2. THE NONLINEAR EFFECTS OF HIGH TECHNOLOGY EXPORTS, R&D AND PATENTS ON ECONOMIC GROWTH: A PANEL THRESHOLD APPROACH TO 35 OECD COUNTRIES

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Abstract

The paper aims at the investigation of the economic growth and R&D thresholds in addition to the evaluation of nonlinear effects of R&D, patents and high technology product exports on economic growth. Within this respective, a panel consisting of 35 OECD member and other countries is analysed with dynamic panel threshold regressions and bootstrap threshold testing methodologies for the 1992–2016 period. The results reveal significant threshold effects of the economic growth rates closely followed by the threshold effects dominated by the share of R&D in the GDP. The empirical findings have significant contributions: i. the impacts of high technology exports are asymmetric and regime-dependent, in addition, positive in both regimes, ii. R&D expenditures have positive effects not only in the high R&D/GDP but also in relatively low R&D/GDP and growth regimes, iii. the R&D in GDP threshold parameter is estimated as close to 0.7% and is compared to the literature. The overall findings coincide with the endogenous growth literature, but with an interesting distinction regarding the positive impacts even at low R&D regimes. The policy suggestions favor the encouragement of R&D and its positive effects on economic growth even for countries that cannot achieve a theoretical 3% R&D in GDP threshold.

Keywords: innovation, high technology exports, economic growth in open economies, threshold regression models
JEL Classification: O3, F10, F43, C24

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1. Introduction

Innovation has been assumed as one of the essential sources of accelerating economic growth by classical and neoclassical economists. In Solow's neoclassical model, technology is an exogeneous factor, hence the proportion of growth that cannot be explained by per worker capital stock could be taken as the technology or the residual. The model incorporates the importance of savings and investment rates effectively in the formation of capital in addition to the roles of depreciation. An important assumption needed to be made was the exogeneity of technological change as it also was noted in the epigraph of Solow's seminal paper Solow (1956). In a further contribution to the Solow model, Mankiw-Romer-Weil introduced the role of human capital in the neoclassical growth framework (Mankiw *et al.*, 1993).

Schumpeterian growth models based on improvements of product quality stimulated by the international trade were another group of endogenous growth models. Although the role of international trade and especially the exports of high technological goods play a crucial role in economic prosperity, such goods necessitate investments that encourage R&D. Aghion and Howitt (1992), propose a growth model based on Schumpeter's creative destruction, where growth is determined as being increasing function of the size of technological progress and qualified labor force in addition to the research productivity, while being a decreasing function of the time preference rate of the individuals (Aghion and Howitt, 1992, 323). As noted by Ustabaş and Ersin (2016), the R&D plays important roles in the creation of technology towards high tech export-based growth policies.

Following Verspagen (2006), a more recent strain of literature also draws attention to technological change in the process of growth. In the so-called "general purpose technologies", the GPT framework of Verspagen (2006), the technological change necessitates evolutionary and development phases, and in the first phases achievement of low economic growth is more likely. Once enough intermediate goods are developed for the new GPT, the old GPT ceases leading to a high economic growth phase (Verspagen, 2006, 3-35). More recently, Fagerberg and Verspagen (2020) notice the importance of technological revolutions that trigger structural change and by dividing the countries into two groups, they note that the countries which fail to adopt new technological revolutions cannot achieve economic growth in addition to catching-up the developed nations and in this process, the specialization in foreign trade plays a major role.

In addition to such arguments, one should also notice the importance of R&D and patents which are important determinants of innovation and technological progress. Innovation processes involve various activities, including the design/conception, R&D, technology transfer, manufacturing and deployment. At microeconomic level, technological improvements can result in a decrease in production costs, therefore enabling the deployment of increasing returns to scale. Moreover, these improvements can create new products or even new industries by also increasing the quality level (Korres, 2012, 224). At macroeconomic level, technological innovations play a crucial part in economic growth by stimulating industries in creating comparative advantage in high technology exports. This comparative advantage leads to increasing returns and endogenous technological development, which rise the standards of living and welfare (Frankel and Romer, 1999). Accordingly, the most commonly used indicators of innovations aim at the measurement of the technological level or innovative capability of a country including patent activities and research and development expenditures (Romer, 1990; Grossman and Helpman, 1991;

Eaton and Kortum, 1999), the share of high technology exports in manufactured products (Fagerberg, 1994; Cuaresma and Worz, 2005; Lee, 2011).

Following the discussion above, our paper aims at the investigation of the impacts of high technology exports, patents and R&D on economic growth within a nonlinear panel methodology for the OECD member and other countries. Based on our literature search, our paper is the first paper that i. investigates the nonlinear impacts of high technology exports, R&D and patents simultaneously on economic growth in distinct regimes; ii. contributes by focusing on the calculation of thresholds of R&D and economic growth that possibly trigger higher economic growth rates. In light of these purposes, the paper aims at providing a bridge between threshold based nonlinear panel methodology and the development literature which focus on the impact of international trade on growth and the empirical literature focusing on endogenous growth.

Among the selected explanatory variables, in addition to R&D and patents, the high technology exports as a ratio to total manufactured exports is a comparatively distinct variable. It possesses a "revealed innovation" type characteristic: it is a direct and observable indicator of the economy's concentration on technology and innovation in the total manufactured exports[4]. One of the most important contributions of the paper is the investigation of the thresholds of R&D in addition to economic growth rates, assuming the share of R&D in total GDP as the threshold variable follows the spirit of theoretical setting of R&D thresholds discussed by Azariadis and Drazen (1990). Further, a general acceptance in the economic theory is that without passing a certain threshold of R&D in total GDP, the benefits of innovation could not exist. However, the countries should not hesitate to invest in R&D, and once the threshold is exceeded (say 3% of GDP in the spirit of Romer, 1991) the endogenous growth is likely to exist (Azariadis and Drazen, 1990). We argue that this setting could be relaxed and statistically the thresholds could be comparatively lower than such *a priori* levels, so that significant impacts of R&D on growth could also exist at lower R&D levels or for periods with low levels of economic growth.

The above-mentioned discussion motivates the paper in answering the following questions. Do nonlinear impacts of R&D, patents and high technology exports exist and if so, do empirical results show the impossibility of having no impacts or no positive impacts of innovation proxies below these thresholds? Should the policy makers not focus on R&D since countries cannot achieve such levels, say 3% R&D in GDP, due to their constraints or if the country achieves a low R&D, should it not expect such benefits of innovations and research? For policies aiming at economic growth, could increasing the share of high technology products in exports be beneficial? Within these aims, the paper is structured as follows. Section 2 reviews the main theoretical and econometric literature. Section 3 is devoted to the dynamic panel threshold analysis and the model. The empirical findings and policy implications are presented in Section 4. Conclusion and discussion are given in the final section.

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[4] *The usage of high technology export variable in our model extends the model to open economies and our paper assumes the investigation of innovation for countries engaged in international trade, a restriction that is not a necessity in the original spirit of endogenous growth theories though such extentions are generally accepted in the literature.*

2. Literature Review

Growth theory, specifically about the issue of technology, is characterized by an important debate between endogenous growth inspired from the neoclassical view and the evolutionary approach (or neo-Schumpeterian) approach. Solow (1956) model assumes that countries will converge to similar steady states depending on the exogenous level of technological progress for given similar fundamentals and the diminishing returns cannot be avoided. The endogenous growth models, on the other hand, estimate that steady states will be different among countries. Jones argues that the number of R&D workers has increased since the 1960s, but growth rates have either been constant or declining, suggesting a semi-endogenous growth model (Verspagen, 2006, 23). In line with this view, Young suggested a model in which an increase in the profitability of innovation could result in a rise of technologies that will lead to an improvement at micro level without raising the economic growth rate (Young, 1993, 443).

Empirical models analysing the relationship between GDP and R&D investment studied by Griliches suggest that knowledge or R&D has a significant impact on productivity increases (Griliches, 1979; Verspagen 1995; Griliches, 1986). According to empirical works on growth and technology assuming the endogenous growth models, international competitiveness and growth are likely to diverge among countries generally as a result of technological competitiveness. Fagerberg (1988) emphasized the essential role of investments to create new production capacities and to employ the potential given by spillover effects of domestic technological competitiveness (Fagerberg, 1988). Coe and Helpman (1995) underline the correlations between total factor productivity growth and R&D weighted by trade flows, indicating that trade is an important source of knowledge spillovers. They indicated that the benefits of foreign research and development on domestic productivity fed on the openness of the economy (Coe and Helpman, 1995). Eaton and Kortum provided a model showing that endogenous research and development and technology diffusion were contributing to economic growth (Eaton and Kortum, 1999).

Reviewing the literature, as of our knowledge, research utilizing R&D, patents and high technology exports simultaneously fails to exist, especially within a nonlinear panel setting. The relevant studies that evaluate these variables separately or two of them simultaneously, are discussed below. Griffith *et al*. (2000) investigate the role of R&D activity in the improvement of the technology transfer in addition to its conventional role of stimulating innovation by using a panel of 12 OECD countries and determine that R&D stimulates growth directly through innovation and indirectly through technology transfer. They also identified that human capital has a significant role in stimulating productivity growth whereas trade had a statistically weak effect on productivity (Griffith *et al*., 2000). Ivus evaluated the impact of strengthened patent rights in developing countries on the exports of developed countries for 1962-2000 period and found that the rise of patent rights encourages patent-sensitive exports. Nunes *et al*. (2011) investigate the relationship between R&D intensity and growth in high-tech and non-high-tech small and medium sized enterprises and they identify a negative and significant relationship between R&D intensity and growth in the non-high-tech SMEs. Sterlacchini (2008) provides important hints for threshold effects of R&D in their findings obtained for European countries for 1995-2002 so that the intensity of R&D has important impacts in value-added. Lee (2011) utilizes quantile panel regressions to evaluate the effects of export specialization in high technology exports on the comparative advantage defined by Balassa indices. In a later paper, Lee (2012) shows that technology and learning by doing proxied by R&D result in thresholds that lead to 'technological divide' of countries in the process of growth. Wu (2010), examined the impact of R&D efforts on innovation and economic growth in China with panel data, system and difference GMM. Wu (2010) determines the positive effects of innovation on China's economic growth and underlines the dominant effect of R&D intensity on regional innovation. Wu (2010) also emphasizes the roles of economic reforms, government investments and infrastructure development and the human capital in innovation and development.

In contrast to the R&D and economic growth relation literature, the empirical studies focusing on high technology exports and growth are evaluated. Ustabas and Ersin (2016) investigated the role of high technology exports on economic growth in South Korea and Turkey and show that high technology exports have positive long-run impacts on growth. Ekananda and Parlinggoman (2017) analyzed the effects of FDI and high-tech export on GDP in a panel of 50 countries for 1992-2014 and suggest the positive effects of high technology exports. Kabaklarlı *et al.* (2018) analyzed the long-term relationship between high-technology exports and various economic variables including the GDP growth rates, patents by residents, and gross capital formation in GDP through a panel cointegration model for 14 selected OECD countries over the period 1989-2015. Their findings suggest positive effects of patents in addition to foreign direct investments which boost high technology exports (Kabaklarlı *et al*., 2018). Erkişi and Boga (2019) examined the relationship between high-technology exports and economic growth in EU-15 countries for period 1998-2017 by including the labor force and gross fixed capital formation as additional explanatory variables to achieve a setting of Cobb-Douglas type production function. Their findings show that the high-tech exports had a decisive effect not only on economic growth but also on gross fixed capital formation and employment (Erkişi and Boğa, 2019)[5].

Recent studies investigate the EU countries with a panel setting. Kacprzyk and Świeczewska (2018) utilize nonlinear in variables models by including interaction terms to evaluate the effects of R&D on growth and their empirical findings put forth that the distance to the world technology frontier matters; significant effects of R&D only exists for businesses that are close to the frontier and the impact of government R&D on growth is insignificant; however, their policy suggestions favor innovation-based policies instead of simply focusing on R&D only to achieve growth. They also suggest that heterogeneity of development levels of EU-28 matters and heterogeneous innovation policies are needed instead of a one model fits all strategy. A more recent contribution is provided by Pelinescu *et al*. (2019) who investigate the heterogeneous impacts of average length of education, human capital and innovation variables included with the patents. Their findings reveal that positive effects of education and human capital in EU and the positive effects of R&D expenditures have the biggest effect as compared to the positive effect of patents. In their policy recommendations, Pelinescu *et al*. (2019) emphasized that encouraging innovation and increasing R&D expenditures have the potential to accelerate economic growth in EU countries. More recently, Chu *et al*. (2020) investigated the effects of intellectual property rights on the take-off from an era of stagnation

[5] *Other interesting papers that utilize threshold models include the following. Aristizabal-Ramirez et al. (2015) analyzed the impact of innovation measured by the innovation index on growth for 147 countries and note the importance of threshold effects. Ahsan and Haque (2017) applied a dynamic panel threshold model for 126 countries for the 1970-2012 period to examine the non-linear effect of human capital on economic growth below and above the capital stock threshold. Kouton et al. (2018) employs a dynamic panel threshold model to analyze the roles of health on growth for 24 Sub-Saharan Africa countries and their empirical results signify the threshold effects of human capital.*

to a state of sustained economic growth. Chu *et al*. (2020) show that in China, strengthening patent protection increased firms' profitability, providing more incentives for firms to innovate, resulting in an earlier departure while stressing that stronger patent protection would slow economic growth by increasing the number of products reducing the market size of each product, and increasing incentives for quality-improving innovation[6].

Reviewing the literature discussed above, the analysis of high technology exports in addition to patents and R&D deserve special attention and various linkages between these variables cannot be neglegted. For this purpose, the static and dynamic panel threshold models of Hansen (1999) and Seo and Shin (2014) will be evaluated in the next section.

3. Dynamic Panel Threshold Methodology

The panel threshold model is a panel variant of the nonlinear time series threshold models of Chan (1993) and Tong (1990)'s threshold regressions. Hansen (1999) generalized the model to panel data. Further extensions introduce dynamic relations which are given in Seo and Shin (2004). A two-regime panel threshold model following Hansen (1999) and Seo and Shin (2014) with dynamic relations is stated as

$$y_{it} = \beta_1' X_{it} I(q_{it-k} \leq \gamma) + \beta_2' X_{it} I(q_{it-k} > \gamma) + u_{it} , \tag{1}$$

where: $\beta_1' = (1, \beta_{1,1}, \beta_{1,2}, \dots, \beta_{1,k})'$ and $\beta_2' = (1, \beta_{2,1}, \beta_{2,2}, \dots, \beta_{2,k})'$ are regime specific parameter vectors, $X_{it} = \left(y_{it-1}, y_{it-2}, \dots, y_{it-k}, x_{it}, x_{it-1}, \dots, x_{it-k} \right)$ is the explanatory variable set including the lagged terms of the dependent variable to control for autocorrelation if necessary and $I(q_{it}, \gamma)$ is an identity function, restricted to take two distinct values [0,1]. The identity function is a function of the distance of the threshold variable q_{it-k} to the optimum threshold γ[7]. For simplicity, a two-regime dynamic threshold panel regression model without matrix notation could be written as,

$$y_{it} = \begin{cases} \beta_{1,0} + \beta_{1,1} X_{it} + u_{1,it} & if \ q_{it-k} \leq \gamma \\ \beta_{2,0} + \beta_{2,1} X_{it} + u_{2,it} i & if \ q_{it-k} > \gamma \end{cases} \tag{2}$$

In both Eq. (1) and (2), u_{it} is assumed $u_{it} \sim N(0, \delta^2)$. The model in Eq. (1) and (2) could be extended to more than 2 regimes if a second threshold effect cannot be rejected. The threshold parameters are assumed to be time invariant (Hansen, 1999, 347). We select the optimum lag length *k*=0, 1, …, *k* for the variable set with the Bayesian information criterion (BIC). The sequential F tests with bootstrapped critical values are calculated for testing the linearity against threshold type nonlinearity (Hansen, 1999). To obtain parsimony, our estimated models assume common threshold parameters following Hansen (1999) and Seo and Shin (2014). Further, the variables are demeaned before threshold testing and by adding the country-specific averages, one could generate country specific threshold evaluations.

6 *They noticed negative effects of patents in later stages and show that the results are consistent with historical evidence of the industrial revolution and recent evidence of the effects of the patent system.*

7 *Therefore, within a dynamic panel threshold regression setting, heterogeneity is allowed in the threshold mechanism.*

4. Empirical Results

4.1. Data

The dataset in the study is obtained from the World Bank WDI database. To achieve balanced panel with the longest possible time period and due to the availability of the R&D data, the sample covers the 1992-2016 period for 35 countries[8]. R&D expenditures is denoted by lrd_{it} and is in million US dollars. $lpat_{it}$ is the total number of resident and non-resident patent applications. The high technology exports in total manufactured exports are denoted by lht_{it}. The real GDP, ly_{it} is in million and constant 2010 US dollars. Variables are subject to natural logarithms. In the panel unit root tests, if the data follows I(d) processes, the data is differenced and denoted by Δ. A second measure of R&D is the percentage of R&D expenditures in the GDP, denoted by $lrdy_{it}$. This variable is only utilized as an exogeneous variable to be tested as a candidate threshold variable due to the discussion given in Section 1 and the economic reasoning. Therefore, two different R&D measures are utilized: lrd_{it} as an explanatory variable and $lrdy_{it}$ as a candidate threshold variable.

4.2. Descriptive Statistics and Panel Unit Root Tests

The descriptive statistics of the dataset is given in Table 1. The general overlook shows that except for the ly_{it} and lrd_{it}, the JB statistics suggest non-normal distribution and this is the case especially for the first differenced variables. Further, the series are investigated with LLC, IPS, ADF-Fisher and MW panel unit root tests. The test results are reported in Table 2. Accordingly, all series, except for the $lrdy_{it}$ are integrated of order 1 and follow I(1) processes and in the analysis, they are to be subject to first differencing. Since $lrdy_{it}$ is stationary at the conventional significance levels, the unit root tests are not reported for its first differenced variant.

Table 1. Descriptive Statistics

Var:	Mean	Max.	Min.	Std.dev.	Skewness	Kurtosis	JB
Level series							
ly_{it}	26.83	30.56	22.72	1.46	-0.03	3.23	1.64 [0.44]
lrd_{it}	27.02	31.56	21.78	1.89	-0.07	2.82	1.53 [0.46]
$lpat_{it}$	8.85	14.11	3.64	1.95	0.26	2.90	8.37 [0.01]
lht_{it}	22.82	27.05	16.75	2.11	-0.54	2.94	35.76[0.00]
$lrdy_{it}$	0.19	1.49	-2.28	0.82	-0.62	2.62	50.82[0.00]
First differenced series							
Δly_{it}	0.04	0.37	-1.01	0.12	-1.38	11.63	2396.82 [0.00]
Δlrd_{it}	0.06	0.99	-1.09	0.15	-1.00	13.41	3277.93 [0.00]
$\Delta lpat_{it}$	0.02	1.82	-1.27	0.21	0.15	21.56	10051.04 [0.00]
Δlht_{it}	0.06	1.64	-0.89	0.20	0.67	11.26	2039.82 [0.00]
$\Delta lrdy_{it}$	0.02	0.89	-0.74	0.09	0.17	28.94	19638.21 [0.00]

Notes. JB is the Jarque-Bera test of normality. The probabilities in the JB test are given in brackets.

[8] *The included countries are Austria, Argentina, Australia, Brazil, Canada, China, Colombia, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, India, Ireland, Italy, Israel, South Korea, Japan, Hong Kong, Netherlands, Mexico, Portugal, Romania, Russia, Singapore, Poland, Sweeden, Turkey, U.K., Uruguay, the U.S., Thailand and Norway. Yearly and continuous R&D data does not exist for other OECD countries. Data for 2017, 2018 and 2019 does not exist for all countries and the method followed requires balanced panels.*

Table 2. Panel Unit Root Test Results

Variable:	LLC	IPS	ADF-Fisher	MW
ly_{it}	3.86	6.04	21.26	17.26
Δly_{it}	-8.23***	-3.01***	120.74 ***	158.30***
lht_{it}	1.14	2.51	54.45	40.43
Δlht_{it}	-14.82 ***	-10.90 ***	262.45***	147.09 ***
lrd_{it}	5.63	6.79	20.09	33.22
Δlrd_{it}	-8.94***	-4.33***	139.50 ***	192.29***
$lpat_{it}$	1.56	-1.96**	39.26	170.77 ***
$\Delta lpat_{it}$	-21.17 ***	-16.83***	435.89***	325.59***
$lrdy_{it}$	-2.59 ***	-2.99 ***	120.29***	130.02 ***

*Notes. *, **, *** denote significance at 10, 5 and 1% significance levels, respectively. LLC: Levin-Lin-Chu, IPS: Im-Pesaran-Shin, ADF-Fisher: Panel ADF Chi-square test and MW: Maddala-Wu unit root test. In all tests, the maximum lag is selected with Bayesian information criterion. LLC, IPS and ADF-Fisher tests are conducted in Eviews 10 and the MW test is obtained from STATA 16.*

4.3. Threshold Analysis and Estimation Results

The optimum threshold parameter estimates and the candidate threshold variables are investigated with sequential F testing procedure suggested by Hansen (1999). The methodology allows the investigation of the possible candidate threshold variables with F tests of linearity against threshold type nonlinearity. The results are reported in Table 3a. This approach eliminates a-priori acceptance of the threshold variable and therefore we repeated the Hansen (1999) panel threshold test for the variables in the study in addition to their lagged terms determined with the Schwarz information criterion (SIC). Though the sequential testing is to be followed, the evaluation of the R&D as a percentage of GDP as a candidate threshold variable also deserves a special attention in terms of the discussion given in Section 1. Therefore, in Table 3a. the null hyporhesis of linearity is tested against the alternative of threshold type nonlinearity, *i.e.*, a linear panel model against a two-regime threshold model. In all tests, trimming is taken as 20% for all variables except for R&D in GDP[9]. Further, economic crises years are included as dummy variables (see notes below Table 3a). For the majority of variables, linearity is strongly rejected at conventional significance levels. However, among all possible candidates, the highest F statistic is calculated as 84.18 for Δly_{it}, the yearly real economic growth rate. In this case, the threshold parameter estimate is calculated as -0.0606, and is statistically significant at 1% significance level.

The results suggest two regimes, which loosely represent the recessionary and the expansionary regimes. The optimum threshold selection is denoted by [1st]. Following a search conducted for a second-best threshold variable candidate, a second-best result is obtained for $lrdy_{it-1}$, the previous year's R&D in GDP with F=60.87 suggesting the rejection of linearity against threshold type nonlinearity. Hence, we aim at estimating two threshold panel regressions with Δly_{it}, our optimum model followed by the second-best model with

[9] *For all threshold tests, dummy variables are included. Further trimming is equal to 0.20 for all variables except the R&D in GDP which lead to consistent results are achieved after 0.30 trimming. Conditions for consistent results are: 1) The regimes should include a minimum of or more than 30% of the total number of observations, 2) results are sensitive to outliers so dummy variables are effective in controlling effects of crisis years. See Table 3a for details.*

$lrdy_{it-1}$ threshold variable. For the second threshold model, the threshold coefficient of lrdyit-1 equals -0.3804. In anti-logarithms, this equals to a R&D in GDP threshold of 0.6836%, close to 0.7% for the analyzed countries.

Table 3a. Linearity against Single Threshold Type Nonlinearity Test Results

Threshold Variable:	Threshold estimate:	F	Bootstap F critical values:		
			10%	5%	1%
Δly_{it}	-0.0606***	84.18 [0.000] (***1st***)	34.35	42.97	48.20
Δly_{it-1}	-0.0066	26.15 [0.20]	32.42	39.21	52.75
Δlht_{it}	-0.0248***	36.83 [0.003]	22.15	24.52	33.20
Δlht_{it-1}	-0.1077***	43.62 [0.000]	22.85	28.26	36.85
Δlrd_{it}	0.0061**	48.18 [0.04]	34.78	44.62	56.68
Δlrd_{it-1}	0.0987**	48.48 [0.14]	31.16	41.18	59.44
$\Delta lpat_{it}$	0.0003***	46.29 [0.00]	24.24	27.37	35.31
$\Delta lpat_{it-1}$	0.0183***	54.22 [0.00]	22.23	25.49	31.73
$lrdy_{it}$	-0.4058***	58.92 [0.00]	18.62	20.97	26.14
$lrdy_{it-1}$	-0.3804***	60.87 [0.00] (***2nd***)	19.32	24.49	31.29

*Notes. All variables are demeaned following the Hansen (1999) methodology. The highest rejection of linearity is denoted with (1st) followed by (2nd). The heteroscedasticity-robust test results are reported. p values are in brackets. *, **, *** denote significance at 10, 5 and 1% significance levels, respectively. All tests are conducted with the inclusion of dummy variables for the crisis years. These are 1999, 2009, 2015 (post effects of 97 Asian crisis and 98 Russian crisis, 2009 global recession; the post effects of 2014 Russian crisis and 2015 Chinese stock market crash). All tests are conducted with 1000 bootstrap replications.*

Lastly, we tested the remaining threshold type nonlinearity, *i.e.*, existence of a second threshold, against the single threshold model. The results are reported in Table 3b. The F statistics for two models - the 1st and the 2nd - are calculated as 20.51 and 14.56. Both F statistics are significantly lower than the bootstrap critical values at the conventional significance levels and suggest the acceptance of the single threshold effect; therefore, the two-regime modeling is suggested.

Table 3b. Remaining Threshold-Type Nonlinearity Test Results

Models:	F statistic for remaining nonlinearity:		Bootstapped critical F values:	
	F	10%	5%	1%
Model 2 with threshold variable= Δly_{it}	20.51	21.63	24.29	33.64
Model 3: with threshold variable= $lrdy_{it-1}$	14.65	20.49	24.86	38.62

Notes. Remaining nonlinearity is statistically rejected at all conventional levels and therefore no asterices are reported. The threshold variables are assumed as Δly_{it} and $lrdy_{it-1}$.

The estimation results are reported in Table 4. In the first column, the baseline linear fixed effects model is reported (Model 1). Model 2 is the optimum model with threshold Δly_{it}, and Model 3 is the second panel threshold model which assumes the R&D share in GDP growth rate in the previous year, $lrdy_{it-1}$, as the threshold variable. The estimation of Model 3 is motivated by the discussions reported in the literature section in addition to the F tests reported in Tables 3a and 3b. While being 50.34 for the baseline model, the F statistics for

Models 2 and 3 are 127.94 and 84.33[10]. Compared to the linear model, Models 2 and 3, favor improvement and the highest goodness of fit is obtained for Model 2 confirming the results in Table 3a.

Table 4. Estimation Results for the Linear and Threshold Models

	Model 1-Baseline	Model 2 – Nonlinear Dynamic Panel Threshold Model		Model 3– Nonlinear Dynamic Panel Threshold Model	
Regimes:	Linear	1 (relatively low growth)	2 (relatively high growth)	1 (low R&D regime)	2 (moderate to high R&D)
q_{it-k}	-	Δly_{it} *(growth rate at year t)*		$lrdy_{it-1}$ *(R&D/GDP at year t-1)*	
γ	-	-0.0606***		-0.3820***	
Δlht_{it}	0.074*** (0.02)	0.098*** (0.03)	0.059*** (0.01)	0.076*** (0.03)	.060*** (0.02)
Δlht_{it-1}	-0.035*** (0.01)	-0.0194 (0.02)	-0.029*** (0.01)	-0.018 (0.02)	-0.053*** (0.01)
Δlrd_{it}	0.594*** (0.08)	0.767*** (0.11)	0.420*** (0.08)	0.502*** (0.11)	0.764*** (0.06)
Δlrd_{it-1}	0.024 (0.04)	0.167** (0.08)	-0.015 (0.02)	0.042 (0.05)	-0.053 (0.07)
$\Delta lpat_{it}$	-0.022** (0.01)	0.008 (0.02)	-0.041*** (0.01)	-.017 (0.02)	-0.034** (0.015)
$\Delta lpat_{it-1}$	-0.010 (0.02)	-0.034 (0.03)	-0.009 (0.02)	0.001 (0.02)	-0.0501* (0.03)
Δly_{it-1}	0.054 (0.06)	-0.082 (0.12)	0.105** (0.04)	.027 (0.11)	.097** (0.05)
D1999	-0.050** (0.02)	-0.033*** (0.01)		-0.048** (0.02)	
D2015	-0.057** (0.02)	-0.045** (0.02)		-0.035** (0.015)	
D2009	-.071*** (0.01)	-0.062*** (0.01)		-0.060*** (0.015)	
cons	.010*** (0.00)	0.022** (0.01)		0.009*** (0.002)	
Adjusted R^2	0.70	0.73		0.72	
F	50.34*** [0.000]	127.94*** [0.000]		84.33*** [0.000]	

*Notes. Standard errors are heteroskedasticity-robust and are given in parantheses. *, **, *** denote significance at 10%, 5% and 1% significance levels, p values are in brackets.*

At the first stage, the baseline linear model is to be evaluated followed by the nonlinear models at the second. For the linear model, the parameters of high technology exports growth rates are statistically significant at 1% significance level and a 1% increase at the current and the previous years' results in a 0.074% increase and a -0.035% decrease in the current year's economic growth rate. The dominant parameter estimate in magnitude is

[10] *Within, between and overall adjusted R square statistics are available, the overall is reported. Note that the adj. R square is 0.73 and 0.72 for Models 2 and 3 while it is 0.70 for Model 1, relatively close however the degrees of freedom play a crucial role. F tests in Table 3a and Table 4 confirm the acceptance of the threshold model over the linear counterpart.*

positive, hence the accumulated effect of a 1% increase in high technology export growth rates on growth is 0.07-0.04=0.03%, leading to the conclusion that the impact on economic growth is statistically positive though close to zero. The R&D has a positive impact on economic growth rates with the highest impact: a 1% increase in *lrd* leads to a 0.594%, almost 0.6% increase in economic growth rates at 1% significance level. In the baseline model, the lagged R&D parameter is 0.024 is insignificant. The reason for inclusion of insignificant parameters is for comparative purposes with the nonlinear models. Note that the parameter of patent is -0.022 and is statistically significant at 5%, suggesting 0.022% decrease in economic growth rates following a 1% increase in patents.

The inclusion of parameter estimates for the 3 dummy variables representing the 1999, 2015 and 2009 economic crises led to coefficients significantly negative which range between -0.05 and -0.07, hence the negative impacts of the crises on the growth rates. The overall results suggest that if the threshold effects are not considered the positive impact of high technology exports exists, but it is not so dominant in terms of size of the coefficients, while R&D has a major positive impact.

The negative but very close to zero effects of patents cannot be rejected. In this sense, our findings reveal a similar finding for patents and R&D as obtained by Pelinescu *et al*. (2019) and confirm the large contribution of R&D to growth. Similar to Pelinescu (2019)'s results for the EU, we obtained very close to zero effects of patents for the analyzed countries. One distinction is the negative parameter estimate in our case, however, in both papers, the parameter estimates are very close to zero[11].

The next stage includes the investigation of the panel threshold models. Model 2 is subject to two regimes: regime 1 is achieved if $\Delta ly_{it} < -0.0606$ if the yearly economic growth is lower than -0.0606% and regime 2 occurs if $\Delta ly_{it} >= -0.0606$, for economic growth rates equal or above -0.0606%. The two growth regimes could be loosely considered as recessionary and expansionary periods for Model 2. Similar to Model 2, Model 3 is subject to two regimes. However, in Model 3, if the natural logarithmic R&D in GDP at the previous year is less than $lrdy_{it-1} < -0.382$ regime 1 occurs and regime 2 is obtained for $lrdy_{it-1} > = -0.382$. Based on the statistical findings, regime 1 represents the low to moderate R&D regime, whereas regime 2 corresponds to relatively high R&D regime. If compared to Model 2, Model 3 is dynamic in in terms of its threshold mechanism. For Model 3, the anti-log of the threshold coefficient is 0.682. Similar to the previous model, if the demeaning is not taken into account, in broad terms, the 1st (2nd) regime prevails if the R&D share in the GDP is below (above) 0.68%. Such findings are interesting, since the theoretical Romer (1991) expectation suggests a ratio around 3%.

[11] *The negative effect could be the result of various economic reasons. As the country encourages patents, it is expected to obtain the knowledge spillover effects of these patents not in the curent year but in the following years, depending on the intellectual property right protection in each country. Once the patent is issued, the realization of the new invention and its commercialization could even take even close to 10 years, depending on the nature of the product. As Acs and Sanders (2012) indicate, patent protection rises incentives to invent and patent knowledge while reducing incentives to commercialize. Another reason is, such a negative effect and/or near 0 no-effect could be the result of patents acting in the opposite direction. If the new invention occurs, applying for patents could be in fact revealing the new invention to those who copy. Therefore, the inventor has reduced tendency for patents especially in an environment with limited patent rights.*

At the next stage, the parameter estimates of Model 2 is to be evaluated. Parameter estimates of the high technology exports are 0.098 in regime 1 and 0.059 in regime 2, which suggest a 1% increase in the current period in the high technology exports results in 0.098% and 0.059% in two distinct regimes. One could expect the opposite, *i.e.*, a higher positive effect in the high growth regime; however, such results could result from diminishing returns type relation suggesting lower positive effects of the high-tech exports for high growth countries and periods. For low growth countries and periods, an increase in high technology exports has a larger positive effect. This result becomes more pronounced if the accumulated response of growth to high technology export is calculated as the sum of significant parameters: 0.059-0.029=0.03, a positive 0.03% increase in economic growth. Overall analysis suggests that although significant and positive effects of high technology exports cannot be rejected, the parameter estimates being close to zero suggest limited effects[12]. The results should be taken as: i. the average[13] effect of high technology exports on economic growth is positive and is regime-dependent, ii. the size of such a positive effect could be low, but also is promising in suggesting the overall potential of high technology exports.

If the nonlinear impact of R&D is evaluated, the general finding shows that the overall impact of R&D is the largest in magnitude in regime 2 in addition to being positive in both regimes. Accordingly, a 1% increase in R&D expenditures results in a 0.767% increase in the economic growth rates in regime 1 and a 0.42% increase in GDP growth in regime 2. Further, the first lag of R&D is significant for regime 1 only suggesting an accumulated impact of 1% R&D increase in the current and previous year is 0.767-0.167=0.60; a 0.6% increase in growth rates during the relatively low growth regime. Compared to the other explanatory variables and their impacts on growth, the largest effect is caused by the R&D expenditures in terms of the size of coefficient estimates: 1% increase in the R&D expenditure contributes to an almost 0.4 to 0.6% increase in the GDP growth rates.

Model 3 assumes that the threshold variable is the % of R&D in the GDP in t-1, the previous year. In this model, a dynamic threshold relation exists, since the lagged threshold variable governs the threshold effect. The inclusion of this threshold variable is due to the economic cautions, as noticed in Sections 1 and 2. It is straightforward to see that various differences are obtained in terms of the parameter estimates as compared to Model 2. First is, as compared to Model 2, the parameter estimates of high technology exports in the current period is 0.076 and 0.06 for regimes 1 and 2, both again statistically positive and significant; however, the differences between the parameter estimates of both regimes are not so pronounced. As a result, if the R&D share in GDP in the previous year is below 0.68%, a 1% increase in high technology exports leads to 0.076% growth in the low to moderate R&D regime. On the other hand, this impact of such an increase on growth is 0.06%, in the moderate to high R&D regime. For R&D, on the other hand, the differences are more striking: if the previous year's R&D in GDP is below 0.68%, a 1% increase in R&D expenditures

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[12] *Note that this finding is an average result in a panel setting since the sample covers 35 countries that not only includes countries with a large share of international trade to GDP such as Germany, France in addition to countries with comparatively low shares of trade to GDP such as Turkey. In addition to the share of exports to GDP, the size of high technology exports embedded in the total exports is another economic issue.*

[13] *As noticed in the data section, the analysis conducted in this paper requires selection of simultaneous existence of R&D, high technology exports and patent data which led us to include the selected 35 countries for the analyzed period.*

results in a 0.502% increase in economic growth in low R&D regimes. However, if the share of R&D is above or equal to 0.68%, a 1% increase in R&D has an even larger positive impact, that is equal to 0.764% increase in the GDP. The findings expose interesting findings. The percentage of R&D in GDP could be obtained at very low rates for the analyzed sample on the average: further, the analyzed countries are industrialized economies having achieved a consideringly high level of economic development. For this sample, the R&D in GDP threshold is comparatively low, as compared to the economic literature (see Section 1 and 2). In contrast to the literature that suggests no impact at low rates of R&D, the findings favor the existence of positive impacts of R&D on economic growth at relatively low levels of R&D percentages. Lastly, Model 3 also has various control variables including 3 dummy variables[14] and the AR(1) term that is statistically significant in regime 2 for both models 2 and 3 suggesting regime specific autocorrelation.

Similar to Models 1 and 2, the results for Model 3 are also in favor of limited but negative effects of patents and this effect is only significant in the second regime that occurs if the R&D percentage in GDP in the previous year is above 0.68%, the moderate to high R&D regime. Accordingly, a 1% increase in patents in the current period results in a 0.04% decrease in economic growth. The negative estimates for patents also coincide with several studies indicating the negative effect of patents on growth for the short term only, while in the long run the positive effect could be obtained (Crosby, 2000; Josheski and Koteski, 2011).

To justify the discussion and to evaluate the long-term impact of patents on GDP, we conducted various tests of cointegration. The results revealed that no long-term relation exists or if accepted, it is limited to the utilized test. Therefore, the long-term analysis cannot be conducted. It should be noticed that such results are for the 4 variable environment and restricted to the analyzed sample [15]. Other than the cointegration tests, to confirm the negative effect of patents, we estimated various models with altered model settings, which led to insufficient goodness of fit results. The correlation between R&D and patents shows no multicollinearity (Rho=0.11); however, we estimated models with patents as the single innovation variable. Lastly, we also excluded R&D from the models to check if the negative effect persists. We observed a positive estimate of patent coefficient at 10% significance level only[16].

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[14] *Further, to capture the outliers and the negative effects of economic crises, dummy variables are included.*

[15] *To test the long-run effects between the analyzed variables and also to test the sign of the impact of the patents in the long-run, we conducted Pedroni and Kao cointegration tests in addition to panel ARDL methodology. The results are available from the first author. Pedroni test results showed no-cointegration and no long-run relation between the 4 variables analyzed. Same holds for Panel ARDL F test. In contrast, Kao test confirms cointegration however it is known to be less prone to various factors and other tests fail to confirm cointegration.*

[16] *To obtain these results, various alterations are needed and the Hansen (1999) methodology should be avoided. Therefore, this is not applicable given the very low F statistic compared to those in Table 3a leading us to conclude that the results are not sufficient. In that case, the threshold effect could be accepted at 5% and the parameter of patent is estimated as 0.04 in the second regime but is insignificant at 5 % significance level (parameter is significant at 10% only).*

4.4. Discussion and Policy Implications

The findings of the study lead to various policy recommendations. One of the most important findings of our study follow Romer's study (1991) in his suggestion that there is a threshold effect of R&D in economic growth. However, such effects and deviations from Romerian threshold will be discussed below. Furthermore, the results strongly suggest that investments focusing on generation of technology should also require strong commitment to R&D.

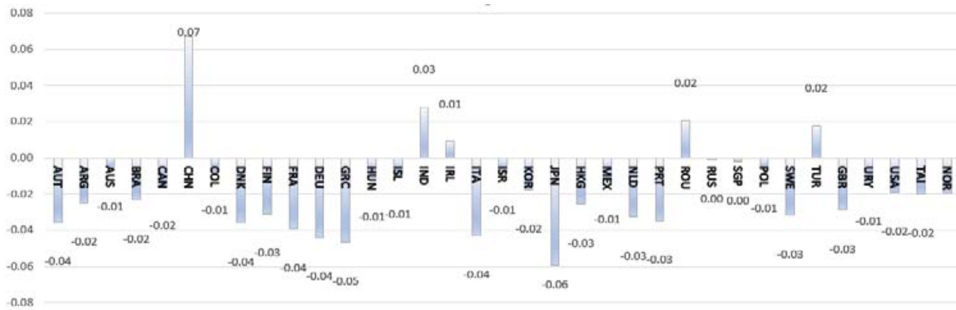
It should be noticed that both R&D and patents represent two innovation variables and they are expected as providing proxies for innovation. Our findings confirm the results of Pelinescu *et al*. (2019) obtained for the EU-28 countries regarding the limited effects of patents and the dominant effect of R&D. Pelinescu *et al*. (2019) also notice the possibility of long-run cointegrated effects between patents and growth after discussing their findings with a set of literature suggesting such results for the EU. Chu *et al*. (2020) show that patent protection has differentiated effects at different phases of economic development. According to Chu *et al*. (2020), the strengthening of patents could boost economy at earlier stages including the take-off in contrast to the limiting effects of patents in the long run. Kabaklarlı *et al*. (2018) obtained findings confirming the long-run effects of patents on growth for a smaller sample of 14 OECD countries in contrast to our sample of 35 OECD and other countries. Josheski and Koteski (2011) obtained long-run positive effects of patents for a smaller set of countries, which are also OECD members, the G7 economies. As noticed before, we tested long-run relations with various cointegration tests including Kao, Pedroni and Panel-ARDL tests. To save space, results are available upon request. Except for the Kao test, both Pedroni and Panel ARDL tests suggest no cointegration among the variables in our sample of 35 countries. The reasoning is that the results specifically show the general tendency in our 35-country sample, the largest number of countries possible due to the availability of the R&D data for the period.

Further, as shown by Pelinescu *et al*. (2019) with their mixed effects models, heterogeneity exists for the EU-28. For the OECD-and-other-35 sample in our paper, the panel threshold methodology allows for modelling of a type of heterogeneity in the threshold effect that governs regime-dependent relations. The country specific threshold estimates of the economic growth and R&D in GDP thresholds of Model 2 and Model 3 are reported in Figures 2 and 3 below.

In Figure 1, where the country specific economic growth thresholds are reported, we notice that they vary in a range of -0.059 to +0.067 for the whole sample. Once we tabulated the data in terms of the thresholds, we noticed that the growth threshold ranges between -0.05 to 0 for 29 countries or for the majority of the countries, 85% of the analyzed countries. The threshold estimate is positive for 5 countries only, however, the average growth threshold is -0.016, suggesting two distinct regimes above and below growth rates of -1.6%[17].

[17] *The panel threshold estimator is a fixed effect estimator that assumes demeaning of the threshold variable analyzed in the models. As a result, a single threshold is reported for both Models 2 and 3. The country specific threshold estimates are calculated as the sum of the country specific average of the optimum threshold variable selected with panel threshold tests plus the panel threshold estimate. Further, since the R&D in GDP threshold variable was in natural logarithms, the figures and discussions at this section are conducted after taking the anti-logarithms of the values estimated for easier economic interpretations.*

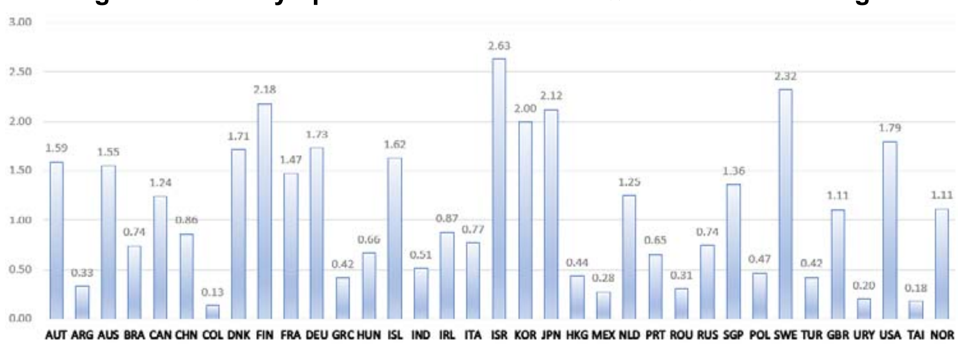
Figure 1. Country-specific Thresholds of Economic Growth Rates



Source: Own calculations.

In Figure 2, the threshold is defined as the R&D in GDP as a percentage. Since the variable was in natural logarithms, the figure includes anti-logarithmic values for easier economic interpretation. If investigated, the heterogeneity of country specific thresholds for the sample is determined. We observed moderate variety and volatility in the R&D thresholds for the analyzed countries. The country specific R&D thresholds are in the range of 0 to 0.5% for 10 countries out of 35, that corresponds to 28.57% of the analyzed countries followed by the 0.5% to 1% threshold range obtained for 8 countries or 22.86% of the sample. For 6 countries, or for 17% of the countries, the threshold is between 1 to 1.5%.

Figure 2. Country-specific Thresholds of R&D in GDP Percentages



Source: Own calculations.

For 7 countries or 20% of the sample, the R&D in GDP threshold ranges between 1.5 to 2% and so far, 31 countries constitute 89% of the countries in the sample. Only 4 countries or 11% in the sample have an R&D in GDP threshold above 2%. Notably, in the analyzed sample, the mean of the threshold is 1.08%, with minimum and maximum values of 0.13% and 2.63%. The results reveal that the R&D in GDP threshold occurs at around 1% in contrast to the theoretical expectation of 3%. The results suggest that countries should engage in R&D investments in both the low and high R&D in GDP regimes. In high R&D in GDP regimes, the effects of R&D expenditures on GDP growth are 48% higher than those in the low R&D regimes, which also favor positive effects of R&D. The impacts of the high technology exports in total manufactured exports lead to economic growth in both regimes; however, the positive effects are relatively less positive in the high R&D regimes. Overall result could be interpreted as diminishing returns to high technology exports in high R&D regimes in contrast to increasing returns to R&D in high R&D regimes. Further, the patents have negative, but very limited negative effects in the short run. Such effects should not be discouraging, since patents are a necessity to encourage innovation through intellectual property rights.

5. Conclusion

In this study, the nonlinear effect of R&D, patents and high technology exports on economic growth covering the period 1992-2016 for a panel of selected 35 countries has been investigated with dynamic panel threshold methodologies. It was found that the threshold effects of the GDP growth rates in the optimum model and the threshold effects of the R&D / GDP ratio for the second-best model cannot be rejected at conventional significance levels. The study offers several contributions in terms of empirical findings as well as policy implications. The paper is among the seminal empirical papers exploring the nonlinear impacts of high technology exports, R&D and patents simultaneously on economic growth in distinct regimes. The findings also allow for suggested country specific threshold effects and a form of heterogeneity in terms of thresholds. Thus, this work contributes to previous literature by combining the threshold-based nonlinear panel methodology with various fields of the development literature focusing on the impact of international trade on growth and the empirical literature focusing on endogenous growth.

According to the findings, given the country specific analysis of the threshold estimates, the majority of the countries achieve a moderate to high R&D regime above the 1% threshold for the R&D in GDP. The finding suggests that the empirical threshold estimate for the analyzed sample is lower than the theoretical expectation of 3%. In addition, in contrast to the theoretical expectation, the countries are observed to benefit from R&D even at the regimes characterized by a low share of R&D in the GDP.

The findings also suggest significant and positive effects of high technology exports on economic growth rates, confirming the positive impact of technology on growth in accordance with a open economy endogeneous growth model. In contrast to the increased effects of R&D in high R&D in GDP regimes, the hich technology exports have a lower positive effect in such regimes. These findings favor a diminishing returns type effect of high technology exports on growth, in contrast to the increasing returns type influence of R&D. Policy recommendations suggest encouragement of R&D investments and countries are likely to benefit regardless of the size of the share of R&D in GDP. Unfortunately, the negative impact of residential and non-residential patents is determined as having coefficients very close to zero. Further analysis is also conducted to investigate long-run effects for the analyzed sample, but failed to confirm either cointegration or the positive effects of patents in the long run. These results are not caused by the nonlinear modelling, since linear estimates also revealed similar effects. The no long-run effect of patents is restricted to the 35-country sample and in the literature smaller samples of OECD countries such as the G7 are shown to reveal such effects. However, the results revealed the central tendency in a panel of the majority of the countries in the analyzed sample.

The overall findings suggest that fostering innovation to achieve growth is a necessity, confirming the endogeneous growth in an open economy which engages in international trade with exportation of high technology manufactured goods. The benefits from R&D are determined to have dominant effects both in low and high R&D in GDP regimes, in addition to relatively lower and higher growth periods. In order to produce and export high technology intensive commodities, policies should focus on the allocation of resources to R&D and although the negative effects of patents are not rejected, engagement in patent activities is a necessity for innovation.

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