Effectiveness of R&D Expenditures Supporting Innovation: A Case Study of OECD Countries

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Abstract: R&D expenditures have been proven to be a key determinant of innovation activities in all developed countries. These are primarily private sources of in-house research, intramural government expenditure on R&D, research and development spending by universities and the public sector (e.g., public laboratories and research institutes). These expenditures are often part of public policies whose proper targeting and management should lead to allocation efficiency and optimal use of available production resources and funding. This paper aims to analyze the effectiveness of these resources used to support R&D activities in 36 OECD countries. We have used the available data from the OECD databases for 2014 and employed the DEA (VRS model) method. The output variable was % share of innovative firms and the GDP of the economy. The results confirm that the efficiency of allocated resources is considerably variable. Only a handful of countries have achieved maximum efficiency in the analyzed period (Estonia, Belgium, Ireland, Chile, South Korea, Mexico, and New Zealand). At the end of the paper, the results were discussed and practical recommendations defined.

1 INTRODUCTION

There are thousands of research studies dealing with innovation, their importance for growth and development, both by individual economic entities and by regions, states, or supranational communities (Autio et al., 2014). At this point, it is an undeniable fact that innovation is a key factor in success (whatever the economic entity thinks of success). Great attention is also paid to the innovation environment and to individual factors, which is perceived as one of the important new factors of production (apart from standard production factors, for example, the quality of the innovation environment is included (Lundvall, 2016; Mairesse and Mohnen, 2004). His work is devoted to all developed countries. Conversely, the backwardness or lack of innovation environment is the reason for the low maturity of some countries. It is, therefore, one of the goals of governments to create an innovation environment in their states (regions) that foster the emergence of innovations and enable all the benefits to be realized (Prajogo, 2016).

There are several scholars who are discussing the above approach to innovation. E.g. Osborne and Brown (2011) are discussing three flaws that can be noticed in the application of public policies to promote innovation. The first problem is the wrong choice of the innovative model. They described the perception of innovation in New Public Management and its interest that innovation is at the center of events and a competitive advantage (De Vries et al., 2016). This was followed by developments inspired by Porter's work, where the engine of development was competition that led to increased efficiency in service delivery (Furman, Porter and Stern, 2002). Further development within the innovation model was directed towards the development of the innovation environment and its components (Carlin et al., 2004).

The second flaw is perceived as the result of a constant effort to improve, which ultimately leads to a high inefficiency in any attempts to create public policies. It turns out that it is necessary to perceive public policy as a complex of processes and too much emphasis on some of the details can overshadow the resulting effect and cause inefficiency. It is therefore, essential for the public sector to understand very well what the innovation process is, what its purpose is, how it is to achieve it. From the observation of practice, it is necessary to point out that innovation processes differ, whether

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they are products or services, as well as differing in individual countries. This greatly hinders the application of unified policies (such as EU territory), leading to an ineffective approach "one-size-fits-all" (Veugelers and Schweiger, 2016).

Osborne and Brown (2011) also put forward the arguments of several scholars who also point to the normative dimension of the word "innovation," which in many cases is perceived as synonymous with the word "good." Even within this perception, it should be remembered that if some of the support processes are financed by public finances, it is possible to perceive them to a certain extent as a public good (Mazzucato and Semieniuk, 2017). However, this aspect is very difficult to apply in practice and encounters many obstacles (Smith et al., 2019).

It is undeniable that innovation is and will be of interest to policy makers in different countries and that the level of effectiveness of these public interventions is very low (Seaden and Manseau, 2001). That is why we need to continuously analyze the effectiveness of individual intervention measures in different countries and define appropriate policy implications for improving public policies.

The paper is structured as follows. The following part presents the theoretical framework in relation to the public policies supporting innovation. The next part describes the data, variables, and methodology. In the third part, the obtained results are displayed and discussed. Finally, the fourth part summarizes the main conclusions.

2 LITERATURE REVIEW

In the beginning, it should be noted that public intervention must be linked to impending market failures or a clearly documented reduction in community welfare. This is the conclusion resulting from a neoclassical economic theory that points to the causes of market failure due to, for example, the existence of externalities or imperfect competition with which clean market mechanisms cannot effectively solve. Sometimes, failure occurs only in the second phase, that is, at the actual implementation of government intervention. Lundvall (2016) describes this as a failure of a system in which there is not enough linkages between the academic sector and industry (despite all government efforts, the application of public policy and the allocation of public funds). Here we can call it as a government failure.

There are several studies that address the effectiveness of state interference, optimization, setting goals and resources, assessing the conditions for achieving Pareto efficiency or optimality (Potts, 2009). All this is happening in dynamic conditions, which are represented by normal economic growth and changes in the structure of the economy (change of economic subjects, their goals, changing customer preferences, etc.). It is mainly about the internal transformation of processes in which determinants (drivers) come in the form of new technologies, new knowledge, revised business strategies, new globalization tendencies, etc. These are the manifestations of the so-called economic evolution described in the early 1980s (Nelson and Winter, 1982). Part of this evolution is the creation of innovation, which since then has been one of the most important drivers of economic transformation everywhere in the world.

In classical, but above all in neoclassical, economic doctrines, scholars have stated that the equilibrium market situation represents a Pareto optimum and does not require any external interference (government intervention in the form of public policy). However, economic development violates this equilibrium and worsens allocation efficiency, which is the reason for public intervention. This requires new types, new goals, and new public policy tools to achieve higher allocation efficiency. However, the new element is the so-called dynamic efficiency (Abel et al., 1989). The general objective remains to achieve maximum social well-being and to maximize the efficiency of the use of production resources.

An example of public policy that is applied in developed countries is a policy of support for small and medium-sized enterprises, innovation, R&D, or industrial policy. The common denominator of these types of public policies is expenditures on research and development activities. Stimulation of each type of expenditure (private, public, university, government, etc.) is the subject of all. Many scholars also draw attention to the crowding-out effect (public subsidies are crowding the private investment out), and that is precisely in support of science and research activities.

Several studies examine the effectiveness of R&D policies in different countries. González et al. (2005) examined the effects of public subsidies on stimulating scientific and research activities in Spanish enterprises. They found subsidies are stimulating the in-house research, but some enterprises did not develop these activities without subsidies at all. These scholars did not find the crowding-out effect of Spanish enterprises in their target group. Czarnitzki et al. (2007) analyzed the effectiveness of the innovation policy supporting cooperation on R&D activities in Germany and Finland. For German companies, no significant impact on R&D activities was found; innovation performance could be improved by public incentives financed from public budgets directed to R&D cooperation. Conversely, the results from Finland confirm that public spending on R&D funding for these companies is crucial. Without subsidies, R&D activities are almost unrealized.

Hall et al. (2000) conducted a broad study on public tax incentives for the development of R&D activities. The individual research studies from many OECD countries were their target group. Results confirmed the trend that there is a shift away from direct subsidies to the R&D area in favor of tax incentives, which, according to the authors of the study, increases the efficiency of the whole innovation system. Guellec et al. (2004) conducted longitudinal research of 16 countries around the world and examined the factors that affect their productivity growth. They found that there are three main factors affecting the performance growth: a source of the funds, the socio-economic objectives of state aid, and the type of public institution conducting research.

It has been demonstrated that different types of R&D funding contribute to increasing innovation potential and consequently increase the performance of the economy. All developed economies apply some form of public policy aimed at supporting R&D activities. It is different how these policies finance and differ significantly in achieving dynamic efficiency. Therefore, the aim of this paper is to provide an overview of the effectiveness of pro-innovation policies implemented in different OECD countries by analyzing different types of R&D funding.

3 DATA AND METHODS

One of the significant approaches to evaluate the efficiency, performance, and productivity of production units (decision-making units - DMUs, e.g., OECD countries) based on the size of inputs and outputs is known as Data Envelopment Analysis (DEA). DEA is encompassing the linear programming technique to depict the efficiency frontier (Hudec and Procházková, 2013) while DMUs should be comparable or homogenous. These units convert multiple inputs into outputs, meaning a set of units that produce the same or equivalent effects that are referred to as the outputs of these units (Prokop, Stejskal and Hajek, 2018).

The mathematical formulation of DEA models considers the existence of a set of homogeneous production units U1, U2, …, Un, wherein each unit produces r outputs and subsequently using m inputs. Then according to Prajogo (2006), we can write:

$$X = \{xij, i = 1, 2, \dots, m, j = 1, 2, ..., n\} \quad (1)$$

is considered as input matrix and

$$Y = \{yij, i = 1, 2, \dots, r, j = 1, 2, ..., n\} \quad (2)$$

is considered as output matrix.

The efficiency rate of Uq unit is generally expressed as the weighted sum of inputs/weighted sum of outputs. The principle of DEA models is that when evaluating the efficiency of a production unit Uq it maximizes its efficiency level, if the efficiency rate of all other DMUs cannot be higher than 1 (100 %). The weights of all inputs and outputs must be greater than zero so that all the considered characteristics in the model are included (to see more, e.g. (Halaskova, Halaskova, and Prokop, 2018; Prokop and Stejskal, 2007).

In this study, we measure the efficiency of different R&D expenditures´ sources (inputs) within 36 OECD countries in 2014 by using input-oriented VRS model operating with variable returns to scale and data from OECD database (available at http://stats.oecd.org). The assumption of variable returns to scale (VRS) considering all types of returns: increasing, constant, or decreasing. As output variables, we are using innovation creation and growth of GDP (all input and output variables are described below in Table 1). According to Griliches (1998) who empirically proved that there is no time delay with a significant impact on the results of analyses, we do not consider time delay between input and output variables.

Table 1. Description of input and output variables.

Input variables		
R&D exp.	Variables	Description
BERD	Business enterprise expenditure on R&D	BERD is seen as an essential factor affecting firms' performance and innovation capacity (Siedschlag et al., 2005; Wang et al.,

		2013). Karahan (2015), e.g., showed that BERD is one of the main determinants of high-tech sectors.
GOVERD	Gov. intramural expenditure on R&D	Finance, human resources, and risks in innovation always limit companies. Therefore, GOVERD represents one of the strategic resources that could support firms´ R&D (Jin et al., 2016). Government support also has a positive relationship with firms´ (industrial) innovation (Doh and Kim, 2014).
HERD	Higher education expenditure on R&D	HERD expenditure could support, e.g., university research, which is the catalyst of new knowledge and driving force of advanced (knowledge) economies (Sharif and Tang, 2014).
PSERD	Public sector expenditure on R&D	Voutsinas et al. (2008) proved that the public R&D expenditure has a positive influence on business and total innovation, which indicates the existence of significant externalities of public sector research.
Output variables		
INNOV	Innovations (Product and/or Process)	Product and/or process innovations are two distinct mechanisms through which countries (firms) can improve their performance and support their competitive advantage in the current global economy (Najafi-Tavani et al., 2018). Therefore, innovations could be underlying drivers of a firm's innovative performance, which can, besides, contribute to general economic development (Prokop, Odei and Stejskal, 2018).
GDP	Gross domestic product	Gross domestic product (GDP) and its growth represent one of the most frequently used indicators of economic growth.

Source: own processing

4 RESEARCH RESULTS

In this part, the results of DEA are showed. We distinguish all 36 OECD countries into two groups – EU countries (23 countries) and the rest of the world (13 countries). Countries that efficiently used selected R&D expenditures´ sources (inputs) in the processes of innovation creation and reaching GDP growth (output variables) reached the rate of effectiveness 1.000. Countries that did not reach the rate of effectiveness 1.000 were not considered effective – less rate of effectiveness means less efficiency of the country.

Surprisingly, only 3 out of 23 (13 %) EU countries were considered as efficient. These countries are Belgium, Estonia and Ireland. Belgium and Estonia are small open economies, characterized by a relatively high dependence on foreign subsidiaries of multinational firms, both in terms of employment and output generation and innovation. In Belgium, agglomeration can be an important catalyst in the innovation process of firms which enjoy a significantly positive impact from for example increased sectoral concentration, controlling for research and development intensity, export intensity, foreign ownership, funding, and own sector employment concentrations (De Beule et al., 2012; Hansen et al. 2011). In Estonia, foreign ownership or participation in larger corporate groups, international markets and cooperation seems to be main determinants of firms´ innovation activities. Moreover, the positive impact of public funding shows that public support has not crowded out private expenditure on innovation in Estonia (Masso and Vahter, 2008). In Ireland, innovation in combination with increased export activities are proved as the main drivers of productivity gains and innovations (Love, 2010). On the other hand, less efficient countries in this group were Czech Republic (0.430), France (0.456), Greece (0.458) and Lithuania (0.458).

In the group, Rest of the World, 4 out of 13 (31 %) countries were considered as efficient. These countries are Chile, Korea, Mexico and New Zealand.

Chile is one of the Latin America countries where business, economic, and policy environments differ between countries and generally diverge from OECD countries and where innovation policy work has made greater strides in the last decade (Crespi and Zuniga, 2012). As in Estonia, foreign ownership or participation in larger corporate groups seems to be an important factor influencing R&D investment and innovations in Chile because the economic superiority of multinational firms can be associated with more sophisticated knowledge assets and easier access to finance and human capital (Girma and Görg, 2007). In Korea and Mexico, increasing ICT penetration is found to be strong, positive, and statistically significant innovation determinant

(Lechman and Marszk, 2015). Moreover, R&D activities and government innovation support systems are considered essential factors for service and technological innovation performance in Korea. Korean Innovation Support System showed that innovation support programs could be classified as supports for tax incentives, finance, technology development, human resources, purchasing, law, and institutional infrastructure, or other indirect supports based on the expenditure approach (Kim et al., 2016). In New Zealand, firms and their performance differ according to the extent to which they have adopted knowledge-management practices (Darroch and McNaughton, 2003) while public research institutes play an essential role in the creation of new knowledge (Lee et al., 2012). On the other hand, less efficient countries in this group were Israel (0.246 – the less efficient country within OECD countries), USA (0.308) and Japan (0.476).

Our results indicate that most OECD countries (29 out of 36; 81 %) have been inefficient in using expenditures on R&D. Therefore, in the next part, we propose some practical implications for these countries (based on the practices that influence innovation and performance in efficient countries, see above). Moreover, DEA models also provide practical implications for each inefficient country. Therefore, we show (in Table 2 in appendix) both original values (that each country reached) and adjusted values (provided by DEA) that show how the input (output) variables should be changed. Note that input-oriented models propose changes focusing primarily on input variables (or even minor changes on the output side). These results show that there is a need to focus on each financial source to avoid increasing inefficiency and to reduce the number of countries that are inefficient because (with the current R&D expenditures) the necessary outputs are not achieved. Therefore, DEA proposes to increase outputs at given inputs or to reduce current inputs. Moreover, DEA also provides information about countries that could be benchmarked for other inefficient countries. Chile and Belgium were proposed as benchmarks for other countries in most cases.

5 CONCLUSIONS

Like the studies above, our study also shows that most of the countries analyzed do not achieve effectiveness in implementing their R&D policy. Only a few countries from the selected file have achieved the highest possible efficiency. For non-European countries, it is mainly Chile, South Korea, Mexico, and New Zealand. These are countries where the financial distribution of R&D has been optimally distributed over the past period. The results do not show that these countries have the greatest innovation performance or the highest GDP growth. The method shows the highest efficiency, i.e., the individual inputs correspond to the maximum achievable outputs. That is why Chile is the most common benchmark for others.

European countries have the highest efficiency in Belgium, Estonia, and Ireland. These are countries that have been continually profiling for many years as a knowledge-based economy, a high degree of openness, digitization, and high education. These are the so-called economic tigers of the European Union. It turns out that setting their public policies is optimal and allows for maximum efficiency.

Our results are confirmed by the findings of Thomas et al. (2009) who result in a growing trend in R&D efficiency in Asia, especially in South Korea. Similarly, we confirm the results of Wang et al. (2007) who came with the conclusion that less than half of the 23 OECD countries (analyzed in their study) are fully competent in their R&D policy. We also confirm their conclusions that the country's English proficiency indicator is a crucial driver of success in science and research.

It can be said that our research is also evidenced by the lower effectiveness of R&D policies and the investment of financial resources in the new Member States. Apart from Estonia, none of these new states have achieved a high level of R&D efficiency. This is confirmed by the findings of the Conte study (Conte et al., 2009) which revealed by their study that there are significant differences in the effectiveness of R&D spending between old and new member countries.

The results of our study show that, despite significant efforts to implement relevant public policies and massive financial support, there is not a significant shift in output indicators in most of surveyed countries. There are crowding out effects, mainly by public funds. It is possible to imply and recommend certain proposals for improvements: countries should be more involved in supporting high technologies, investing in education, supporting specific science and research projects with clearly specified and measurable outputs, applying tax savings or incentive tools that affect the willingness of firms to implement in-house research and invest in it continuously. It is necessary to reduce the dependence of companies and universities on European fund funding, to better define the objectives of the policies in place and to focus more precisely on investment.

This research has also some limitations. One is the quality of data that is input to our analysis. Therefore, the results can only be related to the countries included in the target group. Generalization to other countries or groups of countries can be realized only approximate and often illustrative. The second limitation is the choice of both input and output indicators. It is not possible to avoid any random combination that will not be realistic.

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APPENDIX

Table 1 Results of input-oriented VRS DEA model

				Inputs							
	Country	Efficiency	Bench-marks	BERD (% of GDP)		GOVERD (% of GDP)		HERD (% of GDP)		PSERD (% of firms)	
				Orig.	Adjust.	Orig.	Adjust.	Orig.	Adjust.	Orig.	Adjust.
EU 28 Countries	Austria	0.533	Chile	1.95	1.04	0.15	0.08	0.73	0.37	0.87	0.45
	Belgium	1.000	-	1.52	1.52	0.18	0.18	0.52	0.52	0.7	0.70
	Czech Rep.	0.430	Chile	1.01	0.43	0.35	0.12	0.52	0.22	0.86	0.35
	Denmark	0.852	Chile	1.96	0.88	0.07	0.06	0.95	0.30	1.01	0.37
	Estonia	1.000	-	1.26	1.26	0.2	0.20	0.7	0.70	0.91	0.91
	Finland	0.568	Belgium	2.44	1.39	0.32	0.18	0.77	0.44	1.09	0.62
	France	0.456	Chile	1.48	0.67	0.31	0.13	0.47	0.21	0.78	0.35
	Germany	0.814	Belgium	2.02	1.64	0.43	0.35	0.53	0.43	0.96	0.78
	Greece	0.458	Chile	0.24	0.11	0.17	0.01	0.28	0.12	0.45	0.14
	Hungary	0.662	Chile	0.85	0.55	0.19	0.07	0.24	0.16	0.43	0.24
	Ireland	1.000	-	1.2	1.20	0.08	0.08	0.38	0.38	0.46	0.46
	Italy	0.968	Belgium	0.69	0.67	0.17	0.16	0.36	0.35	0.54	0.52
	Latvia	0.733	Chile	0.15	0.11	0.18	0.01	0.33	0.12	0.51	0.14
	Lithuania	0.458	Chile	0.24	0.11	0.18	0.01	0.48	0.12	0.66	0.14
	Luxembourg	0.941	Chile	1	0.67	0.28	0.09	0.18	0.17	0.46	0.27
	Netherlands	0.902	Chile	1.22	1.10	0.23	0.21	0.7	0.63	0.94	0.84
	Poland	0.540	Chile	0.33	0.18	0.25	0.05	0.31	0.16	0.56	0.22
	Portugal	0.982	Chile	0.7	0.69	0.1	0.10	0.58	0.39	0.68	0.50
	Slovak Rep.	0.540	Chile	0.34	0.18	0.2	0.04	0.28	0.15	0.48	0.20
	Slovenia	0.719	Chile	1.99	1.12	0.34	0.16	0.29	0.21	0.64	0.38
	Spain	0.916	Belgium	0.69	0.63	0.25	0.23	0.36	0.33	0.61	0.56
	Sweden	0.861	Chile	2.31	1.22	0.16	0.14	0.92	0.53	1.09	0.68
	UK	0.485	Belgium	1.1	0.53	0.14	0.06	0.46	0.22	0.6	0.29
Rest of the World	Australia	0.654	Belgium	1.23	0.80	0.24	0.16	0.58	0.38	0.86	0.54
	Canada	0.810	Chile	0.88	0.71	0.15	0.12	0.65	0.43	0.8	0.56
	Chile	1.000	-	0.11	0.11	0.01	0.01	0.12	0.12	0.14	0.14
	Iceland	0.693	Estonia	1.38	0.96	0.46	0.28	0.69	0.48	1.15	0.76
	Israel	0.246	Chile	3.32	0.11	0.07	0.01	0.49	0.12	0.57	0.14
	Japan	0.476	Chile	2.57	0.99	0.29	0.13	0.45	0.21	0.74	0.35
	Korea	1.000	-	3.4	3.40	0.49	0.49	0.41	0.41	0.91	0.91
	Mexico	1.000	-	0.17	0.17	0.13	0.13	0.12	0.12	0.25	0.25
	New Zealand	1.000	-	0.57	0.57	0.29	0.29	0.4	0.40	0.69	0.69
	Norway	0.751	Belgium	0.86	0.65	0.27	0.20	0.52	0.39	0.79	0.59
	Switzerland	0.500	Chile	2.17	0.11	0.02	0.01	0.88	0.12	0.9	0.14
	Turkey	0.805	Chile	0.42	0.34	0.1	0.08	0.4	0.24	0.51	0.33
	USA	0.308	Chile	1.95	0.16	0.34	0.10	0.39	0.12	0.73	0.22

Source: own

Table 3 Results of output-oriented VRS DEA model

				Outputs			
	Country	Efficiency	Bench-marks	INNOV (% of all firms)		GDP (% change)	
				Orig.	Adjust.	Orig.	Adjust.
EU 28 Countries	Austria	0.533	Chile	12.61	12.61	2.22	2.74
	Belgium	1.000	-	17.88	17.88	1.53	1.53
	Czech Rep.	0.430	Chile	9.26	9.26	2.27	4.22
	Denmark	0.852	Chile	10.92	10.92	1.9	2.96
	Estonia	1.000	-	20.07	20.07	3.95	3.95
	Finland	0.568	Belgium	15.86	15.86	1.94	2.36
	France	0.456	Chile	9.47	9.47	1.57	4.40
	Germany	0.814	Belgium	17.66	17.66	1.96	3.24
	Greece	0.458	Chile	-	5.38	1.79	4.92
	Hungary	0.662	Chile	7.5	7.50	1.65	4.80
	Ireland	1.000	-	13.19	13.19	2.16	2.16
	Italy	0.968	Belgium	12.66	12.66	1.42	3.31
	Latvia	0.733	Chile	-	5.38	-	4.92
	Lithuania	0.458	Chile	-	5.38	-	4.92
	Luxembourg	0.941	Chile	8.08	8.08	2.33	4.76
	Netherlands	0.902	Chile	18.66	18.66	0.87	3.81
	Poland	0.540	Chile	6.81	6.81	3.33	4.61
	Portugal	0.982	Chile	12.36	12.36	1.11	4.31
	Slovak Rep.	0.540	Chile	6.5	6.50	2.92	4.70
	Slovenia	0.719	Chile	10.22	10.22	0.63	4.64
	Spain	0.916	Belgium	12.91	12.91	0.98	3.43
	Sweden	0.861	Chile	16.48	16.48	3.04	3.04
	UK	0.485	Belgium	8.75	8.75	2.49	4.06
Rest of the World	Australia	0.654	Belgium	13.4	13.40	3.05	3.16
	Canada	0.810	Chile	13.3	13.30	2.6	4.31
	Chile	1.000	-	5.38	5.38	4.92	4.92
	Iceland	0.693	Estonia	16.77	16.77	2.77	3.22
	Israel	0.246	Chile	5.1	5.38	3.45	4.92
	Japan	0.476	Chile	9.87	9.87	0.96	4.42
	Korea	1.000	-	21.22	21.22	3.99	3.99
	Mexico	1.000	-	-	-	4.17	4.17
	New Zealand	1.000	-	15.01	15.01	2.85	2.85
	Norway	0.751	Belgium	13.73	13.73	3.14	3.35
	Switzerland	0.500	Chile	-	5.38	2.7	4.92
	Turkey	0.805	Chile	8.9	8.90	4.14	4.46
	USA	0.308	Chile	-	1.24	3.38	4.34

Source: own