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# Revisiting the effects of innovation on growth: a threshold analysis

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Since Schumpeter's (1934) seminal work, the existing literature has examined the relationship between innovation and economic growth, arguing for a strictly positive relationship. The recent literature suggests that this relationship might be non-linear. Low levels of innovation will not affect economic growth; yet, when a certain threshold is reached, innovation significantly promotes economic growth. Using panel data information for 147 countries from 2006 to 2012, we employ threshold regressions à la Hansen (1999) to test the hypothesis of a non-linear relationship between innovation and growth. We find evidence that the relationship between innovation and growth is not linear and that only high levels of innovation increase economic growth. The results tend to be stronger when investment and public expenditure are present, suggesting that the quality of institutions is important.

**Keywords:** growth; innovation; threshold

**JEL Classification:** C24; O33; O410



## I. Introduction

Since Schumpeter's (1934) seminal work, innovation has been considered to be one of the key determinants of economic growth. Theoretical and empirical evidence suggests that innovation, understood as knowledge creation, technology developments and research and development investment (de Dominicis *et al.*, 2012), has a positive effect on productivity and economic growth (Mansfield, 1980; Lucas, 1988; Romer, 1990; Griliches and Mairesse, 1991; Lichtenberg, 1992; Grossman and Helpman, 1994).

Within the literature of endogenous growth models, some authors have argued that observed differences in economic development and growth can be explained by the existence of poverty traps and differences in the stages of growth. In explaining these differences, Azariadis and Drazen (1990) introduced the concept of threshold effects, suggesting that it is possible that there exist critical levels of input accumulations, in particular human capital and knowledge, above which growth possibilities may expand rapidly or below which countries might fall into so-called poverty traps. However, most of the

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existing empirical evidence ignores the possibility of such threshold effects in the relationship between innovation and growth, despite the fact that some of the literature acknowledges that total output may respond differently at different stages of innovation (Azariadis and Drazen, 1990; Buesaa *et al.*, 2010).

This article examines the existence of a threshold in the relationship between innovation and economic growth and determines the break point at which innovation affects growth differently. This article contributes to the literature on this topic by providing evidence of the existence of a threshold on the relationship between innovation and growth.

While there have been some previous studies that somewhat addressed the differentiated effect between innovation and growth, to our knowledge, the current literature has not attempted to identify such a threshold in terms of innovation and growth. Some of the existing literature argues that innovation affects growth differently depending on country development and innovation level; countries with high levels of innovation will benefit more from the externalities and spillovers fostered by the innovation and development process, while lower levels of innovation have little to no effect on growth (Bilbao-Osorio and Rodríguez-Pose, 2004; LeBel, 2008; Hasan and Tucci, 2010). Other authors argue that differences in innovation intensity, which is tied to infrastructure and physical and human capital accumulation, as well as firms' capacity to adapt and benefit from the innovation process are key aspects to benefit from the spillovers of innovation and that more innovation can cause growth. Further, countries with low innovation intensity/capacity will not see their growth affected significantly (Buesaa *et al.*, 2010).

Using a panel data set for 147 countries between 2006 and 2012, we find consistent evidence for the existence of a threshold for the relationship between different dimensions of innovation and growth, as argued in Azariadis and Drazen (1990). At early stages of innovation, we identify non-significant effects on growth, and only after a certain threshold are we able to identify a significant and positive effect on growth. This implies that, if a country wants to benefit from the spillovers and externalities associated with innovation, it is necessary for them to make efforts and increase their innovation levels over that threshold. In contrast, mild levels of innovation are ineffective in promoting growth. The article is organized as follows: Section II briefly presents the data. Section III presents the results and Section IV presents the description of the results and their discussion.

## II. Data

The macroeconomic variables and patent information used in this article are obtained from The World Bank Development Indicators (World Bank, 2014) and the Penn World Table (Center for International Comparisons of Production, Income and Prices, 2011) (Table 1). For the main variable of interest, innovation, we use multiple measures that capture different aspects of the innovation capacity of a country, gathered from the World Competitiveness Forum and the World Bank. The variables are measured as indexes (1 to 7) that were constructed using aggregates from the Executive Opinion Surveys weighted by industry participation on national GDP.[1] These variables include information on the ability of a country to innovate, quality of scientific research, innovation and sophistication factors, availability of scientists and engineers, government procurement in high technological products, university–industry collaboration and company spending on research and development and an aggregate innovation index. In addition, we also use data on the number of patents per capita in our models as a proxy of the intensity of the innovation process within a country (Acs *et al.*, 2002; Buesaa *et al.*, 2010).

## III. Methodology

As argued in the previous section, the hypothesis of this article is that the relationship between innovation and growth is not linear. Specifically, based on the literature on innovation and endogenous growth models (Azariadis and Drazen, 1990), the underlying hypothesis is that low levels of innovation, below an unknown threshold, have little to no effect on economic growth. In contrast, when innovation surpasses that threshold, it could have a positive impact on

[1] For detail on the construction of the indexes, see the World Economic Forum (2013–2014). *The Global Competitiveness Report*.

**Table 1. Descriptive statistics**

| Variable | Description | Source | Obs. | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|---|---|
| **GDP per capita growth** | Annual percentage | WDI | 8123 | 2.05 | 6.19 | −62.47 | 102.78 |
| **Population** | Million people | WDI | 11 203 | 23.40 | 97.40 | 0.00 | 1350.00 |
| **GDP** | Constant prices 2005 US$ (billion) | WDI | 8081 | 9135.84 | 15 163.51 | 50.04 | 15 8802.50 |
| **Inflation** | Consumer prices (annual %) | WDI | 6576 | 31.61 | 477.75 | −33.21 | 24 411.03 |
| **Financial development** | Private credit by deposit, money, banks and other financial institutions to GDP (%) | WDI | 5846 | 38.79 | 37.66 | 0.01 | 284.62 |
| **Trade** | Percentage of GDP | WDI | 7706 | 78.37 | 50.82 | 0.31 | 531.74 |
| **Investment** | Investment share of PP converted GDP per capita at 2005 constant prices | Penn Tables | 7959 | 12.61 | 9.35 | 0.29 | 68.06 |
| **Public expenditure** | Government consumption share of PP converted GDP per capita at 2005 constant prices | Penn Tables | 7959 | 23.07 | 11.73 | −33.14 | 111.29 |
| **Innovation index** | Index [1–7] | GCI | 930 | 3.37 | 0.85 | 1.68 | 5.84 |
| **Capacity of a country to innovate** | Index [1–7] | GCI | 930 | 3.30 | 0.94 | 1.53 | 6.14 |
| **Quality of scientific research** | Index [1–7] | GCI | 930 | 3.85 | 1.01 | 1.46 | 6.35 |
| **Innovation and sophistication factors** | Index [1–7] | GCI | 930 | 3.72 | 0.79 | 2.23 | 5.82 |
| **Availability of scientists and engineers** | Index [1–7] | GCI | 930 | 4.18 | 0.81 | 2.16 | 6.29 |
| **Government procurement in high technological products** | Index [1–7] | GCI | 930 | 3.63 | 0.64 | 1.91 | 6.18 |
| **University–industry collaboration** | Index [1–7] | GCI | 930 | 3.52 | 0.92 | 1.51 | 5.93 |
| **Company spending in research and development** | Index [1–7] | GCI | 930 | 3.30 | 0.90 | 1.63 | 6.12 |
| **Number of patents** | Patent application done by residents | WDI | 3836 | 7493.81 | 36 478.48 | 1.00 | 53 5313.00 |

*Source*: WDI: World Development Indicators, Penn Tables and GCI: Global Competiveness from The World Competitiveness Forum.

growth, as the innovation process is large enough to generate positive spillovers and scale effects.

To test this hypothesis, we use a split piecewise regression strategy, akin to the threshold regression analysis described in Hansen (1999) and based on a standard growth model that uses macroeconomic cross-country panel data. Specifically, the model to be estimated takes the following form:

$$g_{i,t} = \alpha_0 + \alpha_1^{'} X_{i,t} + \delta_1 \times INN + \delta_2 \times (INN - th) \times (INN \geq th) + c_i + t_t + \varepsilon_{i,t} \tag{1}$$

where $g_{i,t}$ is the GDP per capita growth; $X_{i,t}$ is a vector of variables that determine growth for country $i$, $c_i$ and $t_t$ are country-specific and time-specific fixed effects and $\varepsilon_{i,t}$ is an idiosyncratic error. In this model, *INN* represents our measure of innovation and *th* is the threshold above which innovation has an additional (positive) effect on growth.[2]

Following a strategy similar to the one described in Hansen (1999), Equation 1 is estimated through OLS. The threshold is identified as the level at which the log-likelihood function corresponding to Equation 1 is maximized, thus providing the best fit for the model. Based on the null hypothesis of no threshold, we test for the significance of the threshold using an F-test, comparing the results to the alternative where there is no threshold effect. The grid search is evaluated using values within the 10th and 90th percentiles of the empirical distribution of the innovation measures.

## IV. Results and Discussion

Table 2 presents the results from the estimation of Equation 1, using various specifications and alternative measures of innovation. With the exception of the number of patent applications, all other models are estimated using a panel between 2006 and 2012. Following Barro (1991), all of the models include variables controlling for the current population size, log of GDP per capita 10 years ago (size), inflation (price stability), private credit as % of GDP (financial development) and terms of trade ($X + M$ as % GDP). In addition, for the selected models, we include time- and country-fixed effects as well as indicators for investment as share of GDP and public expenditure as share of GDP.

The baseline model, which does not include year- or country-fixed effects, shows a clear pattern that innovation has a non-linear effect on economic growth, with low levels of innovation showing negative and non-significant effects on economic growth. According to these estimations, a one-point increase in the innovation scale above the threshold level[3] is associated with a 1.1 to 2.7 percentage point higher economic growth rate. It is possible that some of the estimated parameters between innovation and economic growth are driven by specific and unobserved country characteristics (m1) or global economic trends (m2).

The baseline estimates are robust to controlling for country-fixed effects (m1), with small changes in the magnitude and significance levels. In addition, the estimates of the number of patent applications become positive, although weakly significant. In this case, a 10% increase in the number of patent applications above the threshold level is associated with a 0.08 percentage point increase in the growth rate.

Although the estimates are relatively robust to adding time-fixed effects (m2) to the specification, there are a few changes worth noting. Due to a less parsimonious model that constrains the time variation identification, a few of the estimated parameters (columns 1, 2 and 7) are non-statistically significant. Based on this model, the effect of an increase in one point in the innovation scale is more modest, in the neighbourhood of 0.3 to 1 percentage points of growth.

While model 2 presents our preferred specifications, they do not take into account other factors that based on the literature could be driving economic growth, such as investment and public expenditure. Because using the available information on these variables drastically reduces the working sample, causing the estimated threshold and associated parameters to fluctuate considerably, we estimate the models using the threshold levels found in the preferred specification.

With a few exceptions, controlling for investment reduces the additional effect of the innovation measures on economic growth. As suggested by Lebel (2008), this might be indicative that one of the channels through which innovation affects growth is greater (or more productive) investment. In other words, when adding investment the effect of innovation is lower because innovation is realized through investment. This is observed when looking at the changes of the coefficients of capacity for innovation and company spending on R&D, number of patent applications and, to some extent, government procurement on advanced tech products. The effect when controlling for Government expenditure is similar to controlling for investment. The

[2] Below the threshold, the marginal effect of the threshold is given by $\delta_1$, but above the threshold *th*, it will have a marginal effect equivalent to $\delta_1 + \delta_2$.

[3] Threshold levels are identified below each regression and range between 4 and 5 on a scale of 1 to 7.

**Table 2. Growth threshold regressions**

| | Capacity for innovation | Quality of scientific research | Companies spending in research and development | University–industry collaboration in R&D | Government procurement of advanced tech products | Availability for scientists and engineers | Log(Nr patent applications pc, residents) |
|---|---|---|---|---|---|---|---|
| **Base model: Pop, L10.log GDP pc, inflation, total private credit/GDP, trade** | | | | | | | |
| Innovation | −0.276 | −0.344 | −0.334 | −0.632* | −0.359 | −0.358 | 0.73* |
| | (0.227) | (0.215) | (0.273) | (0.236) | (0.332) | (0.229) | (0.159) |
| (Innovation –*th*) | 2.475** | 1.425*** | 1.71** | 3.327* | 2.739** | 3.073 | −0.255* |
| (Innovation>*th*) | (1.132) | (0.862) | (0.782) | (1.024) | (1.102) | (1.055) | (0.201) |
| Threshold | 4.943 | 5.030 | 4.394 | 4.651 | 4.148 | 5.158 | 2.659 |
| **Model 1: Pop, L10.log GDP pc, inflation, total private credit/GDP, trade, country FE** | | | | | | | |
| Innovation | −0.635** | −0.734*** | −0.481** | −0.866* | −0.635** | −0.451* | −0.42 |
| | (0.317) | (0.274) | (0.318) | (0.270) | (0.416) | (0.291) | (0.516) |
| (Innovation –*th*) | 1.566*** | 1.785 | 1.575*** | 3.341* | 2.319*** | 1.681 | 0.855 |
| (Innovation>*th*) | (0.810) | (0.900) | (0.833) | (1.122) | (1.246) | (1.348) | (0.577) |
| Threshold | 4.387 | 4.868 | 4.360 | 4.623 | 4.066 | 5.096 | 0.611 |
| **Model 2: Pop, L10.log GDP pc, inflation, total private credit/GDP, trade, country FE, year FE** | | | | | | | |
| Innovation | −0.23 | −0.53*** | −0.323 | −1.034** | −0.4 | −0.951 | −0.369 |
| | (0.305) | (0.288) | (0.271) | (0.415) | (0.349) | (1.159) | (0.515) |
| (Innovation –*th*) | 0.427 | 0.824*** | 1.134*** | 1.537** | 1.726*** | 0.808 | 0.897 |
| (Innovation>*th*) | (0.591) | (0.497) | (0.642) | (0.609) | (1.017) | (1.272) | (0.591) |
| Threshold | 4.120 | 4.095 | 4.360 | 3.379 | 4.105 | 3.283 | 0.625 |
| **Model 3: Pop, L10.log GDP pc, inflation, total private credit/GDP, trade, investment, country FE, year FE** | | | | | | | |
| Innovation | −0.106 | −0.729 | −0.177 | −1.073*** | −0.049 | 1.393 | −0.125 |
| | (0.441) | (0.474) | (0.392) | (0.625) | (0.514) | (1.705) | (0.506) |
| (Innovation –*th*) | 0.278 | 1.446** | 0.926 | 1.822** | 0.234 | −1.839 | 0.499 |
| (Innovation>*th*) | (0.813) | (0.718) | (0.862) | (0.824) | (1.206) | (1.823) | (0.582) |
| Threshold | 4.120 | 4.095 | 4.360 | 3.379 | 4.105 | 3.283 | 0.625 |
| **Model 4: Pop, L10.log GDP pc, inflation, total private credit/GDP, trade, public expenditure, country FE, year FE** | | | | | | | |
| Innovation | −0.168 | −0.827 | −0.248 | −1.147*** | −0.142 | 0.942 | −0.279 |
| | (0.448) | (0.504) | (0.383) | (0.638) | (0.537) | (1.662) | (0.509) |
| (Innovation –*th*) | 0.429 | 1.632** | 1.183 | 1.971** | 0.948 | −1.405 | 0.711 |
| (Innovation>*th*) | (0.823) | (0.769) | (0.873) | (0.853) | (1.296) | (1.785) | (0.582) |
| Threshold | 4.120 | 4.095 | 4.360 | 3.379 | 4.105 | 3.283 | 0.625 |
| **Model 5: Pop, L10.log GDP pc, inflation, total private credit/GDP, trade, investment, public expenditure, country FE, year FE** | | | | | | | |
| Innovation | −0.076 | −0.688 | −0.13 | −1.017 | 0.031 | 1.257 | −0.05 |
| | (0.436) | (0.486) | (0.387) | (0.623) | (0.511) | (1.658) | (0.494) |
| (Innovation –*th*) | 0.352 | 1.553** | 1.032 | 1.897** | 0.508 | −1.652 | 0.328 |
| (Innovation>*th*) | (0.771) | (0.727) | (0.847) | (0.825) | (1.219) | (1.782) | (0.562) |
| Threshold | 4.120 | 4.095 | 4.360 | 3.379 | 4.105 | 3.283 | 0.625 |

*Notes*: The dependent variable in all models is real growth GDP per capita.
Robust SE in parenthesis.
Significance levels: *$p < 0.01$, **$p < 0.05$, ***$p < 0.1$.

coefficient of the innovation measure, government procurement of advanced technology products, decreases in magnitude becoming nonsignificant.

It is interesting to note that the coefficients of quality of scientific research and university–industry R&D collaboration remain robust, in magnitude and significance, to the inclusion of investment and public expenditure. These are not affected by the inclusion of investment because they are not realized by companies, that is, quality scientific research and university–industry collaboration depend less on the amount of investment, and in this terms are better measurements of innovation, which include the meaning of innovation, that is, knowledge creation, and exclude relations with other variables such as investment and government expenditure. This suggests that the creation of quality knowledge is one of the main channels through which innovation affects growth. It is, however, less clear why the estimates related to the availability of scientists and engineers are so negatively affected when controlling for investment and government expenditure.

## V. Conclusions

The results presented here support the hypothesis of the existence of a threshold effect in the relationship between innovation and economic growth. Lower levels of innovation seem to generate no growth, while higher levels of innovation have a positive and significant effect on growth. This implies that for countries to benefit from innovation, they require policies that will create larger levels of innovation. Countries might only opt for such policies if they have enough resources to assume the risks of increasing innovation. In this order of ideas, countries located below the threshold should not emphasize their policies on innovation strategies, but on the strengthening the efficient use of their resources, in a way that lead them to be above the threshold, so innovation becomes a policy alternative. This result is in line with Spielkamp and Rammer (2009) and Buesaa *et al.* (2010) because they all consider that once innovation begins and an appropriate environment is developed, its costs diminish and it becomes beneficial.

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