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THE DYNAMIC RELATION BETWEEN TECHNOLOGY ADOPTION, TECHNOLOGY INNOVATION, HUMAN CAPITAL AND ECONOMY: COMPARISON OF LOWER-MIDDLE-INCOME COUNTRIES

Shafaq Salam[1], Muhammad Hafeez[1, *], Muhammad Tariq Mahmood[2], Kashif Iqbal[1] and Kashifa Akbar[1]

[1]Beijing University of Posts and Telecommunications – School of Economics and Management
Beijing, People's Republic of China

[2]Federal Urdu University of Arts & Technology – Department of Commerce
Islamabad, Pakistan

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ABSTRACT

The advent of technologies has stimulated the economic growth of western countries, however, some Asian and African countries are among the Lower Middle Income Countries due to lack of technology adoption and digitally skilled human capital. The use of technologies produces digital competent human capital stock that accelerates economic growth. The prime goal of this article is to explore dynamics of technology adoption, technology innovation, human capital and skill development for Lower Middle Income Countries region over the period 2000-2016 by Generalised Method of Moments and cross sectional dependence. New technology adoption, technology innovation and human capital & skill development indices are formulated. The empirical findings indicate that human capital development & skill and investment have positive linkage with Lower Middle Income Countries economic growth while technology adoption and innovation have different linkage across the Lower Middle Income Countries regions. The panel error correction method was applied to estimate short-run dynamics and convergence rate. The fully modified ordinary least square was applied to authenticate whether the long run estimates are consistent and valid for policy implications. The findings propose policy implications for advance technology adoption and innovation with the focus on human capital development & skill and investment in Lower Middle Income Countries region.

KEYWORDS

technology innovation, technology adoption, human capital, economic growth

CLASSIFICATION

JEL: E10, E24, O32, O33

*Corresponding author, η: hafeez_86@hotmail.com; +86 13051391507;
School of Economics and Management, Beijing University of Posts and Telecommunications (BUPT),
Hadian District, 10, Xitucheng Road, Beijing, People's Republic of China

INTRODUCTION

Information era has stimulated the integration of Information and Communication Technologies (ICT) in all facets of life but more importantly in the education sector. Innovation in teaching and learning with the use of technologies results in the digital competent human capital that in turn will accelerate the economic growth of a country. Technology Achievement Index (TAI) is the scale on the basis of utilization of technology. This index was introduced by [1] in 2002. However, it is unable to measure the country's technological development. Industrial Development Scoreboard was started by [2] in 2003 in order to provide information about the industrial performance, technological advancement, use of ICT and technology imports. Industrial-cum-technological advancement (ITA) index was developed by [2] which aim to provide characteristics of a country's economy based on the role of technology and industry [2]. ITA has four indicators for measuring industrial development based on performance. These indicators are; i) contribution of manufacturing in GDP, ii) contribution of manufacturing in exports, iii) contribution of technologies in manufacturing value added (MVA), iv) contribution of technologies in export. High Technology Indicator (HTI) is comprised of national orientation, technological resources, socio-economic infrastructure and productive capacity. Among these indices, Technological Achievement Index (TAI) is based on the capability of creating and utilizing technology and not on the magnitude of technological development [1].

Human ability, capacity, skill and knowledge are required in a home country to adopt foreign technology. Unfortunately, developing countries and especially Muslim developing countries are lagging behind in the field of science, technology, research and development. Therefore, Muslim countries need to focus on capacity building in order to cope well in knowledge society. Human knowledge and skill are imperative for achieving in technological achievement. However, most of the Muslim developing countries do not meet the basic literacy level. Unfortunately, the education system of Muslim countries does not meet the challenges of information era. Therefore, these countries are required to increase their budget for education sector and take immediate necessary steps for the improvement of education system and should focus more on the pedagogy based on the use of technologies [3].

In existing literature, importance of technology adoption (TAD), technology innovation (TIN) and human capital & skill development (HCS) in economic growth has been examined extensively and provide different results in country specific and regional analysis across the globe. As Lower Middle Income Countries (LMICs) need to find the development threshold level for getting TIN, TAD and HCS fruits [4]. The human capital productivity not only depends upon its level but also the composition of skilled human capital as well as the country's position relative to the use of technologies and adapting technologies [5-7]. Endogenous economic growth had positive linkage with TIN and TAD, respectively [8, 9].

Furthermore, [10] elaborated that the stock of human capital based on knowledge skills and attitude positively impact the adoption of technologies in institutions and organizations that are already in practice in other countries. Though, results from preceding literature of single country and region cannot be generalized for LMICs and its sub-regions due to diverse features. To fill aforementioned gap, this study focuses on the development of human capital and skill development for the adoption and innovation of technologies that are necessary to reduce the Digital Divide and to compete successfully in the contemporary societies. We investigate the impact of TAD, TIN and HCS on economic growth in LMICs sub-regions.

The impact of current study to prior literature in the TAD, TIN, HCS and economic growth is elaborated as follows: First, not any of studies obviously examines the HCS importance as vital driver in enlightening the relationship among TAD, TIN and economic growth. Second, we have developed TAD, TIN and HCS indices because previous studies just incorporated one or two dimensions of TAD, TIN and HCS to investigate the association among TAD, TIN and economic growth. To our best knowledge, this is the first study to measure the effect of HCS, TAD and TIN on the economic growth for LMICs. Third, our article also enhances the existing knowledge by utilizing modern econometric methods as compared to previous studies. As the cross-sectional dependence (CD) test applies to diagnose the concern variable's cross-sectional dependence. The system Generalised Method of Moments (GMM), CD test and Fully Modified Ordinary Least Squares (FMOLS) are used computing relationship among TAD, TIN, HCS and economic growth. Panel Error Correction Method (ECM) is used to compute short run dynamics and convergence rate towards long run equilibrium from short run.

LITERATURE REVIEW

The progress in human capital is an important factor for the economic development of a country. However, human capital is not effective in the process of development unless and until the economy of a country crosses a threshold level of development [4]. Human capital is multidimensional object that constitutes of language, socio emotional skills, health and cognition. These constituents are important in capacity building and human capital development of a person. These are particularly important in developing countries where children with poverty are exposed to diseases, malnutrition, violence and unproductive environments. These factors are hampering the production function of lifelong outcomes for various dimensions of human capital. Human capital development based on health and cognition factors among young children aged between 1 to15 was studied by [11] and they argued that parental cognition and income accounts a lot for the provision of resources to children with better backgrounds. Moreover, health is important for cognitive development as most of the poor families are unable to invest at an early age of child because of poverty when investments are very important for improved health and cognitive development of a child. Parental investment in early childhood plays a significant role in the human capital development and the economic growth of a country [12].

Human capital affects the economic development by impacting total factor productivity (TFP) as higher level of human capital enhances a country's capability to adapt existing technologies or to introduce new technologies according to the demand of the country. Therefore, differences in the economic growth of various countries arise due to the differences in the level of human capital of these countries [13]. The productivity enhancing impact of human capital not only depends upon its level but also the composition of skilled human capital as well as the country's position relative to the use of technologies. Skilled human capital is important for those countries that are adapting technologies [7]. Various studies found positive results when human capital's impact is measured by literacy rate. However, this association of literacy rate and growth is more prominent in low and middle income countries but nor in rich countries [14, 15]. Similarly, [5] carried out their study in 28 provinces of China and were also of the view that levels of human capital affect the productivity rate, in turn, affecting the economic growth of the country. However, in today's economic scenario, skilled human capital is imperative for using existing technologies or innovating technologies for enhancing the economic growth of the country. Moreover, they suggested that in order to facilitate the alteration and enhancing the economic structure, China should adopt the strategy of changing the human capital structure through the promotion of tertiary education to sustain its future growth. In the information era, while dealing with the economic growth, human capital is taken as a function of education, skills and experience. However, physical and cognitive capacities of a person are also important while taking human capital as an important factor for the economic growth of a country [16]. In this regard, developing countries need to focus on the development of human capital for the uplift of their economic position [6].

Few studies also focused on the aspect that human capital is also related to organizational aptitude to bring innovation in order to sustain successfully in competitive environment. Bringing innovation in business depends upon the quality of human capital of the workforce [17]. Moreover, the government's capability to create policy measures and the surety for its effective implementation is also dependent upon the eminence of human capital within its enterprises [18]. Human capital had a positive impact on the adoption of technology while its effect on technological innovation is found insignificant in 45 Sub Saharan African countries [19].

Human capital development is allied with family and society and family plays a vital role in financing human capital development. There exists equilibrium between parental disbursement and child's future earning in relation to the building of child's human capital development and this relationship is crucial for family welfare. Positive attitudes of children with their siblings may develop educational aspiration and cooperation among siblings; hence, this will lead to the high level of human capital development. However, non-cooperative attitudes will produce opposite results. In the same way, children's interaction with their friends from other families also shapes the human capital [20].

Economic development of a country is well determined by its human capital. Various human capitals' attributes help in measuring the status of a country's stock of human capital. However various studies across the world emphasized on the school enrollment and educational attainment. School enrollment data of a country provides valuable information about its expansion, development rate and the investment in education system. In this regard, [21] collected data set of 111 countries based on the school enrollment and educational attainment aged 15-64 from 1870 to 2015. Their study reveals that there is an incredible achievement in educational accomplishment in many countries around the world and these countries experienced momentous economic development. Consequently, this economic progression is escorted by the human capital stock and technology progress combined with decreased fertility and mortality rates. This expansion resulted in transition of many countries from uneducated and low income societies combined with their structural change from agricultural to industrial countries.

Human capital stimulates Research and Development (R&D) with the use of technologies and innovative ideas resulting in the creation of new products and increased productivity. Consequently, progress in the economic growth and the innovative products bring the structural change from underdeveloped to developing and developed countries [10, 22]. Many researchers around the world have focused on the relationship between the human capital and the economic growth through the adoption and innovation of technologies [23]. The majority of existing research work has focused on the economies of developed nations with a developed institutional environment; however, this relationship remains unclear in developing countries with a less developed educational environment. The primary objective of this article is to examine the pattern and impact of human capital with respect to technology adoption and technology innovation in the economic growth of less developed countries in particular.

TECHNOLOGY INNOVATION AND ECONOMIC GROWTH

Technological innovation has brought endogenous economic growth in the small and large business activities [8, 9]. Investments in innovative technology and R&D expenditures are premises for the progress, competitiveness and sustainable economic growth [24]. A research was conducted in developed and developing countries during the period from 2005 to 2007, by [25]. Researchers concluded that technological innovation and skilled labor force has a positive impact on the companies' performance and will boost up the productivity. Implementation of new or improved process, product (goods or services), improved organizational approach or new marketing methods in workplaces or business activities is called as innovation [26]. However, policies, factors and resources of institutions determining the level of productivity are called as competitiveness. Therefore, technological innovation and enhanced competitive strategies are important for countries to sustain successfully in a highly competitive and globalized world economy [27].

TECHNOLOGY ADOPTION AND ECONOMIC GROWTH

The stock of human capital based on knowledge skills and attitude positively impact the adoption of technologies in institutions and organizations that are already in practice in other countries, henceforth, enhance the economic growth of the country [10]. Empirical studies show that technology is invented and adopted first in the countries with advanced economies and later on, it is adopted by the countries with less advanced economies. However, the fact is that all technologies adopted by advanced economies are not appropriate for less advanced economies depending upon the economic structure of these countries [28]. Human capital, R&D resources and the economic status of a country help in the adoption of appropriate technology that will help in the economic development of the country [29]. Political considerations like policy making and decisions about the allocation of capital and human resources for the adoption of technologies in institutions and companies pave the way for towards the economic growth of a country [30]. Consequently, technology adoption for advanced economies demands the educated and digital skilled workforce. Sustainable and innovative economy cannot be achieved without the adoption of technology.

HUMAN CAPITAL & SKILL DEVELOPMENT AND ECONOMIC GROWTH

Education is a vital aspect of all the facets of societies. As knowledge and skills are necessary means for the progress of an institution, organization or a country. Knowledge and skills are combined together as human capital. Investment in education sector (human capital) produces educated workforce that ultimately leads to the increased productivity and economic growth of a country. However, in the Information Era, the use of ICT in education system produces digital workforce that increase the stock of human capital resulting in the increased production and an increased foreign investment [31, 32]. An individual's knowledge, skills and experience is referred to as the human capital [33]. Human capital theory put emphasis on the attainment of knowledge (level of education) and the work experience (training on job) for technology adoption. Consequently, higher the level of education, higher will be the opportunities of bringing innovation in technology to boost up the economic growth. Stock of skilled human capital enhanced growth margins as compared to total human capital [34]. Countries with a small stock of human capital 'school education' may have slower rate of growth rather than developed countries with a large stock of human capital 'tertiary education' [35].

MATERIAL AND METHODS

DATA SOURCE

The current article selected available panel of 48 LMICs from Africa, Asia, Europe, Latin America and South Pacific Ocean region. The study covered time span from 2000 to 2016.The considered LMICs were further categorized into five sub-panels based on respective continent; 18 countries from Africa, 20 countries from Asia, 2 countries from Europe, 5countries from Latin America, and 3 countries from South Pacific Ocean region. The sampleset of LMICs is presented in Table 1 as follows: Technology innovation, Technology adoption, Human capital and skill development, Investment, Labor force and Economic growth were taken under-consideration to explore the linkages among them. The data description and sources are reported in Table 2.

GDP per capita annual growth is taken as proxy of Economic growth. Whereas, labor force and capital are measured by log of total labor force and gross fix capital formation.

Table 1. LMICs countries.

LMICs Regions	Economies
Africa	Angola, Bolivia, Cabo Verde, Cameroon, Congo Rep., Cote d'Ivoire, Djibouti, Egypt Arab Rep., Ghana, Kenya, Lesotho, Mauritania, Morocco, Nigeria, Sudan, Swaziland, Tunisia, Zambia
Asia	Armenia, Bangladesh, Bhutan, Cambodia, India, Indonesia, Jordan, Kyrgyz Republic, Lao PDR, Mongolia, Pakistan, Philippines, Sri Lanka, Syrian Arab Republic, Tajikistan, Timor-Leste, Uzbekistan, Vietnam, West Bank and Gaza, Yemen Republic
Europe	Moldova, Ukraine
Latin America	El Salvador, Georgia, Guatemala, Honduras, Nicaragua
South Pacific	Papua New Guinea, Solomon Islands, Vanuatu

Table 2. Variables description. Source; World Development Indicators 2016 and International Telecommunication Union 2016.

Indicator name	Notation	Description	Data source
Economic growth	ECO	GDP per capita growth(% annual)	WDI
Investment	FCF	Gross fix capital formation (% of GDP)	WDI
Labor force	LF	Log of total Labor force	WDI
HCS Dimensions			
Mean years schooling	**MYS**		
Pre-Primary education	P_1	Duration (years)	WDI
Primary education	P_2	Duration (years)	WDI
Secondary education	P_3	Duration (years)	WDI
Mean school enrollment	**MSE**		
Primary enrollment	SE_1	% of gross enrollment	WDI
Secondary enrollment	SE_2	% of gross enrollment	WDI
Tertiary enrollment	SE_3	% of gross enrollment	WDI
TIN Dimensions			
Fixed-telephone	TIN_1	subscriptions per 100 inhabitants	ITU
Mobile-cellular telephone	TIN_2	subscriptions per 100 inhabitants	ITU
Fixed-broadband	TIN_3	Individuals using the Internet (%)	ITU
TAD Dimensions			
TAD new			
Internet Users	TAD_1	Individuals using the Internet (%)	ITU
High-tech exports	TAD_2	% of manufacturing exports	WDI
TAD old			
Electric power consumption	TAD_3	kWh per capita	WDI

Technology innovation, Technology adoption, Human capital and skill development indices are constructed based on relevant dimensions which are defined by International Telecommunication Union (see Table 1). Before calculating indices, it is necessary to convert all dimensions into same scale and data normalization for aggregation. The individual's indicator is normalized as follows:

$$Indicator\ index = \frac{[X_i - X_{Min}]}{[X_{Max} - X_{Min}]}. \quad (1)$$

In equation (1), X_i is Indicator Value of a Country, X_{Max} – Maximum Value of an Indicator and X_{Min} – Minimum Value of Indicator. The standard approach adopted to assign equal weights to all indicators to compute aggregate index value. The mathematical notation of indices is presented as follows:

Human capital and skill development index (HCS),

$$HCS = \frac{1}{2}[MYS + MSE], \quad (2)$$

where *MYS* is mean year schooling and *MSE* is mean school enrollment and their mathematical notations as follows:

$$MYS = \frac{1}{3}[P_1 + P_2 + P_3] = \frac{1}{n}\sum_{i=1}^{3}[P_i], \quad (3)$$

$$MSE = \frac{1}{3}[SE_1 + SE_2 + SE_3] = \frac{1}{n}\sum_{i=1}^{3}[SE_i]. \quad (4)$$

Technology Innovation index (TIN),

$$TIN = \frac{1}{3}[TIN_1 + TIN_2 + TIN_3] = \frac{1}{n}\sum_{i=1}^{3}[TIN_i]. \quad (5)$$

Technology Adoption index (TAD),

$$TAD = \frac{1}{2}[TAD_{old} + TAD_{new}]. \quad (6)$$

where

$$TAD_{new} = \frac{1}{2}[TAD_1 + TAD_2] = \frac{1}{n}\sum_{i=1}^{2}[TAD_i]. \quad (7)$$

$$TAD_{old} = [TAD_3] \quad (8)$$

MODEL SPECIFICATION

Based on the literature review, this article dedicates to empirically illustrate the dynamic relationships of panel of LMICs countries between technology innovation, technology adoption, human capital & skill and economic growth. We utilized augmented Solow growth model to explore the short run and long dynamics among under-considered variables. The mathematical form of model as follows:

$$ECO_{it} = A_i(t) \cdot FCF_{it}^{\alpha} \cdot LF_{it}^{\beta} \cdot HCS_{it}^{\gamma} \cdot TIN_{it}^{\delta} \cdot TAD_{it}^{1-\alpha-\beta-\gamma-\delta}. \quad (9)$$

By taking logarithm of (9), panel empirical model is presented as follows:

$$\ln ECO_{it} = \ln A_i(t) + \alpha_{it} \ln FCF_{it} + \beta_{it} \ln LF_{it} + \gamma_{it} \ln HCS_{it} + \delta_{it} \ln TIN_{it} + \theta_{it} \ln TAD_{it} + \varepsilon_{it}, \quad (10)$$

where $\theta = 1 - \alpha - \beta - \gamma - \delta$. In Equation (10), ECO, A(*t*), FCF and LF are economic growth, existing technology, investment and labor force, respectively. Whereas, HCS, TIN and TAD are human capital & skill, technology innovation and adoption indices subsequently, and *i* is index of a country, *t* of a time. Equation (11) is the reduced form of dynamics Generalized Method of Moments (GMM) which used to estimate short and long run dynamics of under-considered variables [7]. Panel system GMM is better estimation technique in case of small time span and larger number of cross-sections [36].

$$ECO_{it} = \varphi_{it} ECO_{it-1} + \alpha_{i1} FCF_{it} + \beta_{i2} LF_{it} + \gamma_{i3} HCS_{it} + \delta_{i4} TIN_{it} + \theta_{i5} \ln TAD_{it} + \eta_i + \phi_t + \varepsilon_{it}, \quad (11)$$

where η_i and ϕ_t show specific fixed country effects and time effect, respectively. Indices *i* and *t* indicate country (*i* =1, 2, 3, ..., 48) and time (*t* = 2007, 2008, ..., 2016), respectivelly. Finally, ε_{it} denotes the stochastic error term in *i*-th country in *t*-th time period.

SHORT RUN DYNAMICS

Error Correction Method (ECM) computes the speed of convergence/divergence from short run to long run equilibrium in case of any shock occurred in economy. Panel ECM is utilized to estimate the short run dynamics. The panel ECM mathematical equation can be written as follows:

$$\Delta(ECO_{it}) = \alpha_1 \cdot \Delta(FCF_{it}) + \alpha_2 \cdot \Delta(LF_{it}) + \alpha_3 \cdot \Delta(HCS_{it}) + \alpha_4 \cdot TIN_{it} + \alpha_5 \cdot TAD_{it} + \lambda \cdot ECM_{it-1} + \varepsilon_{it}. \quad (12)$$

In equation (12), $\alpha_{1, 2, 3, 4, 5}$ are estimated parameters, while λ is speed of adjustment from short run to long run equilibrium in presence of any shock occurrence in economy.

ECONOMETRIC STRATEGY

The current article can be divided into five parts with respective of empirical analysis. First part elaborated the geometrical mean and descriptive statistics while cross-sectional dependence and panel unit root by panel fix effects regression model to explore dependence nature of countries and panel unit root among considered variables. Third part explained the short run dynamics while fourth part elaborate the long run dynamics by using GMM and Fully Modified Ordinary Least Square (FMOLS) [37, 38]. GMM is an efficient estimation approach to counter the endogeneity, and cross-section's specific effect issues [38, 39]. It also a better econometric method in case of small number of cross-section as compared to time span [38, 39].

EMPIRICAL RESULTS AND DISCUSSION

GEOMETRICAL MEAN AND DESCRIPTIVE STATISTICS

Figure 1. depicts the mean of ECO, FCF and LF divided by region of LMICs. The European and Asian countries are leader in economic growth and labor force as compared to all other LMICs. Whereas, Asia is ranked one as compared to other LMICs in investment as per percentage of GDP. Patterns of HCS, TIN and TAD are illustrated in Figure 2. Europea is far ahead in HCS and TIN while other regions have almost same pace in HCS level and TIN expect South Pacific region. Latin America maintained highest technology adoption rate as compared to Asia, Africa and Europe.

Table 3 presents the descriptive statistics and correlation matrix. The Panel-A elaborates the descriptive statistics of considered variables. It is worth to be noted that the mean value of FCF is 23.11 higher than ECO and LF while HCS has highest value among HCS, TIN and TAD in case of LMICs. Correlation matrix is reported in lower part of Table 3. ECO is positively associated with FCF, LF, and HCS while TIN and TAD negatively associated with ECO.

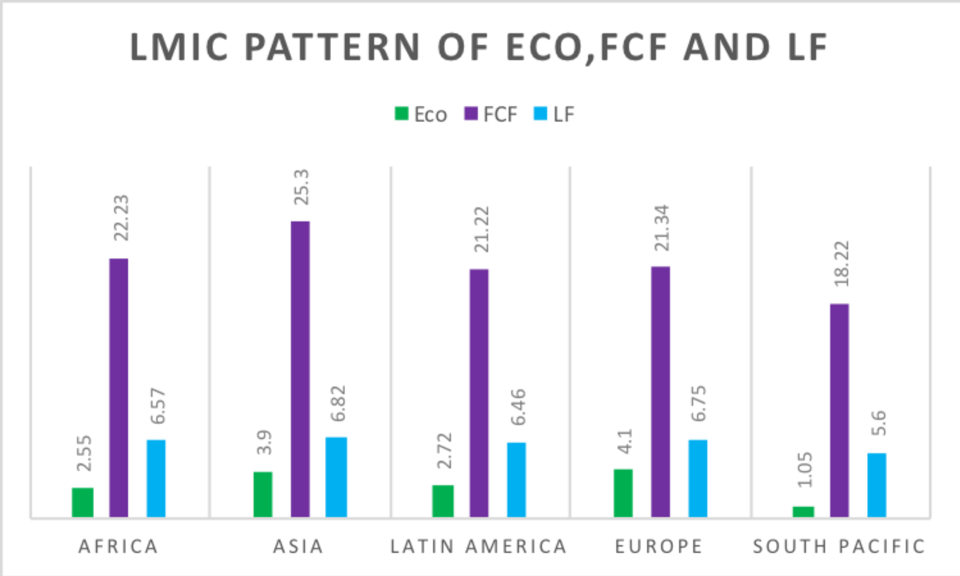

Figure 1. Mean of Eco, FCF and LF divided by region (2000-2016).

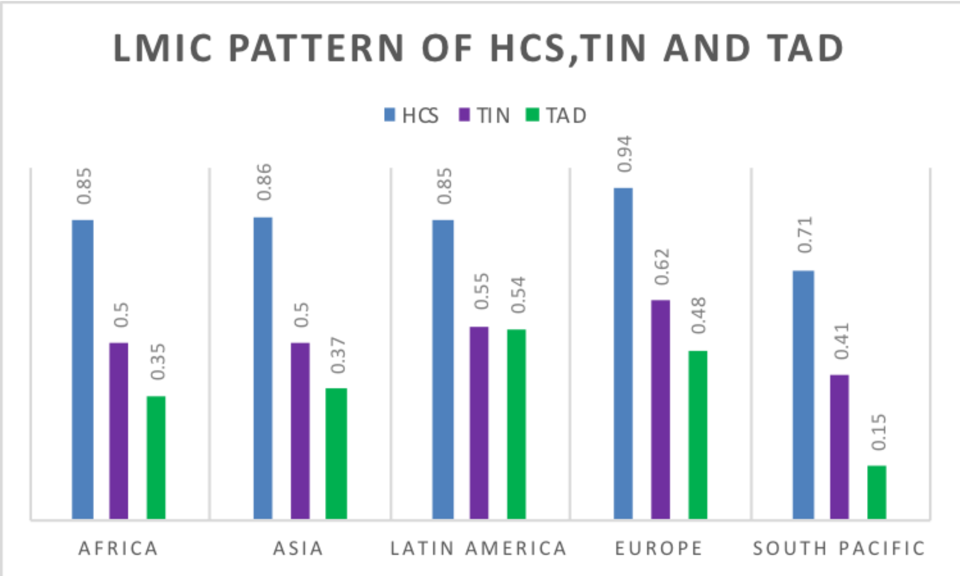

Figure 2. Mean of HCS, TIN and TAD divided by region (2000-2016). Source; (WDI, 2016) and (ITU, 2016)

Table 3. Descriptive statistics and correlation matrix, *N* = 816.

		ECO	**FCF**	**LF**	**HCS**	**TIN**	**TAD**
Panel-A: Descriptive statistics	**Mean**	3,09	23,11	6,61	0,85	0,50	0,37
	Maximum	30,35	68,02	8,70	1,00	1,00	0,97
	Minimum	–29,88	1,52	4,92	0,40	0	0
	Std. Dev	4,23	9,46	0,77	0,17	0,36	0,21
Panel-B: Correlation Matrix							
ECO		1					
FCF		0,225*	1				
LF		0,099*	–0,198*	1			
HCS		0,130*	0,096*	0,013	1		
TIN		–0,061*	0,096*	0,095*	–0,062*	1	
TAD		–0,045	–0,152*	0,478*	0,126*	0,419*	1

*shows 1 % significance level

CROSS-SECTIONAL DEPENDENCE AND UNIT ROOT TEST

Before applying the unit root test, we firstly use cross-sectional dependence (CD) test to diagnose whether the LMICs are cross-sectional dependent or not [40]. The null hypothesis of this test states that all cross-sections are independent. The CD test results are reported in Table 4. The results indicate that null hypothesis is rejected which implies the dataset of LMICs is cross-sectional dependent. Therefore, panel unit roots tests cannot be applied. The utilized panel fixed effects regression and Wald test are used to test unit root in this circumstances [38].

Table 4. Cross-sectional dependence test results.

Variable	CD-statistics	P-value	Variable	CD-statistics	P-value
ECO	21,89	0,000	HCS	48,33	0.000
FCF	4,45	0,000	TIN	133,96	0.000
LF	96,28	0,000	TAD	50,07	0.000

$$\rho_{it} = \theta \cdot \rho_{it-1} + \varepsilon_{it}. \tag{13}$$

Equation (13) depicts the basic unit root mechanism through panel fixed effects regression. ρ_{it} is function of its lag(s) ρ_{it-1}. If coefficient of first lag ($\theta = 1$) is equal to one, then its coefficient restriction hypothesis is validated which means the variable has unit root and the lag has no correlation with the normal variable [39].

Table 5 depicts the unit root tests by panel fixed effects regression and Wald test. The results show that all variables rejected the unit root hypothesis, which means the lagged dependent variables are significantly correlated with its normal variables. The Wald test significantly rejected the null hypothesis of lagged dependent variable not equal to one which implies that these variables contained a unit root process by transforming it at their first lagged.

Table 5. Unit root test results.

Unit root test by panel fixed effects regression						
	ECO	**FCF**	**LF**	**HCS**	**TIN**	**TAD**
ECO(-1)	0,460*					
FCF(-1)		0,915*				
LF(-1)			0,999*			
HCS(-1)				0,556*		
TIN(-1)					0,983*	
TAD(-1)						0,834*
Wald test	–17,26*	–5,55*	–2,33**	–12,50*	–2,35**	–9,09*

*statistically significant at 1 %

**statistically significant at 5 %

LMICs LONG RUN ESTIMATES

Long run estimates are reported in Tables 6 and 7. The graphical comparison of magnitudes of explanatory variables, is illustrated in Figure 3 regardless significance level. In full panel LMICs, a statistical significant increase of 0.10 %, 0.29 and 2.64 units in ECO due to increase 1 % in FCF and one unit increment in HCS and TAD respectively as dynamic system GMM estimates while significant decline of 3.32 %, 7.47 units in ECO due to 1 % and 1 unit increase in LF and TIN [8, 9, 27]. We also estimated FMOLS to validate impact of exogenous variables on ECO [37]. FMOLS results also similar in impact nature with different magnitudes. In FMOLS case, a statistical significant increase of 0.12 %, and 2.97 units in ECO due to increase 1 % in FCF and one unit increment in HCS respectively while significant decline of 12.17 %, and 2.18 units in ECO due to 1 % and 1 unit increase in LF and TIN

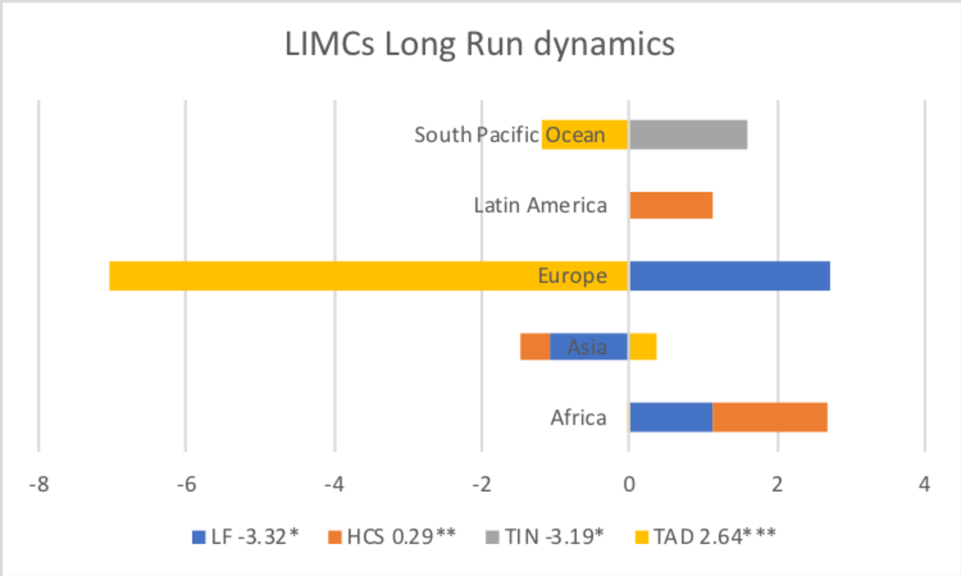

Figure 3. LMICs Long run dynamics.

Table 6. Long run estimates of some LMICs.

	Full Panel		Africa		Asia	
	GMM	FMOLS	GMM	FMOLS	GMM	FMOLS
ECO(-1)	0,21*		0,24*		0,26	
FCF	0,10*	0,12*	0,06	0,07	0,14*	0,13*
LF	–3,32*	–12,17*	1,13	13,20	–1,10	–1,82
HCS	0,29**	2,97*	1,55	4,04*	–0,38	2,89***
TIN	–3,19*	–2,18*	–2,96*	–2,00	–2,01*	–0,60**
TAD	2,64***	1,65	–0,045	–2,68	0,35	–1,08
Sargan-Hansen-J statistic	286,91*		192,15*		203,23*	
Wald statistics	52,71*		22,25*		17,62*	
Instrument rank	141		141		141	

*statistically significant at 1 %
**statistically significant at 5 %
***statistically significant at 10 %

Table 7. Long run estimates of some LMICs.

	Europe		Latin America		South Pacific Ocean	
	GMM	FMOLS	GMM	FMOLS	GMM	FMOLS
ECO(-1)	–0,20		0,18*		0,33*	
FCF	0,35***	0,09***	0,34*	0,23*	–0,01	0,19
LF	2,72	–27,08	3,04**	23,99*	0,84***	15,95*
HCS	5,94**	5,60***	1,12	0,40	1,69**	3,53***
TIN	–7,47*	–8,66*	0,78***	3,68*	1,58	–12,57
TAD	–7,03	–9,52	3,53***	1,34	–1,20	3,87
Sargan-Hansen-J statistic	34,02		120,32*		52,62*	
Wald statistics	12,62*		25,47*		15,72*	
Instrument rank	46		86		61	

*statistically significant at 1 %
**statistically significant at 5 %
***statistically significant at 10 %

respectively. Category-wise analysis indicated enhancement in ECO due to increase in HCS (Africa, Asia, Europe, and South Pacific Ocean), TIN and TAD (Latin America), FCF (Asia and Europe), LF (Latin America and South Pacific Ocean). Sub-panel also explored the reduction in ECO due increase in TIN (Europe), TAD (Asia).

Technology innovation and adoption in education system produce skilled stock of human capital that in turn accelerates the economic growth of a country. However, bringing innovation in technologies require to train the HCS already employed so as to get the positive ECO. Similarly, countries with least technology adoption have shown positive changes in ECO as these countries adopted technologies according to their HCS, FCF, TIN and TAD capacity. R&D, HCS, TIN and TAD are the accelerators of ECO; however, all technologies are not appropriate for all courtiers. Therefore, LMICs need to be specific about the TAD depending upon the HCS, LF and FCF capacities of these countries [19, 29, 30, 35].

SHORT RUN ESTIMATES OF LMICs

Table 8 elaborates short run dynamics of ECO with respect to FCF, LF, HCS, TIN and TAD in panel of LMICs, Africa, Asia, Europe, Latin America and South Pacific Ocean. The magnitudes of explanatory variables comparison is illustrated in Figure 4 regardless significance level.

In short run, FCF had positive impact on ECO in full panel, Africa while FCF had adverse impact on in Europe and Latin America. EUROPE AND Latin America are already technologically

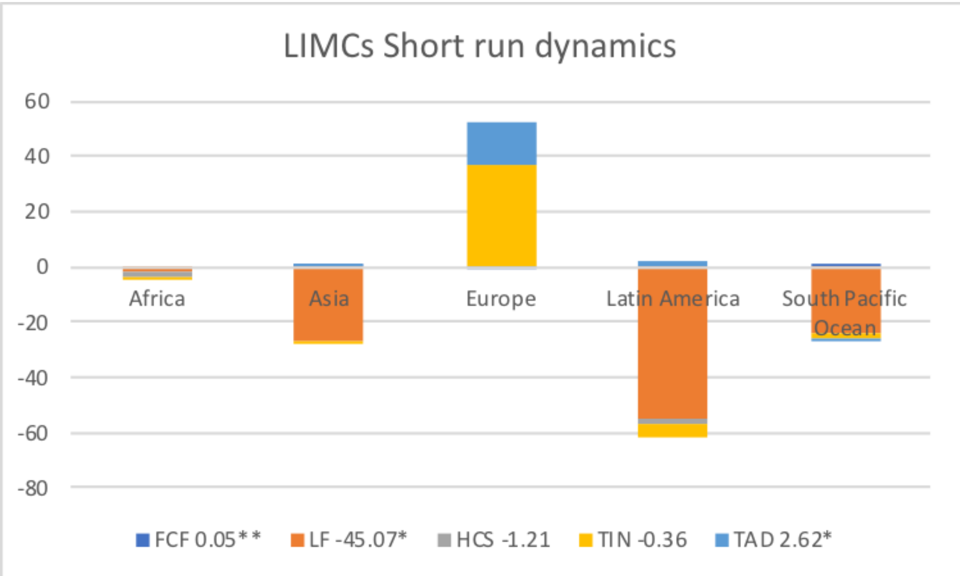

Figure 4. LMICs Short run dynamics.

Table 8. Short run estimates of LMICs.

Variable	Panel division					
	Full Panel	Africa	Asia	Europe	Latin America	South Pacific Ocean
ΔFCF	0,05**	0,10*	0,04	–0,41	–0,41*	0,049
ΔLF	–45,07*	–1,99	–27,00	–20,38**	–54,90	–23,5
ΔHCS	–1,21	–2,13	4,02*	31,40*	–2,13	10,95*
ΔTIN	–0,36	–0,78	–1,26	36,55	–4,89	–2,09
ΔTAD	2,62*	4,52*	0,057	16,01	2,00	–1,48
ECMt-1	–0,623*	–0,58*	–0,536*	–0,51*	–0,34*	–0,42***

*statistically significant at 1 %
**statistically significant at 5 %
***statistically significant at 10 %

advanced countries and are bringing innovation in technologies day by day. Therefore, FCF in full panel has negative impact. However, in countries of Africa and Asia there is ample room for improvement with respect to technology adoption, therefore these countries are showing positive results in FCF in full panel. HCS was positively significant for Asia, Europe and South Pacific Ocean which indicates a 4.02, 31.40 and 10.95 units in ECO as results of one unit increase in HCS. Asian developing countries are bringing reforms in their education system to produce stock of HCS, while African and few Latin American countries still need to work hard for the development of their education system so as to improve their HCS. There was a positively linkage in short run among TAD and ECO in case of Full Panel and Africa.

Panel ECM indicates the speed of adjustment towards long run equilibrium from short run dynamics in case of any shock in economy. Panel ECMt-1 showed 62.3 %, 58 %, 53.6 %, 51 %, 34 % and 42 % annual speed of adjustment towards long in Full Panel, Africa, Asia, Europe, Latin America and South Pacific Ocean, respectively.

CONCLUSIONS AND POLICY RECOMMENDATIONS

This article investigates the effect of TAD, TIN and HCS on economics growth in panel of 48 LMICs from Africa, Asia, Europe, Latin America and South Pacific Ocean region using time span from 2000-2016. For this, we utilize data mining technique to develop TAD, TIN and HCS indices from their all respective dimensions into single aggregate factor. We use CD test to check cross-sectional dependence among LMICs regions. The system GMM used to estimate long run estimates. Moreover, FMOLS applied to affirm the long run estimates from system GMM as robust test. In case any shock happened in economy, panel ECM is applied to estimate the speed of convergence/divergence from short run to long equilibrium.

The main empirical findings indicate that TAD, TIN and HCS are crucial drivers of economic growth. HCS and investment have positive linkage with LMICs economic growth while TAD and TIN have different linkage across the LMCs regions due to diverse features. TIN has negative impact on economic growth of Europe, Africa, and Asia, respectively. While, TAD has insignificant impact on economic growth in all regions expect Latin America.Therefore, LMICs need to be specific about the TAD depending upon the HCS, LF and FCF capacities of these countries [19, 29, 30, 35]. Panel ECMt-1 showed 62.3 %, 58 %, 53.6 %, 51 %, 34 % and 42 % annual speed of adjustment towards long in Full Panel, Africa, Asia, Europe, Latin America and South Pacific Ocean, respectively.

In the Information Era, technology innovation and adoption are imperative for countries around the world to sustain successfully in contemporary societies. Stock of digitally skilled human capital accelerates the economic growth of a country. Economically advanced countries have crossed the threshold level of development by bringing innovation in their education system. These countries allocated substantial amount of fund for education to introduce innovative teaching and learning practices by bringing technologies in their classrooms so as to produce skilled workforce. The stock of digitally advanced human capital is an asset for their economic growth. The study results indicate HCS, TIN and TAD for LMICs of Asia, Africa and South Pacific Ocean regions are negative because these countries are not technology advanced countries. Therefore, there is more number of LMICs in these regions. On the other hand, Europe and Latin America are technological advanced regions and have less number of LMICs, therefore, FCF, LF and TIN and TAD are positive [11]. LMICs of the world are lagging behind in the economic growth. There is an urgent need for these countries to take necessary steps for the reforms in their education system. Concrete policy and strategies, R&D for education reform may help in producing stock of human capital that can boost up the economic growth of these countries. LMICs may adopt technologies that are already in practice in developed countries, however, all technologies are not suitable for these countries; therefore, LMICs need to be specific in selecting appropriate technologies depending upon their need and economic structure [30]. Consequently, these LMICs would be able to reduce Digital Divide and can compete well in the Information Era. The impact of technology innovation and adoption types on economic growth, can be researchable question to dig out deeper insights for future research.

REFERENCES

[1] Desai, M.; Fukuda-Parr, S.; Johansson, C. and Sagasti, F.: *Measuring the technology achievement of nations and capacity to participate in the network age*.
Journal of Human Development **3**(1), 95-122, 2002,
http://dx.doi.org/10.1080/14649880120105399,

[2] UNIDO: *Industrial development report (2005): Capability building for catchingup*.
United Nations Industrial Development Organization, Vienna, 2005,

[3] Ali, T.M.; Kiani, A.K.; Asrar, M. and Bashir, M.: *Technology achievement index of muslim nations-Ranking and Comarative study*.
Journal of Science, Technology and Development **33**(2), 49-62, 2014,

[4] Ahsan, H. and Haque, M.E.: *Threshold effects of human capital: Schooling and economic growth*.
Economics Letters **156**, 48-52, 2017,
http://dx.doi.org/10.1016/j.econlet.2017.04.014,

[5] Li, T. and Wang, T.: *Growth channels of human capital: A Chinese panel data study*.
Journal of China Economic Review (2016 in press),

[6] Hanushek, E.A.: *Economic Growth in Developing Countries: The Role of Human Capital*.
Economics of Education Review **37**, 204-212, 2013,
http://dx.doi.org/10.1016/j.econedurev.2013.04.005,

[7] Vandenbussche, J.; Aghion, P. and Meghir, C.: *Growth, distance to frontier and composition of human capital*.
Journal of Economic Growth **11**(2), 97-127, 2006,
http://dx.doi.org/10.1007/s10887-006-9002-y,

[8] Adak, M.: *Technological Progress, Innovation and Economic Growth; the Case of Turkey*.
Procedia – Social and Behavioral Science **195**, 776-782, 2015,
http://dx.doi.org/10.1016/j.sbspro.2015.06.478,

[9] Galindo, M.-Á. and Méndez, M.T.: *Entrepreneurship, economic growth, and innovation: Are feedback effects at work*?
Journal of Business Research **67**(5), 825-829, 2014,
http://dx.doi.org/10.1016/j.jbusres.2013.11.052,

[10] Teixeira, A.A.C. and Queiros, A.S.S.: *Economic growth, human capital and structural change: A dynamic panel data analysis*.
Journal of Research Policy **45**(8), 1636-1648, 2016,
http://dx.doi.org/10.1016/j.respol.2016.04.006,

[11] Attanasio. O.; Meghir, C.; Nix, E. and Salvatei, F.: *Human capital growth and poverty: Evidence from Ethopia and Peru*.
Journal of Review of Economic Dynamics, 2017,

[12] Grantham-McGregor, S.; Cheung, Y.B.; Cueto, S.; Glewwe, P.; Richter, L. and Strupp, B.: *Developmental potential in the first 5 years for children in developing countries*.
The Lancet **369**(9555), 60-70, 2007,
http://dx.doi.org/10.1016/S0140-6736(07)60032-4,

[13] Aghion, P. and Howitt, P.: *A model of growth through creative destruction*.
Econometrica **60**(2), 323-351, 1992,
http://dx.doi.org/10.2307/2951599,

[14] Krueger, A. and Lindahl, M.: *Education for growth: Why and for whom*?
Journal of Economic Literature **39**(4), 1101-1136, 2001,
http://dx.doi.org/10.1257/jel.39.4.1101,

[15] Hanushek, E.A. and Wößmann, L.: *The Role of Education Quality for Economic Growth*. Policy Research Working Paper No. 4122. World Bank, Washington, 2007,
[16] Alexe, C.M. and Alexe, C.G.: *Human Capital Practices Drive Innovation in Roman*. Procedia Engineering **181**, 943-950, 2017, http://dx.doi.org/10.1016/j.proeng.2017.02.491,
[17] Ployhart, R.E. and Moliterno, T.P.: *Emergence of the human capital resource: a multilevel model*. Academy of Management Review **36**(1), 127-150, 2011, http://dx.doi.org/10.5465/amr.2009.0318,
[18] Amankwah-Amoah, J. and Sarpong, D.: *Historical pathways to a green economy: the evolution and scaling-up of solar PV in Ghana, 1980–2010*. Technological Forecasting and Social Change **102**, 90-101, 2016, http://dx.doi.org/10.1016/j.techfore.2015.02.017,
[19] Danquah, M. and Amoah, J.A.: *Assessing the relationships between human capital, innovation and technology adoption: Evidence from Sub-Saharan Africa*. Technological Forecasting and Social Change **122**, 24-33, 2017, http://dx.doi.org/10.1016/j.techfore.2017.04.021,
[20] Wang, Q. and Yu, X.: *Family linkages, social interactions and investment in human capital: A theoretical analysis*. Journal of Comparative Economics **45**(2), 271-286, 2017, http://dx.doi.org/10.1016/j.jce.2016.09.002,
[21] Lee, J.-W. and Lee, H.:. *Human capital in the long run*. Journal of Development Economics **122**, 147-169, 2017, http://dx.doi.org/10.1016/j.jdeveco.2016.05.006,
[22] Los, B. and Timmer, M.P.: *The 'appropriate technology' explanation of productivity differentials: an empirical approach*. Journal of Development Economy **77**(2), 515-531, 2005, http://dx.doi.org/10.1016/j.jdeveco.2004.04.001,
[23] Nelson, R.and Phelps, E.: *Investment in human, technological diffusion and economic growth*. American Economic Review: Papers and Proceedings **51**(2), 69-75, 1966,
[24] Pece, A.M.; Oros, O.E. and Salisteanu, F.: *Innovation and economic growth*. Procedia Economics and Finance **26**, 461-467, 2015, http://dx.doi.org/10.1016/S2212-5671(15)00874-6,
[25] Norris, E.D.; Kersting E. and Verdier, G.: *Firm Productivity, Innovation and Financial Development*. Working Paper WP/10/49. International Monetary Fund, pp.3-34, 2010,
[26] OECD: *Science, Technology and Industry Outlook: Science & Information Technology*. OECD, 2008,
[27] Sener, S. and Saridogan, E.: *The effects of Science-Technology-Innovation on Competitiveness and Economic Growth*. Procedia – Social and Behavioral Sciences **24**, 815-828, 2011, http://dx.doi.org/10.1016/j.sbspro.2011.09.127,
[28] Comin, D. and Hobijn, B.: *An Exploration of Technology Diffusion*. American Economic Review **100**(5), 2031-2059, 2010, http://dx.doi.org/10.1257/aer.100.5.2031,
[29] Lahiri, R. and Ratnasiri, S.: *Growth Patterns and Inequality in the Presence of Costly Technology Adoption*. Southern Economic Journal **79**(1), 203-223, 2012, http://dx.doi.org/10.4284/0038-4038-79.1.203,
[30] Lahiri, R. and Ratnasiri, S.: *Costly technology adoption, redistribution and growth*. Economic Modelling **33**, 440-449, 2013, http://dx.doi.org/10.1016/j.econmod.2013.04.038,

[31] Qadri, F.S. and Waheed, A.: *Human Capital and Economic Qrowth: Time Series Evidence from Pakistan*.
Pakistan Business Review **12**, 815-833, 2011,

[32] Qadri, F.S. and Waheed, A.:. *Human capital and economic growth: cross-country evidence from low-, middle-and high-income countries*.
Progress in Development Studies **13**(2), 89-104, 2013,
http://dx.doi.org/10.1177/1464993412466503,

[33] Schultz, T.W.: *Investment in human capital*.
American Economic Review **51**(1), 1-17, 1961,

[34] Zagler, M.: *Economic growth, structural change, and search unemployment*.
Journal of Economics **96**(1), 63-78, 2009,
http://dx.doi.org/10.1007/s00712-008-0025-z,

[35] Sunde, U. and Vischer, T.: *Human capital and growth: specification matters*.
Economica **82**(326), 368-390, 2015,
http://dx.doi.org/10.1111/ecca.12116,

[36] Arellano, M. and Bond, S.: *Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations*.
The Review of Economic Studies **58**(2), 277-297, 1991,
http://dx.doi.org/10.2307/2297968,

[37] Hafeez, M.; Chunhui, Y.; Strohmaier, D.; Ahmed, M. and Jie, L.: *Does finance affect environmental degradation: evidence from One Belt and One Road Initiative region*?
Environmental Science and Pollution Research **25**(10), 9579-9592, 2018,
http://dx.doi.org/10.1007/s11356-018-1317-7,

[38] Liu, J.; Yuan, C.; Hafeez, M. and Yuan, Q.: *The relationship between environment and logistics performance: evidence from Asian countries*.
Journal of Cleaner Production **204**, 282-291, 2018,
http://dx.doi.org/10.1016/j.jclepro.2018.08.310,

[39] Yasmeen, R.; Li, Y.; Hafeez, M. and Ahmad, H.: *The trade-environment nexus in light of governance: a global potential*.
Environmental Science and Pollution Research **25**(34), 34360-34379, 2018,
http://dx.doi.org/10.1007/s11356-018-3390-3,

[40] Hashem Pesaran, M.: *General Diagnostic Tests for Cross Section Dependence in Panels*.
Discussion Paper No. 1240. Institute for the Study of Labor, Bonn, 2004,
http://ftp.iza.org/dp1240.pdf.