Patents *Vs* Publications and R&D: three sides of the same coin? Panel Smooth Transition Regression (PSTR) for OECD and BRICS countries

Inglesi-Lotz, R.

Department of Economics, University of Pretoria

Email: roula.inglesi-lotz@up.ac.za

Hakimi, A.,

University of Jendouba, Faculty of Law, Economics and Management of Jendouba

E-mail: abdelazizhakimi@yahoo.fr

Pouris, A.

Institute for Technological Innovation, University of Pretoria

Email: apouris@icon.co.za

Abstract

The paper aims to define the optimal thresholds of publications and Research and development expenditure (R&D) and to investigate their impacts on patenting in OECD and BRICS countries. To do so, we use a dataset of 25 countries divided into two country sub-samples for the period 1996-2013, employing the Panel Smooth Transition Regression model (PSTR).The results indicate that the threshold of publications after which patenting activity is promoted is 8417 publications for the OECD countries and 20848 for the BRICS countries; while the share of R&D in % of GDP should not exceed 1.683% for the OECD countries and 0.975% for the BRICS countries.

Keywords: patents; publications; R&D; PSTR analysis; OECD; BRICS

1. Introduction

The global socioeconomic conditions are characterised by instability and uncertainty; particularly the financial crisis of 2008-2009 has left countries with problems such as low economic growth, high unemployment, rising public debt, but also developmental issues consequently too. Policy makers seek urgently for the reasons of the collapse but most importantly, for the tools, instruments and factors that will assist in recovering. Innovation is the only catalyst that can improve the productivity of the main production factors (capital and labour) but also will increase further the important contribution of technological progress in the growth and development of countries. Over the past decade, studies have shown that technological progress (and ultimately convergence and fusion) is an important driver to economic growth (Hacklin, 2008; Awais et *al*., 2010; and Curren and Lecker, 2011)

Innovation defined as "the introduction of a new or significantly improved product, process, or method" (Raghupathi and Raghupathi, 2017) has different repercussions for economies at different stages of economic development. Schumpeter (1934) advocates that innovation arises from combinations of existing knowledge; while King and Anderson (2002) explain innovation by combining the concepts of modernization, renewal and change. Appreciating the role of innovation to take the world out of the stagnating conditions,it is imperative to understand and examine not only how innovation manifests nationally but also what the dynamics of all factors involved is.

Raghupathi and Raghupathi (2017) discuss that intellectual property (IP) is an important indicator used as an "umbrella term" for patents, copyrights and other expressions. Among them, patent productivity is preferred in the literature due to its direct linkage to the output of technological innovation (Hall et al. 2005). As Lee et al. (2011) explain patents are created, sold, and purchased by organizations thus creating inflows and outflows of knowledge. Kanwar and Evenson (2003) and Hudson and Minea (2013) debate the significant importance of patents to economic growth mainly through stronger patent rights affecting innovation and lead to cost effective technologies which in turn promotes growth and development. However, Park and Ginarte (1997) make a point in showing that the role and significance of stronger patent rights depends highly on countries' income level. They found that there is a positive correlation between strong patent rights and R&D expenditure and growth in upper-income countries. Such a result was also confirmed also by Hudson and Minea (2013), Park (2003), Kanwar and Evenson (2003) and Kim et *al.* (2008) while they show the phenomenon disappears in low-income ones. Pouris and Pouris (2011) investigating the South African intellectual property regime argued that mismanagement in the domain of intellectual property not only fails to support the objectives of the national innovation system but also that it facilitates exploitation by foreign interests and creates substantial social costs.

However, while patents are the first practical steps towards innovation, research publications are the initial outputs and results of research. Research publications are mainly the product of higher education institutions, research institutions and other organisations. Within the bibliometrics approach, indicators such as number of publications or the share of publications of a country to the rest of the world, or the share of publications of a field to total are mainly used (Inglesi-Lotz and Pouris, 2013). A measure of impact and quality of publications can also be found in the number of citations per paper but that indicator shows variability as time passes and it increases through the years. A number of papers have shown the importance of research publications as a proxy of the stock of knowledge or their share to their world have important effects to a country's economic growth (Hatemi-J., et *al*., 2016; Ntuli et *al*., 2015; Inglesi-Lotz et *al*., 2015; Inglesi-Lotz et *al*., 2014; Inglesi-Lotz and Pouris, 2013).

Although research publications and patents are used individually in studies as manifestations or proxies of innovative capacity, the two might present some certain level of interlinkages or correlation, and maybe causality. The two might work in unison towards improving technological progress. Owen-Smith and Powell (2003) showed some evidence that institutions involved in technological commercialization (patents) have a tendency to have higher number of publication numbers compared to those that are not, with a particular focus on life sciences. Another example can be found in a study by Foltz et *al.* (2007) that promoted the idea of the existence of economies of scope between quality adjusted life science patent and publication output, observing synergies between these two manifestations of innovation.

Anecdotal evidence has it that the two indicators are independent and that a system of innovation can move into invention (patent production) without research outputs prevails. A possible theoretical construct however, may argue that a country or region should have a minimum number of publications (research capacity) before it will be able to get involved in invention and innovation. In other words, the argument may be that there is a threshold of publications that is required before a country or region can engage into patenting. The policy implications are profound. Hence, it is necessary to search the threshold of research output that can positively affect development of new patents. This study aims to search the thresholds of publication that can affect patents. This threshold can be influenced by the research and development expenditure. We believe that these two indicators can significantly affect patent under a specific threshold.

While literature on the nexus between research outputs, R&D and patents is not limited (Inglesi-Lotz et *al*., 2015; Inglesi-Lotz et *al*., 2014; Inglesi-Lotz and Pouris, 2013); to date there is no study investigating the thresholds of publications and R&D that affect the possibility of patenting. This paper fills this gap and contributes to the existing literature as follow: contrary to previous studies that investigated only the effect of publications and R&D on patents, in this work, we searched precisely the optimal number of publications and the threshold of R&D that may affect patents. Earlier studies stated that research output and R&D are beneficial for patenting but nothing has been concluded on from which thresholds these two inputs can affect positively or negatively the possibility of patenting.

Starting from the hypothesis that the relationship between two or more variables is non-linear, in recent years the consideration of nonlinearity and more specifically, the existence of a phenomena of regime change has profoundly modified the econometric approaches applied to macroeconomics and finance. Since it is impossible to check these phenomena by performing usual form of linear autoregressive ARMA, ARCH, GARCH or VAR models, nonlinear processes are seemed very useful.

The studies of Quandt (1958) and Goldfeld and Quandt (1972, 1973) are considered as the pioneer works on nonlinear models which started with a piecewise and locally linear AR process. Following these pioneer authors, Tong and Lim (1980) and Tong (1983) have developed the Threshold Autoregressive model (TAR). The TAR model required to specify a lagged variable. However, when the lagged variable is the value of the process in previous period, the autoregressive process becomes self-exciting. Hence, the generalization of the Self-Exciting Threshold Autoregressive (SETAR) model. As econometric approach, the SETAR model has been performed in several studies (Hansen, 1996; Peel and Speight, 1996;

Peel and Speight, 1998, 2000). As the SETAR model is unable to account for continuous and smooth transitions, there was a strong need for another model to address this shortcoming. The Smooth Transition Autoregressive (STAR) model developed by Terasvirta and Anderson (1992) Granger and Terasvirta (1993) Terasvirta (1994) was proposed to solve the varying degrees of AR persistence and speed of adjustment.

The aim of this paper is twofold. First, it seeks the threshold levels of publications and R&D. Second, it investigates theirimpacts on patenting in OECD[1] and BRICS[2]countries. To achieve these goals, we used a dataset of 25 countries divided into sub-samples: the first group contains 20 OECD countries, while the second represents the five BRICS countries.To examine these group of countries, we employed a Panel Smooth Transition Regression model (PSTR) with data for the period 1996 to 2013.

The reminder of this paper is structured as follows: Data and model specification are given in section 2. In section 3, we present and discuss empirical results. Section 4 concludes and gives some policy implications.

2. Methodology and data

To test the linkage between research output, R&D and patents, we will employ a panel econometric technique to investigate the topic in two country groups: the OECD and the BRICS countries. The main reason for choosing these two groups is that OECD includes countries with a variety of characteristics in various geographical areas and variety of policies that however, have some homogeneity in their overall approaches towards innovation, technological progress, and economic growth. The majority of the countries in thegroup consists of industrialized and developed countries with well-established institutions, higher education sectors, and research facilities. On the other side, BRICS are a group of emerging economies with certain policy orientations aiming at achieving economic growth through higher productivity and innovation. However, they are developing economies with all the associated problems of lack of basic services and unstable institutions and political instabilities.

The dataset covers annual data related to 25 countries observed during the period 1996-2013 (due to recent data availability – Science and Engineering (S&E) research output). The whole sample is divided into sub-samples. The first group contains 20 OECD countries, while the second regroups 5 BRICS countries.In this study, we used an econometric model to test the relationship between research output and patents four variables. The first one is called dependent and represent patent (PAT). The three others variables are research output proxied by the number of publication (PUB), expenditure on R&D (R&D) and the annual growth rate of GDP (GDP). The hypothesis that the number of publication, the level of R&D and the number of patentsare characterised by nonlinear relationships motivates us to apply the PSTR model.

[1]The Organisation for Economic Co-operation and Development.
[2]BRICS is the acronym for an association of five major emerging national economies that regroups: Brazil, Russia, India, China and South Africa.

3. The model and variables definition

To investigate the nonlinear relationship between publications, research and development and patents we will specify the following PSTR model. Using this empirical model, we aim to determine the optimal number of publication and the threshold of R&D that can affect patent.The dependent variable$y_{i,t}$ is the number of patents (PAT) and the transition variable $q_{i,t}$is the number publications *(PUB)* and the level of R&D (R&D).

The PSTR model, proposed by González et *al*. (2005), is an extension of the PTR model of Hansen (1999). It is a fixed effects model with exogenous regressors. The PSTR model is considered a nonlinear homogenous panel model. The theoretical modeling of the PSTR is given by the equation (1)

$$y_{i,t} = \mu_i + \beta_0^{'} x_{i,t} + \beta_1^{'} x_{i,t} g(q_{i,t}, \gamma, c) + \varepsilon_{i,t} \quad (1)$$

For *i= 1, . . . , N*, and *t= 1, . . . , T*, where *N* and *T* denote respectively the cross-section and time dimensions of the panel. $y_{i,t}$ is the dependent variable. u_i indicates the vector of the individual fixed effects and $g(q_{i,t}, \gamma, c)g$ is the function of transition which depends on the transition variable of transition(q_{it}), to the parameter of threshold $(C)$and to the smooth transition parameter(γ). $x_{i,t} = (x_{i,t}^1,\ldots\ldots\ldots,x_{i,t}^k)$ is a vector of kk explanatory variables and where $\varepsilon_{i,t}$ is a random disturbance. $\beta_0$and β_1 indicate respectively the parameter vector of the linear model and the non-linear model. The transition function of the PSTR model$g(q_{i,t}, \gamma, c)g$ allows the system to transit gradually. To well define this transition function, González et al. (2005), like Granger and Teräsvirta (1993), Teräsvirta (1994), and Jansen and Teräsvirta (1996) propose the following logistic form of *m* orders in the equation (2):

$$g(q_{i,t}, \gamma, c) = \left[1 + \exp(-\gamma \prod_{j=1}^{m} (q_{i,t} - C_j)\right]^{-1} \quad (2)$$

Where $\gamma > 0$, $c_1 < \ldots < c_m$ and $c = (c_1 \ldots \ldots c_m)$is a vector of level parameter. γ represents the supposed positive smooth parameter. Ibarra and Trupkin (2011) reported that if γ is very high the PSTR model is considered as a model with two regimes.

To investigate the link between output research, expenditure on R&D and patents in OECD and BRICS countries, we used the following model. In this model, patent (PAT) is the dependent variable, the number of publication (PUB) is the first transition variable, R&D is the second transition variable and GDP is an exogenous variable. Hence, the transition function can be written in the equation (3) as follow:

$$PAT_{i,t} = \mu_i + \alpha PAT_{i,t-1} + \beta_0^1 PUB_{i,t} + \beta_0^2 RD_{i,t} + \beta_0^3 GDP_{i,t} + [\beta_1^1 PUB_{i,t} + \beta_1^2 RD_{i,t} + \beta_1^3 GDP_{i,t}] g(PUB_{i,t}, \gamma, c) + \varepsilon_{i,t} \quad (3.1)$$

$$PAT_{i,t} = \mu_i + \alpha PAT_{i,t-1} + \beta_0^1 RD_{i,t} + \beta_0^2 PUB_{i,t} + \beta_0^3 GDP_{i,t} + [\beta_1^1 RD_{i,t} + \beta_1^2 PUB_{i,t} + \beta_1^3 GDP_{i,t}] g(RD_{i,t}, \gamma, c) + \varepsilon_{i,t} \quad (3.2)$$

In the equation (3.1), the transition variable is the number of publication. However in the equation (3.2) it is the level of R&D.

In the non-linear model described above, *(PAT)* is the patents variable was derived from the U.S. Patent and Trademark Office databases. *(PUB)* is the research output variable for all countries and is derived by two editions of Science and Engineering Indicators (2012 and 2016). In the updated 2016, and latest release, the classification and collection method for the number of publications has been altered and hence, in some years, even though overlapping with the 2012 report the figures differ. To deal with this, we have used the figures from 2000-2013 from the latest report (2016) and extrapolated to the past, back to 1996, assuming the same annual growth rates as per the 2012 report.While expenditure on R&D and GDP are collected from the World Bank's World Development Indicators (WDI).Expenditure on R&D *(R&D)*is measured by Research and development expenditure (% of GDP). The fourth variable is the annual growth rate of GDP *(GDP)* measured by the annual percentage growth rate of GDP while $\varepsilon_{i,t}$is the error term.

4. Empirical results and discussion

In this section, we will present and discuss the study's empirical findings. Firstly, a descriptive analysis of all data used in this study is given. Secondly, the test of linearity and the test of the number of transition are performed and discussed. Finally, we estimate the PSTR model.

Table 1. Descriptive statistics

			Whole sample		
Variable	Obs	Mean	Std, Dev,	Min	Max
Pat	450	6,051	2,269	0,693	12,535
Pub	450	9,606	1,702	3,285	12,935
R&D*(in % of GDP)*	396	1,616	0,740	0,371	3,911
GDP*(annual growth)*	450	2,907	3,340	-9,132	14,231
			OECD countries		
Variable	Obs	Mean	Std. Dev.	Min	Max
Pat	360	6,231	2,449	0,693	12,535
Pub	360	9,465	1,787	3,285	12,935
R&D*(in % of GDP)*	317	1,769	0,739	0,371	3,911
GDP*(annual growth)*	360	2,299	2,929	-9,132	11,114
			BRICS countries		
Variable	Obs	Mean	Std. Dev.	Min	Max
Pat	90	5,333	1,062	3,555	8,687
Pub	90	10,168	1,159	8,172	12,903
R&D*(in % of GDP)*	79	1,003	0,293	0,563	1,991
GDP*(annual growth)*	90	5,339	3,769	-7,821	14,231

Note: *Before interpreting statistics of each variable used in this study, it is worth recalling that these values are in Napierian logarithm except GDP which is the annual percentage growth rate of GDPand R&D, which is in % of GDP. To have more precise information, we should practice the exponential function for variables of patents and publications.*

4.1 Descriptive statistics

Table 1 below presents descriptive statistics of all variables used in this study. For each variable, we give average value, standard deviation, minimum and maximum values. Descriptive statistics are presented to describe basic characteristics of data used in this study relative to each country group over the period 1996 - 2013.

Table 1 indicates that the average value of patent (PAT) is 6.051 for the whole sample, 6.231 for the OECD countries and 5.333 for the BRICS countries. The maximum value of patent for the whole sample and the OECD countries is the same with 12.535. However, the maximum value for BRICS countries seems rather weak with a level of 8.687. With regard to the number of publication (PUB), the average value for the whole sample is 9.606 compared to 9.465 in OECD countries and 10.168 in BRICS countries. However, the maximum value is almost similar for the three groups of countries. Statistics indicate a value of 12.935 for the whole sample and the OECD countries compared to 12.903 for the BRICS countries. The variable of R&D expenditure in % of GDP (R&D) registered on average a value of 1.769 % for OECD countries. However, in the BRICS countries the mean value of R&D in % of GDP is 1.003%. The orientation toward promoting R&D in OECD countries compared to the BRICS is confirmed by the maximum value of this variable. Descriptive statistics recorded a value of 3.911 in % of GDP in OECD against 1.991 % in BRICS countries.

Based on the annual percentage growth rate of GDP, we notice that BRICS countries record high level of growth compared to OECD countries. From Table 1, it can be observed that the mean value of GDP growth is 2.999% for the OECD countries and 5.339 % for the BRICS countries. Similarly, for maximum values, statistics registered a value of 14.231% for the BRICS countries against 11.114% for the OECD countries.

4.2 Results of *pre*-tests

Before testing the PSTR model, some pre-tests should be checked. The first one tests the linearity and the second one determines the number of regime. However, the third one defines the optimal threshold. Table 2 below summarizes the linearity test for the threshold of publications and R&D. Three statistics are used to check the non-linearity between publication and patent in the first step and R&D and publications in the second step. These tests are Lagrange Multiplier (Wald test), Lagrange Multiplier (F-test) and Likelihood-ratio test (LR).

Table 2: Linearity test

	PUB ⟶ PAT			R&D ⟶ PAT		
Tests	Whole Sample	OECD	BRICS	Whole Sample	OECD	BRICS
Lagrange Multiplier Wald Test	31.705	8.763	13.061	58.967	50.964	16.114
	(0.000)	(0.012)	(0.001)	(0.000)	(0.000)	(0.000)
Lagrange Multiplier F-Test	15.505	4.198	7.485	32.223	28.175	10.811
	(0.000)	(0.015)	(0.002)	(0.000)	(0.000)	(0.000)
Likelihood-ratio Test	31.938	8.884	16.482	63.755	55.434	21.840
	(0.000)	(0.011)	(0.000)	(0.000)	(0.000)	(0.000)

Values figure in parentheses are the P- values associated to Wald Test, F-test and LR test

4.2.1 The test of linearity

The objective of this empirical study is to confirm that there is a non-linear relationship between research output and patents or between expenditure on R&D and patents. To this end, we conduct a test of linearity against the PSTR model. The null hypothesis is H_0: $\beta_1 = 0$ and the alternative is H_1:$\beta_1 \neq 0H$. However, the test will be nonstandard since, under H_0 the PSTR model contains unidentified nuisance parameters[3]. The transition function $g(q_{i,t}, \gamma, c)$will be replaced by its first order Taylor expansion round γ= 0. The null hypothesis of this test becomes, H_0:$\gamma = 0$.The new function of transition can be written as following in the equation (4):

$$y_{i,t} = \mu_i + \beta_0^{'*} X_{i,t} + \beta_1^{'*} X_{i,t} q_{i,t} + \cdots + \beta_m^{'*} X_{i,t}\, q_{i,t}^m + \varepsilon_{i,t}^* \quad (4)$$

Where the parameter vectors $\beta_1^{'*}, \ldots\ldots, \beta_m^{'*}$ are multiples of γ and $\varepsilon_{i,t}^* = \varepsilon_{i,t} + R_m \beta^* X_{i,t}$ where R_m is the residual of Taylor development. This null hypothesis may be conveniently tested by a Wald and Likelihood ratio tests. If we denote SSR_0 the panel sum of squared residuals under H_0 (linear panel model with individual effects) and SSR1the panel sum of squared residuals under H_1 (PSTR model with two regimes), the Wald LM test can be writtenin the equation (5) as:

$$LM_w = \frac{TN(\, SCR_0 - SCR_1)}{SCR_0} (5)$$

Where; SCR_0 and SCR_1denote the residual squared sum of the panel under the null hypothesis (lineair panel model with individual effects) and the residual squared sum of the panel under the alternative hypothesis (PSTR model with m transition). If the sample size is small, Gonzàlez et al. (2005) suggest the use of the Fisher statistics (LMF) which is definedin the equation (6) as:

$$LM_w = \frac{TN(\, SCR_0 - SCR_1)/mk}{SCR_0/TN - N - mk} (6)$$

Where; k is the number of explanatory variables. LM_F is assumed to follow Fisher distribution with *mk* and *TN - N- mk* degrees of freedom (*F* (*mk, TN- N - mk*)). Under the null hypothesis, all linearity tests follow a chi-2 distribution with *k* degrees of freedom ($\chi^2(k)$).

Table 2 shows that the null hypothesis is rejected at the 1% level for the three tests. Also, linearity is rejected for the whole sample and the two sub-samples. Results imply that it exists non-linear relationship between publication and patents and R&D and patents for the whole sample, the OECD and the BRICS countries. We thus employ the estimation of non-linear model using the PSTR process.

4.2.2 Test of the number of transition

This test identifies the number of transition function. This test aims to check the null hypothesis when the PSTR model has one transition function (*m*=1) against the alternative hypothesis when the model has at least two transition functions (*m*=2). Decisions of this test are based on the LM_w and LM_F statistics. If the coefficients are statistically significant at level of 5%, we reject the null hypothesis and we admit that it exist at least two transition functions. Otherwise, we can't reject the null hypothesis and we conclude that the model has one threshold.

[3]For more details, see Hansen, (1999) González et *al*. (2005), following Luukkonen et *al*. (1998)

Table 3 below indicates the result of the number of regime.This test aims to check the null hypothesis for which the PSTR model has a single transition function *(1 = m)* against the alternative hypothesis that the PSTR model has at least two transition functions *(2 = m).* Statistics of LR and LMF tests are served to decide a single transition against two transitions. Hence, if the statistics of these two tests are significant at the critical level of 5%, we reject the null hypothesis and we conclude that there exist at least two transition functions. In contrary, when coefficients are not significant, we do not reject the null hypothesis and we conclude that the model has two regimes and therefore has one threshold.

Table 3: Test for the number of regimes

PUB (Transition variable)		*Whole sample*		*OECD*		*BRICS*	
Hypotheses	Tests	Statistics	P-value	Statistics	P-value	Statistics	P-value
(1)$H_0 : r = 0; H_1 : r = 0$	LM	23.606	0.000***	28.775	0.000***	9.962	0.041***
	LR	6.595	0.000***	8.274	0.000***	3.937	0.009***
(2)$H_0 : r = 1; H_1 : r = 2$	LM	12.658	0.092	13.566	0.088	3.466	0.483
	LR	2.009	0.073	3.713	0.056	1.078	0.380
R&D (Transition variable)		*Whole sample*		*OECD*		*BRICS*	
Hypotheses	Tests	Statistics	P-value	Statistics	P-value	Statistics	P-value
(1)$H_0 : r = 0; H_1 : r = 0$	LM	9,262	0,054	12,712	0,012**	1,03	0,905
	LR	2,493	0,088	3,471	0,008***	0,297	0,878
(2)$H_0 : r = 1; H_1 : r = 2$	LM	4.543	0.123	8,427	0,061	2.954	0.451
	LR	1.023	0.223	1,943	0,192	1.324	0.619

**** and ** indicate the statistical significance at 1% and 5% level*

Results from Table 3 indicate that both hypothesis without threshold *(r = 0)* and with at least two thresholds *(r = 2)* are rejected at the 1% and 5% significance for the two tests. Based on these results, the whole sample, and the two sub-samples have only one threshold of publications and R&D.

After checking the non-linearity hypothesis between publication and patents and R&D and patents and the number of regime, the third step consists to search the threshold of publication and R&D necessary for each group of countries to engage in patents. In other words, we will determine the optimal level of publications and R&D required for each group of countries to be able to get involved in invention and innovation.

Table 4. Results of threshold values

	PUB ⟶ PAT			R&D ⟶ PAT		
Tests	Whole Sample	OECD	BRICS	Whole Sample	OECD	BRICS
γ	1.900	5.000	5.000	4.000	1.900	5.000
$\boldsymbol{C}$	**11.113**	**9.038**	**9.945**	**2.127%**	**1.683%**	**0.975%**
Equivalent Number of publications[4]	**67038**	**8417**	**20848**	-	-	-
AIC	-1.293	-1.684	-3.651	-1.247	-1.824	-3.396
BIC	-1.223	-1.603	-3.337	-1.178	-1.742	-3.081

[4] Since our data are in logarithm, to search the exact value of threshold, we must practice the exponential function to the constant (C) to get the necessary threshold of publication and R&D for a country to engage in patent.

4.3 The optimal Threshold

Table 4 presents the thresholds of publications and R&D for the three samples; the whole sample, the OECD countries and the BRICS countries.

Table 4 indicates that the threshold of publication for the whole sample is 11.113, 9.038 for the OECD countries and 9.945 for the BRICS countries. Since our data are in logarithm form, to search the exact value of the threshold, we must practice the exponential function to the constant c to get the necessary number of publication to engage in patenting. Hence, the optimal numbers of publications or the thresholds are respectively, 67038 publications for the whole sample, 8417 for the OECD and 20848 for the BRICS countries. For the OECD and BRICS countries, below these numbers of publications, each group of countries is unable to engage in patenting. In contrary, beyond these levels, it is possible for countries to get involved in invention and innovation. An examination of the possibility of each country to engage in patent based on the threshold value indicates that for the OECD countries only three countries cannot response to this threshold. These countries are Iceland, Ireland and Luxembourg[5] with a maximum number of publications respectively of 628, 732 and 7190. These levels of publication are lower than the required threshold of 8417 publications. For the BRICS countries, the threshold for this region is 20848. Only one country cannot engage in patenting activities based on the number of publications. This country is South Africa[6]. This country recorded during the period 1996-2013, a maximum number of publications of 9679 whic is lower than the required threshold of 20848.

With regard to the threshold of R&D, Table 3 shows that the threshold of R&D in percentage of GDP is 2.127% for the whole sample, 1.683% for the OECD group and 0.975% for the BRICS countries. With reference to the results of PSTR model displayed in Table 4, we can conclude that beyond these thresholds, R&D exerts a negative impact on patent. This means that the three sub-samples are only able to get involved in invention and innovation and engage in patenting if they do not exceed these thresholds of R&D. Another observation can be drown from the optimal threshold of publication and R&D. Compared to BRICS countries, results in Table 3 reveal that OECD countries need more R&D and less number of publications to engage in patent.

To conclude the interaction between the number of publications and the level of R&D in % of GDP necessary for each group of countries to engage in patenting, we found that: in the whole sample, publications should not surpass 67038 and the level of 1.683% for the R&D. More than 8417 publications and less than 1.683% of R&D, OECD countries are able to engage in patenting. However, for the BRICS countries the threshold of publications must be beyond 20848 and the level of R&D must be below 0.975% to be able to get involved in invention and innovation and to engage in patenting.

4.4 Discussion of results of the PSTR model

Table 4 presents the estimation of PSTR model for the whole sample of 25 countries and the two sub-samples of OECD and BRICS countries during the period 1996-2013. This estimation is done by applying nonlinear least squares to eliminate the individual effects.

[5] For more details, see Appendix 1 relative to the statistics of number of publications in the OECD countries.
[6] For more details, see Appendix 2 relative to the statistics of number of publications in the BRICS countries.

Table 5: Coefficient estimation of the PSTR model

	PUB ⟶ PAT			R&D ⟶ PAT		
Variables	Whole Sample	OECD	BRICS	Whole Sample	OECD	BRICS
GDP	1.118	1.486	0.162	1.190	1.484	0.748
	10.397***	15.776***	0.606	10.344***	16.077***	2.586***
PUB	0.163	-0.031	0.597	-0.075	-0.107	-0.716
	1.873*	-0.348	1.550	-0.865	-1.385	-1.784
R&D	1.156	1.785	8.396	1.573	3.522	7.693
	18.141***	21.472***	7.188***	10.897***	9.746***	5.322***
PUP* $g(q_{i,t}, \gamma, c)$	-1.889	0.073	0.741	0.378	0.029	0.589
	-8.519***	3.827***	7.114***	7.952***	0.690	5.853***
R&D* $g(q_{i,t}, \gamma, c)$	10.783	-0.505	-8.641	-1.443	-1.883	-6.774
	9.407***	-5.265***	-6.296***	-8.499***	-8.840***	-5.108***
γ	1.900	5.000	5.000	4.000	1.900	5.000
C	11.113	9.038	9.945	2.127%	1.683%	0.975%
Obs	**403**	**325**	**78**	**403**	**325**	**78**

**** indicates the statistical significance at 1% level*

As exogenous variable, results indicate that the level of growth is positively and significantly correlated with the dependent variable (PAT) at 1% level of significance. This positive association is confirmed for the effect of publications on patents and the impact of R&D on patent. The positive and significant correlation is confirmed for the whole sample and the two sub-samples. An increase in the level of GDP increases the possibility of a country to get involved in patenting. Countries with a level of growth will invest in research and development to improve the quality of education, the quality and the quantity of research output, which are able to engage in patenting. These countries provide all necessary inputs to the research activities such as databases, software, skills, international cooperation. In addition, the high level of growth is associated with an improvement of the state of human being. Hence, high fees will not price many potential students out of higher education. The number of students that do not take classes remains very weak.

The variable of R&D expenditure in % of GDP is statistically significant at 1% level of significance and positively correlated with the dependent variable (PAT). The positive and significant relation is confirmed for the whole sample, the OECD and the BRICS countries. The impact of R&D expenditure was considered as a key factor for invention, innovation and patenting. One of the reasons for patents is to stimulate economic and technical development and to foster competition by creating more financial incentive. Much as R&D spending was devoted to stimulate firm invention and innovation. It is also considered as an important indicator of patenting and new products. Our results confirm the finding of Griliches (1984) and Bound *et al.* (1984). These authors found strong evidence between R&D spending and the number of patents. Hall *et al.* (1986) also confirmed the positive association between R&D and patents, Jensen (1987). Similarly, our results are in line with Peeters and Van Pottelsberghe(2006), Bonger and Bansal (2007) who reported that firms that granted effort to R&D experienced a higher level of patenting.

Next, we turn to analyze the effect of publication and R&D as transition variables. In other words, we will interpret the impact of these variables beyond the optimal threshold of publications and expenditure on R&D.

Beyond the optimal thresholds, the number of publications exerts a positive impact on patents in OECD and BRICS countries. Beyond a number of 8417 publications in OECD and 20848 publications in BRICS, these two groups of countries can engage in patenting. However, when the whole sample surpassed the threshold of 67038 publications, the effect of research output on patent becomes negative and countries are unable to engage in patenting. From these results, we can conclude that the optimal number of publications that increases the possibility of patenting is between 8417 and 67038 publications for the OECD and between 20848 and 67038 publications for the BRICS countries. If the number of publications exceeds 67038, the quantity dominates the quality of research output and it is most likely that many of these research projects are not feasible which decreased the possibility of patenting. In addition, patents are more applicable in research related to technology, biological, physical or chemical sciences. However, for social sciences most of the academic research leads to good publications in highly indexed journals. Hence, countries that aimed to engage in patenting thought research output should be more interested to technology, biological, physical or chemical sciences.

For the second threshold relative to the R&D in % of GDP, results displayed in table 5 indicate the opposite effect compared to the number of publication. In other words, beyond the optimal threshold, the effect of R&D in % of GDP on patents becomes negative. To engage in patent, the OECD countries should not surpass the level of 1.683% as expenditure on R&D. Beyond this threshold, the causality between R&D and patent becomes negative. Our results are divergent to the work of Kondo (1999) which supports that patent application increases in proportion to the increase of R&D expenditure and technology quality. The same analysis is for the BRICS countries. The optimal threshold of R&D is 0.975 in % of GDP. To get the possibility of patenting, BRICS countries should not exceed this threshold.

This finding has a possible two-fold explanation. Firstly, the particular allocation of the countries' R&D budget to different fields might play an important role. The possibility to engage in patenting activities through research projects in technology, engineering or chemical fields is higher than that of social sciences and humanities. Secondly, an increase in the budget of R&D may decrease the possibility of patenting production, if that increase is derived from a re-allocation of funds in other sectors (substitution) such as expenditure for education, infrastructure and others that may lead to job creation and productivity improvements.

To summarize, OECD and BRICS countries present similarities with regard to the positive and significant effect of GDP, number of publication and R&D expenditure on the possibility of patenting. Although that descriptive statistics show some differences concerning these variables, empirical findings supported the same effect. However, these countries are divergent in the threshold of publication. This threshold differs between the two sub-samples. Results indicate that the threshold of publication able to get patent is 11.113 for the whole sample, 9.038 for the OECD countries and 9.945 for the BRICS countries. Another important remark relative to effect of the transition variables beyond the optimal threshold could be raised. The effect of the number of publications and R&D as variables of transition is opposite. Beyond the threshold, the number of publications increases the possibility of patenting for the two groups of countries. However, beyond the threshold of R&D this variable decreases the probability of patenting. From these results and based on the optimal threshold, we conclude that patents in OECD and BRICS countries are positively influenced by the number of publications not by the expenditure on R&D.

Table 6. Recapitulation of thresholds of publications and R&D necessary for patenting

Sample	Threshold of PUB	Threshold of R&D in % of GDP	Interval	Possibility of Patenting
Whole sample	67037	2.127	PUB < 67037 R&D < 2.127%	YES
OECD	8417	1.683	PUB > 8417 R&D < 1.683%	YES
BRICS	20848	0.975	PUB > 20848 R&D <0.975%	YES

5. Conclusions and Policy implications

The main assumption in studies examining innovation in its various forms is that the number and growth of academic papers are independent of the patenting production of a country. This paper examines whether there is a threshold in academic publications that will enable invention and innovation, through patenting activity. This study makes also the assumption that a driving factor for the relationship between research papers and patents is the R&D expenditure of the country. To do so, the paper employed a Panel Smooth Transition Regression model (PSTR)that takes into account non-linear characteristics of the relationship.

To summarize, OECD and BRICS countries present similarities with regard to the positive and significant effect of GDP and R&D expenditure on the patent. Although that descriptive statistics show some differences concerning these variables, findings supported the same effect. However, these countries are divergent in the threshold of publication and R&D and in the effect of publication and R&D on patent beyond these thresholds. This threshold differs from group of countries to another. Results indicate that the threshold of publications able to get patent must surpassed 8417 publications for the OECD countries and 20848 for the BRICS countries. While the threshold of R&D should not exceed 1.683% for the OECD countries and 0.975% for the BRICS countries. An examination of the descriptive statistics, we found that the maximum level of R&D was 1.365% for the OECD countries and 0.7% for the BRICS countries. This confirms that these two groups of countries do not surpass the optimal thresholds. Hence, they are able to patents with reference to the optimal threshold which is below 1.683% for OECD and 0.975% for the BRICS.

Several studies make use of seasonal data like quarterly or monthly data to study the nonlinearity behaviour (Hansen, 1996; van Dijk et al., 2002; Singh; 2012). They reported that it is not possible to observe and to detect seasonal transition or adjustment using annual data. Indeed, this study has made use of data with annual frequency due to lack of data in other frequencies, which might be considered a limitation for this study. However, lower frequency of data are not available for the number of publications and patenting activity.

These results have important policy implications. OECD and BRICS countries should allocate the budget of R&D optimally. Institutions and policy makers should ensure that funding is allocated to projects that will result in not only theoretical results but also practical and implementable results in the production process of the countries. To increase the possibility of patenting, OECD and BRICS countries should be oriented toward technological, physical and chemical sciences rather than social sciences. Hence, the most important part of R&D budget should be channelled to these fields.

With regard to the number of publications, the two groups of countries are expected to surpass a specific number of publications in order to increase their patenting activity. Considering this threshold, patents in OECD and BRICS countries are positively influenced by the number of publications not by the expenditure on R&D. OECD countries should aim at reaching more than 8417 S&E publications to increase patent productivity while for the BRICS the threshold is 20848 publications. The majority of the countries in the analysis have achieved their respective thresholds and hence, have engaged in patenting activities, with the exception of Iceland, Ireland, Luxembourg and South Africa. For these countries, further research should be conducted in order to examine possible drivers for increasing the research output in publications terms and hence, ignite the positive relationship with patenting production and hence, betterment of economic productivity and growth.

References

Awais, M., Pervez, A., Yaqub, A., Sarwar, R., Alam, F., and Siraj, S. (2010). Current status of biotechnology in health, *American-Eurasian Journal of Agricultural & Environmental Science*, 7, 210 –220.

Bogner, W.C. and Bansal, P. (2007).Knowledge Management as the Basis of Sustained High Performance. *Journal of Management Studies,* 44 (7), pp. 165–188.

Bound, J, C. Cummins, Z. Griliches, B. H. Hall and A. Jaffe. (1984).*Who Does R and D and Who Patents*,in Z. Griliches (ed.): R&D, Patents, and Productivity, Chicago, University of Chicago Press.

Curren, C., and Lecker, J. (2011). Patent indicators for monitoring convergence examples from NFF and ICT. *Technological Forecasting and Social Change*, 78, 256– 273.

Goldfeld, S. M. and Quandt, R. E. (1972) *Nonlinear Methods in Econometrics*, North-Holland, Amsterdam.

Gonzalez A., Teräsvirta T. and Dick V. D. (2005).Panel smooth transmission regression models, *Working Paper Series in Economics and Finance: Stockholm School of Economics*.

Granger C., and Teräsvirta T. (1993).*Modelling non-linear economic relationships*, Oxford University Press.

Granger, C. W. J. and Terasvirta, T. (1993) *Modelling Nonlinear Economic Relationships*, Oxford University Press, Oxford.

Hacklin, F. (2008). Management of Convergence in Innovation: Strategies and Capabilities for Value Creation beyond Blurring Industry Boundaries: Contributions to Management Science, Springer, Berlin.

Hall, B. H., J. A. Hausman and Z. Griliches. (1986).Patents and R and D: Is There a Lag, *International Economic Review*, 27, pp. 265-283.

Hall, B. H., Jae, A. B., and Trajtenberg, M. (2005). Market value and patent citations. *RAND Journal of economics*, pages 16-38.

Hall, C., Cleveland, C., Kaufmann, R., (1986). Energy and Resource Quality: the Ecology of the Economic Process. Wiley, New York, USA.

Hansen B. E. (1999).Threshold effects in non-dynamic panels: estimation, testing, and inference, *Journal of Econometrics* 93 (2), pp. 345–368.

Hatemi-J, A., Ajmi, A.N., El Montasser, G., Inglesi-Lotz, R., and Gupta, R. (2016). Research Output and Economic Growth in G7 Countries: New Evidence from Asymmetric Panel Causality Testing. *Applied Economics*, 48(24), 2301-2308.

Hudson, J., &Minea, M. (2013). Innovation, intellectual property rights, and economic development: a unified empirical investigation. *World Development*, 46, 66–78

Ibarra R. and Trupkin D. (2011).The relationship between inflation and growth: a panel smooth transition regression approach, *Research Network and Research Centers Program of*

Inglesi-Lotz, R., and Pouris, A., 2013. The influence of scientific research output of academics on economic growth in South Africa: an autoregressive distributed lag (ARDL) application. *Scientometrics*, 95, 131-141.

Inglesi-Lotz, R., Balcilar, M., Gupta, R., (2014). Time-Varying Causality between Research Output and Economic Growth in US. *Scientometrics*, 100, 203-216

Inglesi-Lotz, R., Chang, T., Gupta, R. (2015). Causality between research output and economic growth in BRICS. *Quality and Quantity*, 49(1): 167-176.

Jansen E., and Teräsvirta T. (1996).Testing parameter constancy and super exogeneity in econometric equations, *Oxford Bulletin of Economics and Statistics*, 58 (4), pp. 735–763.

Jensen, E. J. (1987). Research expenditures and the discovery of new drugs. *Journal of Industrial Economics*, 36(1), 83-95.

Kanwar, S., &Evenson, R. (2003). Does intellectual property protection spur technological change? *Oxford Economic Papers*, 55(2), 235–264.

Kim, Y. K., Lee, K., Park, W.G. (2008). Appropriate intellectual property protection and economic growth in countries at different levels of development, *Research Policy*, 41, 358-375.

King, N., & Anderson, N. R. (2002). Managing innovation and change: a critical guide for organizations. Psychology at work. London, England: Thomson Learning.

Kondo. M. (1999).R&D dynamics of creating patents in the Japanese industry, *Research policy*, 28, 587-600

Lee, L-C., Lin, P-H., Chuang, Y-W. and Lee, Y-Y. (2011). Research output and economic productivity: a Granger causality test. *Scientometrics*, 89:465–478.

Luukkonen R., Saikokonen P. and Terävirta T. (1988).Testing linearity against smooth transition autoregressive models, *Biometrica* 75, pp. 491- 499.

Ntuli , H., Inglesi-Lotz, R., Chang, T., Pouris, A., (2015). Does research output cause economic growth or vice versa? Evidence from 34 OECD countries. *Journal of the Association for Information Science and Technology*, 66(8): 1709-1716.

Owen-Smith J, Powell WW. (2003). The expanding role of university patenting in the life sciences: Assessing the importance of experience and connectivity. *Research Policy*, 32(9):1695–1711.

Pakes. A and Grilishes. Z (1984). , Patents and R&D at the Firm Level: A First Look, Chapter pages in book: (p. 55 - 72), http://www.nber.org/books/gril84-1

Park, W. G. (2003). Do intellectual property rights stimulate R&D and productivity growth? Evidence from cross-national and manufacturing industry data. In J. Putnam (Ed.), Intellectual Property Rights and Innovation in the Knowledge Based Economy. Calgary: University of Calgary Press.

Park, W., and Ginarte, J. C. (1997). Intellectual property rights and economic growth. *Contemporary Economic Policy*, 15(3), 51–61.

Peel, D. A. and Speight, A. E. H. (1998) The nonlinear time series properties of unemployment rates: some further evidence, *Applied Economics*, 30, 287–94.

Peel, D. A. and Speight, A. E. H. (2000) Threshold nonlinearities in unemployment rates: further evidence for the UK and G3 economies, *Applied Economics*, 32,705–15.

Peel, D.A. and A.E.H. Speight (1998). Threshold Nonlinearities in Output: Some International Evidence, *Applied Economics*, 30(3), 323-333.

Peeters C. and Van Pottelsberghe de la Potterie B. (2006). Innovation strategy and the patenting 19 behavior of firms, Journal of Evolutionary Economics, 16, 109–135.

Pouris, A. and A Pouris. (2011). Patents and Economic Development in South Africa: Managing intellectual property rights, *South African Journal of Science*, 107, (11/12), 1-10

Quandt, R. E. (1958). The estimation of the parameters of a linear regression system obeying two separate regimes, *Journal of the American Statistical Association*, 53, 873–80.

Raghupathi. V and Raghupathi. W. (2017). Innovation at country-level: association between economic development and patents. *Journal of Innovation and Entrepreneurship*, 6 (4), 1-20

Schumpeter, J. (1934). *The theory of economic development*. Boston, MA: Harvard University Press.

Singh, T. (2012). Testing Nonlinearities in Economic Growth in the OECD Countries: An Evidence from SETAR and STAR Models, *Applied Economics*, 44(30), 3887-3908.

Teräsvirta T. (1994). Specification estimation and evaluation of smooth transition autoregressive models, *Journal of the American Statistical Association*, 89, 208- 218.

Terasvirta, T. and Anderson, H. M. (1992) Characterizing nonlinearities in business cycles using smooth transition autoregressive models, *Journal of Applied Econometrics*, 7, S119–36.

Tong, H. (1983) Threshold Models in Non-linear Time Series Analysis, *Lecture Notes in Statistics*, Vol. 21, Springer, Berlin.

Tong, H. and Lim, K. S. (1980) Threshold autoregression, limit cycles and cyclical data, *Journal of the Royal Statistical Society*, Series B, 42, 245–92.

Appendix 1. Selected statistics of publication in OECD countries *(in number)*

Countries	Austria	Belgium	Canada	Denmark	France	Germany	Greece	Iceland	Ireland	Italy
MAX	12031	16511	58420	12482	72555	101778	11802	***628***	***7190***	66310
MEAN	8553	12095	43223	8422	57709	78722	8093	***359***	***4412***	45628
MIN	5281	8774	30305	5961	45003	58030	3688	***194***	***2338***	30066
Countries	**Luxembourg**	**Netherlands**	**Norway**	**Portugal**	**Spain**	**Sweden**	**Switzerland**	**Turkey**	**UK**	**US**
MAX	***732***	30412	10040	13556	53645	19362	21060	30402	97332	414759
MEAN	***246***	22699	6605	6480	35187	15645	14984	16292	79893	339104
MIN	***27***	17030	4343	1797	19790	13308	10537	4222	66643	271009

Appendix 2. Selected statistics of publication in BRICS countries *(in number)*

	Brazil	Russia	India	China	South Africa
MAX	48622	35542	93349	401435	***9679***
MEAN	24785	28821	43103	170148	***5570***
MIN	6910	24487	19539	26956	***3540***

Note: grey highlight indicates countries that are able to engage in patenting with reference to the threshold of publication; while bold and italics indicate countries that are unable to engage in patent with reference to the threshold of publication.