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Technological Progress in the Models of Economic Growth Using Panel Data: Some New Assessments and Empirical Evidence from BRICS-T Countries

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Abstract

Considering the recent growth pattern of the digital world, this paper investigates the impact of technological progress on economic growth based on endogenous technological change models by using patent applications, mobile phone and internet users, research, and development expenditures as an independent variable to economic growth in BRICS-T countries from 2004 to 2018. Panel data set with various tests is used to provide the relationship between the dependent variable (economic growth) and independent variables for these countries.

The existence of long-run relationship between economic growth and technological variables concludes that technology usage has significant and positive impact on economic growth in the long term. And it reveals the motivation for governments to adopt specific policies by accelerating investments against the productivity paradox. Based on these empirical findings, further policy implications for economic growth and technological development are discussed.

Key words: Information, Communications Technology, R&D Expenditures, Economic Growth, panel data, BRICS-T Countries.

JEL Code: O31; C33; O14

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1. Introduction

Providing basic evidence about the performance and economic size of the nations, economic growth can be defined as the net increase of a country's production capacity over a certain time and statistically measured by the real gross domestic product. Specifically, the economic productivity based on expanding productive capacity of economy is the main factor leading to higher economic growth. Besides the basic driving forces, application of innovations and new technologies lead to the economic growth by improving the productivity (OECD, 1998:3).

In our latest world economies with the Fourth Industrial Revolution, information and communications technology (or technologies) (hereinafter referred to as «I.C.T») have become the most important driving force of the economy by creating new ways of consuming and producing goods and services in various stages of business.

Regarding the country differences, generally the technology and research development are assumed as important contributor to the economic growth especially for developing countries by achieving direct and indirect effects as illustrated as below.

Table 1. The Impact and Benefits of ICT on Economic Growth

Primary Impacts of ICT	Secondary impacts of ICT
ICT Supply Side: Support to domestic production Create extra employment Make greater fiscal revenues Correct balance of payments deficit	ICT use: Spur capital accumulation Improve firms' productivity Support a *more* open market Help improve financial inclusion Strengthen *rural economy*

Source: Andrianaivo and Kpodar, 2011: 6

According to table 1, the *effect* of ICT use on *economic growth can be* divided into two effects: 1) Direct: *the* link between changes in *technology* and productivity leads to increase in output, employment, government revenue and export 2) Indirect: technological development will increase the profit rate of firm by decreasing cost of production

In spite of all theoretical expectations, empirical evidences found on the link between ICT and growth are still inconclusive. Main controversy focusing low growth with technological development, which called as the Solow Paradox resolve the less impact of technology on economic growth by measuring growth in terms of the productivity. For example, there has been little increase in measured productivity in the U.S. economy since the mid-1970 (Isbell, 2001:253). Gordon (2014) also argue that USA has experienced low growth rate since 1970 and this change is associated with the productivity of the current technological sectors which have dropped in more recent times. Among economists including Solow (1987) view the impact of technology on productivity as insignificant in business and claims that worker productivity may diminish due to technological progress.

Some economists have also criticized that contribution of technology on economic growth has been overestimated. The idea states that "we tend to overestimate the effect of technology in the short run and underestimate the effect in the long run" known as Amara's Law (Gammack, Hobbs, & Pigott, 2011:368). According to this law, technological change may develop different from the human expectations and follow hype cycle due to the ICT crimes such as burglary, robbery, fraud in the short-run and environmental pollutions in the long run.

The BRICS is the *acronym* standing for Brazil, Russia, India, China, South Africa was created by Jim O'Neill[4]. They represent approx. 25 percent of world's GDP are significant and accepted as main locomotive blocks for the world economies. On the other hand, according to Word Bank Turkey is also very dynamic country considered as the fastest among the G20 countries due to 11 percent in 2021.

Even the BRICS plus Turkey countries have been experienced a stellar growth due to the several supporting factors such as cheap labor, abundance of natural resources and export facilities, the share of low technology and innovations on their economic growth or trade have been criticized (Radulescua et. all, 2014:609).

Table 2. High-technology exports (% of manufactured exports)

2009	14,7	9,6	9,5	31,9	5,8	2	24,3	21,2
2010	12,5	9,3	7,7	32,1	6,2	2,1	22,6	20,6
2011	11,1	8,3	7,8	30,4	6,2	2,1	20,6	18,7
2012	11,8	9	7,6	30,8	6,6	2,1	20,1	18,6
2013	11,9	10,6	8,8	31,5	6,5	3,1	20,1	18,5
2014	12,3	12	9,2	29,6	6,6	3,3	20,4	18,6
2015	14,4	15,9	8	30,4	7,4	3,4	21,3	19,4
2016	15,9	15,7	7,6	30,2	6,6	3,03	22,4	19,7
2017	14,3	12,2	7,3	30,9	5,6	3,2	19,2	20,1
2018	14,7	11,3	9	31,4	5,2	2,6	18,4	19,9
2019	14	12,8	10,2	30,7	4,8	3,02	18,6	20,2
2020	11,3	9,2	11	31,2	5,6	3,1	19,4	21,7

Source: World Bank, 2022

[4] He is former vice c*hairman* of *Goldman Sachs.*

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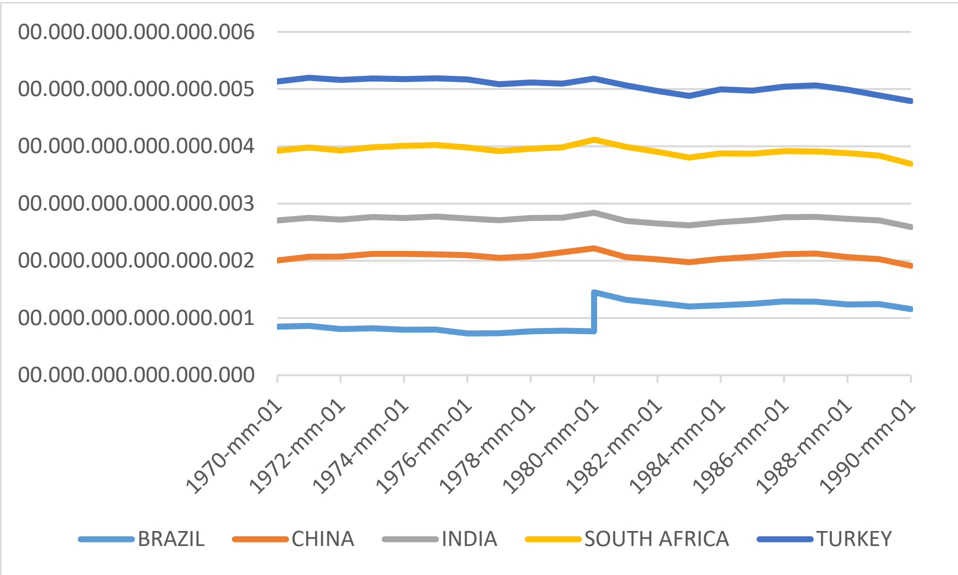
*T*he time plots for Brazil, China, India, South Africa and Turkey showing that productivity during the 1970 and 1990s does not follow the stable path while it slowed slightly in some countries during these years, increased in the others. This unstable trend has caused some criticism and raised some questions about the impact of technology on productivity and growth.

Figure 1. Total Factor Productivity at Constant National Prices[5]



Source: Retrieved 22 June, 2021, from https://fred.stlouisfed.org/series/RTFPNARUA632NRUG

For this reason, the impacts of technology on economic growth have been adrressed and analyzed by several theoritical studies. Also several growth theory models have been introduced and developed to explain the impact of technological progress on economic growth since the the begining of the classical theories. Despite previous economists' efforts, the first worth studying to analyse the impacts of technological changes on growth belongs to Schumpeter (1939). Growth can be succeeded by the competition between new and old technology according to Schumpeter. This growth process in which new innovations are replaced with old ones. Following Schumpeter studies, the basic assumption of the neoclassical growth model claims that economic growth is related to the efficient investment, through technological advances (Boianovsky, 2018:4). The technological innovations also determine the long-run economic equilibrium under the neoclassical growth model. However, technological progress is considered as exogenous factor which means that growth is determined by the factors outside of the economy (savings, technological innovations and progress, national output,

[5] Notes: not included Russia due to no value available earlier than 1990 in FED (https://fred.stlouisfed.org/series/RTFPNARUA632NRUG)

returns of capital). The latest approach known as endogenous growth models emphasizes that information and communication technologies can led to economic growth by increasing the productivity. Most popular approach among endogenous growth models is known as the AK model developed by Romer (1986) and Lucas (1988). The endogenous economic growth model considers the technological progress as endogenous variable and formulated as AK model as follows:

$$Y = K^{\alpha}(ALy)^{1-\alpha}$$

(The AK model)

where Y, K, L are output, capital stock, labor per worker, respectively. α is a constant equal to the capital share, $1-\alpha$ refers to labor share and A is TFP (Total Factor productivity per worker) in the model.

Chen and Dahlman (2004) have formulated the following production function by considering the standard endogenous model:

Y = A(g, e, r, i)
F(K, L)

where g, e, e, I define structure of the economy, level of education, level of nation's innovation, infrastructure of information and communication respectively. In this model, by including level of technology[6] (A), it is possible to succeed the persistent growth with increasing return to scale for K+L+A.

Following the growth theories and economist views on the relation on technology and economic growth, we attempted to examine the relationship between technology and growth rate of GDP in BRICS- T countries.

Based on the motivation described above, we discuss how policy makers can foster growth by examining the relations between growth and innovation in BRICS countries plus Turkey using annual data for the period 2004- 2018. This study contributes to technology-growth nexus through several ways. For the first time, it addresses this issue by using the endogenous model in line with Chen and Dahlman (2004) for BRICS-T countries. Secondly, we present a comprehensive analysis with very advanced econometric techniques by classifying BRICS-T based on their level of income. For this aim, we initially investigate panel unit root tests for determining the appropriate co-integration relationship between relevant variables by using Westerlund Durbin-Hausman test based on the endogenous model in line with Chen and Dahlman (2004). Then, panel dynamic common correlation effects mean group estimator (*CCEGM*) *model* is applied to investigate the causal link between the growth and technology variables.

The paper is organized in the following sections: section 2 reviews the literature on the relations between economic growth and ICT. In Section 3, we

[6]New idea, information, communication technologies

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describe the source of data and methodological procedures applied and results of econometric estimations in this paper. In the final section, we conclude our paper and present recommendations and some suggestions for future studies.

2. RELATED LITERATURE AND HYPOTHESES

There are many studies in the literature that examine the relationship between technological development and economic growth by using different methodologies, data sources, different periods with time series and cross-sectional data. Most empirical studies have concluded that there are positive contributions of technological development to economic growth in most countries, with exception for the middle- or low-income countries. For example, Lee et al. (2015) provided econometric *evidence* on the relationship between technology (ICT) and economic growth in many developed countries but not in developing countries.

Generally, empirical studies employing the impact of technology on economic growth ca be divided into two categories based on the methodology (Ferhadi et al., 2012:2). The first set of research studies employ the growth accounting while the second investigates this impact by applying the panel data techniques to investigate the impact of ICT on economic growth. We present a summary of empirical studies on the impact of technology on economic growth by dividing into two broad categories.

Table 3. A Summary of Empirical Studies on the Impact of ICT on Economic Growth

Reference	Countries and Periods	Methodology	Result
Jorgenson and Stiroh, 2000	The U.S., the period 1959–98 and the period of the late 1990s.	Time series, inpout output regression analysis	Technology and capital stock are main determinants of economic growth in the U.S.
Oliner and Sichel, 2000	USA, 1974-1995 and 1996-1999	Back of the envelope methods,	Impact of technological progress on economic growth is bigger in 1996 – 1999 than in 1974-1995
Özyurt,2009	China, 1952–2005	the ordinary least squares (OLS) with the Cobb–Douglas	These results are strong evidence of the existence of production

		production function	technology in Chinese economy
Michaelides et all., 2004	Russia, 1992-1999	Ordinary Least Squares (O.L.S.) with the Cobb–Douglas production function	Positive impact of the technological level on the Russian economy are found
Panel data regression techniques			
Madden and Savage, 1998	27 transitional and Central Europe Countries	Panel OLS Test	No casual relation between telecommunications infrastructure investment and economic growth
Pohjola (2000)	The 39 advanced and developing countries		No relationship between information communication technologies and growth.
Chackraborty and Banani (2003)	12 Asian countries	Panel cointegration and causility	Long run cointegration but No causality relation
Czernich et al. (2011)	1996-2007, 25 OECD countries	Panel OLS Test	Positive spillover effect of broadband impact on growth in GDP per capita.
Şen and Pehlivan (2018)	Brıcs plus Turkey, 1999-2016	Panel Cointegration and Causilty Test	Causal and long term relationships exit between techolonghy and growth.
Soomro et al. (2022)	BRICS 2000 to 2018	Panel GMM Test	The empirical estimates provides a relationship between per capita ICT and growth positively and significantly

Reviewing the selected studies in the literature, we see different opinions regarding technological development’s impact on economic growth. That brings our motivation to check empirical analysis for BRICS plus Turkey regarding the following hypothesis for research question: Technological development (broadband, mobile, R&D, innovation) has positive effect on economic growth.

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3. RESEARCH METHODS AND MATERIALS

In this study, the Cobb-Douglas production function is modified by adding the technology for BRICS_T countries covering 2004-2018 periods. Our dataset includes 6 emerging countries including Brazil, Russia, India, China, South Africa, and Turkey.

The natural logarithm of all variables is used to investigate the elasticity coefficients. In empirical modelling, GDP is denoted as LY, capital is denoted as LK, labor is denoted as LL and technology is denoted as LT. All data obtained from data base of World Bank in yearly form.

For the empirical analysis, the composite index of technology is constructed by employing principal component analysis (PCA) to measure the aggregated effect of the sub-components of technology. We employ broadband, mobile, R&D and education index variables as sub-components of technology. Including the broadband, mobile, R&D and education index into the regression models, it is possible to obtain inconsistent results because of the high correlation between the indicators[7]. At this point, the problem of multi-collinearity is solved by the application of PCA method [8]. Using these four indicators (in natural logarithms), we develop an aggregate measure (LT) to denote the technology.

To investigate the impacts of technology on production function for BRICS_T countries, we used the model specification denoted in equation (1):

$$\mathrm{LY_{it}} = \lambda_\mathrm{i} d_t + \alpha_{1\mathrm{i}}\mathrm{LK_{it}} + \alpha_{2\mathrm{i}}\mathrm{LK_{it}} + \alpha_{2\mathrm{i}}\mathrm{LT_{it}} + u_{\mathrm{it}}$$

$$u_{it} = \theta_i f_t + \varepsilon_{it}\ , \qquad \text{i=1,2,…,N and t=1,2,…T} \qquad (1)$$

where LY, LK, LL and LT denote natural logarithm of GDP, capital, labor and technology respectively, dt and ft refer the observed and unobserved common effects, and ε_{it} represents the error term.

Six methods are followed to identify the panels**.** *The methodical* approach of our paper firstly begins to check the cross-sectional dependence properties of all variables. If individuals in the panel data have the cross-section dependence problem, the analysis of all series for different countries are affected by similar important events that might cause biased problem on both unit root test and all regression estimators among individuals in the panel dataset (Kok and Munir, 2015:9). The Bias adjusted LM test introduced by Peseran et al. (2008) was used

[7] We did not share correlation matrix results for each country in order to save space. Results could be taken from authors upon interest.
[8] Principal component analysis used to reduce a large number of correlated variables to smaller numbers of uncorrelated variables. For details of PCA analyses, see Coskun et. al. (2017).

to check the problem of cross-sectional dependence among the variable each *variable* due to the greater time dimension relative to the cross-sectional dimension in the panel.

After we found cross-sectional dependence in the errors, we employed the CIPS (Pesaran, 2007) panel unit root test which is robust when cross-sectional dependency is valid. The evidence supporting the cross-sectional dependence between the variables, we employed the cross- sectional augmented panel unit root test (CIPS) developed by Peseran (2007) since it considers the presence of *cross-sectional* dependence. Later then, this paper performed second generation Durbin Hausman cointegration test formulated by Westerlund (2008) to check long -run *relationship* between variables.

The Durbin Hausman cointegration test considers the cross-sectional dependence problem and consists of two tests: panel (DHp) and group (DHg). And all consider the *null hypothesis* that *there* is *no cointegration*. Identifying the *cointegrated relationship*, *we* employed the *slope homogeneity* test developed by Swamy (1970) and improved by Pesaran and Yamagata's (2008) with large number of observations and time scope in panel data.

Finally, *we present* the *dynamic* common correlated effects mean group estimator (*dynamic CCEGM*) proposed by Pesaran and Chudik (2015) and compare long term elasticity coefficients of the Dynamic CCEGM model with CCEGM model and AMG model to provide the best accurate results related to the effects of technology on economic growth for BRICS plus Turkey.

3.1 EMPIRICAL RESULTS

To begin our empirical analysis, we first investigate cross sectional dependence properties of our data by applying the Bias Adjusted LM tests which set up null hypothesis as there is no cross-sectional relations. Results of the bias Adjusted LM tests are reported in Table 4 and reject null hypothesis at 1 percent significance level for BRICS_T countries.

Table 4. Cross Sectional Dependence Results

	Value
Bias Adjusted LM Test	132.6*

Note: * indicates 1 percent significance level. Null hypothesis shows no cross-sectional dependence.
Source: Authors' calculations

For the presence of the cross-sectional dependence problem, we employed CIPS test proposed by Peseran (2007) to check the stationarity of variables which allows the cross-sectional dependence. The results of the CIPS test show that all

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variables are stationary in the first differences[9]. Determining all variables stationary in the first level is considered as evidence of cointegration relation between variables (Hjalmarsson and Österholm, 2007). So, we performed the Durbin-Hausman test to investigate co-integration relationship between the variables by which takes the cross-sectional dependence into consideration.

The Durbin-Hausman test includes 2 tests including The Durbin-Hausman panel test (DHp) and The Durbin-Hausman group test (DHg). The null hypothesis in both tests assumes the existence of co-integration relationship between the variables.

Table 5. Westerlund Durbin-Hausman Test Results

	Value
DHg	5.801*
DHp	9.884*

Note: * indicates 1 percent significance level. Null hypothesis shows no co-integration relationship.
Source: Authors' calculations

The results from the application of The Durbin-Hausman cointegration test among the data sets strongly show rejection of the null hypothesis of no *cointegration* at the *%1* percent *significance for both* DHp and DHg tests. Evidence support the evidence of a structural long-run association between technology and economic growth for BRICS-T.

The following step is to investigate the slope homogeneity properties of our model by employing the Pesaran and Yamagata (2008) tests which also take cross section dependence into account.

Table 6. Slope Heterogeneity Test Results

	Value
$Swamy\ \hat{S}$	38.974*
$\tilde{\Delta}$	8.758*
$\tilde{\Delta}_{adj}$	10.595*
$\hat{\Delta}$	3.495*
$\hat{\Delta}_{adj}$	3.252*

Note: *indicates %1 significance level. Null hypothesis slope homogeneity
Source: Authors' calculations

[9] We did not report CIPS test results in order to save space. Results could be taken from authors upon interest.

According to Table 6, all 5 statistics reject null hypothesis of slope homogeneity. Thus, we assume that the slope is heterogeneous. This study then used Dynamic CCEGM model proposed by Pesaran and Chudik (2015) approach for panel data which allow for cross-sectional reliance and slope heterogeneity problem. The dynamic CCEMG model results are presented in Table 7.

Table 7. Dynamic CCEMG Estimator Results
(Dependent Variable: LY)

Variable	**Value**
LY(-1)	0.293**
LK	0.217*
LL	0.613*
LT	0.042*
C	1.129

Note: * and *** denotes 1 percent and 5 percent significance level
Source: Authors' calculations

According to Table 7, effect of capital, labour and technology on GDP found positive and statistically significant for BRICS_T countries. Long term coefficients is presented in Table 7.

Table 7. Long Term Coefficients from Dynamic CCEMG Model

Variable	**Value**
LK	0.306*
LL	0.867*
LT	0.059*
C	1.597

Note: * denotes 1 percent significance level
Source: Authors' calculations

In the long run, a 1% rise in capital and labour would increases economic growth by 0.306 percent and by 0.867 percent, respectively. And specifically a 1 percent rise in technology boosts economic growth by 0.059 percent emphasizing the significance of technology for economic growth for BRICS-T countries. This approach is consistent with an investigation revealed by Soomro et al. (2022) for BRICS- T economies. Our research hypothesis that technological progress spur economic growth in BRICS-T economies is confirmed by the long-run estimation.

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4. CONCLUSION

This study investigates the empirical relations between the technological progress and economic growth (GDP) based on endogenous growth model using the panel data set of "BRICS-T" for the period 2004—2018 from "World Development Indicators" (WDI) of World Bank and indicators. To reach the goal of the study, we employ various the second-generation panel data econometric methods that provide reliable results in heterogeneous data sets. Applying the CIPS and CADF unit root analysis for all stationary data at first- difference, we examined the association in the long run by utilizing Westerlund panel cointegration analysis. Evidence of cointegration analysis support the evidence of a structural long-run association between technology and economic growth for BRICS-T.

Finally, *we employed the* Dynamic CCEGM model proposed by Pesaran and Chudik (2015) approach for defining the estimator of the long-run relations in panel data. According to test results, a 1% rise in capital and labour would increases economic growth by 0.306 % and by 0.867%, respectively. And specifically, a 1% rise in technology boosts economic growth by 0.059%, emphasizing the significance of technology for economic growth for BRICS-T countries.

The empirical outcomes of this study confirm the significant positive impact of technology on economic growth with the rest of the production factors: *labour*, *capital*. This result overlaps consensus that innovations and technological developments are positively associated with economic growth. According to the United Nations Information Technology Report (2021) the ranking of the BRICS-T countries in terms of total score (ICT, skills, R&D, Industry, Finance) is as follows: China - 25th place (1 among BRICS countries), Russian Federation-27 (2), Brazil – 41 (3), India - 43 (4), South Africa - 54 (5) [8]. Unfortunately, none of BRICS-T countries rank the first ten meaning that the relationship between technology and economic growth among the BRICS countries has not satisfied the expectations and that needs to be advanced in the *world* of *futures* technology.

However, the question remains as to what governments in BRICS-T to do in the technology area. The empirical results of the study have some following policy implications. The governments in BRICS-T countries can play more active role to stimulate the direct government fund and launch some tax incentives for *research and development* (*R&D) projects*. Even specific assessments of each country are needed, they can generally allocate some investment on digital transformation of firms in business and protect effectively the intellectual property rights, and form institutional between public and the private sector. Finally, they might offer the larger broadband services, support all educational infrastructure about innovations and technology.

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