X 10.7 or newer; Any 64 or 32-bit compatible Linux System	Unlimited constraints and variables*	GUI	Text file; Scripts; Graphs; Projections; Plots; Tables; Codes; General Scores, Specific Results; Statistics, indexes; Weights, Lambdas, Slacks, Virtual and Partial Prices information	US$295 for academics / US$595 for NPO (government) / US$595 for business	Free online documentations (Reference Guides and Manuals); Video Tutorials; Training classes (optional); Blog, Forums; Online FAQ; Phone, Fax and Email support;
STATA - DEAS - (Ji and Lee, 2010)	FDH/DEA Models	Ibidem	Ibidem	GUI	Ibidem	Ibidem	Ibidem
STATA - SFA - (Kumbhakar et al., 2015)	SFA Models	Ibidem	Ibidem	GUI	Ibidem	Ibidem	Ibidem
STATA - sfcross and sfpanel -	Panel Data Models and SFA Models	Ibidem	Ibidem	GUI	Ibidem	Ibidem	Ibidem

(Belotti and Ilardi, 2013) **STATA - tenonradial, teradial, teradialbc, nptestind, and nptestrts -** (Badunenko and Mozharovskyi 2016)	DEA/SFA Models	Ibidem	Ibidem	GUI	Ibidem	Ibidem	Ibidem

Dedicated Software	**Dimensions**						
	Frontier models	System requirement	Variable and Constraints Limitation	User interface	Reports' structure	Cost	User support
BSFM (Arickx et al. 1997)	Bayesian SFA	Unavailable	Unlimited constraints and variables*	BSFM Graphical User Interface	Unavailable	Unavailable	Unavailable
DEA-Excel (Jablonský, 2014)	DEA models	Windows XP, Vista, 7, 8, 8.1 and 10; MS Excel 97 - 2016	200 DMUs and constraints, 20 input/output variables	MS Excel spreadsheet	Text file; Graphs; Projections; Tables; General Scores and Specific Results	Free	Not Available
DEAFrontier (Zhu, 2002; 2014)	FDH/DEA Models	Windows XP, 7, 8, 8.1 and 10; MS Excel 1997 - 2003 and Excel 2007 - 2016	200 DMUs and constraints, 200 input/output variables	MS Excel spreadsheet	Text file; Scripts; Graphs; Projections; Tables; General Scores and Specific Results; Weights, Lambdas and Slacks	US$699 + US$1000 (Excel Solver) for academics / US$1499 + US$1000 (Excel Solver) for business	1-month Free Technical Support; Free User's Guide and Online FAQ; Book of models and applications (optional) (US$139.22)
DEAQual (wak2.web.rice.edu)	DEA Models	Windows NT, 2000, XP, Vista, 7, 8, 8.1 and 10; MS Excel 1997 - 2007	Unavailable	MS Excel spreadsheet	Text; Graphs; Projections; Tables; General Scores and Specific Results	Free	Unavailable

DEAOS.com (https://deaos.com)	DEA Models	Web Server (Compatible with any browser)	Unavailable	DEAOS.com Graphical User Interface (Can resort to Text Editor and/or MS Excel file)	Text; Tables; Graphs; Plots; Figures; Projections; General Scores, Indexes, Weights and Specific Results	Free	Email support
DEAP (Coelli, 1996)	DEA Models	IBM Lahey F77LEM / 32; File Manager (For early Windows 9x/NT versions), MS-DOS Windows 2000, XP, 7, 8, 8.1 and 10	Unlimited DMU's and constraints*, 99 input/output variables	DOS Command-Line Prompt, Text Editor or Excel spreadsheet	Text file with Main Scores and Results	Free	Free User's Guide; Email technical support
DEA-Solver-Pro (Cooper et al., 2006)	FDH/DEA Models	Windows 9x/NT early versions, 2000, XP, 2003, Vista, 7, 8, 8.1 and 10Excel 97 - 2016	Up to 60000 DMUs and constraints, unlimited number of input/output items*	MS Excel spreadsheet	Text; Graphs; Charts; Figures; Projections; Tables; General Scores, Summary Statistics, indexes; and Specific Results, Weights, Lambdas and Slacks	US$800 for academics / US$1,600 for business	Free User's Guide; Email technical support; Training classes (optional) (US$200 for up to 20 students)
DPIN (O'Donnell, 2010)	DEA Models	Windows XP or Vista	5000 observations (among constraints and resource items)	DOS Command-Line Prompt, Text Editor or Excel spreadsheet	Text file with Main Scores and Results	A$495 + goods and service tax for academics / A$995 + goods and service tax for business / Free Standard DPIN Edition	Free User's Guide; Email technical support
EMS (Scheel, 2000)	FDH/DEA Models	Windows 9x/NT early versions, 2000, XP, Vista, 7, 8, 8.1 and 10	5000 DMUs and constraints, 40 input/output variables	EMS Graphical User Interface (Can resort to Text Editor and/or Excel spreadsheet)	Text and Tables; General Scores and Specific Results, weights, Lambdas, Benchmarking, costs and slacks	Free	Free User's Guide; Email technical support

Frontier (Coelli, 1996b)	SFA Models	IBM compatible Lahey F77LEM / 32 with DOS extender	Unlimited constraints and variables*	DOS Command-Line Prompt, Text Editor or Excel spreadsheet	Text file	Free	Free User's Guide; Email Technical Support
Frontier Analyst (Hussain and Jones, 2001)	DEA Models	Windows XP, Vista, 7 or 10	From 75 to 20,000 DMUs and constraints,** unlimited number of input/output items*	Frontier Analyst Graphical User Interface	Text; Tables; Graphs; Charts; Maps; Efficiency Plots; Figures; Projections; General Scores, Target Values; Summary Statistics, Indexes; and Specific Results, Weights, Lambdas, Benchmarking and Slacks	From £195 to £995 + £289 (optional) (1 year maintenance) for academics / From £395 to £3995 + £289 (optional) (1 year maintenance) for business **,***	User's Guide, Workbook; 3 months free Email and telephone technical support; Remote Connection; Training class (optional) (£395 for academics or £495 for business)
Inverse DEA 1.1 (Wei et al. 2000)	Inverse DEA	Unavailable	Unavailable	Inverse DEA Graphical User Interface	Unavailable	US$890 for academics / US$2000 for business***	Unavailable
LIMDEP (Greene, 1995)	DEA/SFA Models	Windows XP, 2003, Vista, 7, 8, 8.1 and 10	50000 observations (among constraints and resource items)*	LIMDEP Graphical User Interface	Text File; Tables; Graphs; Charts; Plots; Figures; Projections; General Scores, Target Values; Summary Statistics, Indexes; and Specific Results, Weights, Lambdas, Benchmarking and Slacks	US$595 for academics / US$995 for NPO / US$1095 for business	User's Guide Documentation; Email technical support; Online FAQ and Video Tutorials
MaxDEA (Cheng, 2014)	FDH/DEA Models	Windows XP, 2003, Vista, 7, 8, 8.1 and 10	Unlimited constraints and variables*	MS Access database	Text; Tables; Graphs; Plots; Figures; Projections;	Up to US$1780 for academics / Up to US$4000 for	Free User's Guide, Textbook; Manual; Email technical

					General Scores, Dual Prices; Summary Statistics, Indexes; Weights, Lambdas, Peers and Slacks	business **,***	support; Online FAQ and Video Tutorials
NLOGIT (Greene, 2002)	DEA/SFA Models	Windows XP, 2003, Vista, 7, 8, 8.1 and 10	50000 observations (among constraints and resource items)*	NLOGIT Graphical User Interface	Text File; Tables; Graphs; Charts; Plots; Figures; Projections; General Scores, Target Values; Summary Statistics, Indexes; and Specific Results, Weights, Lambdas, Benchmarking and Slacks	US$795 for academics / US$1295 for NPO / US$1495 for business	User's Guide Documentation; Email technical support; Online FAQ and Video Tutorials
OnFront	DEA Models	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable
Open Source DEA (opensourcedea.org)	DEA Models	Windows 7, 8, 8.1 and 10; Mac OS X and Linux Systems	Unlimited constraints and variables*	Open Source DEA Graphical User Interface	Text; Scripts; Tables; Graphs; Code; Plots; Figures; Projections; General Efficiency Scores and Status, Indexes; Weights, Peers and Slacks	Free	Online User's Guide (Tutorials); Troubleshooting Guide; Email support
PIM-DEAsoft (Thanassoulis, 2001)	DEA Models	Windows 2000, XP, 2003, Vista, 7, 8, 8.1 and 10	50 DMUs and constraints, unlimited number of input/output items*	PIM-DEASoft Graphical User Interface	Text File; Tables; Graphs; Charts; Plots; Figures; Projections; General Scores, Summary Statistics, Indexes; and Specific Results	£100 for academics / £200 for business	Email technical support; Training classes (optional); 3 months free maintenance;
ISYDS (SIAD) (Meza et al., 2005)	DEA Models	Windows NT, XP, 2003, Vista, 7, 8, 8.1 and 10	150 DMUs and constraints, 20 input/output variables	ISYDS Graphical User Interface	Text; Tables; General Scores	Free	Paper

SmartDEA (Akçay et al., 2012)	DEA Models	Windows 2000, XP, 2003, Vista, 7, 8, 8.1 and 10	Unavailable	SmartDEA Graphical User Interface (Can be integrated to MS Excel spread sheet)	Text; Tables; Graphs; Plots; Figures; General Scores	Unavailable	Unavailable
TFPIP (Coelli, 1997)	DEA Models	IBM Lahey F77LEM / 32; File Manager (For early Windows NT versions), MS-DOS Windows 2000, XP, 2003, 7, 8, 8.1 and 10	Unlimited constraints and variables*	DOS Command Prompt and Text Editor	Text file	Free	Free User's Guide; Email support
WebdeA (sites.google.com/ site/dsslabunipi/tools)	DEA Models	Web Server (Compatible with any browser)	Unavailable	Webdea Graphical User Interface (Can resort to Excel spreadsheet or Text Editor)	Text; Tables; Figures; Projections; General Scores; Specific Results, Indexes, Slacks, Weights, Lambdas	Free	Online Summary of Features; Video Tutorials; Email support;
WinBUGS Griffin and Steel, 2007)	SFA Models	Windows NT, Server (2003, 2008 and 2012), XP, Vista, 7, 8, and 10	Unlimited constraints and variables*	WinBugs Graphical User Interface	Text; Tables; Graphs; Plots; Figures; Projections; General Scores, Indexes, Weights and Specific Results	Free	User's Guide; Book (£27.76) Training classes (optional); Online FAQ; Email support

* Limited by CPU memory capacity

** Depending on the purchasing order

*** Perpetual license (no need of renewal)