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Analyzing the Mediating Role of Exports, FDI, and Eco-Efficiency in Innovation-Energy-Output Nexus

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Abstract

The development of nations depends more on innovation and energy consumption than on factor endowment. Investing more, producing more with less, and exporting surplus production assures sustained growth. This study utilizes the panel data from 2010 to 2019 from 36 developed and 80 developing countries using the structural equation modeling (SEM) approach. The study confirms the positive impact of innovation and energy consumption on foreign direct investment, exports, and output. However, the impact of innovation on output is higher in developing countries and the impact of energy consumption is higher in developed countries. The impact of energy consumption on eco-efficiency with undesirable output (EEUO) is negative. Exports of goods and services, foreign direct investment, and eco-efficiency also positively impacts the output. The study validates the new growth theory and ecological modernization theory. The study also identifies exports, investment, and eco-efficiency as mediating variables that foster the impact of innovation and energy consumption on output. The study suggests more focus on innovation, eco-efficiency, and clean energy consumption for developed and developing countries. Although developed countries are less prone to this issue, a potential environmental concern exists for sustainable growth and development.

Keywords: *Innovation; Energy consumption; Eco-efficiency with Undesirable Output; Structural Equation Modeling*

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INTRODUCTION

The concept of innovation in economic theory and growth models is not new. Pioneering literature suggests that innovation explains economic growth (Schumpeter, 1911, 1939). Later, the neoclassical model of Solow (1956), the endogenous growth models of Romer (1986, 1990), Grossman and Helpman (1991a,b), Aghion and Howitt (1992), and the semi-endogenous growth model of Jones (1995a,b) explained how innovation promotes economic growth. All the above models showed that a higher level of innovation causes an increase in per capita income.

Traditionally, labor, capital, and productivity are considered major factors that cause economies to grow (Saleem, Shahzad, Khan, & Khilji, 2019). There are some other factors as well that are integral to the growth prospectus. For example, international trade is an important channel for transferring innovative products from developed countries to developing countries (Martínez-Zarzoso & Chelala, 2021). It boosts the process of industrialization and the transformation of economies from low to lofty standards. The issue becomes more important when it comes to the knowledge that some trading nations are still in a state of misery and some countries completely ripened the benefits of international trade and followed export-led growth trajectory. This emphasizes the convergence of economies being innovative and exporting or importing and imitating.

Since traditional literature is just concerned with innovation-growth linkages and their causal relationships (Martínez-Zarzoso & Chelala, 2021). The macroeconomic literature, to the best of our knowledge, is deficient to explain the path through which innovation explains the process of economic growth. The authors find it imperious to trace the linkages between innovation, trade, eco-efficiency, and economic growth. The current study addresses the path mechanism of innovation, trade, and eco-efficiency toward economic growth. The gap in the recent empirical literature provides the authors with strong reasons to believe that it endures fundamental importance to explore how and through which channels innovation, trade, and eco-efficiency explain the process of economic growth and development apart from labor and capital.

The objective of the present study is to explore the impact of innovation and energy consumption (EC) on economic output and the possible mediating role of exports of goods and services (EGS), foreign direct investment (FDI), and eco-efficiency with desirable and undesirable (EEUO) on output. The data from 116 developed countries (DCs) and developing countries for the period of 2010-2019 have been utilized for empirical analyses. This study quantifies the direct and mediating impact of EGS, FDI, and EEUO using the structural equation modeling (SEM) approach. The current study is more novel than the previous studies in multiple ways. Firstly, it examines the direct and indirect impacts of innovations on output through the channels of eco-efficiency, exports, and FDI. Secondly, the present study examines the effects of ENC on output through the channels of exports of goods and services, eco-efficiency, and FDI. The study is a pioneering attempt to explain the innovation-growth nexus using the path-modeling framework. It explains how

other macroeconomic variables like trade, investment, and eco-efficiency foster the process of economic growth due to innovation. The study would enrich the decision-making literature for policymakers, economic planners, governments, and academicians. Furthermore, it would help in understanding the process of innovation, trade, and eco-efficiency in developed and developing countries. It would open avenues for the development of a comprehensive economic policy to exploit the innovation and economic growth process.

LITERATURE REVIEW

Sohag et al. (2015) analyzed the dynamics of energy use, technological innovation, economic growth, and trade openness in the case of Malaysia. They employed the ARDL data analysis technique and used the time series data from 1985 to 2012. Their findings suggest that technological innovation increases energy efficiency and reduces ENC. Resultantly, GDP and trade openness increase. However, Zhou and Luo (2018) claimed that higher education and technological innovation promote economic growth. The findings of Pradhan, Arvin, Bahmani, and Bennett, (2017) indicated that innovation, ICT index, economic growth, macroeconomic variables; government consumption expenditures, trade openness, FDI, and gross capital formation has a bi-directional relationship and innovation granger cause these macroeconomic variables including economic growth. In another study, Liu and Xia (2018) found that R&D investment and technological innovation are vital determinants of sustainable development.

The Ulku (2004) verified the assumption that R&D expenditures increase the level of innovation and improve the per capita GDP. Yang (2006) used the data of patents either obtained by a domestic or foreign firm in Taiwan and found that there exists a positive relationship between innovation and economic growth. He concluded that post-war economic growth was mainly due to innovation. Pece, Simona, and Salisteanu (2015) empirically investigated the links between innovation and economic growth. They estimated a positive relationship between innovation, R&D expenditures, the number of patents, and trademarks for CEE countries. Maradana et al. (2019) analyzed the data of the European Economic Area and found that innovation granger causes economic growth.

Economic growth improves the well-being of mankind and innovation impacts well-being positively (Aldieri, Bruno, & Vinci, 2019). This induces public entities to provide a conducive environment to nurture innovative activities. Particularly innovation indicators: investment in technology, R&D expenditures, patents, and trademarks ensures competitiveness and sustainable economic growth. Pradhan, Arvin, Nair, and Bennett (2020) used the data of six different innovation indicators like the number of patents, trademark applications, number of researchers, scientific and technical journal articles per thousand population, research and expenditures, and high-tech exports as a percent of GDP and constructed an index of innovation. They found that innovation positively impacts economic growth in the EU region.

Santacreu (2015) emphasized that innovation is a major source of economic growth. The author argued that, apart from total factor productivity, and endogenous growth

models, innovation adoption explains 65 percent of economic growth in developing countries and 75 percent of variations in economic growth in developed countries. Law, Sarmidi, and Goh (2020)physical capital and human capital framework, innovation is postulated to be the main driver for robust economic growth. Using time series techniques, we discover very attention-grabbing findings that highlight the impact of innovation on economic growth for Malaysia. First, the innovation measured by the quantity of a total number of a patent application is statistically insignificant. The result is robust for various innovation measurements, including total local patent application and total foreign patent application. Interestingly, switching to total patent grant instead of a total number of patent application (local or foreign analyzed the impact of innovation on economic growth using the neoclassical growth model for Malaysia. They emphasized that apart from labor, and capital, innovation is the main driver of economic growth. In a similar study conducted by Jian, Fan, Zhao, and Zhou (2021), some patents are used as a proxy for innovation. Along with business creation, innovation has a positive impact on the economic growth of 31 Chinese provinces.

Hu (2015) discussed the dynamics of economic and technological catchup effects in Singapore. He found that innovation measured by patents and R&D has a nonlinear impact. The countries, that acquire technological capabilities earlier, move to the next ladder of economic growth and development. Yu, Huarng, and Lai (2021) did a configurable analysis of innovation by qualitative comparative analysis while exploring the economic growth of OECD countries. They analyzed the subcomponents of input innovation of the global innovation index like institutions, infrastructure, human capital and research, market sophistication, and business sophistication. Empirical analysis shows that in the sample and out-sample forecasting validate the findings that innovation is positively linked with the GDP.

Energy consumption (ENC) is one of the sources of productivity growth, and an increase in living standards and causes exports to rise (Thapa-Parajuli et al., 2021). Some studies in recent empirical literature contributed to renewable and non-renewable ENC and growth relationships. For instance, a global panel of 102 economies, (Diaz, Muñoz, & Moreno, 2020) confirm that both renewable and NREC are beneficial to economic development. Extending the analysis further, examine the transmission channels of ENC to economic growth. For instance, the interaction of FDI inflows with intuitional quality in African economies significantly affects growth (Miao, Lang, Borojo, Yushi, & Zhang, 2020). There is little literature that ENC promotes economic growth through the transmission channel of exports.

Recent research focusing on the role of innovation(s) in greenhouse gas (GHGs) reduction, investment, human capital, exports of goods and services, FDI inflows, growth, and development has attracted the attention of researchers. For instance, Innovation in Environment-Related Technologies (IERTs) showed effects on environmental sustainability. Positive shocks to IERTs reduces carbon emissions but the negative shock shows opposite results (Ahmad & Zheng, 2021). Environmental innovations (EIs) help to reduce CO2 emissions It is also notable that the impact of EIs may be different across economies since less developed economies show higher levels of heterogeneity (Töbelmann & Wendler, 2020). Enhanced R&D in

clean technology innovation significantly reduces GHG emissions and positivity and significantly stimulates economic growth (Ali et al., 2021)

THEORETICAL FRAMEWORK AND HYPOTHESIS DEVELOPMENT

Theoretical Framework

Neoclassical model (Solow, 1956; Ames & Rosenberg, 1963), the endogenous growth model (Romer, 1986, 1990), the endogenous innovation growth model (Grossman, & Helpman, 1990) focused on knowledge accumulation, trade, and growth. They proposed the new growth theory in which they explained how innovation and international trade explained economic growth. They proposed that innovation and human capital are endogenous (Aghion & Howitt, 1992) and provide a connection between international trade and economic growth. Schumpeter's (1942) view is that large firms usually monopolies have an advantage over small firms and firms operating in the competitive environment in innovative activities because they can finance their R&D programs and can internalize them. These models and theories depict that innovation is an integral component of economic growth and sustainable development. However, to accelerate the augmentation process of innovation, some mediating variables are also central to it.

Developed countries increase investment in R&D and clean technology innovation. Innovation significantly reduces GHG emissions and stimulates economic growth (Ali et al., 2021). This study focuses on the concept of doing more with less i.e., environmental productivity that innovation plays a greater role in a clean environment and efficient production. Ecological Modernization theory (EM) intends to improve environmental quality through resource-efficient innovation (Jänicke, 2020).

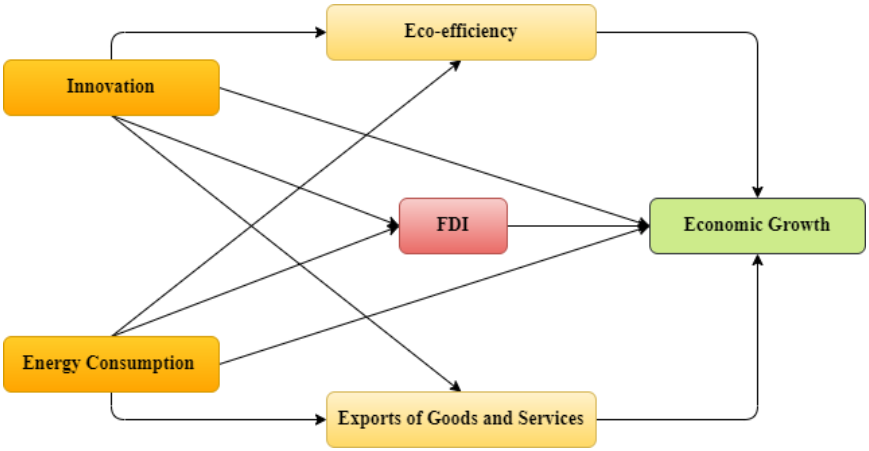

Figure 1: Proposed Model

3.2 Hypothesis Development

This section represents the hypothesis formulated to empirically verify the relationship between innovation, ENC, exports, FDI, eco-efficiency, and economic growth. Many studies (Romer, 2010; Rosenberg, 1976; Schumpeter, 1942) showed a positive relationship between innovation and economic growth. Innovation granger causes economic growth (Maradana et al., 2019).

H1: Innovation has a significant positive impact on output in developed and developing countries.

However, it is needed to testify that macroeconomic variables like FDI, Exports, and efficiency that are central to innovation may mediate the relationship. For example, Pradhan, Arvin, Bahmani, and Bennett, (2017) indicated that innovation, ICT index, economic growth, macroeconomic variables; government consumption expenditures, trade openness, FDI, and gross capital formation has a bi-directional relationship and innovation granger causes these macroeconomic variables including economic growth. The null alternative hypothesis is written as:

H2: Exports, FDI, and eco-efficiency positively mediate the innovation-output relationship.

Wan, Luo, Li, Wang, and Liang (2015) emphasized that it is the R&D and environmental investment that increases the firm value and improves eco-efficiency. This relationship strengthens the innovation-growth relationship considering eco-efficiency as a vital determinant (Safitri et al., 2019). The innovation, FDI, research and development expenditures for science and technology positively change the eco-efficiency (Wang, Wang, Lu, & Fan, 2021).

ENC is also a vital component of economic growth. Any increase in ENC leads to a higher production level of goods and services. This causes the output of countries to rise (Zeraibi, Balsalobre-Lorente, & Shehzad, 2020). ENC may explain greater variations in economic growth. The alternative hypothesis is written as:

H3: Energy consumption has a significant positive impact on output in developed and developing countries.

There is sufficient literature that ENC boosts economic development. However, there is little literature on the connection between ENC, innovation, economic growth triangle, and mediating variables. The literature suggests that there exists a feedback effect, and bidirectional causality between ENC, trade, and output in the long run (Ben Jebli & Ben Youssef, 2015). The alternative hypothesis is written as:

H4: Exports, FDI, and eco-efficiency positively mediate the ENC-output relationship.

METHODOLOGY AND DATA ISSUES

4.1 Methodology: Structural Equation Modelling (SEM)

Sustainable development is a multidimensional phenomenon as compared to economic growth and development. The development is unsustainable until accompanied by evolving innovation and eco-efficiency. Keeping in view, the determinants of output are analyzed using Structural Equation Modelling (SEM) framework. Innovation is considered a vital determinant of economic growth along with ENC as a control variable. It is the major component that explains the variations in the business cycle (Schumpeter, 1939). However, it is argued that innovation also indirectly impacts the output via channels of exports, investment, and eco-efficiency. To model this causal framework, the SEM-path model is being adopted for empirical verification of the argument.

To estimate a mediating effect, many methodologies are presented in the literature. However, in recent literature, structural equation modeling is widely used for primary as well secondary data either cross-sectional or panel data. In SEM, two approaches are widely used. One is covariance-based (CB-SEM) and the other is partial least square (PLS-SEM). The former is used to test the existing theories and relationships while later is used for an exploratory stage for theory building and prediction (Hair, Matthews, Matthews, & Sarstedt, 2017)knowing the appropriate technique can be a challenge. For example, when considering structural equation modelling (SEM. Therefore, the current study is based on the CB-SEM methodology to empirically verify the mediation effect.

Data Description and Sources

This section describes the definitions, units of measurement, and sources of data. The sample size consists of N number of countries and T number of observations (N x T). The study used the real panel data of 116 countries from the fiscal year 2010 to 2019 taking 2010 as a base year. The Global Innovation Index (GII) ranks about 140 countries on innovation performance based on 80+ indicators. The innovation index varies from 0 to 100 scale. Any value close to one hundred expresses a higher level of innovation in the economy. The eco-efficiency index is estimated by the non-oriented, non-radial Slack-Based Model (SBM) by Data Envelopment Analysis (DEA) using five indicators (Tone, 2001; Tone, 2004). The eco-efficiency varies from the value of 0 to 1. Any value close to one describes the nation's efficient frontier level. The notations adopted, units of measurement and sources of data are mentioned in Table 1.

Table 1: Descriptions of the variables

Variable's type	Variable name	Definition	Unit	Source
Dependent variable	Output (GDP)	The real value of goods and service	US Million $	WDI
Inde-pendent variables	Global Inno-vation Index (GII)	The average value of input innovation and output innova-tion index.	Index	World Intellec-tual Property Organization (INSEAD)
	Energy Con-sumption (ENC)	Primary energy consumption	Millions of tons of CO_2 equivalent	Global Carbon Project
Mediating Variables	Export of Goods and Ser-vices (EGS)	The total value of exports to the rest of the world	US Million $	WDI
	FDI	Total Foreign Di-rect Investment	US Million $	WDI
	Eco-efficiency (EEUO) with desirable and undesirable output	Value of eco-nomic output/ environmental cost	Index	Constructed with Data Envelop-ment Analysis (DEA)

EMPIRICAL ESTIMATION AND ANALYSES

The estimates of the SEM-Path model as presented in a schematic diagram shown in the theoretical section, are given in Table 2. The data is divided into two sub-samples i.e., developed countries and developing countries, and the findings are also compared with all countries' sample data. The direct effect of exports on output is significant and stronger in developing countries as compared to developed countries; however, the difference is marginal. A one percent increase in exports causes a 0.38 percent and 0.46 percent increase in output in developed and developing countries, respectively. The foreign direct effect is significant in developing countries but insignificant in developed countries. The EEUO has a greater impact on output in

developed countries as compared to developing countries. One percent increase in EEUO causes output to rise by 0.79 percent in developed countries and just a 0.18 percent increase in output in developing countries. This shows that developed countries are more efficient as compared to developing countries. One percent increase in innovation leads to a 0.19 and 0.27 percent increase in output in developed and developing countries, respectively. However, in all countries' sample data (model 1); a 1 percent increase in innovation leads to a 0.32 percent increase in output. ENC showed a significant positive impact on output in all three models. One percent increase in ENC causes output to rise by 0.69 percent in developed countries and 0.47 percent increase in developing countries.

The exogenous variables have a significant and strong positive impact on mediating variables. The first mediating variable is the export of goods and services (EGS). One percent increase in innovation causes EGS to increase 0.89 percent in all countries' sample model. The impact of innovation in developing countries is twice stronger as compared in developed countries. One percent increase in innovation leads to a 0.26 and 0.55 percent increase in EGS in developed countries and developing countries, respectively. As compared to the impact of ENC on output, the impact on EGS is higher. One percent increase in ENC increases the EGS by 0.92 percent, 0.75, and 0.91 in all countries, developed countries and developing countries, respectively.

Table 2: SEM-Path Model Direct Effect

		Model 1	Model 2	Model 3
		All Countries	Developed Countries	Developing Countries
Endogenous Variables	Independent Variables	Coefficients (Std. error)	Coefficients (Std. error)	Coefficients (Std. error)
LGDP	LEGS	0.4318***	0.3872***	0.4689***
		(0.0171)	(0.0284)	(0.0216)
	LFDI	0.0231**	0.0002	0.0247*
		(0.0110)	(0.0115)	(0.0145)
	EEUO	0.5246***	0.7910***	0.1854**
		(0.0611)	(0.0741)	(0.0859)
	LGII	0.3211***	0.1979422**	0.2734***
		(0.0406)	(0.0416)	(0.0553)
	LENC	0.5641***	0.6940***	0.4754***
		(0.0147)	(0.0202)	(0.0197)
	_cons	4.1677***	4.730446***	4.2730***
		(0.1550)	(0.2625)	(0.2122)

LEGS	LGII	0.8905***	0.2615**	0.5562***
		(0.0954)	(0.1104)	(0.1126)
	LENC	0.9227***	0.7589***	0.9186***
		(0.0170)	(0.0214)	(0.0186)
	_cons	4.6684***	8.2829***	5.5223***
		(0.3347)	(0.3993)	(0.3932)
LFDI	LGII	0.7522***	0.2004	0.4982***
		(0.1374)	(0.2253)	(0.1603)
	LENC	0.7592***	0.6610***	0.7232***
		(0.0244)	(0.0437)	(0.0265)
	_cons	2.8998***	7.5509***	3.5273***
		(0.4819)	(0.8147)	(0.5601)
EEUO	LGII	0.1510***	0.1846***	0.0155
		(0.0217)	(0.0371)	(0.0237)
	LENC	-0.0057	-0.0095	-0.0266***
		(0.0038)	(0.0072)	(0.0039)
	_cons	-0.18716**	-0.2311*	0.3915***
		(0.07638)	(0.1343)	(0.0828)

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The second mediating variable is FDI. The impact of innovation and ENC is highly significant on FDI. One percent increase in innovation causes a 0.75, 0.2, 0.49 percent increase in FDI in all countries, developed countries, and developing countries, respectively. However, the impact of eco-efficiency on FDI is almost the same in all countries i.e., 0.7 percent due to a per percent increase in EEUO. The third and last mediating variable is eco-efficiency with undesirable output. The findings are interesting. The innovation impact is significant in developed countries and insignificant in developing countries. The impact of ENC is significant in developing countries and insignificant in developed countries. However, the impact of both variables is marginal.

The exogenous variables: innovation and ENC have mediating impact on output also. The total mediating impact of innovation and ENC via export, FDI, and eco-efficiency is highly significant. One percent increase in innovation mediates output by 0.27 percent in developing countries, 0.24 percent in developed countries, and

0.48 percent in all countries' data samples. The mediating impact of ENC is higher in developing countries as compared to developed countries. One percent increase in ENC mediates the output via EGS, FDI, and EEUO by 0.44 percent in developing countries, 0.3 percent in developed countries, and 0.41 percent in all countries' data sample.

The total impact of exogenous variables on output is given in Table 3. The total impact of innovation i.e., direct, and indirect effect is 0.8023 (0.3211+0.4812). It shows that a one percent increase in innovation leads to a 0.8 percent increase in output in all countries' sample model. However, the total impact of innovation on output in developed countries is twice less as compared to all countries' sample model. Developing countries are largely affected by innovation as compared to developed countries. Again, ENC has a strong impact on output as shown by the coefficient value in all three models. One percent increase in ENC increases the output by 0.9771 percent (0.5641+0.4130), 0.9955 percent (0.6940+0.3015), and 0.9192 percent (0.4754+0.4438) in all countries, developed countries, and developing countries respectively.

Table 3: SEM-Path Model Mediating and Total Effect on LGDP

		Model 1	Model 2	Model 3
Endogenous Variable	Exogenous Variables	All Countries	Developed Countries	Developing Countries
Mediating effect	LGII	0.4812***	0.2473***	0.2703***
		(0.0513)	(0.0669)	(0.0577)
	LENC	0.4130***	0.3015***	0.4438***
		(0.0158)	(0.0226)	(0.0199)
Total effect	LGII	0.8023***	0.4452***	0.5437***
		(0.0635)	(0.0768)	(0.0786)
	LENC	0.9771***	0.9955***	0.9193***
		(0.0113)	(0.0149)	(0.0129)

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The result of the study reveals that in all three models (i) all countries, (ii) developed countries, and (iii) developing countries; innovation and energy consumption positively impact the FDI, EGS, and Output. However, the ENC negatively impacts the EEUO as suggested by the literature. All the mediating variables also showed a positive impact on the output. However, their impact slightly varies in developed and developing countries.

The equation level goodness of fit statistics R-squared and R is given in Table 4. Both statistics show considerable variation and association among variables. The

equation level goodness of fit statistics shows the higher value of the coefficient of determination and a strong degree of linear association among dependent variables and their predictors except for the equation of eco-efficiency with undesirable output.

Table 4: Equation-level goodness of fit

	Model 1		Model 2		Model 3	
	All Countries		Developed Countries		Developing Countries	
depvars	R-squared	R	R-squared	R	R-squared	R
LGDP	0.9532	0.9763	0.9316	0.9652	0.9357	0.9673
LEGS	0.7416	0.8611	0.6973	0.8350	0.7593	0.8714
LFDI	0.4846	0.6961	0.4336	0.6585	0.4921	0.7015
EEUO	0.1596	0.3996	0.1116	0.3341	0.1908	0.4369
overall	0.9119		0.8938		0.8832	

Apart from equation-level goodness of fit, the goodness of fit (overall) shows the stability, validity, and significance of all three models. The likelihood ratio chi2 and p-value show the best fit. The population error statistics like RMSEA is less than 5 percent showing the best fit (MacCallum, Browne, & Sugawara, 1996). The p-value is higher than 5 percent suggesting no more suitable and closer to this model exists among competing models. The most important statistics are CFI and TLI. In all three models, both values are close to 1 (>0.9 and 0.75) confirming the best fit (Bentler, 1990; Sivo, Xitao, Witta, & Willse, 2006). The size of residual statistics is well gauged by SRMR and CD statistics. SRMR values close to 0 represent the best fit while CD values close to 1 represent the best fit. SRMR value of all three modes is close to 0 (<0.08) and the CD value is close to 1 and hence shows the best fit (Byrne, 2013). The detailed estimates given in Table 5 show that the overall goodness of fit of all models represents the best fit of observed data.

Table 5: Goodness of fit (Overall)

	Model 1	Model 2	Model 3
	All Countries	Developed Countries	Developing Countries
Likelihood ratio			
chi2_ms(1)	2.158	1.736	1.897
p > chi2	0.142	0.188	0.163
Population error			
RMSEA	0.032	0.045	0.045
pclose	0.593	0.368	0.368

Information criteria			
AIC	12458.59	3105.99	8257.22
BIC	12590.05	3207.03	8383.71
Baseline comparison			
CFI	0.999	0.950	0.990
TLI	0.998	0.889	0.976
Size of residuals			
SRMR	0.018	0.030	0.055
CD	0.912	0.972	0.911

DISCUSSION OF RESULTS

The empirical estimates of the innovation-growth and ENC-output relationship show that both variables along with mediating variables are central to economic growth. The direct effect of exports on output is significant and stronger in developing countries as compared to developed countries; however, the difference is marginal. This shows that export-led growth is predominant both in developed and developing countries but the economic benefits for developing countries are larger (Kalaitzi & Chamberlain, 2021). FDI is a fundamental variable for strengthening the productive capacity of economies. However, the present estimates show that FDI is significantly impacting the output in developing countries (Dinh, Vo, The Vo, & Nguyen, 2019; Li & Tanna, 2019), but it does not have any significant impact in developed countries. The developed countries already reached the take-off and further investment leads to a marginal impact on growth only. The impact of EEUO is positive in developed and developing countries (Wang, Zhao, & Zhang, 2022). However, EEUO has a greater impact on output in developed countries as compared to developing countries (Barduchi, Falguera, de Oliveira Gobbo, & Mariano, 2020). This shows that developed countries are more efficient and cautious towards environmental concerns of production as compared to developing countries.

The impact of innovation on economic growth is stronger in developing countries as compared to developed countries. However, the difference is marginal. Many studies in the literature (Bitencourt et al., 2019; Maradana et al., 2019; Romer, 2010; Rosenberg, 1976) suggested a positive relationship between innovation and economic growth. The findings of this study can be generalized as the estimates are based on developed and developing countries. Pradhan, Arvin, Nair, and Bennett (2020), (Law et al., 2020), (Jian et al., 2021) also confirmed the positive relationship between innovation and economic growth. Therefore, the study findings assure the positive relationship between innovation and economic growth.

The study findings are consistent with those (Kiriyama, 2012) that emphasized that FDI allows domestic firms to acquire efficient and innovative inputs and technologies from foreign affiliates. It is evident that concluded that MNCs are involved in knowledge and technology transfer from developed to developing countries

(Wong, 2003). The study concludes the positive and significant impact of FDI and exports in all three samples (Pradhan et al., 2017). Earlier studies like (Ghanbari & Ahmadi, 2017), and (Lee, 2011) showed a positive impact of innovation on export performance. The impact of innovation on exports in developing countries is twice stronger as compared in developed countries. (Pereira, Bento, & Priede, 2013) showed that technological innovation increases exports at the country level, but the results cannot be generalized. This study generalized the findings for entire sample, developed countries and developing countries that innovation causes exports to rise.

The impact of innovation on EEUO is significant and positive in developed countries and insignificant in developing countries. This shows that developing countries and are not too innovative efficient. However, developed countries are highly efficient and a further increase in innovation leads to a higher level of EEUO. However, the findings suggest a positive impact of innovation on EEUO (Luo, Lu, Muhammad, & Yang, 2021). Many other studies reported positive results between innovation and eco-efficiency (Chen, Si, & Chen, 2020; Luo et al., 2021; Zhu, Wang, & Zhu, 2021). The innovation proxies like R&D (Safitri et al., 2019; Wan et al., 2015) have a positive impact on eco-efficiency. These findings also validate the ecological modernization theory (Jänicke, 2020) as innovation is proven as resource efficient.

ENC showed a significant positive impact on output in all three models. As compared to the impact of innovation, the impact of ENC on output is higher. This shows that ENC is also a vital component of economic growth. Any increase in ENC leads to a higher production level of goods and services. This causes the output of countries to rise (Ben Jebli & Ben Youssef, 2015; Zeraibi et al., 2020). In some studies (Bhattacharya, Paramati, Ozturk, & Bhattacharya, 2016; Shahbaz, Raghutla, Chittedi, Jiao, & Vo, 2020) only the REC-growth relationship is focused on and concluded positive relationship like our findings on total ENC (Shahbaz, Zakaria, Shahzad, & Mahalik, 2018). In a recent article; Zeraibi, Balsalobre-Lorente, and Shehzad (2020) found a connection between ENC, technological innovation, and economic growth. Their findings reveal that a 1 percent decrease in ENC decreases economic growth by 12.5 percent. One percent increase in trademarks/patents increases economic growth by 8.2 percent. This shows that ENC and innovation are significant determinants of sustainable development.

The impact of ENC is highly significant and has a positive impact on exports and FDI. A strong positive impact on ENC is observed in developing countries as compared to developed countries. The reason may be that a slight increase in ENC in developing countries significantly increases the production of goods and services and exports. The developed countries are already attained a mass level of production by the industrial revolution and a slight increase in ENC just has a marginal effect on exports of goods and services. Previous studies' findings like those (Sadorsky, 2012), (Ben Jebli & Ben Youssef, 2015), and (Katırcıoğlu, Fethi, Kalmaz, & Çağlar, 2016) are consistent with the present results however their findings were not generalizable due to limited scope.

In the developing countries sample, ENC impact on EEUO is significant and

negative but negative and insignificant in developed. The literature is deficient to explain the direct empirical causal relationship between ENC and EEUO. However, innovation improves energy efficiency and lowers the level of EC in countries (Pan, Uddin, Saima, Jiao, & Han, 2019; Tu, Hu, & Shen, 2019). With a higher level of ENC, the EEUO is lower. For the estimation of EEUO, ENC is considered as an input indicator along with labor and capital. That is why a negative relationship is expected. However, developed countries are energy efficient and an increase in ENC may have a marginal impact on eco-efficiency.

The innovation and ENC showed a strong mediating impact on output. The total mediating impact of innovation and ENC via export, FDI, and eco-efficiency is highly significant. The mediating impact of ENC is higher in developing countries as compared to developed countries. These findings suggest that ENC and innovation impact can be accelerated by exports, FDI, and EEUO meeting the goals of sustainable development (Goto & Odagiri, 2003). Concludingly, it is inferred that the mediating impact of innovation via EGS, FDI, and EEUO is higher in developing countries as compared to developed countries. Nevertheless, the total impact of ENC is higher in developed countries as compared to the total impact of innovation, which is higher in developing countries.

CONCLUSION

The study examines the impact of innovation and ENC on output. It estimates the mediating impact of exports, FDI, and eco-efficiency with desirable and undesirable output. A broad sample of data has been taken to empirically verify the innovation-growth and ENC-output relationship including the mediation impact of core variables that may mediate the relationship. The panel data of 136 countries including 36 developed countries, and 80 developing countries for the period of 2010 to 2019 have been examined. The key conclusion derived is discussed below.

The first objective of the study was to analyze the impact of innovation on output. The findings of the study suggest that innovation is a vital ingredient of economic growth as suggested in the literature. The direct impact, indirect impact, mediating impact, and total impact on innovation on economic growth are higher in developing countries as compared to developed countries. This shows that developing countries are at the initial stages of economic growth and development and a slight increase in innovation causes output to rise. In developed countries, the innovation level is already at take-off and a further increase in innovation has a marginal impact on economic growth and development.

The second objective is to examine the path mechanism if exists. The mediating variables: EGS, FDI, and EEUO are considered accelerator variables that enhance the impact of innovation on economic growth. The direct effect of mediating variables showed a strong positive and significant impact on economic growth. The mediating impact of innovation via these variables in developing countries is higher as compared to developed countries. It can be concluded that innovation is playing a greater role in the economic advancement of developing countries. The higher the level of innovation, the higher will be convergence between developed

and developing countries. This convergence is due to an increase in exports, FDI and efficiency levels in developing countries.

The third objective is to examine the impact of ENC on output. The direct impact and total impact of ENC on output are higher in developed countries as compared to developing countries. However, mediating impact of ENC on output is higher in developing countries. This shows that economies are sensitive to energy dependency. Still many countries are energy deficient to meet the productivity demand of the economy. The availability of plentiful energy resources will boost the productive capacity and convergence may take place to catch up between developed and developing countries. The fourth objective of the study is to examine the mediating role of EGS, FDI, and EEUO in the ENC-output relationship. The mediating impact of EC is higher in developing countries as compared to developed countries. This shows that EGS, FDI, and EEUO are extremely sensitive to ENC, and higher ENC increases EGS, FDI, and EEUO which in turn foster the process of economic growth.

The study findings suggest that the nations must focus on innovation activities to expand the productive capacity and production efficiency to enhance the exports of goods and services, FDI, and eco-efficiency considering the less environmental cost to economies. Furthermore, clean energy consumption may further increase green growth and sustainable development. Conventional energy consumption has an accelerating impact on exports of goods and services, and FDI. However, higher ENC causes eco-efficiency to fall. The study findings suggest that clean energy consumption may enhance the eco-efficiency level of developed and developing countries. Although developed countries are less prone to this issue, a potential environmental concern exists for sustainable growth and development.

The study findings concluded that innovation and ENC are fundamental determinants of economic growth. The export of goods and services, FDI, and eco-efficiency with desirable and undesirable output are identified as mediating variables that foster the impact of innovation and ENC on economic growth. However, the study has some limitations also. For example, the present study used the global innovation index and does not distinguish the impact of innovation input and innovation output. Secondly, the energy consumption impact may also be disaggregated into renewable energy consumption and non-renewable energy consumption for further insight.

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