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# Technology, Human Capital and Growth: Further Evidence from Threshold Cointegration

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**Abstract:** This paper assesses whether the linkages between R&D, human capital and productivity growth in a panel of EU manufacturing industries over the period 1980-2002 are affected by a critical level of human capital. To employ our data in an efficient manner, the study makes use of a dynamic threshold-based analysis, which determines endogenously the sample splitting procedure. The estimates indicate the presence of a threshold level based on the size-level of human capital. Countries with human capital levels above the threshold receive higher productivity growth benefits from higher R&D.

*JEL Classification:* O40; L60; C23.

**Keywords:** Productivity growth, R&D, Human capital, Threshold effects, Manufacturing industries, EU countries, Panel data.

## INTRODUCTION

Recent theories of innovation-driven growth models have stressed the importance of innovation efforts as a key propagator of economic growth<sup>1</sup>. These models assume that spillover effects, generated by knowledge transmission mechanisms, are strong enough to maintain R&D costs on a constant basis. This in turn allows sustained total factor productivity (TFP) growth. A number of studies explore empirically the contribution of R&D spillovers to a country's TFP level, while a smaller body of empirical work examines the same issue at industry level by considering the international intra-industry R&D spillovers [4]. Overall, the evidence suggests that R&D spillovers increase productivity of the country/industry [5, 6]. A new group generation of R&D-based studies considers a different approach that relates the two primary variables, which comes in two varieties, one that incorporates diminishing returns to the stock of knowledge in R&D [7, 8] and the alternative, which considers a fully endogenous 'Schumpeterian' environment. According to this version, there are constant returns to the stock of knowledge in R&D, which implies a close association between the behavior of R&D and TFP growth. Within such an environment, R&D is crucially needed to outweigh the negative impact of more product varieties on the association under study. [9-12] compare the above two alternative versions of the new generation models against the real world TFP trends over the post-war period. Their results provide support to the Schumpeterian version.

A shortcoming of the innovation-driven growth models is that they do not adequately consider the role of human

capital. This approach stems from the seminal works [13, 14], which employed the neoclassical theory of growth and introduced endogenous growth models. These models emphasize the mechanisms linked to the actual dynamics of growth. The empirical evidence on the role of human capital on growth has, however, generated mixed results. Although the majority of empirical efforts have shown that human capital, being a complementary factor with technological capital, yields positive effects in fostering technological change, diffusion, and, thus, growth [15-20]; and others have yielded disappointing results about the role of human capital in the relevant process. [21-28] have attempted to rationalize this mixed evidence by claiming that it could be the outcome of econometric difficulties when specifying growth regressions. [29-32] claim that the differentiation in the empirical finding is probably due to the presence of the bias generated by the mis-measurement of schooling data, while [33, 34] attribute it to the fact that educational indicators seem to disregard differences in educational quality. [35] attributes it to omitted variables in the relevant regressions, while they emphasize the importance of reverse causation from expected growth to schooling.

Human capital, capable of working with the new technologies created by innovation efforts, facilitates the realization of R&D spillovers. Moreover, it accounts for innovations different from the R&D sector. In other words, models that do not account for an explicit role for human capital fail to consider the need for the presence of qualified labor, qualified enough to work with the new technologies created by innovation efforts. The complementary character between R&D activities and human capital has been emphasized. [36-40] developed theoretical models where the steady-state rate of growth is determined by the rate of R&D investment and human capital accumulation. A large stock of human capital facilitates the absorption of new products and new ideas and discoveries [41, 42]. On the empirical basis, [43] consider explicitly the role of human capital and they

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<sup>1</sup> See [1], [2], [3].

conclude that its omission results in overestimation of the R&D coefficients. However, they provide contradictory results as to the impact of human capital on TFP. The same picture emerges when it comes to international intra-industry studies (e.g. [4])<sup>2</sup>.

The studies mentioned above have assumed a linear relationship between the two variables under investigation. [45-48] emphasize threshold externalities between certain variables, such as human capital, and economic growth. A relatively recent study, [49] investigates the nexus between economic growth and human capital by allowing for the presence of a non-linear relationship between the two variables. Their findings validate the presence of non-linearity. However, to the best of our knowledge, only a handful of studies have investigated so far whether the linkages of R&D spillovers, human capital and TFP (used as a proxy for growth) are affected by the level of human capital available in each country. [50, 51] argue that different levels of human capital vary in the extent to which they facilitate technology absorption and, therefore, affect the speed of growth. In particular, low human capital levels do not allow a country or an industry to take advantage of the 'incorporated' knowledge *via* domestic and foreign R&D diffusions. In other words, R&D spillovers tend to have a stronger growth enhancing effect where the population has higher education above an estimated threshold. As claimed by [52], this would suggest a non-linear process, which indicates that the efficiency of economies in benefiting from new technologies depends critically on their absorption capacity that is crucially determined by the level of knowledge [53]. [39] and [40] also argue that there exists a critical level of human capital above and below which the impact of R&D on productivity growth differs. Consequently, the novelty of the paper is to explore such a dynamic complementarity of R&D spillovers and human capital and its impact on total factor productivity (TFP) for a number of European Union countries across industries, in a non-linear fashion through recent methodological approaches, such as threshold cointegration methodologies.

To this end, the paper makes use of a threshold estimation procedure, suggested in [54], who recommend a methodology that allows estimation of a cointegrating relationship and a single threshold when both are unknown in an error correction model (ECM). Their methodology with one cointegrating vector and a single threshold effect is based on a Lagrange Multiplier (LM) test (the so called supLM test) for the presence of a threshold. According to this test, the null hypothesis of linearity is tested against the alternative of threshold cointegration. On the modeling front, we use [55] model specification, where long-run growth is endogenously driven by R&D investments. However, the model is extended to consider the role of human capital in enhancing R&D spillovers.

The rest of the paper is organized as follows: The following section presents the econometric specification and

data used. Econometric methodology and empirical estimates are reported in the next section. The final section concludes the paper.

## MODEL SPECIFICATION AND DATA

To identify the non-linearity that describes the R&D spillovers-productivity growth relationship we make the assumption that productivity growth can be enhanced through a higher portion of human capital in the production line combined with R&D activities. This is a valid argument since the knowledge can be transmitted through such R&D activities. Next, we make the hypothesis that human capital affects productivity growth through its favorable impact on R&D; the productivity payoffs from R&D are mediated by the level of human capital reached. Moreover, we make the assumption that there exists some critical levels of human capital above and below in which the positive contribution of R&D to productivity growth differs. In particular, we are making the assumption that the productivity growth response to increased R&D will be greater for those countries with higher human capital than those with lower human capital. Thus, the relationship between R&D and human capital may be non-linear rather than linear. Assuming a single threshold, the TFP growth equation yields:

$$\Delta \log F_{ijt} = \beta_{0ij} + \beta_1 \Delta \log HC_{ijt} + \beta_2 I(\Delta \log HC_{ijt} \leq \gamma) \Delta \log S_{ijt} + \beta_3 I(\Delta \log HC_{ijt} > \gamma) \Delta \log S_{ijt} + \varepsilon_{ijt} \quad (1)$$

or

$$\Delta f_{ijt} = \beta_{0ij} + \beta_1 \Delta hc_{ijt} + \beta_2 I(hc_{ijt} \leq \gamma) \Delta s_{ijt} + \beta_3 I(hc_{ijt} > \gamma) \Delta s_{ijt} + \varepsilon_{ijt} \quad (1)'$$

where subscript *i* refers to the country, *j* to the industry and *t* to time; *F* represents total factor productivity (TFP); *S<sub>ijt</sub>* is the technology effect; *HC<sub>ijt</sub>* is human capital. The indicator function *I* sorts the data to create various sub-samples;  $\varepsilon_{ijt}$  is i.i.d. error term. According to (1), human capital is treated as another input in an underlying Cobb-Douglas production function. The threshold model addresses the following problems: i) how to jointly estimate the threshold value  $\gamma$  and the slope coefficients  $\beta_1$ ,  $\beta_2$ , and  $\beta_3$  ii) how to test whether such a single threshold does exist.

Our sample consists of nine European countries (Great Britain, Finland, France, Germany, Italy, Belgium, Netherlands, Spain and Portugal) and 21 manufacturing industries in each country over the period 1980-2002. The size of our sample as well as the time span was mainly determined by the availability of R&D investment and human capital data. The same International System of Industries Classification code was used in all industry-level data sources. The manufacturing industries and their ISIC codes are presented in the Appendix.

To control for data quality and, therefore, draw sharp inferences we employ human capital estimates from both [56, 57] and [58] databases. Data comes from the EU KLEMS database provided by the University of Groningen. The human capital data is provided at country level and of 5-yearly average. It is not available on an industry level. We interpolate between five-yearly and extrapolate observations

<sup>2</sup> [4] uses the Barro and Lee [41] human capital database, while, [44] relies on human capital estimates from the de la Fuente and Doménech [32] database.

using STATA’s linear interpolation (extrapolation) function. We have to combine this data with the country-industry level data by repeating it every time we utilize industry level data. Import measures, such as imports from the whole world, were also obtained from the [59] *Bilateral Trade Database*. All price figures are expressed in euros at 1995 purchasing power parity (PPP). The estimations and test procedures make use of GAUSS software.

**ECONOMETRIC METHODOLOGY AND EMPIRICAL RESULTS**

**Unit Root Tests**

The null hypothesis of non-stationarity versus the alternative that the variable is stationary is tested using the group mean panel unit root test (or 't-bar' test) of Im *et al.* [60]. This test is based on the Augmented Dickey-Fuller (ADF) statistic [61] and allows each member of the cross section to have a different autoregressive root and different autocorrelation structures under the alternative hypothesis. The results are reported without and with a trend in Table 1. The hypothesis that all the variables contain a unit root is accepted at the 1% significant level, suggesting that all the log variables in our study are I(1).

**Table 1. Unit Root Tests**

Variables	W/o Trend	W/ Trend	W/o Trend	W/Trend
	Levels		First Differences	
f	-0.34(3)	-0.64(3)	-10.36(2)*	-11.25(2)*
hc	-2.11(3)	-2.46(2)	-6.55(2)*	-7.12(1)*
s	-2.02(3)	-2.37(3)	-7.63(1)*	-10.62(2)*

Notes: f = the log of total factor productivity, hc = the log of human capital, and s = the log of R&D expenses. Figures in brackets denote the number of lags in the augmented term that ensures white-noise residuals. The optimal lag length was determined through the Akaike information Criterion (AIC) and the Schwarz-Bayes Information Criterion (SBIC).  
\* Significant at 1%.

**Cointegration Tests**

Panel cointegration tests, based on [62] Fully Modified OLS (FMOLS) tests and reported in Table 2, reveal the presence of a long-run relationship among the variables of total factor productivity, human capital and R&D expenses and the employment of an Error Correction (EC) model must be followed. Thus, model (1)’ in an EC form yields:

$$\Delta f_{ijt} = \beta_{0ij} + \beta_1 \Delta hc_{ijt} + \beta_2 I(hc_{it} \leq \gamma) \Delta s_{ijt} + \beta_3 I(hc_{it} > \gamma) \Delta s_{ijt} + \beta_4 EC_{ij(t-1)} + \varepsilon_{ijt} \quad (1)''$$

**Table 2. Cointegration Tests**

Panel v-stat	27.684413*
Panel rho-stat	-27.155982*
Panel pp-stat	-26.353791*
Panel adf-stat	-9.347736*
Group rho-stat	-27.274034*
Group pp-stat	-27.190045*
Group adf-stat	-9.793459*

Notes: An asterisk denotes the rejection of the null hypothesis of no cointegration.

**Threshold Cointegration Estimations**

Once cointegration among the three variables under investigation was identified and to remain consistent with the threshold model (1) or (1)’ we make use of the methodology of threshold cointegration, which allows non-stationary variables to be modeled accordingly. In particular, the methodology of threshold cointegration combines both non-linearity and cointegration. This particular methodology is necessary to explain the long-run equilibrium relationship by a cointegration test, while assuming the feature of asymmetric adjustment. The linear case assumes the tendency to move towards the long-run equilibrium for every time period, the asymmetric or threshold case emphasizes the possibility that movements towards the long-run equilibrium need not occur in every period. Thus, there exists a discrete adjustment to equilibrium only when the deviation from the equilibrium exceeds a critical threshold. Threshold cointegration could characterize the discrete adjustment in terms of the case where the long-run relationship does not hold inside a certain band, but then remains active if the system gets too far from the equilibrium. However, for this methodology to be materialized the estimation of the cointegrating vector must be observable for the grid research to be clear. To this end, [54] suggest a methodology that allows estimation of a cointegrating relationship and a single threshold (as in our case) when both are unknown in an error correction model (EC). They propose a methodology with one cointegrating vector and a single threshold effect based on a Langrange Multiplier (LM) test (the so called supLM test) for the presence of a threshold. According to this test, the null hypothesis of linearity is tested against the alternative of threshold cointegration.

In addition, to ensure that the threshold estimations include sufficient observations in one of the regimes, we restrict the minimization problem to values of  $\gamma$  such that at least 1% of the observations lie in both regimes. The lag length selection of the model is determined by the Akaike criterion, leading to the results of 1 lag at both the case of the Barro & Lee definition and of the de la Fuente and Doménech definition of human capital. Table 3 reports the dynamic long-run results. The results are reported under both alternative human capital measures. The first column reports the results under the Barro & Lee measure. The point estimate of the threshold  $\gamma$  is equal to 9.2991 or 9.3 years. The human capital coefficient is shown to be positive (0.074), which is consistent with theoretical arguments supporting a positive effect of this variable on growth. However, the R&D interaction coefficient turns out to be statistical significant only in the case where human capital exceeds the endogenously determined threshold. Below this critical or threshold level the impact of R&D growth turns to be insignificant. Therefore, if the value of the human capital stock exceeds 9.3 years, each percentage point increase in R&D growth leads to a 0.042 percentage point increase in TFP growth. The second column of Table 3 replicates the estimations under an alternative definition of human capital, the one provided by de la Fuente and Doménech. The results lend support to those reached before. More specifically, the

**Table 3. Estimations of the Threshold Productivity Growth Model**

HC	Barro & Lee	de la Fuente and Doménech
Constant	-0.036 (2.11)*	-0.027 (2.36)*
$\Delta \log HC_{ijt(t-1)}$	0.074 (4.06)**	0.093 (3.79)**
$\Delta \log F_{ijt(t-1)}$	0.336 (4.23)**	0.341 (4.17)**
$\Delta \log S_{ijt(t-1)} I(\Delta \log HC_{it} \leq \gamma)$	0.016 (1.24)	0.021 (1.37)
$\Delta \log S_{ijt(t-1)} I(\Delta \log HC_{it} > \gamma)$	0.042 (3.49)**	0.049 (3.65)**
$EC_{ijt(t-1)}$	-0.045 (-4.77)**	-0.051 (-5.49)**
Threshold Value (%)	9.2991 ≈ 9.3	9.4356 ≈ 9.4
Observations	2268	2268
Adjusted R <sup>2</sup>	0.36	0.33
supLM	6.12 [p=0.00]	6.74 [p=0.00]
F-statistic	23.54**	20.11**

Notes: The F-statistic tests the null that all coefficients are jointly equal to zero. SupLM is the Hansen and Seo [54] statistic. The results reject the null hypothesis of no threshold (linearity).

\* Significant at the 5 percent level.

\*\* Significant at the 1 percent level.

human capital coefficient is shown to be positive again (0.093), while the threshold estimation turns to be now 9.4356 or 9.4 years. Thus, if the value of the human capital stock exceeds 9.4 years, each percentage point increase in R&D growth leads to a 0.049 percentage point increase in TFP growth.

Moreover, in both cases the effect of R&D expenses on TFP growth in the second regime is stronger than in the first regime in terms of the coefficient size. The second regime occurs when the human capital value exceeds the threshold. This is the regime with the lower number of observations representing the 37.5% of the total sample. Finally, the supLM statistic, proposed by [54], is also reported along with its associated asymptotic p-value calculated using the fixed regressor boot-strap proposed by [63], with 10,000 replications. This statistic tests the null hypothesis of a linear

model against the threshold specification. As it can be seen from the results in Table 3, the null hypothesis is clearly rejected in favor of threshold cointegration.

Table 4 provides some robustness tests of the estimated link between TFP growth and R&D by adding the imports share as a control variable in the relevant regression:

$$\Delta \log F_{ijt} = \delta_{0ij} + \delta_1 \Delta \log HC_{ijt} + \delta_2 I(\Delta \log HC_{it} \leq \gamma) \Delta \log S_{ijt} + \delta_3 I(\Delta \log HC_{it} > \gamma) \Delta \log S_{ijt} + \delta_4 \Delta \log IMP_{ijt} + \delta_5 EC_{ijt(t-1)} + \eta_{ijt} \quad (2)$$

or

$$\Delta f_{ijt} = \delta_{0ij} + \delta_1 \Delta hc_{ijt} + \delta_2 I(fc_{it} \leq \gamma) \Delta s_{ijt} + \delta_3 I(fc_{it} > \gamma) \Delta s_{ijt} + \delta_4 \Delta imp_{ijt} + \delta_5 EC_{ijt(t-1)} + \eta_{ijt} \quad (2)'$$

The import share captures the impact of international

**Table 4. Robustness Estimates of the Threshold Productivity Growth Model**

HC	Barro & Lee	de la Fuente and Doménech
Constant	-0.0081 (2.43)*	-0.0061 (2.71)**
$\Delta \log HC_{ijt(t-1)}$	0.065 (4.62)**	0.078 (4.18)**
$\Delta \log F_{ijt(t-1)}$	0.297 (4.48)**	0.314 (4.73)**
$\Delta \log IMP_{ijt(t-1)}$	0.052 (3.83)**	0.059 (4.07)**
$\Delta \log S_{ijt(t-1)} I(\Delta \log HC_{it} \leq \gamma)$	0.014 (1.08)	0.016 (1.18)
$\Delta \log S_{ijt(t-1)} I(\Delta \log HC_{it} > \gamma)$	0.053 (4.20)**	0.060 (3.92)**
$EC_{ijt(t-1)}$	-0.037 (6.33)**	-0.040 (5.19)**
Threshold Value (%)	9.2995 ≈ 9.3	9.4521 ≈ 9.4
Observations	2268	2268
Adjusted R <sup>2</sup>	0.38	0.37
supLM	7.14 [p=0.00]	7.68 [p=0.00]
F-statistic	26.79**	24.51**

Notes: Similar to Table 3.

trade on the relationship under investigation [64-66]. Emphasis is given on the role of imports since they could affect both innovation and technology transfers. Imports embody foreign technology and could raise an industry's output through reverse-engineering. As industries successfully imitate imported goods, they gain more insight as to how these goods are engineered, and can improve upon. In other words, imitation of foreign technology improves the chances of invention as well [67]. In addition [68] argues that imports should be considered alone on the grounds that imported intermediate and capital goods embody new technologies.

The results are reported again under both alternative human capital measures. The technology coefficient is shown again to exert a positive impact on the rate of growth in both definitions, while the R&D interaction coefficient turns out to be statistically significant again only in the case where human capital exceeds an endogenously determined threshold level. If the value of the human capital stock exceeds 9.3 years, each percentage point increase in R&D growth leads to a 0.053 percentage point increase in TFP growth under the Barro & Lee human capital measure. Under the de la Fuente and Doménech human capital measure the threshold turns to be 9.5 years. Thus, if the value of the human capital stock exceeds 9.5 years, each percentage point increase in R&D growth leads to a 0.060 percentage point increase in TFP growth. The coefficient of imports share is positive in both alternative human capital measurements, which validates the reverse-engineering hypothesis. Once again, in both cases the effect of R&D expenses on TFP growth in the second regime is stronger than in the first regime in terms of the coefficient size. Finally, the supLM statistic displays that again the null hypothesis is clearly rejected in favor of threshold cointegration.

## CONCLUSIONS

The results of this study provide some insights into the relative importance of the joint role of human capital in economic growth in models that consider the explicit role of technological knowledge spillovers. Using appropriate human capital data, econometric techniques that apply a threshold cointegration model that considers the possibility of a non-linear relationship between TFP growth, human capital and R&D expenses, the cross-country and cross-industries empirical findings for ten European countries over the period 1980-2002 provide evidence in favor not only of the inclusion of human capital as an explanatory variable in explaining TFP behavior, but also in favor of the presence of threshold effects on human capital in the technology-productivity growth link, that is, whether human capital above a threshold level allows certain channels of technology diffusion to have a greater impact on productivity growth.

Accordingly, the empirical findings show that countries with human capital level above the threshold receive higher productivity benefits from increased R&D. The interpretation of the non-linear relationship between productivity growth and TFP needs some discussion and further research is more than a

necessity. A tentative explanation may be the relative importance of absorptive capacity for industries that use high skilled human capital and are in a better position to exploit knowledge spillovers, thus, reducing costs of production. The results may be of high interests not for industries themselves but also for policy makers who design and support educational systems in identifying the mechanism of TFP growth dependencies on the interaction of human capital and R&D expenses. Further research analysis on a firm-based status could shed more light on this issue since the hypothesis of identical firms within industries cannot be accepted without any doubt.

## APPENDIX

### Manufacturing Industries and ISIC Codes

Manufacturing Industries	Abbreviation	ISIC Code (Rev. 3)
Food products, beverages and tobacco	FOD	15-16
Textiles, textiles products, leather and footwear	TEX	17-19
Wood and products of wood and cork	WOD	20
Pulp, paper, paper products, printing and publishing	PAP	21-22
Coke, refined petroleum products and nuclear fuel	COK	23
Chemicals excluding pharmaceuticals	CHE	24 less 2423
Pharmaceuticals	PHA	2423
Rubber and plastics products	RUB	25
Other non-metallic mineral products	ONM	26
Iron and steel	IAS	271+2731
Non-ferrous metals	NFM	272+2732
Fabricated metal products (excluding machinery and equipment)	FAB	28
Machinery and equipment, n.e.c.	MAC	29
Office, accounting and computing machinery	OFF	30
Electrical machinery and apparatus, n.e.c.	ELE	31
Radio, television and communication equipment	RAD	32
Medical, precision and optical instruments	MED	33
Motor vehicles, trailers and semi-trailers	MOT	34
Building and repairing ships and boats	SHI	351
Aircraft and spacecraft	AIR	353
Other Manufacturing (Furniture; Manufacturing n.e.c.; Recycling)	OMA	36+37

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