# Threshold effects in the patent-growth relationship: a PSTR approach for 60 developed and developing countries

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## Abstract

This study analyzes whether there is a threshold effect in the innovation-growth relationship. Using data from the period 2008–2017, we perform an analysis using 60 countries in the whole sample and a split-sample analysis in which we separate developed countries (36) from developing countries (24). The results for the panel smooth transition regression (PSTR) model indicate that there is a threshold effect in the innovation-growth relationship. We find that below the threshold, the effect of innovation measured by the number of patents is not significant for developed and developing countries. However, surpassing the optimal threshold, the effect becomes positive only for the whole sample and developed countries. Furthermore, findings also indicate that research and development expenditure, domestic and foreign investments stimulate economic growth.

**Keywords:** innovation; patents; growth; PSTR analysis; developed; developing countries.

## 1. Introduction

Society, businesses, industries and economies in their entirety benefit from the process of innovation, and the notion is not new in the economic literature. In the 1950s, Solow (1956) argued that technological progress (innovation) and economic growth have a long-run relationship. Innovation, defined as the process of developing new or improved products, processes and methods (Raghupathi and Raghupathi 2017), has the potential to improve economic systems by increasing the productivity of all factors of production, financial systems, infrastructure development and quality of living standards.

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Many studies highlight that technological advancements are an important contributor to economic growth and a pillar determinant of the level of growth (Hacklin 2008; Awais et al. 2010; Curren and Lecker 2011; Fagerberg, Martin, and Andersen 2013; Bekhet and Abdul Latif 2018; Inglesi-Lotz, Hakimi, and Pouris 2018). Technological advances are even considered as an important determinant as capital stock and labour (Inglesi-Lotz, Van Eyden, and Du Toit 2014)..

Innovation strength has been examined with several measures in empirical studies on the innovation-growth relationship (Fagerberg, Martin, and Andersen 2013; Bekhet and Abdul Latif 2018). Mobile phones and the Internet are the most frequently used measures to explain the relationship between technological advances, innovation and economic growth (Sepehrdoust 2018; Ficawoyi 2019; Haftu 2019). In contrast to these studies, we use patents to measure innovation. More precisely, we use patents in force. A patent that has expired no longer carries any rights of exclusivity for its holder. Patents expire for several reasons. For example, failure to pay maintenance fees, the age of the patent and invalidation are considered the main reasons that make patents expire . However, when a patent is in force, the owners have a monopoly right of exclusivity and sell the underlying invention. Patents provide to the owner the right to exclude others from exploiting the patented technology. In contrast to an invention that is not patented, competition allows the use of this invention freely without making any payment. Theoretically, patents are one of the most important elements in intellectual property rights. Economically, firms in particular and societies in general benefit from the patent system. Patents play a crucial role in promoting innovation that contributes to easy knowledge sharing and efficient use of resources. Thus, patents result in an increase in the investment activity that stimulates economic growth..

More recent literature (see Aristizabal-Ramirez and Canavire-Bacarreza 2015) argues that the innovation-growth relationship might present nonlinear characteristics: Initial low levels of innovation might not have a high impact on economic growth, but from a certain threshold point further, the impact might become stronger through a number of positive loop channels, such as the higher quality of human capital that is produced from the innovation process that, in turn, can improve the future human capital further. The concept of threshold was explained initially by Azariadis and Drazen (1990). They argue that there might be a particular point where the accumulation of inputs and knowledge might be such that above that point the 'growth possibilities may expand rapidly or below which countries might fall into so-called poverty traps.' Bilbao-Osorio and Rodríguez-Pose (2004) also discuss that this might be why countries with high economic growth tend to innovate more and benefit substantially from innovation.

The purpose of this study is to investigate the relationship between innovation (patents) and economic growth for a balanced panel of 60 countries divided into 36 developed countries and 24 developing countries over the period 2008–2017.

s the innovation-growth relationship can be nonlinear, we perform the panel smooth transition regression (PSTR) model as the econometric approach.

Since the seminal work of Schumpeter (Schumpeter 1934), an important stream of literature has argued that the innovation-growth relationship is linear (Lach 1995; Zeira 2011; Niwa 2016; Maradana et al. 2017; Saito 2017). However, few studies have investigated the nonlinear relationship (Aristizabal-Ramirez and Canavire-Bacarreza 2015). It is obvious that less developed countries should continue to work on patents, as they are considered one of the factors of innovation. These countries are currently at such a level of development that they cannot fully benefit from the production of patents. Hence, determining the threshold of patents that stimulate economic growth remains very interesting. This study fills this research gap and contributes to existing literature by determining the optimal threshold of innovation that affects economic growth. First, in contrast to Aristizabal-Ramirez and Canavire-Bacarreza (2015) who use Hansen's (1999) PTR model, we use Gonzalez, Teräsvirta, and Dick (2005) model which is considered an extension of the PTR model. Second, Aristizabal-Ramirez and Canavire-Bacarreza (2015) used a whole sample of 147 countries over the period 2006–2012. In the present study, we split the whole sample of 60 countries into two sub-samples. The first sample includes 36 developed countries, and the second sample 24 developing countries. This is to better understand the dynamic nonlinear relationship between innovation and growth in developed and developing countries. Consequently, some policy recommendations could be addressed to each group of countries. Third, most previous studies that focused on the innovation-growth relationship use information and communication technology and technological advances as proxy for innovation. However, in this study we use patents in force to measure innovation.

This paper is structured as follows. A brief literature review is given in section II. Section III presents the data and method. Empirical results are discussed in section IV. Section V concludes and addresses some policy recommendations.

## 2. Literature review

Solow (1956) proposed one of the most well-known economic growth theories based on the assumption of no government intervention, no technological growth and no population growth. Relaxing one of the main assumptions to make the model more representative of the real world, he includes effectiveness in production function inputs: Capital and labour could become now more effective at an exogenous rate of technological progress. That is the first attempt to endogenize technological progress in a study of economic growth by introducing the Solow residual or total factor productivity that by who also define technological progress. Arrow (1962) also proposes that technological progress can be endogenized as the result of learning about the labour; while Romer (1990) almost three decades later assumes that knowledge is a public good: 'It is the presence of patents, copyrights and other economic incentives related to investment that enable inventors to earn profits so as to cover the initial costs of developing new ideas.'

The empirical studies analysing the relationship between innovation and economic growth and decoding the dynamics between the two indicators show diverging results. Some studies establish a positive relationship (Hasan and Tucci 2010; Bielig 2015; Alexiou, Nellis, and Papageorgiadis 2016; Maradana et al. 2017; Lee and Lee 2019), while others show the existence of a negative relationship through the negative consequences on social exclusion and inequality (Stiglitz 2012; Aghion et al. 2015), or no relationship (Sweet and Eterovic 2019 Sweet, C. , and D.Eterovic . 2019. "Do Patent Rights Matter? 40 Years of Innovation, Complexity and Productivity." *World Development* 115: 78–93. [Crossref], [Web of Science ®], [Google Scholar]).

Furthermore, some of the existing literature argues that the innovation-growth relationship is influenced indirectly or directly by the innovation level or the innovation intensity. For example, Bilbao-Osorio and Rodríguez-Pose (2004), LeBel (2008) and Hasan and Tucci (2010) report that the effect of innovation on growth depends on the level of innovation and the development process. They argue that countries with a high level of innovation benefit economically more than countries with lower innovation which has little to no effect on growth. Other researchers find that positive effects of innovation on growth depend on the infrastructure, the physical and human capital accumulation. As Buesa et al. (2010) report, countries with low innovation intensity or capacity do not see their growth affected significantly.

Based on a sample of 58 countries for the period 1980–2003, Hasan and Tucci (2010) ordinary least squares (OLS) results show that countries hosting firms with higher-quality patents also have higher economic growth. The authors also conclude that countries that increase the level of patenting also witness a concomitant increase in economic growth.

More recently, Sweet and Eterovic (2019) focus on the effects of patent rights systems on total factor productivity growth by using dynamic panel regression analysis for 70 countries from 1965 to 2009. They find that the effects of stronger or more rigorous patent systems are not significant for productivity growth in developing and industrialized countries. They conclude that although patent rights are increasingly irrelevant to productivity, the relationship between economic complexity and productivity is highly positive and significant. Across the last 40 years, industrial advancement, stagnation or decline appears deeply intertwined not with patent rights but with economic complexity.

Lee and Lee (2019) examine the impacts of national innovation systems on economic growth. They use an NIS composite index developed by U.S. patent data as a weighted sum of three, four or five variables among the following: concentration of assignees, localization, originality, diversification and cycle time of technologies. They confirm the significant and robust impacts of national innovation system indices on economic growth.

Maradana et al. (2017) investigate the long-run relationship between innovation and per-capita economic growth in 19 European countries over the period 1989–2014. They base their study on six indicators of innovation: patents-residents, patents-non-residents, research and development expenditure, researchers in research and development activities, high-technology exports, and scientific and technical journal articles. Using the cointegration technique, the authors show evidence of a long-run relationship between innovation and per-capita economic growth in most of the cases. In addition, using the Granger causality test, they find the presence of unidirectional and bidirectional causality between innovation and per-capita economic growth.

Bielig (2015) investigates the economic impact of registered intellectual property at the German Patent Office in Munich between 1999 and 2009 on German economic development. Results indicate that intellectual property has a significant impact on economic development in Germany.

Based on a sample of 42 developed and developing countries over the period 1998–2011, Alexiou, Nellis, and Papageorgiadis (2016) find that stronger levels of patent enforcement are positively and significantly associated with economic growth. In addition, they conclude that inward foreign direct investment (FDI) flows have a mediating role in positively improving this effect for all countries, and in particular for developed countries.

Other studies report that the positive effect of innovation on growth is closely related to patent protection (Gould and Gruben 1996; Iwaisako and Futagami 2013; Saito 2017). Gould and

Gruben (1996) use cross-country data on overall levels on patent protection, trade regime and country-specific characteristics, and show that the degree of patent protection is an important determinant of economic growth. Moreover, Gould and Gruben (1996) find that this relationship is slightly stronger in relatively open economies than in relatively closed economies. However, Iwaisako and Futagami (2013) argue that strengthening patent protection enhances innovation. Nevertheless, strengthening patent protection also impedes capital accumulation, and therefore, may lower growth in output. Strengthening patent protection allows firms producing intermediate goods to charge higher prices and reduces the volume of production. This process reduces the demand for capital and capital rents, and consequently, discourages capital accumulation, and then impedes economic growth. The result shown by Iwaisako and Futagami (2013) contradicts previous studies where innovation is the sole driving force for economic growth. Furthermore, in an open economy model where technologies are transferred, and capital is imported from abroad, the strictest protection of patents boosts technology adoption from abroad but hampers capital accumulation, and thus, the association between patent protection and output cannot be monotone.

In a recent study, Saito (2017) formulates a simple R&D-based growth model where firms engage in R&D activities in the final and intermediate goods sectors, and examines the effect of patent protection analytically. The results indicate that strengthening patent protection is likely to increase the technology level of the final goods sector relative to the intermediate goods sector in most cases. Moreover, Saito (2017) demonstrates that if R&D productivity in the final goods sector is lower than that in the intermediate goods sector, the relationship between patent protection and economic growth is an inverted-U shape. Finally, the results show that an increase in R&D productivity in the intermediate goods sector can reduce the welfare-maximizing level of patent protection.

Although linear studies on the innovation-growth relationship are abundant, few works studied the nonlinear relationship. For example, using panel data information for 147 countries from 2006 to 2012, Aristizabal-Ramirez and Canavire-Bacarreza (2015) test the hypothesis of a nonlinear relationship between innovation and growth. Their results support that the relationship between innovation and growth is not linear, and that only high levels of innovation increase economic growth. They show the importance of the quality of institutions to the extent that the results tend to be stronger when investment and public expenditure are taken into account in the empirical model. However, in that study, Aristizabal-Ramirez and Canavire-Bacarreza (2015) use a whole sample of 147 countries, and they apply for a PTR model. There is no comparative analysis between developed and developing countries or between countries that are more technologically advanced and others that are less technologically advanced. For the empirical approach, the authors use a PTR model or an extension of this model, which is the PSTR model. This model allows to define the optimal threshold and to examine the effect of the transition variable below and above the threshold.

Fiaschi and Lavezzi (2007) model states that the pattern of international technological spillovers was altered, because of nonlinearities in the growth process and of the ‘appropriateness’ of technology, taking the poorest countries further away from the technological leaders, and therefore, unable to exploit their technologies.

In summary, innovation can be considered important for potential economic growth. The ultimate effect of innovation is ambiguous. Thus, what evidence do we have that it is nonlinearly linked to growth? The lack of nonlinear studies that analyse the innovation-growth relationship motivates us to explore this relationship for a sample of 60 developed and developing countries over the period 2008–2017.

## 3. Methodology

### 3.1 Data

To explore the non-linear relationship between innovation and growth, we used a sample of developed and developing countries. Initially, the whole sample is based on 114 countries. Total sample was reduced to only 60 countries due to the unavailability and the continuity of country's level informations. Countries for which data on patents were missing are excluded. Also, countries with informations that not available for at least five years are excluded too. Due to several geographic, economic and social differences and In order to better understand the dynamic relationship between innovation and growth, the whole sample was divided into two sub-samples. The first sub-sample covers 36 developed and the second one is related to 24 developing countries[2]. This study covers the period of 2008 to 2017. We have limited this study only to this period since we are constrained by the availability of data related to patents.

Contrary to previous studies that used patents count (Su and Moaniba, 2017) or patents applications or patents grants (Sinha, 2008; Dosi et al., 2015), we used in this study patents in force as measure for innovation. Data on patents in force were collected from the Word Intellectual Property Organization (WIPO *henceforth*). Data for this variable are available from 2008 to 2017[3].

### 3.2. Empirical approach, model specification and variables definition

Considered pioneering works that tested nonlinear relationships, the studies of Quandt (1958) and Goldfeld and Quandt (1972) start with a piecewise and locally linear AR process. The threshold autoregressive (TAR) model was developed by Tong and Lim (1980) and Tong (1983). In a TAR model, a lagged variable should be specified. However, the autoregressive process becomes self-exciting when the lagged variable is the value of the process in the previous period. Thus, the self-exciting threshold autoregressive (SETAR) model is generalized. Several empirical studies use the SETAR model (Hansen 1996; Peel and Speight, 1998a, 1998b; Peel and Speight 2000). The limitations of the SETAR model to account for continuous and smooth transitions appeals for the smooth transition autoregressive (STAR) model. Initially, this model was developed by Terasvirta and Anderson (1992), Granger and Teräsvirta (1993) and Teräsvirta (1994).

Hansen (1999) developed new empirical methods based on panel data. This model is applied to the investment decision for 565 US firms. The author defined a threshold regression model with individual-specific effects for panel data. Proposed by Gonzalez, Teräsvirta, and Dick (2005), the PSTR model is an extension of Hansen's (1999) PTR model. In Hansen's (1996), Van Dijk, Franses, and Paap (2002) and Singh's (2012) nonlinear studies, the authors use seasonal data, such as quarterly or monthly data, to explore nonlinear behaviours. According to these authors, it is not possible to observe and detect seasonal transitions or adjustments using annual data. Thus, one of the limitations of the PSTR methodology is the use of annual frequencies. For example, due to the unavailability of quarterly or monthly data, some studies

[2] These countries are listed in appendix A1.
[3] For more details, see this patents statistical profile at this link https://www.wipo.int/ipstats/en/statistics/country_profile/profile.jsp?code=NL

use annual observations that tend to smooth some of the nonlinearities that maybe embodied in relatively high-frequency quarterly data. It is not possible to observe and detect seasonal transitions or adjustments using annual data. Theoretically, the PSTR is given by equation (1):

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

Where*i= 1, . . . , N*, and *t= 1, . . . , T*. *N* and *T* denote respectively the cross-section and time dimensions of the panel. In this model, the dependent variable is $y_{i,t}$. $u_i$ indicates the vector of the individual fixed effects. The PSTR model is based on a function of transiting$g(q_{i,t}, \gamma, c)$. This function of transition is depended on a transition variable denoted ( $q_{it}$ ). $(C)$ and $(\gamma)$ represent the parameter of threshold and the smooth transition parameter. $x_{i,t} = (x_{i,t}^1, \ldots\ldots\ldots, x_{i,t}^k)$ is a vector of $k$k explanatory variables and where $\varepsilon_{i,t}$ is a random disturbance. $\beta_0$and $\beta_1$ indicate respectively the parameter vector of the linear model and the non-linear model.

To determine this transition function, like Granger and Teräsvirta (1993), Teräsvirta (1994), and Jansen and Teräsvirta (1996), González et al. (2005), propose the following logistic form of *m* orders in the equation (2):

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

Where $\gamma > 0$, $c_1 < \ldots < c_m$ and $c = (c_1 \ldots \ldots c_m)$is a vector of level parameter. $\gamma$ represents the supposed positive smooth parameter.

To explore the dynamic relationship between innovation and growth for a sample of 60 countries, we used the following econometric model and the transition function is given in the equation (3):

$$GDPG_{i,t} = \mu_i + \alpha GDPG_{i,t-1} + \beta_0^1 PAT_{i,t} + \beta_0^2 RD_{i,t} + \beta_0^3 FDI + \beta_0^4 INVES_{i,t} + \beta_0^5 POPG_{i,t} [\beta_1^1 PAT_{i,t} + \beta_1^2 RD_{i,t} + \beta_1^3 FDI + \beta_1^4 INVES_{i,t} + \beta_1^5 POPG_{i,t}] g(PAT_{i,t}, \gamma, c) + \varepsilon_{i,t} (3)$$

In this model, patent the growth rate of GDP is the dependent variable. Patent in force (PAT) is transition variable. RD is the expenditure on research and development which is measured by Research and development expenditure (% of GDP). FDI is the net inflows of foreign direct investment in % OF GDP. INVES is the domestic investment measured by Gross fixed capital formation (% of GDP). POPG is the annual growth of population in %. $\varepsilon_{i,t}$is the error term. The definitions of the variables and their sources are summarized in Table 1..

**Table 1. Variables definition**

| Variables | Definitions | Source |
|---|---|---|
| GDPg | GDP growth (annual %) | WDI (2008-2017) |
| PAT | The Napierian logarithm number of patents in forces by year. | WIPO (2008-2017) |
| RD | Research and development expenditure (% of GDP) | WDI (2008-2017) |
| FDI | Foreign direct investment, net inflows (% of GDP) | WDI (2008-2017) |
| INVES | Gross fixed capital formation (% of GDP) | WDI (2008-2017) |
| POPG | Annual growth rate of population (in%°) | WDI (2008-2017) |

### 3.3 Descriptive statistics and correlation matrix

Information about descriptive statistics and the correlation matrix to avoid the multicollinearity problem is given. For the descriptive analysis, we provide information about the mean, the maximum, the minimum and the standard deviation. As the whole sample is divided into two sub-samples, the descriptive analysis is related to developed and developing countries.

The statistics given in Table 2 indicate that the mean value of GDP per capita for developed countries is 1.400%, with a maximum value of 25.55% and a minimum value of −14.81%. Regarding developing countries, we notice that, on average, these countries registered a growth rate of 3.570%; the highest level is 11.11%.

**Table 2. Descriptive statistics**

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| | | | *Whole sample* | | |
| Gdpg | 600 | 2.270 | 3.726 | -14.814 | 25.557 |
| Pat | 569 | 9.832 | 2.440 | 3.611 | 14.909 |
| Rd | 463 | 1.382 | 1.004 | 0.015 | 4.348 |
| Fdi | 600 | 6.727 | 18.288 | -43.463 | 252.308 |
| Inves | 600 | 22.735 | 5.905 | 5.128 | 47.686 |
| Popg | 599 | 0.734 | 1.122 | -2.258 | 5.367 |
| | | | *Developed countries* | | |
| Gdpg | 360 | 1.400 | 3.476 | -14.814 | 25.557 |
| Pat | 346 | 10.693 | 2.259 | 3.611 | 14.909 |
| Rd | 305 | 1.786 | 0.971 | 0.329 | 4.348 |
| Fdi | 360 | 8.275 | 23.063 | -43.463 | 252.308 |
| Inves | 360 | 21.890 | 3.894 | 10.217 | 38.092 |
| Popg | 359 | 0.563 | 0.892 | -2.258 | 5.322 |
| | | | *Developing countries* | | |
| Gdpg | 240 | 3.576 | 3.713 | -14.759 | 11.114 |
| Pat | 223 | 8.497 | 2.087 | 4.625 | 14.550 |
| Rd | 158 | 0.601 | 0.463 | 0.015 | 2.107 |
| Fdi | 240 | 24.001 | 7.870 | 5.128 | 47.686 |
| Inves | 240 | 4.406 | 5.494 | -15.989 | 54.835 |
| Popg | 240 | 0.989 | 1.360 | -1.666 | 5.367 |

The innovation process is measured by the yearly number of patents in force. Statistics show that the mean value of patents [3] in developed countries is 10.693 against 8.49 for developing countries. One of the most important drivers for innovation, invention and patenting is research and development expenditure. From the descriptive statistics, we notice that developed countries put more importance on research and development than developing countries. For example, we find that the mean value of R&D expenditure is 1.786% for developed countries against only 0.600% for developing countries. In addition, the dominance of developed countries is confirmed regarding the maximum value. Developed countries record a maximum value of 3.3% compared to only 2.1% for developing countries.

Investment activity is measured by domestic and foreign direct investment. On average, developed countries register 21.89% as gross domestic capital formation against only 4.400% for developing countries. In addition to local investment, statistics indicate that the average value of FDI is 8.27% for developed countries against 24% for developing countries. From these statistics, to grow output, we conclude that developed countries give more importance to domestic investment. In contrast, it is clear that, on average, developing countries attract more foreign direct investment than developed countries.

After descriptively analysing all variables, we check for possible multicollinearity problems. Table 3 presents the results of the correlation matrix. Results displayed in Table 3 indicate that the level of correlation between all variables in this study is very weak. Thus, we confirm the absence of the autocorrelation problem. To check for multicollinearity, we use variance inflation factors (VIFs) which range from 1 upward. A value of 1 means that the predictor is not correlated with other variables. The higher the value, the greater the correlation of the variable with other variables. The VIF values for all variables are lower than the value of 10 as acceptable threshold (Verbeek 2012). Thus, the variables are considered less collinear to the dependent variable.

**Table 3. Correlation Matrix**

| | Gdpg | Pat | Rd | Fdi | Inves | Popg |
|---|---|---|---|---|---|---|
| Gdpg | 1.0000 | | | | | |
| Pat | -0.0927 | 1.0000 | | | | |
| Rd | -0.1161 | 0.4115 | 1.0000 | | | |
| Fdi | 0.0424 | -0.1241 | -0.0838 | 1.0000 | | |
| Inves | 0.3470 | 0.1241 | 0.0040 | -0.0170 | 1.0000 | |
| Popg | 0.2602 | -0.1256 | 0.0316 | 0.0813 | 0.0213 | 1.0000 |

## 4. Empirical results and discussion

### 4.1 Results of *pre*-tests

Before estimated the PSTR model, three pre-test should be initially done. The first one checked the non linearity between the dependent variables and the transition variable. The second aims to test the number of regimes while the third one defines the optimal thresholds.

#### *4.1.1 The test of linearity*

The fundamental hypothesis of non-linearity should be initially confirmed. To this end, we used three tests of linearity: Lagrange Multiplier Wald Test, Lagrange Multiplier F-Test and Likelihood-ratio Test. The objective of these tests is to check if the relationship between the dependent variable (GDPG) and the transition variable (PAT) is non-linear. The null hypothesis is $H_0$: $\beta_1 = 0$ and the alternative is $H_1$:$\beta_1 \neq 0H$. Table 4 presents the results of the test of linearity.

**Table 4: Linearity test**

| | | Patents → growth | |
|---|---|---|---|
| Tests | *Whole Sample* | *Developed countries* | *Developing countries* |
| Lagrange Multiplier Wald Test | 11.095 | 21.014 | 10.450 |
| | (0.025) | (0.000) | (0.033) |
| Lagrange Multiplier F-Test | 2.432 | 4.890 | 2.402 |
| | (0.047) | (0.000) | (0.048) |
| Likelihood-ratio Test | 11.237 | 21.797 | 10.845 |
| | (0.024) | (0.000) | (0.028) |

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

Results displayed in table 4 indicate the null hypothesis is rejected at the 1% and 5% levels for the three tests. Furthermore, we confirm that the linearity is rejected for the whole sample and the two sub-samples. Hence, the relationship between innovation and growth is non-linear for the whole sample, the developed countries and the developing countries.

*4.1.2 Test of the number of regimes*

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 *LR* and *F* statistics. Results of this test are given in table 5. Results indicate that the P-value are statistically significant at 1% and 5% level, Hence, we reject the null hypothesis and we admit that at least two transition functions exist and that the model has one threshold.

**Table 5: Test for the number of regimes**

| *PAT (Transition variable)* | | *Whole sample* | | *Developed Countries* | | *Developing Countries* | |
|---|---|---|---|---|---|---|---|
| Hypotheses | Tests | Statistics | P-value | Statistics | P-value | Statistics | P-value |
| *(1)$H_0 : r = 0; H_1 : r = 0$* | LR | 54.637 | 0.000*** | 66.256 | 0.000*** | 12.393 | 0.034 |
| | F | 8.714 | 0.000*** | 11.679 | 0.000*** | 1.880 | 0.046 |
| *(2)$H_0 : r = 1; H_1 : r = 2$* | LR | 83.021 | 0.000*** | 83.685 | 0.000*** | 27.356 | 0.037** |
| | F | 7.899 | 0.000*** | 8.671 | 0.000*** | 2.572 | 0.001*** |

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

*4.1.3 The optimal Threshold*

Table 6 indicates that the optimal thresholds of patent differ from one group of countries to another. As for example, the threshold is 103053 for the whole sample, 109207 for the developed countries and only 16798 for the developing countries. Compared to the mean values, we found that these thresholds are far away from the average values.

**Table 6. Results of threshold values**

| | → Patent | Growth | |
|---|---|---|---|
| | *Whole Sample* | *Developed Countries* | *Developing Countries* |
| $\gamma$ | 5.000 | 5.000 | 3.000 |
| $\boldsymbol{C}$ | **11.543** | **11.601** | **9.729** |
| **Equivalent Number of patents**[4] | **103053** | **109207** | **16798** |
| AIC | 2.180 | 2.210 | 1.944 |
| BIC | 2.282 | 2.347 | 2.170 |

### 4.2 Discussion of results of the PSTR model

Table 7 presents the estimation of PSTR model for the whole sample of 60 countries and the two sub-samples of 36 developed and 24 developing countries during the period 2008-2017. This estimation is done by applying nonlinear least squares to eliminate the individual effects.

**Table 7. Estimation results of the PSTR model**

| Variable | *Whole Sample* Coeff | T-Stat | *Developed Countries* Coeff | T-Stat | *Developing countries* Coeff | T-Stat |
|---|---|---|---|---|---|---|
| *First regime* | *PAT<103053* | | *PAT<109207* | | *PAT<16798* | |
| PAT | 0.378 | 0.975 | 0.249 | 0.471 | 0.667 | 1.224 |
| RD | 0.439 | 3.407*** | 1.075 | 3.909*** | 0.886 | 1.393 |
| FDI | -0.008 | -0.957 | -0.009 | -1.016 | 0.106 | 1.360 |
| INVES | 0.309 | 5.830*** | 0.416 | 4.820*** | 0.034 | 4.470*** |
| POPG | -0.802 | -1.805* | -1.281 | -2.507** | -1.487 | -1.407 |
| *Second regime* | *PAT >103053* | | *PAT >109207* | | *PAT >16798* | |
| PAT | 0.072 | 2.160** | 0.189 | 2.359** | 0.172 | 0.283 |
| RD | 0.132 | 2.484** | 0.661 | 4.845*** | 0.734 | 0.334 |
| FDI | 0.277 | 6.470*** | 0.269 | 6.143*** | 0.473 | 4.092*** |
| INVES | -0.162 | -1.153 | -0.081 | -1.132 | -0.229 | -0.619 |
| $\gamma$ | 5.000 | | 5.000 | | 3.000 | |
| *C(Threshold)* | 11.543 | | 11.601 | | 9.729 | |
| Equivalent Number of patents | 103053 | | 109207 | | 16798 | |
| AIC | 2.180 | | 2.210 | | 1.944 | |
| BIC | 2.282 | | 2.347 | | 2.170 | |
| **Obs** | **441** | | **296** | | **145** | |

****, ** and * indicate the statistical significance at 1%, 5% and 10% levels*

The results in Table 7 indicate that below the optimal threshold, the effect of innovation (patents) is positive but not statistically significant for the whole sample and the two sub-samples. However, surpassing these optimal thresholds, the level of growth positively and statistically significantly responds to innovation only for the whole sample and developed countries. For example, a 1.00% increase in innovation (number of patents) increases growth by 7.20% for the whole sample and 18.9% for developed countries. Countries with high

[4] Since the numbers of patents 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 patents.

innovation and technological advancement create new technologies, providing new means to combine raw materials, will grow faster compared to less advanced countries. These results corroborate the work of Castellacci (2008), Hasan and Tucci (2010), Mansfield (1980) and Scherer (1982)..

Below or above the optimal thresholds of patents, the effect of research and development expenditure is found to be positively and statistically significantly correlated with the level of growth. This positive effect is confirmed for the results of the whole sample and only for developed countries. Research and development expenditure is considered an important contributor to economic growth. An increase of 1.00% in the domestic investment leads to an increase in growth of 41.6% for developed countries and 3.40% for developing countries. The positive impact of R&D is theoretically proved through its positive effect on innovation and total factor productivity. These results are consistent with the works of Blanco, Gu, and Prieger (2015) and Sokolov-Mladenović, Cvetanović, and Mladenović (2016).

Regarding the effect of investment on growth, the results indicate that below the optimal threshold of patents, only domestic investment exerts a positive and statistically significant effect on the level of growth for the whole sample and the two sub-samples. However, we find that FDI does not exert a statistically significant effect. Domestic investment is considered the most important channel for growth. It creates more stable job opportunities and more added value. The highest level of investment is associated with the highest economic growth.

Countries that register high levels of investment have the highest level of growth, such as Japan, South Korea and Singapore. These results are in line with the works of Adams (2009) and Tang, Selvanathan, and Selvanathan (2008).

Surpassing the optimal thresholds, the effect of FDI and domestic investment becomes the opposite. In other words, we find that above the patent threshold, FDI is positively and statistically significantly related to GDP growth. An increase of 1.00% in the level of FDI increases growth by 26.9% for developed countries and 47.3% for developing countries. FDI can stimulate economic growth through spillover effects, such as new technology transfer, formation and development of human capital, increased export and capital accumulation. Moreover, FDI is considered a driver for growth because it creates more job opportunities and improves local firm competition, and integration into the global economy. These results are in line with the works of Choi and Baek (2017) and Ridzuan, Ismail, and Che Hamat (2017).

Below the optimal threshold, population growth as an indicator of the labour force is found to be negatively and statistically significantly associated with the level of growth only for the whole sample and developed countries. A high level of growth population reduces the rate of capital formation and reduces the efficiency of the labour force. Moreover, a large population leads to higher unemployment and to an adverse effect on per-capita income. Countries that record rapid population growth face several environmental problems due to the natural resource degradation that could create several food supply problems especially in agriculture-based economies. Findings of this research are in line with those of Galor and Weil (2000) and Li and Zhang (2007).

Table 8 below summarize possible scenarios where innovation (number of patents) can exert a positive and significant impact on growth for the whole sample, developed countries and developing countries.

**Table 8. Summary of patent thresholds that positively affect economic growth**

| Sample | Thresholds of patents | Interval | Positive impact |
|---|---|---|---|
| *Whole sample* | 103053 | PAT > 103053 | YES |
| *Developed countries* | 109207 | PAT > 109207 | YES |
| *Developing countries* | 16798 | PAT >16798 or < 16798 | NO |

From results in table 8, we can conclude that countries of the whole sample can benefit from the positive effect of patents on growth only when they surpassed the number of 103053 patents per year. Below this number, the effect is found to be insignificant. For the developed countries, we found that these countries are invited to surpass the number of 109207 patents to have a positive impact on growth. For developing countries, either below or above thresholds, there is no positive response from patent to growth. This means that these countries should be more interested on other factor that positively affect growth. As for example, we found in this study that R&D exert a positive and significant effect on growth. Hence, more importance should be granted to the research and development expenditure that getting precisely level can positively impacts the number of patent that positively affects growth.

## 5. Conclusions and Policy implications

Motivated by the importance of innovation in the economies of developed and developing countries, this paper explores the innovation-growth relationship for a sample of 60 developed and developing countries. Although linear studies are abundant, few studies examine the nonlinear relationship. Therefore, we perform a PSTR model to define the optimal threshold of patents that can affect economic growth.

Taking into account several geographic, economic and social differences, the whole sample of 60 countries is divided into two sub-samples (developed and developing countries) to better understand this nonlinear relationship and to get the full benefits from a comparison of the results. Empirical results indicate that there is a threshold effect in the innovation-growth relationship. These thresholds differ from one group of countries to another. For example, the optimal threshold is 103,053 for the whole sample, 109,207 for developed countries and only 16,798 for developing countries. Furthermore, we find that below the optimal threshold, the effect of innovation measured by the number of patents is not statistically significant for developed and developing countries. However, surpassing the optimal threshold, the effect becomes positive only for the whole sample and developed countries.

These results can provide important policy implications for developed and developing countries. Developed countries are invited to surpass the number of 109,207 patents per year to benefit from a positive impact on growth. This means that these countries should work on patents to stimulate economic growth. However, these countries should be vigilant regarding negative consequences of innovation. As innovation is considered the main factor for economic growth, many studies report that innovation increases social inequalities and exclusion (Stiglitz 2012; Aghion et al. 2015). In this case, these countries are also invited to work more on open innovation to avoid social exclusion and to be beneficial to all.

To benefit from the positive effect of patents on economic growth, developing countries should increase their research and development expenditure. R&D expenditure is considered one of the most important factors to increase research output and the possibility of patenting. Another policy recommendation could be addressed to less developed countries. At this level of development, these countries cannot fully benefit from the production of patents. They need more time for profits from patent activity. Thus, developing countries should continue to work on local patents and consider imported innovation (high-technology imports) to grow output.

Like all research studies, the present study has several limitations. First, we use the total number of patents in force as a measure of innovation. However, the use of patents by field, especially patents in technology, could be more appropriate to assess the innovation-growth relationship. Second, we do not use other types of patents, such as patent applications, patent granted or quadratic patent families for a robustness check. Third, we use annual data. One of the most limitations of the PSTR model is the use of annual data. The nonlinear PSTR model may not fit very well to annual data. Annual observations tend to smooth some of the nonlinearities that maybe embodied in relatively high-frequency quarterly data. It is not possible to observe and detect seasonal transitions or adjustments using annual data. This is why several studies apply seasonally data (quarterly or monthly) to study nonlinearity behaviour (Hansen 1996; Van Dijk, Franses, and Paap 2002; Bielig 2015).

The use of seasonal observations and the use of different types of patents as a robustness check could drastically improve the findings of this study and can be an interesting topic for future research.

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**Appendix 1**. Sample of Developed and Developing Countries

| Developed countries | | | | Developing countries | | | |
|---|---|---|---|---|---|---|---|
| 1 | Australia | 19 | Italy | 1 | Armenia | 19 | Serbia |
| 2 | Austria | 20 | Japan | 2 | Bosnia and Herzegovina | 20 | Turkey |
| 3 | Belgium | 21 | Latvia | 3 | Brazil | 21 | Ukraine |
| 4 | Canada | 22 | Lithuania | 4 | Bulgaria | 22 | Uzbekistan |
| 5 | Chile | 23 | Luxembourg | 5 | China | 23 | Vietnam |
| 6 | Croatia | 24 | Malta | 6 | Colombia | 24 | Zambia |
| 7 | Cyprus | 25 | Netherlands | 7 | Costa Rica | | |
| 8 | Czech Republic | 26 | New Zealand | 8 | Egypt | | |
| 9 | Denmark | 27 | Norway | 9 | Georgia | | |
| 10 | Estonia | 28 | Poland | 10 | Guatemala | | |
| 11 | Finland | 29 | Portugal | 11 | Hungary | | |
| 12 | France | 30 | Singapore | 12 | India | | |
| 13 | Germany | 31 | Slovak Republic | 13 | Jordan | | |
| 14 | Greece | 32 | Spain | 14 | Kazakhstan | | |
| 15 | Hungary | 33 | Sweden | 15 | Madagascar | | |
| 16 | Iceland | 34 | Switzerland | 16 | Mexico | | |
| 17 | Ireland | 35 | United Kingdom | 17 | Peru | | |
| 18 | Israel | 36 | United States | 18 | Romania | | |