Innovation Policy and R&D Efficiency in Emerging Countries: a Stochastic Frontier Analysis

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Abstract
Understanding the process of innovation and its relationship with public policy was analyzed in many studies conducted in advanced economies. In the context of developing countries, some authors have even understated the role of innovation. This paper addresses these issues, which are relatively neglected in the literature. It focuses on the evaluation of innovation policy in emerging countries. Such evaluation is very crucial as it serves as a guide to public spending and resource allocation. In this study, we aim to examine the impact of public support on R&D efficiency in 10 emerging countries over the period from 2001 to 2010. The stochastic frontier approach is applied to estimate the relative efficiency of R&D of each country and its determinants. We estimate two stochastic frontier models where human and physical resources of R&D are the inputs employed to produce an output: patents in the first model and scientific publications in the second model. Determinants of R&D efficiency are innovation policy instruments: increase of R&D investments, promotion of interactions between the actors of innovation system, promotion of human capital, and protection of intellectual property rights. Results are different depending on the nature of the output. Indeed, in the case of patent-oriented R&D efficiency, only the tools for human resources and intellectual property rights allow to improve the level of national R&D efficiency. In the case of scientific publication-oriented R&D efficiency, public research, human resources and intellectual property rights are effective public tools to improve R&D management quality.

Keywords: innovation, innovation policy, R&D efficiency, stochastic frontier analysis

JEL classification: O3

Introduction

According to Arrow (1962), technology is endogenous. He stresses that the production process of technology generates positive externalities due to the characteristics of scientific knowledge (uncertainty, inappropriability and indivisibility). That is why private actors under invest in research and development. According to neoclassical theory, market failure is the main reason for public intervention in research activities. Innovation policies promote the supply side such as the increase of Research and Development (R&D) investments.

The innovation system approach states that the concept of "market failure" is not appropriate to justify state intervention. Rather, it is appropriate to speak about "systemic problems" which are mainly related to investments and infrastructures, learning capacity and transition from a technological phase to a more advanced one (Smith, 2000; Woolthuis et al., 2005). These problems have shown the need for a different type of tools for innovation policy, which are oriented to both supply and demand side. The demand side innovation policies in emerging countries should aim to facilitate domestic innovation activities and promote the absorption of existing innovations through foreign direct investment, participation in R&D projects in collaboration with multinational companies and other international dimensions.

In both approaches, it's necessary for governments to intervene in the innovation field in order to remedy the inability of the market to meet the needs of society. Governments should promote innovation through a public innovation policy.

In this paper, we will focus on studying four types of instruments related to innovation policy: the increase of R&D investments, the promotion of interactions between actors of the innovation system, the promotion of human capital and the system of intellectual property rights.

According to Cowan and Van de Paal (2000), innovation policy is defined as "*A set of policy actions to raise the quantity and efficiency of innovative activities, whereby "innovative activities" refers to the creation, adaptation and adoption of new or improved products, processes, or services.*"

Under this definition, the purpose of innovation policy is twofold: improvement of both quantity and quality. It aims to influence not only the output of innovation, but also the relationship between its inputs and outputs.

While several academic works have investigated the impact of government actions on outputs of innovation, papers dealing with innovation policy and its relation with R&D management quality are

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relatively limited. The influence of innovation policy instruments on R&D efficiency is not well considered in the existing literature.

In this study, we try to address this gap by dealing with the following problem: What is the impact of innovation policy on the efficiency of R&D expenditures in emerging countries?

The purpose of this paper is to analyze, in emerging countries, the impact on the efficiency of R&D spending of the increase of R&D investments (by performing public research and funding private research), the promotion of interactions between actors of the innovation system (public research organisations / private companies and national / multinational companies), the promotion of human capital and the system of intellectual property rights.

It is believed that this paper will contribute to the already substantial body of R&D literature concerned with knowledge-based economies. First, as few studies have examined R&D efficiency at the national level, this study provides unique empirical evidence to evaluate national R&D efficiency in emerging countries. Indeed, the majority of previous works have focused on studying the efficiency in a number of developed and emerging countries. While it is necessary and useful to compare the efficiency scores between countries at different development levels to detect whether the emerging economies catch up with the developed ones, it is also important to compare the efficiency scores between countries with similar levels of development as they compete with one another to catch up more quickly with advanced countries. Second, examining the relationship between innovation policy instruments and national R&D efficiency can provide insightful policy implications for each individual nation to help establish a well functioning environment. These should in turn help foster economic development and improve the allocation of scarce R&D resources.

The remainder of this paper is organized as follows: Section 2 briefly reviews literature regarding national R&D efficiency and its determinants. Section 3 proposes the empirical methodologies and introduces the dataset. Section 4 displays the estimated R&D efficiency scores and explores the impact of innovation policy instruments on R&D efficiency. The final section includes concluding remarks.

Literature review

Many authors have been interested in the issue of R&D efficiency and its determinants. For example, Wang and Huang (2007) studied the relative efficiency of R&D activities in 30 countries. They considered R&D manpower and capital stock as measures of inputs and patents and academic publications as measures of output. The authors found that enrollment in tertiary education and academic English proficiency allow for increasing R&D efficiency.

Wang (2007) conducted a study on 30 countries (23 of which are OECD members) during the years 1998-1999-2000 to analyze the R&D efficiency. He used the stochastic frontier approach where researchers and R&D expenditures represent the inputs in the process of research and development, and the number of patents and scientific publications represent its output. Results show that public spending has no significant effect on R&D efficiency.

Conte et al. (2009) studied the R&D efficiency for 32 countries (EU 27 and 5 other countries) during the period 1990-2006. They found that research conducted by the higher education sector has a positive effect on scientific output measured by the number of publications.

Li (2009) estimated a stochastic frontier model to explain the disparity in innovation performance between regions of China. The results show that income spent by the regional government for R&D activity, R&D activities of universities and research institutes and industrial structure are significant determinants of innovation efficiency.

Hu et al. (2014) applied the stochastic frontier analysis in order to compare the R&D efficiency in 24 countries during the period 1998-2005. They found that the protection of intellectual property rights, technology cooperation between companies, the transfer of knowledge between the industry and higher education institutions, the agglomeration of R&D infrastructure and the involvement of the government in the R&D activities allow to significantly improve national R&D efficiency.

The study of Chen et al. (2011) focuses on a sample of 16 European, four Asian, and four North and South American countries during the period from 1998 to 2005. The authors used the Data Envelopment Analysis (DEA) by adopting three outputs: patents, royalties and license fees and scientific publications; and two inputs, namely research and development capital stock and R&D manpower. The results show that

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countries with low average levels of total efficiency are Poland, Romania, Russia and Mexico. Romania has the lowest mean score of efficiency. The results suggest that the sample countries are more efficient in the production of scientific papers, relatively efficient in patenting and less efficient in royalties and license fees, given a fixed amount of R&D spending.

In the case of patents and royalties and license fees, the knowledge stock, private R&D, R&D performed by higher education, the interaction between private companies and foreign companies, and collaboration between companies and universities have a positive impact on efficiency.

In the case of scientific publications, results show that public R&D contributes to improve efficiency, while intellectual property rights and private R&D have a negative effect.

Guan and Chen (2012) studied the efficiency of the national innovation system in 22 OECD countries using DEA. They found that IPRs, robustness of the legal environment for technology development, openness to international trade, R&D financed by the private sector, R&D performed by universities, the degree of development of venture capital markets, technological cooperation between enterprises and collaboration in R&D between universities and industry all contribute to improving the level of efficiency of innovation.

This study aims to enrich the existing literature by focusing on the following instruments of innovation policy: the promotion of human capital, the system of intellectual property rights, increased R&D investment, and promotion of interactions between different actors in the innovation system.

Methodology

This paper considers a production framework of R&D activities based on production theory. Each country is considered as a decision unit that employs human and physical resources of R&D as inputs to produce an output such as patents and scientific publications. The stochastic frontier approach is applied to estimate the relative efficiency of R&D of each country and its determinants.

This approach pre-specifies a functional form for the best frontier and decomposes the error term into two components. The first is the random term (V_k), which takes into account the error measurements, specifications and uncertainties that may affect the production process.

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The second component is the technical inefficiency effects in the production (U_k).

Although the SFA has been criticized for predetermining the functional form, it has the advantage of separating the random error from inefficiencies to improve the accuracy of the estimated efficiency. Indeed, a part of the inefficiency may be related to random shocks whose effect could not be corrected through improved efficiency. It is also preferable that all variables are correctly measured because measurement errors could have important implications, by considering for example a decision unit as efficient while it is not so. The method of stochastic frontier allows to take into account measurement errors and to distinguish them from inefficiency.

In this paper, the stochastic frontier approach is preferred since innovation is risky, uncertain and difficult to measure.

By using the SFA, efficiency studies often adopt an estimation procedure in two stages. The first step is to specify and estimate a stochastic frontier in order to derive inefficiencies of decision units, assuming that these inefficiencies are distributed identically. The second step is to regress estimated inefficiencies on a set of characteristics of the decision unit (referred to as environmental variables) in order to explain the differences between inefficiencies. This two-step process suffers from serious econometric problems, due to the inconsistency of assumptions regarding the independence of the inefficiency effects in the two estimation steps (Coelli 1996). To remedy these problems, some models in one step have been developed. They estimate simultaneously inefficiencies and the potential relationship between environmental variables and estimated inefficiencies. Among these models, we cite that of Battese and Coelli (1995) which is used in this study.

The R&D production function

Following Griliches (1990), our study considers the international research and development activity in the context of a production function in different countries.

In the production framework used in this research, all countries are supposed to have access to the same technology but its operation differs from one country to another depending on specific conditions such as resources availability, the structure of relative prices of inputs and the economic environment.

R&D production function of different countries has the following general form:

$$Y_{kt} = f(X_{kit}) \quad \textbf{(1)}$$

where: k=1,….., K (country), i=1,…., N (inputs), t=1,…..T (years)
Y_{kt} is the R&D output of country k at time t.
X_{kit} is the input i of country k at time t.

All inputs and outputs in this function are assumed to be homogeneous.

The wide variety of inputs resulting from the use of data from different countries requires the use of a flexible functional form. The most used is the translog form which is characterized by elasticity of substitution between inputs. Moreover, it is a general form of several well-known production functions such as the Cobb-Douglas form. A translog production function at time t can be written as:

$$\ln Y_{kt} = \beta_0 + \sum \beta_i (\ln X_{kit}) + ½ \sum \beta_{ii} (\ln X_{kit})^2 + ½ \sum \sum\beta_{ij} (\ln X_{kit}) (\ln X_{kjt}) \quad \textbf{(2)}$$

where: Y is the output quantity, X_i and X_j are the inputs i and j, respectively. ln is the natural logarithm. $\beta_i\beta_{ii}$ et β_{ij} are parameters to be estimated and are independent of countries.

The stochastic frontier model

The ability of a production unit to transform inputs into outputs is affected not only by its technical efficiency but also by external factors relating to its environment. This research aims to determine the impact of variables representative of public support for innovation on the level of efficiency. To do this, we use the frontier model of technical efficiency of Battese and Coelli (1995) taking into account factors that may influence the efficiency of a production unit and which is applicable on panel data.

The model of Battese and Coelli (1995) may be expressed as:

$$Y_{kt} = f(X_{kt}, \beta) \exp (V_{kt} – U_{kt}), \quad \textbf{(3)}$$

where: k = 1,…, k country ; t = 1,…, T (year)
Y_{kt} is the production output of k^{th} country at time t.
X_{kt} is a vector (1*i) of production inputs relative to k^{th} country at time t.

β is a vector (i*1) of parameters to be estimated.
V_{kt} are random errors which are assumed to be iid N(0, σ^2_v) and independent from U_{kt}.
U_{kt} are non-negative random variables, which are assumed to account for technical inefficiency in production and are assumed to be iid as truncations at zero of the N(m_{kt}, σ^2_u).

$$m_{kt} = Z_{kt}\delta + W_{kt} \quad \textbf{(4)}$$

where: Z_{kt} is a vector of environmental variables, which may affect the efficiency of a production unit and δ is a vector of parameters to be estimated. The parameters σ^2_v and σ^2_u are replaced with $\sigma 2 = \sigma^2_v + \sigma^2_u$ and $\gamma = \sigma^2_u / \sigma 2$ for the purpose of estimation using the ML method.

Within the stochastic approach, deviation from the possible maximum production may be due to inefficient country or random factors involved during the production process. The more the γ value is close to 1, the more this difference is mainly attributed to the inefficiency of the country, and therefore the random effects are reduced (the model would be deterministic). This indicator will have a key role to justify the statistical consistency of the model.

The stochastic production frontier model to be estimated in this paper is defined as follows:

$$\ln Y_{kt} = \beta_0 + \sum \beta_i (\ln X_{kit}) + \tfrac{1}{2} \sum \beta_{ii} (\ln X_{kit})^2 + \tfrac{1}{2} \sum \sum\beta_{ij} (\ln X_{kit}) (\ln X_{kjt}) + V_{kt} - U_{kt} \quad \textbf{(5)}$$

where: Y_{kt} is the production output of k^{th} country at time t.
X_{kt} is a vector (1*i) of production inputs relative to k^{th} country at time t.
β is a vector (i*1) of parameters to be estimated.
V_{kt} are iid N(0, σ^2_v).
U_{kt} are iid N(m_{kt}, σ^2_u)

$$m_{kt} = \delta_0 + \delta Z_{kt} + W_{kt} \quad \textbf{(6)}$$

where Z_{kt} is a vector of environmental variables which may affect the efficiency of a production unit and δ is a vector of parameters to be estimated.

Parameters are estimated using FRONTIER 4.1 program developed by Coelli (1996).

Sample Selection

This study considers two empirical models with two different outputs. The first model (Model n°1) will focus on ten emerging countries: Bulgaria, Croatia, Hungary, Latvia, Mexico, Poland, Romania, Russia, South Africa and Turkey. The period covered is 2001-2010. The second model (Model n°2) will be applied to the same sample during the 2001-2009 period[1]. The sample of the study and the periods are selected according to data availability.

Data

We present below the variables, their measures and sources of data. We specify variables used to measure output, inputs and factors related to the environment ie related to public support for innovation.

Output

The output of R&D spending is measured by two indicators. (PAT) is the annual number of patent applications filed by the inventors of each country with the United States Patent and Trademark Office (USPTO). In the absence of reliable data, we use data from USPTO. However, using data from the USPTO induces restrictions on the scope of our study. Indeed, innovations registered in the US patent office are international, excluding thereby local innovations which are very important in emerging countries.

The second measure of output is the number of scientific publications (PUB). It is the annual number of papers published in Science Citation Index international journals and the annual number of papers published in Social Sciences Citation Index international journals. These publications were selected by the indicators of science and engineering in 2014 from the National Science Foundation (NSF, 2014)[2].

Inputs

Like the majority of studies (Wang, 2007; Lee and Park, 2005; Thomas et al., 2009), our study includes financial capital and human capital in the estimation of R&D production function.

The R&D manpower (MRD) measured in full time equivalent is all persons employed directly in R&D as well as those providing direct services related to R&D, such as managers, and administrators (OCDE, 2002).

Concerning the stock of knowledge, the variable introduced reflects the cumulative R&D. For each country, we calculate the stock of research and development (SRD) using the method of perpetual inventory (OCDE, 2001) and based on gross domestic R&D expenditures (in thousands Power Parity Purchase).

Data on inputs are from UNESCO database.

Environmental variables

For environmental variables reflecting innovation policy instruments, data are from UNESCO database and Fraser Institute.

- Public research

Salter and Martin (2001) cited case studies and surveys focusing on various forms of economic benefits of scientific research. These studies identify different types of benefits generated by research funded by public funds: increasing the stock of useful information, offering new instrumentations and methodologies, providing expertise and qualified labor force, providing access to expert and information networks, solving complex technological problems and allowing the creation of new businesses.

A variety of empirical work showed a positive and significant effect of public research on the production of knowledge in companies (Jaffe, 1989; Beise and Stahl, 1999; McMillan et al., 2000; Lofsten and Lindelof, 2002; Cassia et al., 2009).

Public research is measured by two variables, namely the share (in Gross domestic Expenditures on R&D (GERD)) of research carried out by the government sector (RDGOV) and research performed by the higher education sector (RDHE).

- Public financing of private R&D

According to David et al. (2000), several benefits can be derived from public funding for private innovation activities. First, the R&D public contract for small business reduces the capital costs of the firms in question, especially the start-up with limited financial resources. Such a contract is a good signal for external funding sources to apply a lower risk premium in case of granting credit. Second, the subsidized R&D activity is assumed to produce effects of learning and training enabling the company to learn about new science and engineering and subsequently improve the level of efficiency in the implementation of its own R&D projects. Moreover, when public funds are spent on the construction of research infrastructures, acquisition of research equipment and management of fixed costs to consolidate specialized research teams, the firm involved will be able to achieve other R&D projects with its own resources at a lower cost, and subsequently realize high yields. Finally, the technical knowledge associated with the R&D project funded by the government and directed by the company may have implications for increasing the marginal rate of return for other firms in the same industry as well as for firms in other industries.

However, two principal arguments have been advanced on behalf of supposing that public expenditures for industrial R&D would exert a ''crowding out'' effect on private R&D investment: the substitution effect and the effect of input prices. First, R&D financed by the public sector can directly replace R&D projects financed by the private sector. This would occur where contracts are targeted in areas of technological development that firms otherwise would still find it worthwhile undertaking. Second, public funds may indirectly substitute for private R&D by increasing the demand for R&D. The increase of such a demand results in higher costs of research inputs, and therefore a lower rate of return (Goolsbee, 1998).

In this study, public funding of private R&D is measured by the RDBGOV variable representing the share (in GERD) of R&D performed by the business sector and funded by the government.

- Promotion of interactions between the public research sector and businesses

Several countries have implemented initiatives in order to stimulate the research partnership between the business sector and public research organizations (universities and public research laboratories). These initiatives come in various forms such as licensing agreements, research contracts between university researchers and enterprises (Adams et al., 2001; Caloghirou et al., 2001; Tether and Tajar, 2008), joint publications (Hicks et al., 1996), the use of the technical infrastructure of universities, attending conferences and meetings (Cohen et al., 2002), the formation of new businesses in form of spin-off and start-up (Zucker and Derby, 2001 ; Zucker et al., 1998, 2002), and the mobility of researchers between academia and industry (Bania et al., 1992).

Such partnerships may increase the utilization and transfer of academic knowledge to the private sector.

To measure the transfer of public sector knowledge to the business sector, some studies have considered the R&D expenditures performed by the higher education sector and financed by companies (Conte et al., 2009; Li, 2009). In this paper, we prefer to consider the entire public sector (both sectors of higher education and government). Thus, we use a measure that reflects the collaboration between public and private research sectors.

The RDCOLPP variable will be measured by the share (in GERD) of research and development spending carried out by the higher education and government sectors and financed by the private sector[3].

➢ Promotion of collaboration between multinational companies and businesses

Emerging countries do not have enough resources like those of developed countries. That's why it is necessary that their national innovation systems are more open to external actors. Multinational Companies (MNC) are an important source of knowledge in their innovation systems (Narula and Dunning, 2000). Although the entry of foreign subsidiaries increases competition for local producers, their research activities may generate positive spillovers for local businesses (Cincera et al., 2003). Indeed, R&D of MNCs allow to change the innovation system of a country. Through their R&D, foreign subsidiaries become part of the innovation system, interact with local innovators, science and technology institutes and government agencies. This interaction provides a channel for technology spillovers from MNCs to local innovators. Thanks to the expansion of R&D activities within a country by a MNC, the national innovation system of the host country is linked with the global R&D network of MNCs as well as over the innovation systems worlwide. Studies of Girratana and Torrisi (2002); Cincera et al. (2003); Liefner et al. (2006); Bakker et al. (2008); Sun and Du (2011) and Sastre (2015) demonstrate the benefits of collaboration between multinationals and domestic enterprises.

In this paper, RDCOLBF is measured by R&D expenditures incurred by the business sector and financed by the foreign sector (as share of gross domestic expenditures on R&D).

➢ Promotion of human resources

Human capital accumulation is crucial for innovation and it drives in turn the countries' technological change level (Nelson and Phelps, 1966; Romer, 1990). It influences the innovation of emerging countries in two main ways: On the one hand it allows the generation of new knowledge (Gumbau Albert and Maudos, 2009; Jaumotte and Pain, 2005; Ulku, 2007). On the other hand, it enables the adoption and adaptation of

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existing ideas (Griffith et al., 2004; Teixeira and Fortuna, 2010; Fu et al., 2010).

In this empirical work, we use a measure reflecting capital expenditures in human capital. This is the share in GDP of public expenditure on education (EDUC) (Source: UNESCO).

- Protection of intellectual property rights

The industrial sector underinvests in research and development because of problems associated with weak appropriability of innovation benefits. The protection of intellectual property rights (IPR) is a mechanism used to cope with these problems. The patent, an exclusive right granted for an invention, affects innovation primarily through its effects on the rate of imitation. The model of Arrow (1962) points that the profits of the innovator decline due to competition when imitation occurs. The protection of ideas through robust IPR prevents such imitation. Therefore, it guarantees return on investment and promotes the generation of new knowledge.

Allred and Park (2007); Kanwar (2007); Ang (2010) and Lin et al. (2010) found a positive relation between protection of intellectual property rights and innovation activities.

In this paper, protection of intellectual property rights is measured by the index of strength of the legal system and protection of intellectual properties (IPR). This index takes a value between 1 and 10. A high value reflects that IPR protection system is sound. The data source for this variable is Fraser Institute (www.freetheworld.com).

The problem in assessing the R&D efficiency is the presence of a time lag between the provision of inputs and outputs prediction. Like Wang (2007) and Guan and Chen (2010), we take two years of difference between the inputs and output data. Thus, in models 1 and 2, data for patents and scientific publications are taken for the periods 2003-2012 and 2003-2011, while data on the knowledge stock and R&D manpower as well as environmental variables relate to the periods 2001-2010 and 2001-2009, respectively.

Descriptive statistics

Table 1 below provides descriptive statistics for outputs (PAT, PUB), inputs (SRD, MRD) and environmental variables (RDGOV, RDHE, RDBGOV, RDCOLPP, RDCOLBF, EDUC, IPR).

	Mean	Median	Standard Deviation	Minimum	Maximum
PAT	162.04	103	161.61	3	888
PUB	4158.639	2503.1	4215.31	120	15147.8
SRD	17123279	10319525.9	24030518.3	282520.8	115819387
MRD	124190.2	29696	270537.2	4858	1008091
RDGOV	29.02	25.7	13.61	7	71.4
RDHE	27.43	26.75	14.4	5.2	67.9
RDBGOV	7.97	3.88	10.54	0.011	38.8
RDCOLPP	6.02	5.78	3.01	0.58	14.95
RDCOLBF	3.8	2.5	3.77	0.004	21.28
EDUC	4.45	4.73	0.83	2.34	5.82
IPR	5.54	5.59	0.77	3.63	7.06

Table 1. Summary statistics of the variables

The number of patents corresponds to the period 2003-2012.

The number of scientific publications corresponds to 2002-2011. The other variables correspond to the period 2001-2010.

Countries of our sample have an average number of patent applications filed with the USPTO equal to 162.04 with a more or less strong dispersion: Patents reach 888 in some countries while they are 3 for others.

For scientific publications, they are on average 4158.6 with high dispersion: They reach 15147.8 for some countries while they are 120 for others.

In terms of inputs, the stock of knowledge is 17123279 on average, with a minimum level equal to 282520.829 and maximum reaching 115819387. Staff employed in the R&D sector is on average 124190.2 with a minimum equal to 4858 and a maximum reaching 1008091.

For environmental variables, research and development performed by sectors of government and higher education are on average of 29.02% and 27.43% of GERD respectively. On average, government finances business R&D by 7.97% of total R&D expenditures. The business sector finances public sector by a share equal to 6.02% of GERD. The foreign sector finances R&D activities of companies by a share equal to 3.8% of gross domestic expenditures on R&D.

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Emerging countries included in our sample have an average share in GDP of public expenditure on education equal to 4.45 and a medium level of IPR equal to 5.54 (on a scale of 10 points).

Presentation and interpretation of results

Statistical model consistency

	Model n°1			Model n°2		
Null Hypothesis (H0)	LR test	Statistics Chi-Square Mixed (5%)	Decision	LR test	Statistics Chi-Square Mixed (5%)	Decision
T1. H0: $B_{ij} = 0$	16.818	7.045	H0 rejected	86.374	7.045	H0 rejected
T2. H0: $\gamma = 0$	12.851	2.706	H0 rejected	79.477	2.706	H0 rejected
T3. H0: $\delta 0 = \delta 1 = \delta 2 = ... = \delta 7 = 0$	38.822	14.853	H0 rejected	71.336	14.853	H0 rejected

Table 2. Results of hypotheses testing

Model n°1 is the patent oriented R&D efficiency. Model n°2 is the scientific publication oriented R&D efficiency.

The gamma value is important to justify the interest of our study. In our case, γ is significant at 5%. This parameter reaches a value of 0.61 and 0.39 in models 1 and 2, respectively. This means that technical inefficiency of research and development spending plays an important role in explaining the distance from the production frontier, but that the role of random factors is equally important. It is a result consistent with the specific nature of the innovation process which is uncertain. This step allows us to justify the value of having considered a stochastic frontier rather than deterministic one which neglects the effects of random factors.

It also seems important to investigate whether one of the two forms of the production function is more suitable than the other. For this, using LR (Likelihood Ratio) given by the software used, we test the following hypothesis H0 : $\beta_{ij} = 0$ ($\beta 3 = \beta 4 = \beta 5 = 0$). So, if H0 is accepted and the coefficients β_{ij} are zero, the Cobb Douglas function is the most suitable. The LR test between the null hypothesis H0 and the alternative hypothesis H1 is given by the application of the model and is based on the following statistic:

LR = -2 {ln [L(H0) / L(H1)]}
LR = -2 {ln [L(H0)] - ln [L(H1)]}

where ln is natural logarithm, L(H0) and L(H1) are the likelihood functions for the hypotheses H0 and H1 and therefore represent the likelihood ratio values respectively for the Cobb-Douglas and translog function.

This statistic follows a mixed Chi-square distribution whose number of degrees of freedom is equivalent to the number of restrictions imposed[4].

H0 will be rejected if LR $>\chi^2$ (n, α)[5].

The H0 hypothesis is rejected here, as we see in Table 2 (T1 test), which justifies why a translog form is more suitable for our test. For the remainder of this analysis and interpretation of results, we will talk of the coefficients obtained by applying the model in translog function.

Two other tests will be performed to the function as translog. The first (marked T2 in Table 2) compares the hypothesis H0: $\gamma = 0$ with the alternative hypothesis H1: $\gamma > 0$. This test allows again to see if the stochastic production frontier is appropriate in our case. The critical value given directly by the software with the LR, follows again a mixed Chi2 distribution. Finally, we are testing another hypothesis (T3 test), always for translog form H0: $\delta 0 = \delta 1 = \delta 2 = \delta 3 = \delta 4 = \delta 5 = \delta 6 = \delta 7 = 0$ to determine if it is legitimate to study the effects related to technical inefficiency[6].

As shown in Table 2, the three hypotheses tested are rejected at 5%. According to the various tests, we can conclude that the most suitable form for the production function, between the Cobb-Douglas and translog function, is the latter and that the stochastic form is more appropriate. We have demonstrated the validity of the model studied here and then we can look forward to the results of our study.

R&D efficiency scores

The descriptive statistics of technical efficiency scores of the countries studied are reported in Tables 3 and 4.

The minimum and maximum patent oriented efficiency scores are respectively 12.5% and 94%. They are respectively 6% and 98% for publication oriented R&D efficiency.

	Mean	SD	Min	Max
Bulgaria	0.428	0.134	0.149	0.607
Croatia	0.373	0.055	0.267	0.444
Hungary	0.662	0.061	0.564	0.728
Latvia	0.382	0.077	0.289	0.563
Mexico	0.458	0.187	0.301	0.937
Poland	0.250	0.083	0.147	0.392
Romania	0.262	0.111	0.125	0.427
Russia	0.385	0.115	0.243	0.551
South africa	0.727	0.057	0.688	0.848
Turkey	0.252	0.092	0.131	0.403
All countries	0.417	0.041	0.125	0.937

Table 3. Scores of patent oriented R&D efficiency

	Mean	SD	Min	Max
Bulgaria	0.583	0.068	0.480	0.676
Croatia	0.887	0.050	0.811	0.978
Hungary	0.800	0.124	0.582	0.912
Latvia	0.930	0.026	0.878	0.951
Mexico	0.542	0.057	0.474	0.661
Poland	0.874	0.054	0.769	0.941
Romania	0.343	0.184	0.163	0.655
Russia	0.127	0.049	0.057	0.190
South africa	0.667	0.163	0.449	0.841
Turkey	0.964	0.015	0.931	0.979
All countries	0.666	0.057	0.057	0.979

Table 4. Scores of scientific publication oriented R&D efficiency

The analysis of efficiency scores reported in Tables 3 and 4 shows that the best performance of national innovation systems is recorded in the case when the output is measured by scientific publications. Indeed, the mean of efficiency score is 67% for publications and 41% for patents, indicating potential improvements of 33% of innovation results and 59% respectively with the same spending levels. This result is consistent with the results of Wang (2007), Wang and Huang (2007) and Chen et al. (2011) where the mean technical efficiency is higher when scientific publications are adopted as output rather than patents.

- The most efficient countries:

For patent oriented R&D efficiency: South Africa, Hungary and Mexico. This is due to the large number of patents.

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For publication oriented R&D efficiency: Turkey, Croatia and Latvia.

- The most inefficient countries:

For patent oriented R&D efficiency: Romania, Turkey and Poland.
For publication oriented R&D efficiency: Romania and Russia.

Note that Romania is among the least efficient countries regardless of the orientation of efficiency (patents or scientific publications). This result corroborates that found by Chen et al. (2011).

Determinants of inefficiency term

The performance of a country in terms of transforming R&D inputs into outputs is influenced by its technical skills and other factors relating to the environment.

Equation (6) defined above becomes to (7):

$$m_{kt} = \delta 0 + \delta 1\ RDGOV + \delta 2\ RDHE + \delta 3\ RDBGOV + \delta 4\ RDCOLPP + \delta 5\ RDCOLBF + \delta 6\ EDUC + \delta 7\ IPR + W_{kt} \quad \textbf{(7)}$$

Estimation results of this equation are reported in Table 5 which reports the results of the two models: Model n°1 where the output is the annual number of patents and Model n°2 where the output is the annual number of scientific publications.

For Model n°1, we find that public research (measured by R&D performed by sectors of government and higher education) has negative effect on the R&D efficiency. This result corroborates that found by Wang (2007) and Chen et al. (2011). Thus, public R&D does not affect the efficiency oriented towards patents because the public research activities do not often seek patent creation but aim more the provision of public goods.

Public R&D funds for the business sector have negative and not significant effect on the efficiency of spending on research and development. This result confirms that the financial resources of the government devoted to R&D of companies are not favourable to the R&D efficiency.

The same applies to variables reflecting interactions within the innovation system. Indeed, the coefficient for the collaboration between the public and private research sectors is not significant. This result does not support the study of Hu et al. (2014). It is not consistent with the

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empirical studies showing the benefits of such collaboration as Adams et al. (2001), Caloghirou et al. (2001) and Tether and Tajar (2008).

Variables of the production function	**predicted signs**	**Model n°1 Output = PAT**		**Model n°2 Output = PUB**	
		Coef.	**t-values**	**Coef.**	**t-values**
Constant		-51.544	-52.001 ***	-40.87	-19.94 ***
SRD	+	6.966	44.903 ***	2.919	6 ***
MRD	+	-0.21	-31.454 ***	3.827	4.877 ***
$(SRD)^2$	+	-0.414	-3.493 ***	0.205	2.57 ***
$(MRD)^2$	+	-0.352	-1.42	0.522	3.839 ***
SRD*MRD	+	0.553	1.604	-0.88	-4.194 ***
Determinants of inefficiency term	**predicted signs**[7]	**Coef.**[8]	**t-values**	**Coef.**	**t-values**
Constant		2.239	3.302 ***	4.085	5.331 ***
RDGOV	-	1.26	1.285	-1.892	-2.818 ***
RDHE	-	2.648	2.233 **	-4.231	-4.602 ***
RDBGOV	-	1.641	1.095	2.168	2.385 ***
RDCOLPP	-	0.355	0.627	0.602	1.012
RDCOLBF	-	-0.382	-0.577	-0.78	-1.006
EDUC	-	-0.381	-2.505 **	-0.553	-2.243 **
IPR	-	-0.438	-4.275 ***	- 0.379	-4.44 ***
σ^2		0.617	2.979 ***	0.089	4.31 ***
Γ		0.608	2.283 **	0.391	2.078 **
Number of Observations		92		86	
*, **, *** : Coefficients are significant at 10%, 5% and 1%.					

Table 5. Estimation results of Models 1 and 2

The results found may be due to the shortcoming that may exist in both sectors: companies and public research institutes (laboratories, research centers, universities). In fact, we can say that the absorption capacity among businesses is low. These are not able to assimilate immediately scientific knowledge generated by public research organizations.

Moreover, we can interpret the results found by joining Liefner et al. (2006) when they say that knowledge acquisition from research institutes has its own barriers. First, research institutes must have the ability to develop new technologies, which is a precondition not satisfied in several emerging countries. Second, research institutes in several countries are funded by governments and are forced to only fulfil the educational and basic research functions. In such circumstances, they have minor motivations to engage in cooperation with industry and in technology transfer. Third, research institutes and companies differ greatly in terms of working environments and objectives. Effective and intense cooperation must overcome all these barriers. However, our results can be explained by a long-term effect associated with this instrument. Indeed, Berman (1990) shows that an increase in industry funding for universities R&D has a positive and significant impact on the volume of R&D expenditure of the industry, but these benefits appear with a considerable delay.

We also found that collaboration between MNCs and domestic companies does not have a significant effect on efficiency. This result is not consistent with studies highlighting the important role of promoting such collaboration as those of Liefner et al. (2006) and Bakker et al. (2008). It highlights the lack of absorption capacity which may hinder the positive dynamics. Links failures in these countries can be explained by organizational failures of domestic firms to restructure and develop the linkage capabilities.

Only the proxies of human capital and intellectual property rights have a positive and significant effect, at 5% and 1% respectively, on national R&D efficiency. These results corroborate those found by Wang and Huang (2007) and Hu et al. (2014).

For Model n°2, where the output of R&D expenditures is measured by the annual number of scientific publications, we find the same results but with a difference in the effect of public research. Indeed, apart from the significant and positive impact of education and protecting IPR, research performed by government and higher education sectors is favourable also for the R&D efficiency.

So when efficiency is oriented towards scientific publications, public R&D has a positive impact on efficiency. This indicates that public R&D targets generally scientific research and/or aims to develop technology to meet the needs of industrial development. So public R&D will necessarily publish scientific articles rather than filing patent

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applications. This result can be explained by the lack of motivation of researchers in public sector to patent their inventions. By patenting, researchers will not necessarily have the reward of their efforts. They make use of other means of appropriability. In addition, patenting is expensive.

Moreover, in light of this result, we conclude that universities and public laboratories in the countries of our sample play a passive role. Indeed, they prefer to publish scientific articles to create inventions. This may be due to shortcomings within the educational system that fosters a purely academic training versus vocational one which is more related to practice.

Conclusion

The purpose of this paper was to examine the role of innovation policy in the R&D efficiency. By applying stochastic frontier model of Battese and Coelli (1995) to data for ten emerging countries, we find different results depending on the nature of the output. In fact, when the output is represented by patents, only the tools for human resources and intellectual protection rights contribute to improve the level of national R&D efficiency. When the output is represented by the scientific publications, public research, human resources and intellectual property rights are effective public tools to improve R&D management quality.

From this study, we detect the effectiveness of some public instruments to promote innovation and the fragility of others. Indeed, human resources and protection intellectual property rights are very important in emerging countries. Governments should also support research and development activities in universities as they allow to improve publication oriented R&D efficiency. We conclude however that the innovation system in emerging countries is not yet developed well enough to enable a more efficient management of scarce resources as interaction between its actors does not improve national R&D efficiency.

Although this study contributes to the already substantial body of R&D literature, it suffers from some weaknesses. Indeed, the results of the analysis of efficiency are by nature relative. We found that Romania is the least efficient country. Hence, we may question whether the results concerning the other economies would remain valid, if that country had not been considered in the sample. Moreover, for the variables representing the promotion of collaboration between public and private research sectors and between national and multinational companies, measures used reflect the cooperation in financial terms. They do not include the impact of staff mobility between the three categories of actors which is also important in the generation of new knowledge.

Finally, we propose new avenues for further analyses. One possibility is to use other measures for intellectual property rights and the promotion of collaborations within the innovation system and compare the results with those found in the present paper. A second way is to expand the instruments of innovation policy to include variables such as competition policies and promotion of capital risk.

Notes

1. We drop 2010 in this second model because of the lack of data on scientific publications.
2. National Science Foundation (2014) Science and engineering indicators. National Center for Science and Engineering Statistics, and the Patent BoardTM, Special Tabulation (2013) from Thomson Reuters, SCI and SSCI. Available at http://thomsonreuters.com/products_services/science/
3. The UNESCO database defines gross domestic expenditure on R&D as the sum of spending performed by four sectors: business, government, higher education and private nonprofit. We calculate for the ten countries of our sample and for the period 2001-2010 R&D expenditures (in % GDP) in each sector. We find that the average share of the private non profit sector is 0,7% of GDP. It is a very low percentage. That's why we do not consider such sector. In this study, private sector is the business sector.
4. Table of Kodde and Palm (1986, p.1246).
5. The number of restrictions is the number that differentiates the two equations tested, n is the number of restrictions (or degrees of freedom) and α is the tolerance threshold.
6. To find LR value, L(H0) must be determined by applying the FRONTIER model in the case where no inefficiency factor intervenes, so just with the factors of production.
7. Predicted signs with respect to the inefficiency score.
8. A negative sign (positive) indicates a positive (negative) impact of the variable considered on the efficiency level.

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