Professor Simona Cătălina ȘTEFAN, PhD
E-mail: simona.stefan@man.ase.ro
The Bucharest University of Economic Studies

Professor Ion POPA, PhD
E-mail: ion.popa@man.ase.ro
The Bucharest University of Economic Studies

Professor Cezar-Petre SIMION, PhD
E-mail: cezar.simion@man.ase.ro
The Bucharest University of Economic Studies

Teaching Assistant Ștefan Cătălin POPA, PhD
E-mail: catalin.popa@man.ase.ro, Management Department,
The Bucharest University of Economic Studies

Associate Professor Marius-Ioan PANTEA, PhD
E-mail: marius.pantea@e-uvt.ro
Management Department, West University of Timișoara

Associate Professor Daniel BOTEZ, PhD
E-mail: daniel63331@yahoo.com
“Vasile Alecsandri” University of Bacău

MEASURING THE EU MEMBER STATES RD&I AND TECHNOLOGY TRANSFER PROCESS EFFICIENCY: A DEA APPROACH

Abstract. *The main objective of this paper is to analyse the efficiency of the technology transfer process in the 27 EU member states in support of the strategies formulation to improve the efficiency of technology transfer processes. Therefore, a conceptual framework was proposed based on the efficiency of the RD&I system and technology transfer. Following this conceptual framework, two DEA models were applied to evaluate the efficiency of the two subprocesses (RD&I system and technology transfer). The results revealed some highly efficient DMUs, but also that a relatively large number of countries are inefficient in terms of one or both subprocesses of technology transfer. The article also presents a series of strategies that policy makers can adopt to directly or gradually improve technology transfer efficiency to reach countries with highly efficient transformation of human and financial resources allocated to RD&I into visible results in the economic sector.*

Keywords*: DEA, efficiency, RD&I, technology transfer*

JEL Classification: C02, C11, C45, C46, C63

DOI: 10.24818/18423264/57.1.23.13

1. INTRODUCTION

Globally, but also in the European Union, the issue of the efficiency of R&D activity is an important one that has preoccupied decision-makers in the field for a very long time. Europe, as a whole, is less likely than other areas to turn research results into commercial successes. Mansfield (1975) pointed out that technology transfer (TT) is one of the elements that conditions performance at both the microeconomic and macroeconomic levels, and its efficiency influences the economic growth and development of countries. One of the Commission's reports (2007) stated that European universities have far fewer inventions and patents than North American universities. The situation remains the same today.

Evaluating the efficiency of R&D activity has been a matter of interest for researchers because R&D is complex systems with successions of inputs and outputs (Guan et al., 2016). Data envelopment analysis (DEA) is the most used method to measure the efficiency of R&D activity (Wang and Huang, 2007; Chen, Ku and Fu, 2018), but also of TT processes (Anderson, Daim and Lavoie, 2007; Gao et al. 2019). The research conducted in this article had as objectives: (1) analyse the efficiency of the RD&I system and the process of transfer of technology to the economic sector in the 27 EU member states and (2) formulation of strategies to improve the efficiency of the overall TT process.

The importance of this study lies in the fact that it conducts an analysis of the effectiveness of RD&I at the European Union level, but also that, compared to other previous studies (relatively few in all European Union countries), it proposes a series of measures by which certain countries achieve an improvement in TT processes and the efficiency of the national research system.

2. LITERATURE REVIEW

The concept of R&D has over time countless approaches and meanings, most of which equate the term with a systematic process conducted to discover, interpret, revise/reinterpret new theories, phenomena, events, facts, behaviors or practical applications of theories, legal phenomena, or events. Especially in the context of moving toward an information society, each country perceives its own RD&I system as a knowledge, results, new or improved process generator, which are capitalised by the economic environment through TT processes (Ștefan et al., 2020). There are several studies in the literature which showed that the progress of science and technology is the main indicator of long-term sustainable development and economic growth. Numerous studies have also been conducted showing the effect of investments in RD&I on the productivity and profitability of firms in various industries and economic sectors (Gonzalez and Gascon, 2004).

Other studies, such as those conducted by Arvanitis et al. (2008) and Bishop et al. (2011), showed the influence of research conducted by universities on the innovative potential of companies and the influence of research conducted from public funding sources on research conducted at the firm level. For example, the study conducted by Arvanitis et al. (2008) showed that new knowledge emerged from research conducted by universities had a positive impact on the volume of sales of new products in the case of companies. Bishop et al. (2011) concluded that the interaction of companies with universities intensifies the use of research results in the form of patents and new solutions to solve problems.

However, the vast majority of the existing literature on TT is focused on the public sector as a source of TT and on the private sector as the recipient of this process (Thursby and Thursby, 2007). Research institutes and publicly funded universities are the main generators of results that are taken over in the private sector through TT processes. Christensen (2013) considers that the scientific knowledge generated by universities can be the basis for the creation of new industries and can make a significant contribution to economic development.

That is why many countries have tended in recent decades to increase government spending on the RD&I sector because they are aware of the role that the results of this sector play in the competitiveness of nations. However, only the increase in R&D spending (approached in recent decades as investment in R&D) does not guarantee scientific and technological progress, nor does it transfer the results of research to the economic and social environment. That is why most governments have tried to prioritise investment in research and development (especially those for the public sector) and to use new mechanisms for funding research and development based on competitiveness. Therefore, trust-based funding has been replaced by performance-based funding as a research policy tool applicable to the public sector (Sorlin, 2007).

If initially the studies in the literature focused on the resources allocated to research and later development, the problem of the efficiency of the allocation of these resources appeared in the specialised literature. The formulation of resource allocation policies in the RD&I sector is influenced by the evaluation of the efficiency / inefficiency of activities in this field.

Wang and Huang (2007) applied the production framework associated with DEA to quantify the efficiency of research activities in 30 countries. They found that less than half of the 30 countries are effective in terms of net efficiency and that most countries have greater benefits in terms of publications than in terms of patents. Wang and Huang concluded that for most of the countries analysed, the effectiveness of public policies in the field of research and development must increase, as well as the efficiency of research and development activity. The main limitation of Wang and Huang's research is that it did not consider a complete list of output indicators. Hashimotoa and Haneda (2008) used a DEA / Malmquist index methodology to measure changes in R&D efficiency of the Japanese pharmaceutical industry at both firm and industry level. The research conducted by Hashimotoa and Haneda (2008) revealed a significant reduction in the R&D efficiency of the Japanese pharmaceutical industry during the ten years analysed. Firms continued to increase the financial resources allocated to R&D, although the efficiency of R&D activities at the company level did not improve.

Beneito, Rochina-Barrachina and Sanchis (2015) analysed R&D efficiency starting from the observation that innovation rates vary at the level of companies and using data from manufacturing firms in Spain. They concluded that, at the level of the companies analysed, the results of innovation activity within the companies depend on the duration of the investments in research and on the interruptions that appear in the realisation of the research-development activities. Reduced commitment at the company level to research-development activity generates a reduction in R&D efficiency.

Chen, Ku and Fu (2018) proposed a new dynamic model of DEA for measuring the efficiency of multiperiod regional R&D activities. They applied this dynamic model to China's regional research and development systems. Han et al. (2017) investigated the effect of investments in R&D activity on the efficiency of R&D activity in China's high-tech industry. Based on the use of DEA to generate quantitative indices at the sectoral level in this study, the authors concluded that the efficiency of investment in research did not increase although R&D spending in China's high-tech industry increased significantly over time. analysed. The main identified problem was the inefficiency of TT and, in general, the commercialisation of the research results.

Xiong, Yang and Guan (2018) used a two-stage dynamic DEA model to evaluate the R&D activity carried out in the research institutes of the Chinese Academy of Sciences during 2012-2015. Research by Xiong, Yang and Guan has shown that institutes have had a number of improvements in R&D efficiency based on increasing the efficiency of TT processes. However, there is still much to be done at the level of the analysed entities to improve the transfer processes of the results of research activities and new technologies. Another situation seems to exist in the case of the efficiency of TT carried out in Chinese universities. According to research by Gao et al. (2019) using the two-stage DEA model, TT from Chinese universities is inefficient and the effect of public funding on the efficiency of TT processes is negative, except for the top universities. The research conducted by Gao et al. (2019) seems to confirm the results previously obtained by Anderson, Daim and Lavoie (2007) using a DEA approach to measure the efficiency of TT processes within universities, their research showing that top universities have a high technological transfer efficiency.

In the literature, the issue of R&D efficiency and TT has been addressed using DEA in various variants both at the level of entities involved in TT processes (universities, institutes, companies) and at the level of industries, regions, or countries. However, studies on R&D efficiency and TT in countries of the European Union through the use of DEA are relatively few and do not refer to all countries of the European Union. This is an additional argument in favour of the usefulness of this study.

3. CONCEPTUAL FRAMEWORK OF TT EFFICIENCY ANALYSIS

RD&I sector efficiency analysis has been an important research direction over time, both internationally and in Romania. As the level of analysis was tackled at organisational, regional, or country levels. However, most of these studies analysed the efficiency of the RD&I sector as a whole, not considering the complexity of this process and the fact that its results at the organisational level are, in fact, those felt in the economic sector.

TT is considered to be a complex process, including a stage of creation/accumulation of new technologies and a stage of their dissemination. The success of this process, as a whole, depends on a good management of all the activities involved (Ho, Liu, Lu & Huang, 2014). Therefore, the conceptual framework to analyse the efficiency of the TT process in the EU member states that we propose (Figure 1) implies an overall process that includes two subprocesses. The first subprocess takes place within the RD&I system. At this level, specific human and financial resources are transformed into intermediate outputs, which, in turn, will become inputs for the second subprocess, that of TT itself. Thus, we start from the premise that the global process is efficient only insofar as both subprocesses are, in turn, efficient.

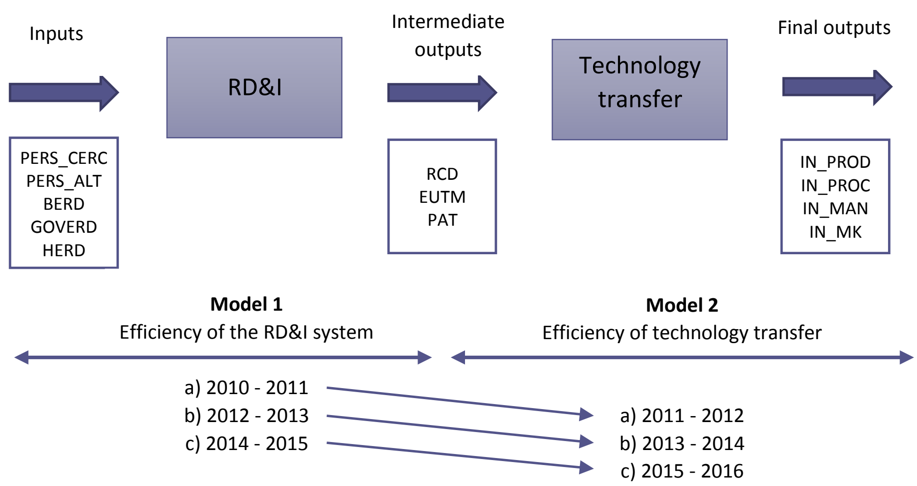


Figure 1. Conceptual framework for analysing the efficiency of TT
Source: adapted from Wang, Hang, Sun, & Zhao (2016); Guan & Chen (2010)

Given that it is assumed that the results of each of the subprocesses do not appear immediately but at a certain time interval, similar research used a time lag between input and output variables, varying between two (Cullmann, Schmidt-

Ehmcke & Zloczysti, 2012) and three years (Guan & Chen, 2010; Wang & Huang, 2007). Therefore, in the case of this research, the input variables for Model 1 were collected for the years 2010, 2012 and 2013, those for intermediate outputs for 2011, 2013 and 2015, and the variables representing the final outputs – 2012, 2014 and 2016, therefore at a difference of one year for each of the subprocesses.

4. MATERIAL AND METHODS

4.1. Data envelopment analysis (DEA)

DEA is a data-oriented technique which can determine, on the basis of specific input and output variables, which of the analysed countries efficiently transform inputs into outputs, and to what extent other countries are inefficient in this process. Therefore, the nonparametric technique of DEA was selected. According to Wang and Huang (2007), the DEA technique is suitable for evaluating the efficiency of R&D activities for several reasons: (1) it does not require specific weights of the input and output variables, thus overcoming the impossibility of attaching a relative importance of the same R&R results, since they do not have a market price, (2) DEA can handle simultaneous multiple inputs and outputs, (3) the functional relationship between inputs and outputs should not be specified, and (4) it required very few assumptions, thus making it preferable to analyse multiple and complex relationships (sometimes unknown) between multiple input and output variables (Cooper, Seiford, Zhu, 2004). Since it is a benchmarking technique, in addition to the efficiency relative scores, additional information is also provided, which may be used to improve the efficiency of not so efficient DMUs, so they may move to the efficiency frontier.

4.2. DEA models and variables

For this study, the 27 member countries were considered decision-making units (DMU). The comparative analysis of the efficiency of TT in the 27 EU member states will (also) involve two stages, for each of which a DEA model will be built. This approach will also allow for the identification (for each country) of the subprocesses that are responsible for the inefficiency of the overall process, as well as ways to streamline them.

To obtain relevant efficiency results, it is important to select the appropriate input and output variables. Some of the input and output variables used in the two DEA models are also found in other literature research on RD&I efficiency and TT. Hashimotoa and Haneda (2008) considered the financial resources allocated when using DEA / Malmquist index methodology to measure changes in R&D efficiency of the Japanese pharmaceutical industry. Wang and Huang (2007) used in the analysis: researchers, technicians, and patents. Guan et al. (2016) used full-time equivalent researchers (FTE) to measure R&D manpower and gross domestic expenditure on R&D (GERD). Anderson, Daim and Lavoie (2007) considered as inputs total research spending, license and option agreements, patent application, and as outputs licensing income, startup companies. Beneito et al. (2007) considered average number of product innovations, current R&D

expenditures (running costs). Chen, Kou and Fu (2018) used in the analysis of R&D capital stock, R&D expenditure, R&D personnel, domestic granted patents.

The previous research mentioned above provided information on the kinds of variables that we should consider as inputs and outputs of the two proposed models. They are briefly presented in the following and are included in Table 1, along with their sources.

Table 1. Input and output variables

Variables		Symbol	Unit of measure	References	
Input variables for model 1					
X1	R&D personnel - researchers	PERS_CERC	FTE	Eurostat, 2020a	Total R&D personnel by sectors of performance, occupation and sex
X2	R&D personnel – other than researchers	PERS_ALT	FTE		
X3	Intramural R&D expenditure in the business enterprise sector	BERD	Million euro	Eurostat, 2020b	Intramural R&D expenditure by sectors of performance and type of R&D activity
X4	Intramural R&D expenditure in the government sector	GOVERD	Million euro		
X5	Intramural R&D expenditure in the higher education sector	HERD	Million euro		
OUTPUT VARIABLES FOR MODEL 1/INPUT VARIABLES FOR MODEL 2					
Y1	Registered community designs	RCD	Number	Eurostat, 2020c	Registered Community designs
Y2	European union trademark applications	EUTM	Number	Eurostat, 2020d	European Union Trademark Applications
Y3	Patent applications to the EPO by priority year	PAT	Number	Eurostat, 2020e	Patent applications to the EPO by priority year
OUTPUT VARIABLES FOR MODEL 2					
Z1	Product innovative enterprises	IN_PROD	Number	Eurostat, 2020f; 2020g; 2020h	Community Innovation survey, 2012, 2014 and 2016
Z2	Process innovative enterprises	IN_PROC	Number		
Z3	Organisation innovative enterprises	IN_MAN	Number		
Z4	Marketing innovative enterprises	IN_MK	Number		

Note: FTE – full-time equivalent. *Source: authors' conception*

To follow the evolution in time of the efficiency measured by the two models, each of them considered three successive intervals, respectively, 2010-2012, 2012-2014, and 2014-2016, data were collected for period 2010-2016, the analysed period being limited by data availability. All data sets were retrieved, for the 27 EU member states from the Eurostat database (see Table 1 for each reference), being processed by means of DEAP application, version 2.1 (Coelli, 1996).

5. EMPIRICAL RESULTS

Six models were built, for each of them the input and output data being selected from three consecutive intervals (2010-2012, 2012-2014 and 2014-2016). To obtain relative efficiency scores, DEA, assuming variable return-to-scale (VRS) and constant return-to-scale (CRS) were used. Based on the assumption that the 27 countries aim to maximise the output values resulting from the given inputs, the output-oriented DEA models were selected.

5.1. Analysing the efficiency of the RD&I system efficiency (Model 1)

The first analysis of the two-stage process was the RD&I system. In order to be provided a dynamic picture for a 6-year time span, three separate DEA models were built for three successive intervals, respectively, 2010-2011 – Model 1a, 2012-2013 – Model 1b and 2014-2015 – Model 1c. The technical efficiency (TE) and scale efficiency (SE) scores are presented in Table 2.

Table 2. Technical and scale efficiency relative scores of the RD&I system

Country (DMU)	**Model 1a (2010-2011)**			**Model 1b (2012-2013)**			**Model 1c (2014-2015)**		
	TE		**SE**	**TE**		**SE**	**TE**		**SE**
	CRS	VRS		CRS	VRS		CRS	VRS	
Number of efficient DMUs	13	14	13	11	15	11	11	16	11
Mean score	0.802	0.844	0.945	0.744	0.839	0.876	0.785	0.858	0.917
Minimum score	0.203	0.221	0.453	0.226	0.247	0.446	0.263	0.266	0.383

Note: CRS – constant return to scale. VRS – variable return to scale. TE - Technical efficiency. SE – scale efficiency. RS – return to scale. drs – decreased return to scale. irs – increased return to scale. Source: own calculations based on the data series mentioned and estimated using DEAP2.1 (Coelli, 1996).

Regarding the efficiency of the RD&I sector, it can be seen that there are a fairly large number of countries whose RD&I systems are capable of turning financial and human resources into outputs with maximum efficiency. When referring to the **VRS technical efficiency** of RD&I systems, more than half of the countries analysed operate at maximum efficiency and their number is increasing (from 14 in 2010-2011 to 16 during 2015-2016). On the other hand, there are also Croatia and, to a lesser extent, Greece and the Czech Republic, whose average score for the entire period analysed is less than 0.5. Taking into account the **technical efficiency in the CRS hypothesis**, the number of countries whose RD&I system is efficient is significantly lower and decreases during the analysed period (from 13 in the period 2010-2011 to 11 in the period 2014-2015). On the other hand, for all three periods analysed, the average score of technical efficiency in the CRS hypothesis is lower than the technical efficiency in the VRS hypothesis, which means that the inefficiency is due not only to the way in which RD&I systems are able to turn inputs into outputs but also to the inadequate scale at which they operate. In this respect, in addition to Croatia, Greece, and the Czech Republic, also Lithuania and Spain can be mentioned.

It can also be seen that for nine of the countries analysed (Austria, Bulgaria, Cyprus, Denmark, Germany, Latvia, Luxembourg, Malta, and the Netherlands), both the score of pure technical efficiency and that of scale efficiency (SE) are maximum for all three analysed intervals, which recommends them as examples both in terms of the efficient way of transforming resources into results, operating on an appropriate scale, and for the constancy with which they manage this performance.

In order to analyse the efficiency of the Romanian RD&I system in a European context, we first compared the evolution of the technical efficiency score of the Romanian RD&I system with the EU27 average score (Figure 2a). As shown in Figure 2a, if in the 2010-2011 interval the VRS relative score of Romania was roughly the EU average (0.839 compared to 0.844), in subsequent periods of acquaintances it fluctuated, dropping below the EU average in 2012-2013 (to 0.759), while in 2014-2015 it increased much above this average, reaching the value of 1.000, which indicates maximum efficiency. Considering the CRS hypothesis (which also includes scale efficiency), the efficiency of the Romanian RD&I system was lower than the EU27 average in the period 2010-2011 and 2012-2013, while in the period 2014-2015 it far exceeded this average, reaching maximum efficiency (1.00).

5.2. Analyzing the TT process efficiency (Model 2)

The second stage of the two-stage process proposed in the research framework was the TT stage, through which intermediate outputs are transformed into final outputs useful for the economic sector, represented by the number of enterprises that have introduced new products, new processes, new management, or marketing methods. To calculate technical efficiency (TE) and scale efficiency (SE) scores for three consecutive intervals, three separate DEA models were also built, respectively, 2011-2012 – Model 2a, 2013-2014 – Model 2b, and 2015-2016 – Model 2c. The technical efficiency (TE) and scale efficiency (SE) scores are presented in Table 3.

Table 3. Technical and scale efficiency relative scores of the TT process

Country (DMU)	Model 2a (2011-2012)			Model 2b (2013-2014)			Model 2c (2015-2016)		
	TE		SE	TE		SE	TE		SE
	CRS	VRS		CRS	VRS		CRS	VRS	
Number of efficient DMUs	2	9	2	1	12	1	2	11	2
Mean score	0.342	0.734	0.449	0.382	0.785	0.493	0.389	0.749	0.527
Minimum score	0.059	0.195	0.101	0.128	0.241	0.129	0.112	0.242	0.181

Source: own calculations based on the data series mentioned and estimated using DEAP2.1 (Coelli, 1996).

Regarding the efficiency of transfer of technology to the economic sector (models 2a, 2b, and 2c), it can be seen that there are also a number of countries that are able to efficiently transform intermediate outputs into final outputs. However, it can be noted that, compared to the first three models analysed, the number of countries that carry out the TT process efficiently is smaller, and the biggest differences can be observed in the CRS technical efficiency. Regarding the **technical efficiency of VRS,** it can be seen that for seven of the countries analysed (Croatia, Czech Republic, Germany, Greece, Italy, Malta, and Portugal), the relative scores are maximum for all three intervals analysed, which recommend them as examples, both in terms of the efficient way of transforming resources into results and for the constancy with which they manage this performance. On the opposite side are Luxembourg, Denmark, and, to a lesser extent, Slovakia and Slovenia, whose average score for the whole analysed period is less than 0.5. From the perspective of CRS technical efficiency, only Croatia has maximum efficiency in the three analysed periods, while Malta and Lithuania only during 2015-2016. On the other hand, for the three periods analysed, the average score of the CRS technical efficiency is much lower than that of the VRS technical efficiency, which means that the inefficiency is due not only to the way that they are able to transform the intermediate outputs into final outputs. But also, to inadequate operating scale. It should also be noted that for almost all countries where the TT process is not carried out with maximum efficiency, there is a decreased return to scale. However, among the most inefficient CRS TT processes are those in Denmark, Luxembourg, and Spain. However, note that in many of these cases, the inefficiency is largely due to scale inefficiency.

To analyse the efficiency of the TT process in Romania in a European context, we first compared the evolution of the VRS and CRS technical efficiency score for Romania with the average score of the 27 European countries. This evolution is illustrated in Figure 2b.

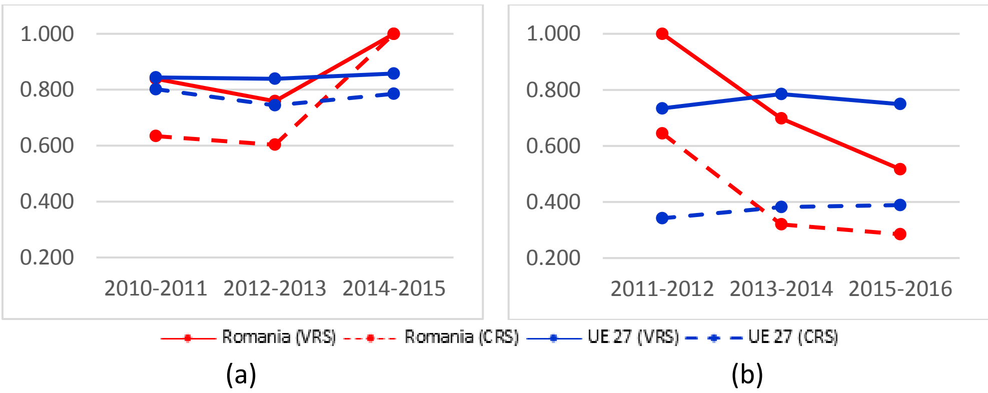


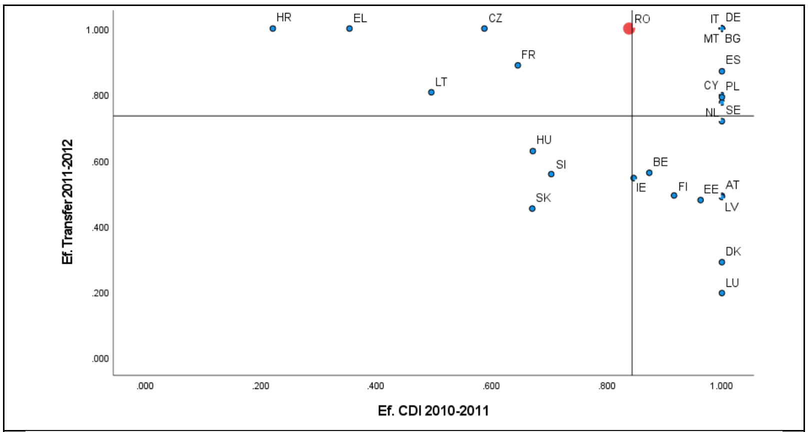
Figure 2. RD&I system's (a) and TT process (b) technical efficiency scores of the Romanian compared to the EU27 average

In the VRS hypothesis, as can be seen in Figure 2b, if in the 2011-2012 period the relative score of Romania was the highest (1.00), in the next interval it experienced a sharp decline, falling well below the EU27 average (to 0.698 in 2013 -2014 and 0.517 in 2015-2016). Furthermore, assuming CRS (which includes scale efficiency), the efficiency of TT in Romania is (also) above the EU27 average in 2011-2012, while in 2014-2015 it fell below the EU27 average, reaching 0.320 during the interval 2013-2014 and 0.285 in 2015-2016. As in the case of many of the 27 European countries, it can be seen that the relative score of the efficiency of the TT process in the CRS hypothesis is much lower compared to the VRS hypothesis, which denotes low scale efficiency. This difference, although also observed in the analysis of the RD&I system (Model 1), is much more obvious for the TT process (Model 2).

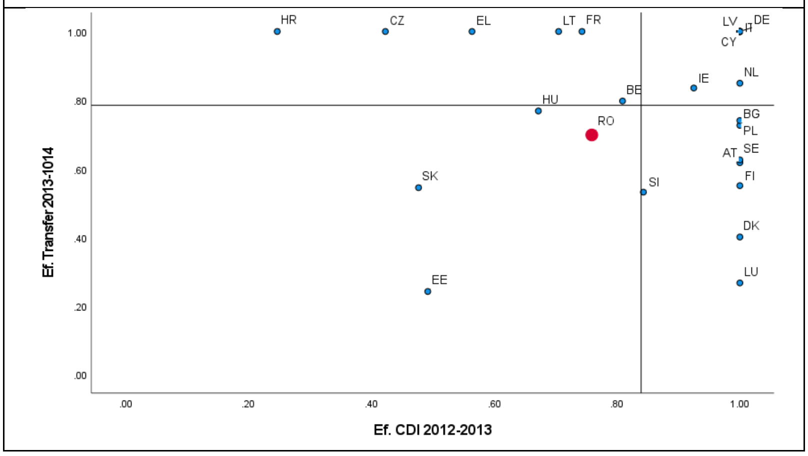
5.3. Integrated analysis (M1 and M2)

According to the conceptual framework, the overall process of transforming the human and financial resources allocated to the RD&I sector into visible results in the economic sector is integrated and includes two subprocesses. We thus start from the premise that the global process is efficient only insofar as the two subprocesses are in turn efficient. Moreover, the proposed conceptual framework also allows the identification (for each country) of the subprocesses that are responsible for the inefficiency of the global process.

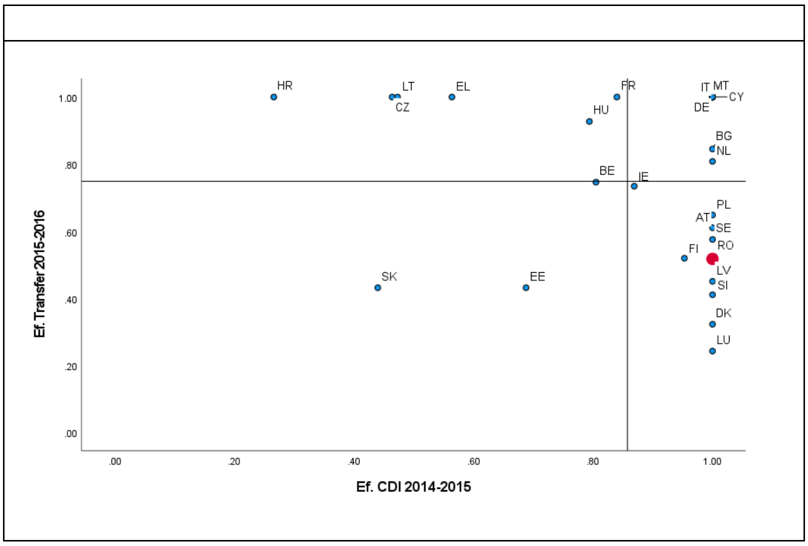
In this sense, in the following tree figures (3 a, b, and c), the 27 countries analysed were represented, for each of the three intervals, as follows: (1) On the horizontal axes: the relative scores of the VRS technical efficiency of the RD&I system, highlighting the countries with a maximum score, those with scores above the EU27 average and those with scores below this average, and (2) Vertical axes: the relative scores of the VRS technical efficiency of the TT processes, highlighting (also) the countries with a maximum score, above the EU27 average and below this average, respectively.



(a)
2010 - 2012



(b)
2012 - 2014



(c)
2014 - 2016

Figure 3. Integrated analysis of technological transfer efficiency

Depending on the position on the two axes, four groups of countries can be delimited:

- *Group A*. There are a few countries (such as Croatia, Greece, and the Czech Republic) to which France and Lithuania are added in the last two intervals, whose RD&I system is among the most inefficient (according to Model 1), but which transforms with maximum efficiency intermediate outputs in new or improved products and processes and new managerial and marketing approaches (according to Model 2).
- *The second group (group B*) includes Germany, Italy, Malta, and Portugal. These countries are efficient, in all three periods analysed, both in terms of transforming human and financial resources into intermediate outputs (according to Model 1) and transferring these results to the economic sector (according to Model 2). To these can be added Bulgaria in the period 2010-2012, Cyprus, Latvia, and Spain in the period 2012-2014, and Cyprus and Spain in 2014-2016.
- *The third group (group C*) is that of countries for which the VRS technical efficiency score is below the EU average in terms of both the efficiency of the RD&I sector and TT. This category includes Slovakia for all analysed intervals, Hungary and Slovenia for 2010-2012, Estonia, Hungary, and Romania in 2012-2014, and Estonia in 2014-2016.
- *Group D* includes Luxembourg, Denmark, Austria and Sweden, whose RD&I system operates with maximum efficiency in all three analysed intervals (according to Model 1) and transforms intermediate output much more efficiently into new or improved products and processes and new managerial and marketing approaches (according to Model 2).

Groups A, B, and D may also include countries whose technical efficiency of the RD&I sector and/or TT, although not maximum, is above the average of the EU27.

As can be seen, the situation is different from country to country, this recording (the other side), and changes in time by switching from one group to another. For instance, in the case of Romania:

- In the period 2010-2012 Romania was placed in group A, having a maximum efficiency of the TT process, but a score below average for the efficiency of the RD&I system.
- In the next period (2012-2014), there was a decrease in the relative score of the transfer process efficiency, but also a smaller decrease in the relative score of the RD&I system efficiency, so that it was included in group C.
- The period 2014-2016 was marked by a better use of RD&I resources, so that the relative efficiency score increased, reaching 1.00, while the efficiency of the second subprocess, respectively, that of the transformation of intermediate output into final ones, it was achieved with decreasing efficiency. As a result, in the period 2014-2016 Romania was included in group D.

6. STRATEGIES TO IMPROVE THE EFFICIENCY OF THE OVERALL TT PROCESS

As stated, according to the conceptual framework, the overall process of TT is an integrated one, which assumes that it is effective only insofar as the two subprocesses are in turn efficient. After, in the previous subchapter, the subprocesses that are responsible for the inefficiency of the global process have been identified for each country, it becomes possible to outline strategies for streamlining the global process.

In this regard, the model proposed by Wang, Hang, Sun and Zhao (2016) to improve the innovation processes of newly established enterprises in the energy field in China can be adopted. The model is illustrated in Figure 4.

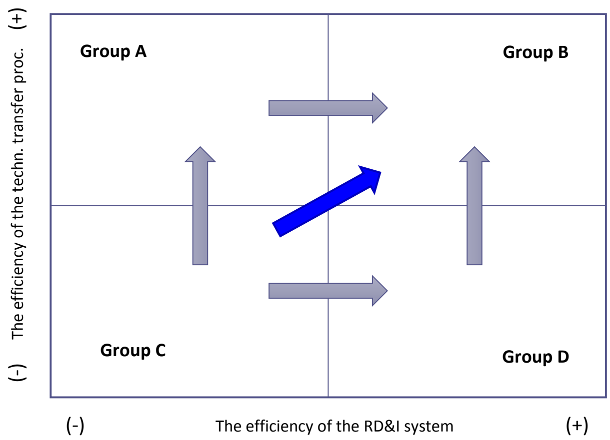


Figure 4. Strategies for streamlining the global TT process
Source: adapted from Wang, Hang, Sun, & Zhao (2016)

According to the model, for countries in groups A, C and D, three strategies can be followed to become efficient, both in terms of the RD&I system and TT, and therefore to be included in group B (Wang, Hang, Sun & Zhao, 2016):

- Method 1 (A → B and D → B). The first method is applicable to countries included in groups A and D and consists of optimising only one of the subprocesses, namely, the one at the level of the RD&I system or the TT process so that the countries in these groups would reach group B.
- Method 2 (C → A → B or C → D → B). The second way is a gradual one, being applicable to the countries that at a certain moment belong to group C. It consists in the optimisation, in a first stage of one of the subprocesses (the one at the level of the RD&I system, or the technological transfer), thus reaching group D or A, in order to address in the second stage, the efficiency of the other subprocess, following which the country will be included in group B.
- The third method (C → B) is also applicable to countries that are currently in group C and consists of a simultaneous optimisation of both subprocesses, thus directly moving into group B.

For each of the ways to streamline the TT process described above, the DEA analysis also makes it possible to determine targets for input and output variables for each of the inefficient countries, in order to achieve, in turn, maximum efficiency.

Going further on the example of Romania, for Model 1, Table 4 includes both the initial values of the input and output variables and the efficiency opportunities (including “radial movement” and “slacks”), by increasing the output, respectively, the registered community designs (RED), European Union trade mark applications (EUTM) and patent applications (PAT) and the elimination of excess inputs, respectively, number of researchers (PERS_CERC), staff engaged in research, excluding researchers (PERS_ALT), and research expenditure in the government sector (GOVERD). Furthermore, in an output-oriented DEA, reducing excess input would not increase the efficiency of the RD&I system efficiency; however, it could be done without affecting it. It should be noted that the only inputs that are not in excess in any of the periods when the RD&I system is inefficient are expenditure on research in companies (EBRD) and those in higher education (HERD).

Table 4. Opportunities for efficiency improvement - Model 1

Variables	Model 1a (2010-2011)		Model 1b (2012-2013)		Model 1c (2014-2015)	
	Initial values	**Possible improv.**	**Initial values**	**Possible improv.**	**Initial values**	**Possible improv.**
RCD	150	190.480	173	167.728	213	0
EUTM	635	121.466	462	146.596	650	0
PAT	60.420	11.557	85.100	27.003	93.510	0
PERS_CERC	19780	-13726.500	18016	-13883.544	18109	0
PERS_ALT	6391	-3933.89	13119	-10525.214	13282	0
BERD	219.548	0	251.034	0	238.410	0
GOVERD	210.672	-87.223	263.553	-154.530	247.045	0
HERD	140.384	0	127.069	0	87.531	0
PEERS	Cyprus, Luxemburg, Poland, Netherlands		Latvia, Luxemburg, Netherlands, Germany		Romania	

Source: own calculations based on the data series mentioned.

The table also includes (for each period) the countries that can serve as a model of efficiency of the RD&I system (peers) for Romania. As can be seen, these include not only countries with considerable resources in terms of research funding and employees but also a high level of the results obtained (such as the Netherlands and Germany), but also countries (such as Cyprus or Luxembourg) which, despite their small size, are able to make efficient use of their financial and human resources. In this context, it can be observed that in the period 2014-2015, since Romania was one of the countries with the maximum efficiency, it could be considered as a (peer) model for Croatia.

We were also interested in the streamline the technological transfer process (Model 2), which include radial movements and slacks (Table 5), by increasing the outputs, respectively, the number of companies that have introduced in the last two years products (IN_PROD) and new or improved processes (IN_PROC) and new managerial (IN_MAN) and marketing approaches (IN_MK) and decreasing surplus inputs, respectively, patent applications (PAT). Regarding PATs, it should be noted that decreasing their number does not increase efficiency but is possible without affecting the value of the relative VRS efficiency score.

Table 5. Opportunities for efficiency improvement - Model 2

Variables	Model 2a (2011-2012)		Model 2b (2013-2014)		Model 2c (2015-2016)	
	Initial values	Possible improv.	Initial values	Possible improv.	Initial values	Possible improv.
IN_PROD	985	0	1018	1459.171	948	2080.037
IN_PROC	1340	0	1216	1839.304	996	2868.34
IN_MAN	4073	0	1898	820.014	1661	1552.244
IN_MK	3981	0	1875	1325.147	1463	2300.199
RCD	150	0	173	0	213	0
EUTM	635	0	462	0	650	0
PAT	60.42	0	85.1	-20.408	93.51	-11.95
PEERS	Romania		Croatia, Greece, Portugal		Greece, Croatia, Portugal	

Source: own calculations based on the data series mentioned.

The table also includes (for each period) the countries that can serve as a model of efficiency of the TT process (peers) for Romania, Croatia, Greece, and Portugal, respectively. In this context, it can be seen that in the period 2014-2015, since Romania was one of the countries with maximum efficiency, it could be considered as a model (peer) for Luxembourg.

7. RESEARCH IMPLICATIONS

The research conducted leads to some implications in terms of policies in the field of research and development, but also of TT in both Europe and Romania. *At the European level*, TT policies could be improved by: facilitating the exchange of experience and good practices between national authorities / universities / research institutes / industry partners in countries with more efficient TT systems and similar institutions in countries in which the efficiency of TT is lower; the inclusion in European Union-funded programmes of components such as the development and expansion of SMEs with advanced and disruptive technologies (through support provided especially for the early stages of technology development); stimulation of KETs; better integration of public and private investment in research and innovation as a facilitator of TT; integration of business, research, higher education and entrepreneurship.

In the case of Romania, the policies in the field of TT should be doubled by a series of policy elements aimed at the efficiency of the research system as a whole: the development of the national research system, increasing the number of researchers, modernization, and efficient use of research infrastructure. supporting innovation ecosystems associated with smart specialisations and better national-regional correlation of smart specialisation areas.

8. CONCLUSIONS

In this research, starting from some previous studies (Wang, Hang, Sun & Zhao, 2016; Guan & Chen, 2010), a conceptual framework for analysing the efficiency of TT was adapted. Following this model for the study of RD&I system efficiency and TT, DEA was applied at the level of the European Union, and the 27 member countries were considered decision-making units (DMU). Two models were used. The first model was used to evaluate the efficiency of the RD&I system, and the second model was built to evaluate the efficiency of the TT process.

The VRS technical efficiency of RD&I systems shows that more than half of the countries analysed operate at maximum efficiency and their number is increasing. However, according to the technical efficiency in the CRS hypothesis, the number of countries whose RD&I system is effective is significantly lower. For nine EU countries (Austria, Bulgaria, Cyprus, Denmark, Germany, Latvia, Luxembourg, Malta, and the Netherlands), both the score of pure technical efficiency and that of scale efficiency are maximum for all three intervals analysed. Regarding the efficiency of TT to the economic sector, it can be seen that there are also a number of countries that are able to efficiently transform intermediate outputs into final outputs. The VRS technical efficiency shows that for seven of the countries analysed (Croatia, Czech Republic, Germany, Greece, Italy, Malta, and Portugal), the relative scores are maximum for the three intervals analysed. These countries can be seen as an example for other countries in the European Union.

The integrated analysis (considering the models for the two subprocesses) showed that there are four groups of countries. The main group includes countries that excel both in terms of transforming human and financial resources into intermediate output but also in terms of transferring these results to the economic sector in all periods analysed (Germany, Italy, Malta, and Portugal).

In the paper, strategies were developed for the countries in each group so as to reach in terms of the efficiency of the RD&I system and the TT process at the level of the countries placed in the main group. These strategies (methods) envisage both an immediate transition from one stage to another and a gradual transition, based on the improvement of one of the two subprocesses analysed.

We consider the research carried out to have two important limitations. The first limitation is related to the time distance between the available data on TT and the timing of the analysis of the efficiency of TT, which may not capture the most recent developments and trends in the field. The second limitation concerns the fact that only the most important elements influencing the efficiency of the R&D system (elements for which official statistics exist at the European level) have been considered.

Future research directions include conducting analyses on the efficiency of TT, including, as they appear, more recent statistics and the inclusion of other input and output elements both in the analysis of the efficiency of the research system and in the analysis of the efficiency of the TT process.

ACKNOWLEDGEMENT

This research was partially conducted with the support received within the research project "Analysis of the current situation of Romanian research and ways to achieve the transfer of new technologies in the productive sector, in the effort to develop the knowledge-based economy", The Bucharest University of Economic Studies.

REFERENCES

[1] **Anderson, T.R, Daim, T.U, Lavoie, F.F. (2007),** ***Measuring the efficiency of university technology transfer.*** *Technovation,* 27(5), 306-318, DOI: 10.1016/j.technovation.2006.10.003;

[2] **Arvanitis, S., Kubli, U., Woerter, M. (2008),** ***University-industry knowledge and technology transfer in Switzerland: what university scientists think about co-operation with private enterprises.*** *Research Policy*, 37(10), 1865-1883;

[3] **Beneito, P., Rochina-Barrachina, M.E., Sanchis, A. (2015),** ***The path of R&D efficiency over time.*** *International Journal of Industrial Organization,* 42, 57–69, DOI:10.1016/j.ijindorg.2015.07.001;

[4] **Bishop, K., D'Este, P., Neely. A. (2011),** ***Gaining from interactions with universities: Multiple methods for nurturing absorptive capacity***. *Research Policy,* 40(1), 30-40;

[5] **Chen, K., Kou, M., Fu, X. (2018),** ***Evaluation of multi-period regional R&D efficiency: An application of dynamic DEA to China's regional R&D systems.*** *Omega*, 74, 103–114;

[6] **Chen, K.H., Guan, J.C. (2012),** ***Measuring China's regional innovation systems: an application of a relational network DEA***. *Regional Studies*, 46(3), 355–377;

[7] **Christensen, C. (2013),** ***The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail.*** Boston: Harvard Business Review Press;

[8] **Coelli, T.J. (1996),** ***A Guide to DEAP Version 2.1: A Data a data envelopment analysis (computer) program***. *CEPA Working paper 96/08*. Armidale: Centre for Efficiency and Productivity Analysis, University of New England. Available: https://economics.uq.edu.au/cepa/software, accessed August 20, 2020;

[9] **Cooper, W.W., Seiford L.M., Zhu J. (2004),** ***Data Envelopment Analysis.*** **In: Cooper W.W., Seiford L.M., Zhu J.** (eds) *Handbook on Data Envelopment Analysis. International Series in Operations Research & Management Science,* 71, Springer, Boston, MA. DOI:10.1007/1-4020-7798-X_1;

[10] **Cullmann, A., Schmidt-Ehmcke, J., Zloczysti, P. (2012),** ***R&D efficiency and barriers to entry: a two stage semi-parametric DEA approach.*** *Oxford Economic Papers*, 64(1), 176-196. DOI:10.1093/oep/gpr015;

[11] **European Commission (2007),** ***Improving knowledge transfer between research institutions and industry across Europe, DG Research and DG Enterprise and Industry****,* EUR 22836, Brussels;

[12] **Eurostat. (2020a-h),** ***Science and technology.*** Eurostat: https://ec.europa.eu/eurostat/web/science-technology-innovation/data/database;

[13] **Gao, Q., He F., Moosa, A., Lv, Q. (2019),** ***The efficiency of technology transfer in Chinese key universities.*** *Journal of scientific& industrial research*, 78(9), 582-588;

[14] **Gonzalez, E., Gascon, F. (2004),** ***Sources of productivity growth in the Spanish pharmaceutical industry (1994–2000).*** *Research Policy* 33(5), 735–745;

[15] **Guan, J., Zuo, K., Chen, K., Yam, R.C.M. (2016),** ***Does country-level R&D efficiency benefit from the collaboration network structure?.*** Research Policy, 45, 770–784, DOI: 10.1016/j.respol.2016.01.003;

[16] **Guan, J., Chen, K. (2010),** ***Measuring the innovation production process: A cross-region empirical study of China's high-tech innovations.*** *Technovation,* 30(5-6), 348-358, DOI:10.1016/j.technovation.2010.02.001;

[17] **Hashimoto, A., Haneda S. (2008),** ***Measuring the change in R&D efficiency of the Japanese pharmaceutical industry.*** *Research Policy 37(10),* 1829–1836, DOI:10.1016/j.respol.2008.08.004;

[18] **Ho, M.H., Liu, J.S., Lu, W.M., Huang, C.C. (2014),** ***A new perspective to explore the technology transfer.*** *The Journal of Technology Transfer,* 39, 247-275, DOI:10.1007/s10961-013-9298-7;

[19] **Mansfield, E. (1975),** ***East-West technological transfer issues and problems, international technology transfer: Forms, resource requirements, and policies.*** *American Economic Review*, 65(2), 372-376;

[20] **Sorlin, S. (2007),** ***Funding diversity: performance-based funding regimes as drivers of differentiation in higher education systems***. *Higher Education Policy* 20, 413–440, DOI:10.1057/palgrave.hep.8300165;

[21] **Ștefan, S.C., Simion, C.P., Popa, Ș.C., Potcovaru, A.M. (2020),** ***Enablers and Barriers of Technology Transfer in Romanian Organizations in the Context of the Knowledge-Based Economy: A Factor Analysis***. *Management Research & Practice*, 12(4), 40-48;

[22] **Thursby, J.G, Thursby, M.C. (2007),** ***University licensing.*** *Oxford Review of Economic Policy*, 23(4), 620–639, DOI:10.1093/oxrep/grm031;

[23] **Wang, E.C., Huang, W. (2007),** ***Relative efficiency of R&D activities: A cross-country study accounting for environmental factors in the DEA approach.*** *Research Policy*, 36(2), 260-273, DOI:10.1016/j.respol.2006.11.004;

[24] **Wang, Q., Hang, Y., Sun, L., Zhao, Z. (2016),** ***Two-stage innovation efficiency of new energy enterprises in China: A non-radial DEA approach.*** *Technological Forecasting and Social Change*, 112, 254-261, DOI:10.1016/j.techfore.2016.04.019;

[25] **Xiong, X., Yang G.l., Guan Z. (2018),** ***Assessing R&D efficiency using a two-stage dynamic DEA model: A case study of research institutes in the Chinese Academy of Sciences***. *Journal of Informetrics*, 12(3), 784-805, DOI:10.1016/j.joi.2018.07.003.