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Technology, Health, Education and Economic Growth Nexus: Evidence from High Income OECD Countries

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Abstract

Human capital and technology, along with physical capital, have been the subject of extensive empirical studies of economic growth since 1980. In this study, we added human capital to the model in the form of health and education, and technology in the form of domestic and foreign technologies. We also divided the education variable into primary, secondary, and tertiary. The research covers 27 high-income OECD countries for the period 1990-2020. In the analysis, the FGLS estimator, which is resistant to heteroscedasticity, cross-section dependence and panel-specific autocorrelation, is employed. As a result, a unit increase in foreign technology increases national income by 0.037%, and a domestic technology by 0.023%. It is clear that foreign technology has higher impact on economic growth compared to the domestic technology. While primary school education has no significant effect on growth, that secondary school education increased growth by ≅0.069% and tertiary by ≅0.30%. Accordingly, it is seen that tertiary education has a much greater effect on economic growth than the effect of physical capital (≅0.22%). It can be said that this situation reveals the importance of tertiary education in the production and spillover of technology.

Keywords: Human Capital, Technology, Economic Growth, Education, Health, OECD Countries, FGLS.

Introduction

Although it is seen that human capital has been included in economic growth models since the 1980s, it is relatively new that human capital in the form of education and health take their place in the empirical literature together with innovation. With the globalizing world, high-tech products have gained importance, while the need for qualified manpower has increased. The increasing need has accelerated the developments in human capital in the forms of education and health. The progress in health, education, and technology raises the standard of living of both individuals and societies.

Education provides positive externalities on economic growth. In this context, while the high level of education affects economic growth positively, increasing growth also raises the level of education and creates a positive cycle on the economic growth rate (Van Den Berg, 2001: 386-387). The first reason for the growth cycle is investments in human capital.

One of the important factors affecting the productivity of labor, which is the basic element of economic growth, is health. By contributing to the accumulation of human capital, health positively affects economic growth (Sachs, 2001: 24). Advances in health also encourage education. Improvements in health occur not only with the personal developments of individuals, but also with developments in the economy (Van Den Berg, 2001: 51-55). Advances in health increase life expectancy and productivity, encouraging individuals to invest in education to improve skills or acquire new skills.

In addition to human capital, technology also is a critical role in determining the competitiveness of countries. Romer (1986), the main power that ensures and sustains the growth is innovations introduced together with R&D. Technology contributes to a country's productivity and economic growth, increasing its per capita GDP. The growth rate of countries becomes associated with technology leadership. In a country that growth rate is less than that of its technology leaders, there is a relative gap between its GDP and living standards.

When it comes to economic growth, human capital gains more importance in developed countries, where physical capital investments are much higher than in developing countries. On the other hand, in developing countries, physical capital investments are more prominent. For this reason, economic growth helps economic development in developing countries and welfare in developed countries.

In this study, unlike the studies in the literature, we separated technology as domestic technology and foreign technology. We have classified that human capital is as a form of education and health. We categorized the education as primary, secondary, and tertiary. By including these variables into the economic growth model, which is developed by in Weil (2007), we examined their effects on growth for 27 high-income OECD countries over the 1990-2020 period.

Literature Review

There are many studies that try to explain the relationship between health, education, and technology. In the literature, although the direction of the relationship differs from country to country, it is generally concluded that education, health, and technology growth positively.

Most scholars have examined influence human capital in their studies (Nelson and Pelps; 1966). Especially after the study of Romer (1986), it is seen that there has been a significant increase in studies focused on economic growth. Recent studies on endogenous growth models have examined the effects of technology-based productivity increases on growth. Along with Lucas (1988)'s study that takes into account human capital in the form of training and education, Romer (1990) revealed the effect of R&D investments on economic growth through productivity growth. Weil (2007), made a significant contribution to the literature in his theoretical and empirical study, in which he investigated the effects of health on economic growth, taking into account education. Barro (2013), reveals the positive effect of human capital as form of education on economy's ability to spillover new technologies, by including secondary and higher education in the analysis.

The level development of and growth of countries is carefully related to their technological level (Jones and Williams, 2000). While the research and development expenditures of societies provide their technological development, they also provide the economic growth in countries (Bilbao-Osorio and Rodriguez-Pose, 2004). Because the increase in research and development expenditures will increase productivity and improve wages (Sylwester, 2001). Such domestic and foreign research and development expenditures affect growth (Coe and Helpman, 1995). It positively affects economic growth not only by R&D expenditures, but also by creating employment in technological development.

While the effects of health, education and technology on growth in the literature are examined separately, in some studies they are all included. Studies investigating the effect of education and health on economic growth revealed that these variables have positively impact on economic growth (Van Zon and Muysken 2003; Li and Liang 2009; Beraldo et al. 2009; Wang 2011; Siddique et al. 2018; Vongpanya et al. 2018; Matousek and Tzeremes 2021). What's more, it is also revealed that an increase in economic growth raises investment in human capital and physical capital therefore causes improved health (Li and Liang 2010; Yang 2020; Pradhan 2011).

The role of education and health in growth actually depends on technology. Improvement in health and education should produce scientific knowledge and products. The added value of knowledge should create technology with scientific knowledge and thus make growth more sustainable (Krugman and Wells 2011).

The following Theoretical Model is based on the model presented by Weil (2007). The technology variable is divided into domestic and foreign technology; The human capital in the education form was divided into three as primary, secondary and tertiary, and its effects on economic growth were examined.

Theoretical Model

In the Solow (1956) growth model, output is defined as a function of labor, physical capital and technology. Mankiw, Romer, and Weil (1992) extended the Solow's growth model by adding human capital. In this context, considering the research of Weil (2007), which includes health and education as forms of human capital, we can express the production function of a country at time t with the following Cobb-Douglas form:

$$Y_t = A_t\, K_t^{\alpha}(\, hL_t)^{1-\alpha} \tag{1}$$

where Y represents the total output of a country in period t. A, K, L, and h notations represent productivity measure, physical capital stock, number of workers, and human capital per worker, respectively. α is the coefficient of K and takes values between zero and one. In order to express the production function in the form of output per-worker, Eq.1 is divided by L;

$$y_t = A_t\, k_t^{\alpha}(\, h_t)^{1-\alpha} \tag{2}$$

Since human capital will be added to the model in the form of education (s) and health (v), it can be expressed as in Eq. 3.

$$h_t = s_t^{\beta}\, v_t^{\gamma};\ 0 < \beta + \gamma < 1 \tag{3}$$

In the literature, productivity (A_t) is associated with technology. Since the technology can be imported as well as produced in a country, the term of productivity has been added to the model in the forms of domestic technology (Ad) and foreign technology (Af) as in Eq.4.

$$A_t = Ad_t^{\delta}\, Af_t^{\omega}; 0 < \delta + \omega < 1 \tag{4}$$

Considering Eq.4, the production function can be restated as in Eq.5

$$y_t = Ad_t^{\delta}\, Af_t^{\omega}\, k_t^{\alpha}(s_t^{\beta}\, v_t^{\gamma})^{1-\alpha} \tag{5}$$

Eq.5 can be converted into linear function, as in Eq.6, by taking logarithm.

$$lny_t = \delta lnAd_t + \omega lnAf_t + \alpha lnk_t + (1-\alpha)\beta lns_t + (1-\alpha)\gamma lnv_t \tag{6}$$

Schooling can be added into the equation as human capital in the form of education by dividing primary, secondary, and tertiary. Eq.7 shows the school enrolment (st) as the sum of primary (ps), secondary (ss) and tertiary (ts).

$$lns_t = (lnps_t + lnss_t + lnts_t\,) \tag{7}$$

Considering Eq.7, the production function can be expressed as in Eq.8

$$lny_t = \delta lnAd_t + \omega lnAf_t + \alpha lnk_t + (1-\alpha)\beta(lnps_t + lnss_t + lnts_t\,) + (1-\alpha)\gamma lnv_t \tag{8}$$

Results

In the model where economic growth per-worker is the dependent variable, capital per-worker and technology are the basic components of economic growth. Education and health in the forms of human capital, were added to the model. In addition, the technology in the form of productivity, was divided into two parts as domestic technology and foreign technology and added to the model.

In this context, using the data of 27 high-income OECD countries[1] between 1990 and 2020, the effects of education and health variables, which are the components of human capital, on growth, and the effects of domestic and foreign technology, which are the components of productivity, on growth were examined. Country specific data for the variables mentioned were obtained from the World Bank Database.

Panel data analysis will be employed in the empirical part of this research. In this context, a general linear panel data model is as follows (Baltagi, 2005).

$$Y_{it} = \alpha_{0it} + \sum_{k=1}^{K} \beta_{kit} X_{it} + \varepsilon_{it} \tag{9}$$

or to put it more clearly:

$$Y_{it} = \alpha_{it} + \beta_{1it} X_{1it} + \beta_{2it} X_{2it} + \cdots \beta_{kit} X_{kit} + \varepsilon_{it}\,) \tag{10}$$
$$i = 1, 2, \dots \dots \dots, N \qquad and \qquad t: 1, 2, \dots \dots \dots, T$$

In the Model given in Eq.10, i, which expresses the cross-sectional dimension, and t, which expresses the time dimension, are sub-indices. Y_{it} is the value of the dependent variable for i[th] cross-section at time t; α_{it} represents the constant term; β_{kit} is the K X 1 dimensional vector of parameters; X_{kit} denotes the value of the explanatory variable for i[th] cross-section at time t.

The theoretical model given in Eq.8 can be converted to econometric form based on panel data model described in Eq.10 to employ in the empirical analysis. Accordingly, the reconstructed model is expressed in Eq.11.

$$lny_{it} = \alpha_{it} + \beta_1 lnAd_{it} + \beta_2 lnAf_{it} + \beta_3 lnk_{it} + \beta_4 lnps_{it} + \beta_5 lnss_{it} + \beta_6 lnts_{it} + \beta_7 lnh_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$
$$Countries\ (i) = 1, 2, \dots \dots \dots, 27 \qquad and \qquad Years\ (t): 1990, \dots \dots \dots, 2020$$

The variables of the model in Eq.11 are described below with the notation and indicators.

Output	y	GDP per worker (constant LCU)
Capital	k	Gross fixed capital formation per worker (constant LCU)
Technology - Domestic	Ad	Patent applications per-worker, residents
Technology – Foreign	Af	Imported Technology (% of merchandise imports)

[1] Note: "Australia, Austria, Belgium, Canada, Chile, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Rep., Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States."

Health	h	Life expectancy at birth, total (years)
Education	ps	School enrollment, primary (% gross)
Education	ss	School enrollment, secondary (% gross)
Education	ts	School enrollment, tertiary (% gross)

The descriptive statistics are reported in Table 1.

Table 1.
Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
y	837	2741129	8683843	10831.91	67900000
k	837	18144.23	8697.821	1813.774	78429.82
Ad	837	27162.27	73119.58	15	384201
Af	837	71.87276	8.104992	42.75677	86.04682
h	837	79.16795	2.680495	69.10122	84.50196
ps	837	102.2242	5.013511	78.36396	132.8818
ss	837	109.8051	18.43281	59.85119	236.7405
ts	837	62.3766	22.69881	4.50	156.2218

Homogeneity and CD-Test of the Model

Testing slope homogeneity is crucial to choose the proper unit root test and panel data estimator. Assuming that the coefficients are homogeneous while heterogeneous causes biased results. For this purpose, Delta test developed by Blomquist and Westerlund (2013), which considers heteroskedastic and serially correlated errors, was performed and the results are reported in Table 2. The null hypothesis of "slope coefficients are homogenous" was rejected, and it was concluded that slope coefficients are heterogeneous.

Table 2.
Slope Homogeneity and Cross-sectional Independence Tests

CD-Test	LM CD : 5.905	(Prob.=0.0000)
Homogeneity (Delta)	Delta adj: 4.403	(Prob.=0.0000)

The accuracy and reliability of the findings of the analyzes made without considering the cross-section dependency become questionable (Pesaran, 2004). Therefore, to support the delta test outcomes, the null hypothesis of “error cross-section independence” was tested with the Breush-Pagan LM test and the results are reported in Table 2. The null hypothesis of “error cross-section independence” was rejected and therefore the existence of cross section dependence confirmed. In selection of proper unit root test method, cross section dependence and heterogeneity should be considered.

Stationary of the Series

Stationarity is a condition that can affect the behavior of the series. The stationarity of the series of the variables forming the panel is important for the reliability of the estimations. In case the series are not stationary, the standard assumptions for asymptotic analysis lose their validity, the estimation results are misleading, and a spurious regression relationship emerges (Vosvrda, 2013).

Therefore, the stationarity of the series was tested with the Pesaran (2006) CADF Unit Root Test, which takes into account cross-sectional dependence and heterogeneity, and the results are reported in table 3.

Table 3.
Pesaran CADF Panel Unit Root Test

Variables	CIPS Stat.	
	I(0)	I(1)
y	-2.332	-
k	-1.847	-4.505*
Ad	-1.824	-5.315*
Af	-1.405	-4.800*
h	-1.965	-5.197*
ps	-2.061	-4.074 *
ss	-1.827	-3.858*
ts	-1.457	-4.165*

Notes: critical values are -2.30 (1%), -2.16 (5%) and -2.08 (10%).

According to the test statistics values in Table 4, only the GDP per-worker variable is stationary in level. In another word it is integrated of order zero - I(0)-. All the other series are nonstationary in levels, but stationary in the first differences. In another word all series, except GDP per-worker are integrated of order 1 - I(1)-.

Empirical Model Specification

In the selection of the appropriate panel data model, initially, it is necessary to determine whether the models contain individual and time effects. In order to determine which of these effects is valid, Likelihood Ratio (LR), F and Breusch-Pagan Lagrange Multiplier (LM) tests were performed, and the results are reported in the Table 4.

Table 4.
Test Results to Decide on the Appropriate Model Selection

Test Statistics	Individual Effect (H_0: No individual effect)	Time Effect (H_0: No time effect)
LR	3052.24 (Prob=0.000)	0.00 (Prob=1)
F	5773.75 (Prob=0.000)	2.46 (Prob= 0.9956)
LM	9123.60 (Prob=0.000)	0.00 (Prob=1)

According to the LM test results, the LM statistic was compared with the 1 degree of freedom χ^2 table, and the null hypothesis that" the variance of the individual effect was equal to zero" was rejected. In accordance with the results of the F test, the F statistic was compared with the F distribution table, and the null hypothesis that "the individual effects were equal to zero" was rejected. Based on the LR test results performed to determine whether the model includes individual effects, the LR statistics were compared with the 1-degrees-of-freedom χ^2 table, and the null hypothesis that "the standard errors of the individual effects was equal to zero" was rejected. As a result, it is concluded that all models indicated existence of individual effect and therefore, the Classic model is not suitable.

Considering the time effect, according to the LM test results, the LM statistics were compared with the 1 degree of freedom χ^2 table, and “the null hypothesis that the variance of the time effect was equal to zero” was not rejected. According to the results of the F test, the F statistic was compared with the F distribution table, and “the null hypothesis that time effects were equal to zero” was not rejected. According to the LR test results, the LR statistics were compared with the 1 degree of freedom χ^2 table, and the null hypothesis that “the standard error of the time effect was equal to zero” was not rejected. As a result, none of the test results indicated the existence of time effect, and concluded that the model includes individual effect

As a result of the LR, F and LM Tests, it was revealed that the classical method could not be applied. Accordingly, Hausman Test was performed to decide which of the Random Effect or Fix Effect estimators would be appropriate, and the results were reported in Table 5.

Table 5. Model Specification Test

Hausman Test Statistics	χ^2 (7) = 0.25 (Prob = 0.9999)

According to the model specification test result in Table 5, the Hausman test statistic was compared with the χ^2 table with 6 degrees of freedom, and the null hypothesis that “the difference in coefficients not systematic” was not rejected. Therefore, it was decided that the fixed effects estimator is inconsistent, and the random effects estimator is appropriate for estimation of the model.

Existences of autocorrelation, heteroscedasticity and cross-sectional independence have critical importance in model selection process. Therefore, further research is required to determine the existence of these three conditions.

Levene, Brown, and Forsythe's Test was performed to test the existence of heteroscedasticity. Bhargava, Franzini and Narendranathan, and LBI tests were applied to test the existence of autocorrelation. Even though cross-section dependence test had been performed before stationary tests, to robust the results, Friedmen’s, Frees’s and Pesaran’s test statistics added into Table 6. Hence, the results of autocorrelation, heteroscedasticity and cross-sectional independence tests performed to determine whether there is any deviation from the basic assumptions of the model and outcomes are reported in Table 6.

Table # 6

Test Results of the Model's Basic Assumptions

<table>
<tr><td rowspan="3">Heteroskedasticity Test
H_0: No heteroskedasticity</td><td>W0 = 15.4831567 df(26, 810) Prob > F = 0.0000</td></tr>
<tr><td>W50 = 9.7007359 df(26, 810) Prob > F = 0.0000</td></tr>
<tr><td>W10 = 13.6388047 df(26, 810) Prob > F = 0.0000</td></tr>
<tr><td rowspan="2">Autocorrelation Test
H_0: No Autocorrelation</td><td>DW = .13106392 < 2</td></tr>
<tr><td>LBI = .31453980 < 2</td></tr>
<tr><td rowspan="3">Cross-sectional
Independence Test
H_0: Cov(u_{it}, u_{jt}) = 0</td><td>Friedman's test statistic = 41.746** Prob = 0.0261</td></tr>
<tr><td>Free's test statistic = 6.788* Prob = 0.0000</td></tr>
<tr><td>Pesaran's test statistic = 13.228 Prob = 0.5486</td></tr>
</table>

In the Random Effect model, heteroscedasticity was tested with Levene, Brown, and Forsythe's Test. The test statistics (W0, W50 and W10) were compared with the (26, 810) degrees of freedom Snedecor F table, and the H0 hypothesis of “the variances are equal", was rejected. The results indicate the existence of heteroscedasticity.

In Table 6, autocorrelation test includes DW test statistic proposed by Bhargava, Franzini and Narendranathan, and LBI test statistic suggested by Baltagi-Wu. In the random effects model, the calculated values of each test statistic are $\cong 0.1310$ and $\cong 0.315$, respectively, and are less than the critical value of 2. Therefore, the null hypothesis of “H0: No Autocorrelation” is rejected. This result implies the existence of autocorrelation in the model.

According to Cross-sectional independence test results in Table 6, The test statistics and probability values of Friedman and Pesaran are "142,333; Probe = 0.0000 and 13.228; Probe=0.0000", respectively. In both tests, the null hypothesis of "there is no Cross-sectional independence " was rejected.

Since the results of the basic assumption tests of the model revealed the existence of autocorrelation, “Feasible Generalized Least Square (FGLS)” has been performed in the model estimation as it allows heteroscedasticity, cross-section dependence and panel-specific autocorrelation. The results of the FGLS Estimation are reported in Table 7.

Table 7
FGLS Regression Estimation Results

y	Coef.	z	P>z
k	.2202689*	42.89	0.000
Ad	.0233935*	12.31	0.000
Af	.0365359*	10.14	0.000
h	.0466225*	41.35	0.000
ps	-.0160377	1.13	0.259
ss	.0692337*	9.39	0.000
ts	.3037322*	47.79	0.000
_cons	5.514203	41.70	0.000
Observation: 837 Groups : 27	Wald chi2(7) = 6575.32 Prob > chi2 = 0.0000		Estimated covariances : 378 Estimated autocorrelations: 27

* Statistically significant (p<.01)

According to the estimation results reported in Table 7, except primary school enrollment, coefficients of all the other variables are positive ($\beta > 0$) and significant ($p < 0.01$) .

a) A 1% increase in the gross fixed capital formation (k) , which is an indicator of capital, increases the national income by $\cong 0.22\%$. This result is in appropriate with all theoretical growth models.
b) A 1% increase in patent applications of residents (Ad), which is an indicator of domestic technology, increases the national income by $\cong 0.023\%$.
c) A 1% increase in the imported technology(Af), which is an indicator of foreign technology, increases the national income by $\cong 0.037\%$.

d) A 1% increase in life expectancy at birth (h), which is an indicator of health, increases national income by $\cong 0.047\%$.
e) p-value of coefficient of primary school enrolment (ps) is higher than 0.5% $(\beta_5 > 0.05)$ and therefore it is not significant.
f) A 1% increase in secondary school enrollment (ss), which is an indicator of education, increases national income by $\cong 0.069\%$.
g) A 1% increase in tertiary school enrollment (ts), which is an indicator of education, increases national income by $\cong 0.30\%$.

The impact of capital per-worker on GDP per-worker is significantly high compared to the other variables. Foreign technology has more impact on GDP per-worker compared to the domestic technology generated by residents. Health in the form of human capital has a positive impact on GPD per-work. Primary school is insignificant. However, the impact of higher education on GDP per-worker is significantly high. The impact of secondary school on GDP per-worker is positive, but significantly lower than tertiary school.

Conclusion, Discussion and Managerial Implications

Throughout history, accelerating the economic growth of countries has been the focus of scientists. Many factors are important for ensuring the economic growth and welfare level of countries. Mainly; education, health, and technology are vital drivers of economic growth. Health and education which we also consider as human capital, are positively affected by the economy. The level of technology also positively effects economic growth. With the globalizing world, high-tech products and human capital have gained importance, while the need for qualified manpower has increased. The increasing need has accelerated the developments in human capital in the forms of education and health. The progress in health, education, and technology raises the standard of living of both individuals and societies. Efficient use of labor, capital, natural resources and technology is required to increase the level of welfare. This is possible mainly through the effectiveness of human capital and technology. This is one of the driving forces that pushed us to this research. In this study, we reveal the effects of human capital in the forms of health, education, and technology in the form of foreign and domestic on economic growth.

In this context, using the data of 27 high-income OECD countries between 1990 and 2020, the effects of education and health variables, which are the components of human capital, on growth, and the effects of domestic and foreign technology, which are the components of productivity, on growth were examined. Life expectancy was used as the health variable and we separated the education variable as primary, secondary, and tertiary to examine the effects of education levels separately. A unit increase in life expectancy, which use as a health variable increases national income by 0.047%. The level of technology in the form of both domestic and foreign have positive impact on economic growth. A unit increase in foreign technology increases national income by 0.037%, and a unit increase in domestic technology increases national income by 0.023%. It is clear that foreign technology has more impact on economic growth compared to the domestic technology generated by residents in high-income OECD countries. While primary school education has no significant effect on economic growth, it was revealed that secondary school education increased growth by ≅0.069% and tertiary education increased economic growth by ≅0.30%. Accordingly, it is seen that tertiary education has a much greater effect on economic growth than the effect of physical capital (≅0.22%). It can be said that this situation reveals the importance of tertiary education in the production and spillover of technology.

Every investment in people increases the productivity of countries, first, of individuals and then of society. Increased yields turn into investments. As life expectancy increases, people prioritize long-term investments. Therefore, investing human capital in high-income OECD countries is the crucial in economic development and so the level of welfare. Then, with increasing human capital, high-tech products increase. It's a cycle. Education and health are indispensable investments. Efficiency in this investment increases the technology level of countries and provides more prosperous societies. Educated and healthy societies lead to increased economic growth.

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