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Impact of Energy Price on Technological Innovation through the channel of Human capital: The Case of Developed and Developing Economies

ABSTRACT

This Study investigated the moderating role of human capital in the relationship between energy price and technological innovation for 81 developed and developing countries from the period 1990-2019. For empirical investigation, we have employed fixed effect, random effect, and generalized method of moments (GMM). This study analyzed the conditional effect of energy price on technological innovation at different levels of human capital. According to findings, both developed and developing countries experience an increase in technological innovation when energy prices are high. The moderating role of human capital, confirms that energy price and human capital are substitutes in explaining the relationship with technological innovation. It is proposed for policy implications that financial support is required to increase technological innovation because it is an expensive investment to pursue. Furthermore, to build the absorptive capacity of the country, which in turn increases factor productivity, nations need to develop their human capital.

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Author's contribution in the article: 1- Conceived and designed the analysis, 2- Reviewed and compiled the literature, 3- Collected the data, 4- Contributed data or analysis tools, 5- Performed the analysis, 6- Wrote the paper, 7- Financial support for the conduct of the study, 8-Other

1. INTRODUCTION

The process of the invention has a crucial part in economic progress (Solow, 1956). Therefore, it is important to investigate the influencing forces that affect technological innovation at the national level. The studies on innovation in both emerging and developed countries have received a lot of interest, as more empirical efforts are being made to understand innovation. The price of energy is a key element in determining technological innovation because changes in the relative price of energy can lead to its substitution by other production components. This will promote the development of technologies that save energy. Hicks (1932) is recognized for highlighting the importance of energy prices as a driver for technological advancement.

The primary goal of this study is to examine how energy price affects technological innovation. It is also aimed at identifying other factors such as human capital that are important in determining technological innovation. Our analysis has emphasized both demand-side and supply-side factors of technological innovation. On one hand, demand-side factors encourage technological innovation by raising the value of new innovative activities. According to demand-pull theories of innovation, Hicks (1932) claimed that increasing energy prices cause the development of more energy-saving technologies. Therefore, suitable energy prices are essential to promote technological innovation. On the other hand, supply-side factors primarily examine how the availability of existing knowledge would affect the direction and rate of technological advancement. The existing knowledge stock has been taken into consideration while determining the direction of technological innovation, despite being overlooked by literature on the induce innovation hypothesis.

The results of technological advancement are measured by patent counts. These are considered useful pieces of information about the innovation's nature (Archibugi & Planta, 1996; Griliches, 1990; He et al., 2018; Lam et al., 2017; Li & Lin, 2016; Schleicha et al., 2017). As a result, the most accurate measure of technological innovation patents is also used as a proxy variable for technological innovation (Wang et al., 2012). There are a lot of innovations, but only a small number of them are significant enough to merit patenting (Johnstone et al., 2009). Using patent counts as a proxy for technological innovation has two additional benefits. First, patent counts are linked to technological innovation and can be divided into different technological fields. Second, information on the number of patents is easily available (Cohen et al., 2017; Lindman & Söderholm, 2016). Thus, the total number of patents is a reliable indicator of technological innovation.

The findings of previous literature on the link between energy price and technological innovation are still up for debate. Some findings indicate that energy price has a substantial positive impact on the level of technological innovation (Kim, 2014; Kumar & Managi, 2009; Lin & Chen, 2019). Fewer studies, on the other hand, showed a conflicting or nonexistent association between energy prices and technological advancement (Holladay et al., 2019; Mulder et al., 2014; Nie & Yang, 2016). This suggests that it is essentially an empirical question to determine how energy prices affect innovation. As a result, there is a need to investigate whether rising energy prices promote or deter technological innovation. This leads us to look into the link between energy prices and technological advancement while taking into account the importance of human capital. This is because highly educated people can adopt new technologies more quickly and effectively (Blundell et al., 1999). Additionally, they are best prepared to recognize and take advantage of emerging technological opportunities and to enhance a company's capacity for absorption (Cohen & Levinthal, 1990; Goedhuys et al., 2014).

Following are the ways that this approach advances the literature: First, we look at the demand and supply factors that influence technological innovation. From the perspective of the demand side, we have included energy prices. From the supply side, we have added how the existing technological knowledge affects future technological innovation. Second, we empirically explore the interactive role of human capital in the relation between the price of energy and technological innovation. Third, unlike most other studies which focused on specific firms, industries, or countries we employed data that includes a large number of countries. This analysis provides a clear demonstration of the effect of energy prices on technological innovation across a wide range of developed and developing countries.

The paper is organized into four parts. Part, one includes a review of the literature, the second part is discussed as theoretical framework, and the third section includes techniques and data sources. The results, conclusion, and findings are discussed in the final section.

2. LITERATURE SURVEY

2.1 Energy Price and Technological Innovation

To empirically look into the link between energy prices and technological innovation, the theory of induced innovation hypothesis is mostly used in the literature (Popp, 2002). The idea of "induce innovation" is a key hypothesis that explains how energy prices influence the technological innovation of firms. With the increase in energy prices, energy-related businesses and firms are motivated to develop and move to new energy technologies which help reduce the production cost and save extra energy when energy prices are high (Ikenberry, 1986).

Popp (2002) makes use of patent data to empirically investigate the link between energy prices and energy-saving technologies. The study discovered that energy price significantly and positively contributes to technological innovation. Kumar & Managi (2009) determine the change in technological innovation because of the change in oil price and confirms that oil-price induce technological innovation when the oil prices are high for a long time. Gasoline prices have a strong beneficial impact on patents (Kim, 2014). Lin and Chen (2019) conclude that an increase in electricity price has a favorable effect on patenting in the long run. Some scholars, on the other hand also hold the opposite viewpoint. For example, Nie and Yang (2016) determines that higher the level of energy price leads to deter firms' productivity. According to Holladay et al. (2019), subsidies related to energy and price have no substantial impact on individual decisions to invest in new energy technology. Mulder et al. (2014) looked at the example of OECD countries and indicate that energy price has a limited effect in explaining changes in energy productivity. The literature makes it quite evident that establishing a relationship between energy prices and technological innovation is an empirical issue.

Nicolli and Vona (2016) studied the factors that influenced the development of renewable energy in EU nations. They found that the advancement of solar power technology and renewable energy sources was positively impacted by rising electricity prices. Nunes and Catalão-Lopes (2020) discovered that the price of oil had a considerable beneficial influence on patent counts for alternative energy. These results are consistent with (Cheon & Urpelainen, 2012; Verdolini & Galeotti, 2011). Noailly and Smeets (2015) analyze firm-level data on patents and determine how knowledge, market size, and energy prices influence the level of technologies at a micro level. Moreover, Kruse and Wetzel (2016) used data from 26 OECD nations and discovered that rising energy prices had a substantial positive impact on innovative activities. In addition, increasing electricity price will signal a higher profit in the future, which will drive innovation of renewable energy technologies (Schleicha et al., 2017).

Technological advances play an important role in solving environment-related issues and energy policies. The use of energy (or carbon) taxation is frequently mentioned in literature as a means of minimizing greenhouse gas emissions. However, technological advancement is included as an exogenous variable in the majority of the environmental policy models. The relationship between energy pricing and innovation that leads to energy savings is examined in many empirical studies. Most studies employ firm-level industrial data and assess technology either in terms of outputs (e.g., the number of patents cited, granted, or filed in the field of energy-saving technological innovation) or inputs (e.g., new investment in research and development activities in energy-saving technological innovation). Rising oil prices can also support the current level of innovation (Cheon & Urpelainen, 2012).

Thus, literature confirms that energy price has a positive and substantial impact on technological innovation. According to some researchers, rising energy price will encourage the development of renewable energy technology (Johnstone et al., 2019; Nicolli & Vona, 2016; Schleicha et al., 2017). Others find that lower electricity price enhances renewable energy technologies (He et al., 2018). There is a controversy on the positive and negative impact of energy price on technological innovation. This study not only see the impact of energy price on technological innovation, but also see the moderating impact of human capital in the relationship between two variables.

2.2 Human Capital and Technological Innovation

Economic growth can be influenced directly or indirectly by human capital, especially by the development of technology. Acemoglu and Autor (2012) argue that human capital can influence technological progress through a variety of channels. First, given the required access to an educational resource, those with the greatest talents can advance technology by using their human capital. These individuals are most likely responsible for the advancement of technology. Second, individuals in general may have an impact on technology due to the externalities associated with human capital. It also modifies and strengthens the incentives to invest in new technologies. For instance, if there are few individuals with the necessary skills, likely, technology will not be profitable enough.

It has taken significantly longer for human capital to become a significant contributor to economic growth. Human capital's important contributions only emerged after the middle of the 20th century. Specifically, Becker (1964) is widely recognized as the originator of human capital theory, emphasizing that the quality of work is driven by human resources. Similarly to this, Arrow (1962) points out how experience affects technological progress. Nelson and Phelps (1966) also emphasize the significance of human capital in the implementation and adoption of new technology. Later, Schultz (1975) stated that workers with more human capital are better equipped to adapt to changes in the economic structure and new technology.

The knowledge, potential skills, and capacities that people have access to be referred to as human capital. It has been considered important for the competitive advantage of people, companies, and organizations. Gimeno et al. (1997), for instance, discovered a positive relationship between economic stress at the level of the entrepreneur, firm, and the overall level of human capital, as determined by educational attainment and work experience. At the national level, there is a connection between human capital and innovation that is based on "conversions," or the transformation of various forms of capital into resources and other forms of economic benefit. Several researchers have examined and verified this conversion process at the micro level (Gradstein & Justman, 2000). It is generally believed that those who invest more time and effort into improving their skills, acquire more education, and have more work experience are better suited to both earn high and contribute to society.

Moreover, innovation has various relationships with human capital given that it is a knowledge-intensive activity. According to Black and Lynch (1996), increasing organizational productivity means investing in human capital through formal education and on-the-job training. Similarly to this, Cannon (2000) suggested that human capital promotes macroeconomic output when both physical and mental efforts are increased by individuals to support economic growth. As a result, there is a growing demand for innovative procedures and innovations to support general growth in economic activity.

3. METHODOLOGY

3.1 Data Sources

The present study investigates 81 developed and developing nations from 1990 to 2019 using a balanced panel data collection (44 developing; 37 developed). Based on previous literature, we have included many variables that are important to technological innovation. These variables were notably added to the model that we have developed. The variables described as follows: Patent counts, including residents and non-residents (TECH), energy price (EP), human capital (HC), foreign direct investment (FDI) as a percentage of GDP, imports as a percentage of GDP (IMP), manufacture value added as a percentage of GDP (MANUF) and gross domestic product at constant 2015 US$ (GDP). The data related to TECH, FDI, IMP, and MANUF has been taken from the World Bank (WDI, 2019). For energy prices, spot crude oil price data is collected from British Petroleum Statistics. Data on HC is taken from the Penn World Table 9.1. Table 1 presents the summary of variables, expected signs of the parameters, and their sources.

Table 1: Variables Description

Variables	Definition	Expected Sign	Source
Technological Innovation (TECH)	Patents counts, residents and non-residents		WDI
Energy Price (EP)	Spot crude oil price, Brent US$	+/-	BP Statistics
Human Capital (HC)	Human capital index, based on education level and educational standards.	+	PWT 10.0
Foreign Direct Investment (FDI)	Net Foreign direct investment, as a percentage of GDP	+	WDI
Gross Domestic Product (GDP)	Gross Domestic Product (constant 2015 US$)	+	WDI
IMPORTS (IMP)	Imports of goods and services (% of GDP)	+	WDI
Manufacture value added (MANUF)	Manufacture value added as a percentage of GDP	+	WDI

3.2 Methodology

3.2.1 Theoretical Framework

Hicks (1932) explained the partial theory of invention in his well-known chapter "Distribution and Economics Progress" in the theory of Wages, which, while irrelevant to the theory of distribution, nevertheless embodies the use of concepts that have so captured the economist's view that the theory of invention has achieved a certain fame of its own. Indeed, the terms "labor-saving" invention, "autonomous" invention, and "induce" invention are becoming so popular and frequent to the economist that now they are in use more frequently without interrogating the utmost theory of technological innovation on which they are based. The Hicksian explanation is based on a distinction between induced and autonomous inventions, as well as a difference between labor-saving and very labor-saving innovations.

The theory of induced innovation is frequently referred to as the demand-pull theory of innovation. It highlights the significance of the change in relative price in determining the direction and speed of technological innovation. It is stated that "a change in the currency values of the factors of production is itself a major impetus to the invention, and to the discovery of a specific kind directed to economizing the use of a fairly expensive factor." This hypothesis has important policy implications. Increased investment in research and development to look into new prospects would further affect future input use as a result of changes in input prices beyond their immediate effects on input use.

Hicks (1932) thought that changes in prices of various factors would lead to promoting technological advancement. This will further lead to the replacement of one manufacturing production technique with a different input-output ratio. As a result, it will encourage technological innovation in the use of production factors in more cost-effective ways. Binswanger (1974) introduced uncertainty in the theory of induced innovation hypothesis. He explored that the rising expected cost of one factor induces research and development activities and a decrease in the use of another factor. The major focus of the theory of induced innovation is how the direction of technological innovation is affected by changes in factor prices.

A thorough theoretical framework for the link between energy prices and technological innovation has been built by Hicks' research methodology. In general, the cost of production may rise with the increase in the price of any factor of production. Typically, businesses offer lower production costs in two ways. One approach is to employ technological innovation to make the factor of production more effective, hence minimizing the utilization of the factor that is relatively expensive. The alternative approach is to search for comparable different factors such as energy prices. An increase in the relative price of energy will encourage the business to increase energy-saving technological innovation and enhance the efficiency of conventional energy (Verdolini & Galeotti, 2011). This is because energy is an essential component of production that cannot be replaced by another component, such as stock of capital and labor (Sohag et al., 2015; Zhou & Teng, 2013). In this regard, higher energy prices will have an induced effect on energy saving and alternative energy technologies, with a stronger effect on development and environment-friendly technologies.

Although innovation is a well know determinant of economic growth, it can be difficult to understand what drives firms to innovate (Montalvo, 2006). According to Fulmer and Ployhart (2014), human capital, which includes skills, knowledge, and other abilities that can to converted into production is essential to a company's ability to innovate and organize information (Protogerou et al., 2017; Subramaniam & Youndt, 2005). People with more educational skills are more likely to have higher technical skills, increased income, and more varied spending habits. An increase in the level of energy price may provide an incentive for users for adjusting their energy consumption. With the increase in energy prices, more incentives are available to the users for managing higher energy costs. Highly educated workers might be able to adapt to new technology more rapidly and effectively (Blundell et al., 1999). They are more effective in recognizing and investigating advanced technologies, and also helpful in supporting a company's absorption capacity (Cohen & Levinthal, 1990).

3.2.2 Empirical Model

To conduct an empirical analysis of the factors influencing technological innovation, the basic functional equation of the framework is defined as follows.

$$TECH_{i,t} = f(EP_{i,t}, HC_{i,t}, FDI_{i,t}, GDP_{i,t}, IMP_{i,t}, MANUF_{i,t}) \quad (1)$$

Where in the above equation, TECH is a technological innovation which is the main dependent variable. For the independent variable, we have added energy price (EP) and human capital (HC). Following the literature, we also added some control variables, including FDI which is a foreign direct investment as a percentage of GDP, IMP is the sum of imports of goods and services as a percentage of GDP, MANUF is the manufacturing value added which is used to measure the size of the economy. Then we have added GDP which is gross domestic product 2015 US$ per capita, to see the impact of economic development on technological innovation.

$$lnTECH_{i,t} = \beta_0 + \beta_1 lnEP_{i,t} + \beta_2 lnHC_{i,t} + \beta_3 lnFDI_{i,t} + \beta_4 lnGDP_{i,t} + \beta_5 lnIMP_{i,t} + \beta_6 lnMANUF_{i,t} + \varepsilon_{i,t} \quad (2)$$

The impact of some unobservable elements on the independent variable is not taken into account by standard static panel models such as fixed and random effect models. For instance, because technological advancement is a continual process, it is influenced not just by the most recent influencing variables but also by earlier technologies. Therefore, adopting a static panel model will result in estimation error. As a result, we added the first order lag of the dependent variable to the framework and construct the dynamic panel linear regression model as follows:

$$lnTECH_{i,t} = \beta_0 + \alpha lnTECH_{i,t-1} + \beta_1 lnEP_{i,t} + \beta_2 lnHC_{i,t} + \beta_3 lnFDI_{i,t} + \beta_4 lnGDP_{i,t} + \\ +\beta_5 lnIMP_{i,t} + \beta_6 lnMANUF_{i,t} + \varepsilon_{i,t} \quad (3)$$

The interaction term (EP*HC) is incorporated into the model to advance it further. Exploring the relationship between energy pricing and technological innovation as moderated by human capital is the major purpose of establishing the interaction term.

$$lnTECH_{i,t} = \beta_0 + \alpha TECH_{i,t-1} + \beta_1 lnEP_{i,t} + \beta_2 lnHC_{i,t} + \beta_3 (lnEP_{i,t} * lnHC_{i,t}) + \beta_4 lnFDI_{i,t} + \\ \beta_5 lnGDP_{i,t} + \beta_6 lnIMP_{i,t} + \beta_7 lnMANUF_{i,t} + \varepsilon_{i,t} \quad (4)$$

where, β_0 represents constant, α refers to the coefficient of the lag term of TECH, and other variables are defined in the same manner as those in Eq (2). The parameters that need to be evaluated are represented by $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7$. i stands for regions and t for the year, the random error term is $\varepsilon_{i,t}$. The effect of human capital is captured as follows:

$$\frac{\Delta TECH}{\Delta EP} = \beta_1 + \beta_3 HC \quad (5)$$

The conditional impact of human capital on the relationship between energy prices and technological innovation is seen in Equation 5. The parameter can take on various signs, e.g. if both β_1 and β_3 have the same sign then one can interpret that HC reinforces the effect of EP on TECH, while if β_1 is positive and β_3 is negative, then HC reduces the positive effect of EP on TECH and vice versa. To remove possible heteroskedasticity all variables are in natural logarithm form. Table 2 displays the statistical analyses of each variable.

3.3 Estimation Method

We first estimate Eq. (3) and Eq. (4) by employing a fixed effect model. This approach helps in preventing the cross-sectional heteroscedasticity driven by the differences in technical development between various countries. We have performed Hausman test as the first step as systematic choice between fixed effect and random effect. The fixed effect model is better way to use the panel data set and it offers many advantages. In fixed effect approach intercept vary across terms but they keep constant over time. Since the lag term of the dependent variable is closely connected with the error term, we added it as an independent variable in Eq. (4). Lag term of each independent variable is selected as the instrumental variable and then Hansen test is carried out to verify the validity of these instrumental variables. The endogeneity of the explanatory variables in the fixed effect model could lead to estimate bias. To further estimate Eq. (3) and Eq. (4) we make use of the dynamic GMM model. Due to the characteristics associated with GMM, it is believed to be an appropriate technique for estimating dynamic panel model (Blundell & Bond, 1998). The dynamic panel data model has two distinct types: Difference-GMM (Arellano & Bond, 1991) and System-GMM. Most of these distinct models each offer advantages of their own. To reduce individual effects, the Difference-GMM applies a first-order differential process to the model and includes any potential higher-order lag terms as an instrumental variable. Comparatively to Difference-GMM, System-GMM can increase estimation efficiency and evaluate independent variable that does not change over time. An equation for systematic estimation that combines Difference-GMM and level GMM is called System-GMM, and it is more effective than Difference-GMM.

4. RESULTS

4.1 Empirical Analysis

Table 2 shows the descriptive statistics in panel (a) and includes mean value of the variables, standard deviation and its minimum and maximum values. Panel (b) shows the correlation matrix along with their significance.

Table 2: Summary Statistics and Correlation Matrix

Panel (a): Descriptive Statistics					Panel (b): Correlation matrix						
Variable	**Mean**	**Std. Dev**	**Min**	**Max**	**TECH**	**EP**	**HC**	**FDI**	**IMP**	**MANUF**	**EG**
TECH	12.393	8.421	0.696	27.69	1.000						
EP	392.0	2422.0	0.679	47398.82	-0.048**	1.000					
HC	2.696	0.634	1.039	4.351	0.116***	-0.08***	1.000				
FDI	19.234	11.378	0 .696	38.968	0.040**	0.060**	0.065*	1.000			
IMP	19.061	11.369	0.696	38.789	-0.0089	-0.06***	0.043**	0.040**	1.000		
MANUF	16.087	11.003	0.696	35.569	0.090***	0.014	0.013	0.090*	0.054**	1.000	
EG	3.173	4.252	-41.8	19.68	0.040*	0.014	0.083***	0.987**	-0.076*	0.052*	1.000

Notes: Levels of significance ***, **, * are 1, 5, & 10%.

For empirical analysis we have analyzed the linkages between energy price and technological innovation for the case of developed and developing countries. First, we present the results for 44 developing countries. Table 3 presents the empirical results on the link between energy price and the level of technological innovation. Panel (a) displays the findings of the influence of energy price on technological innovation, without considering the moderating role of human capital. These results are based on pooled ordinary least square (POLS), fixed effect (FE), random effect (RE), and system GMM and are presented in columns 1, 2, 3, and 4. On the other hand, panel (b) shows the moderating role of human capital that influence price and technology. These results including interaction terms are presented in panel (b) in columns 5, 6, 7 and 8.

Table 3 shows that the value of the lag term of the dependent variable is significantly positive for both the baseline model (eq. 3) and the interaction term model (eq. 4). This indicates that existing technologies will encourage the development of new technologies. These results are consistent with the findings of Lin and Zhu (2019). Regarding energy price, the sign of the coefficient is positive in all models indicating that rising energy prices can promote technological innovation. With higher prices, energy consumption will be costly, resulting in significant economic benefits for infrastructure using more energy-efficient and environmentally friendly technology. Companies will encourage to implement technological innovation under these circumstances (Yang et al., 2019). The observation that rising energy prices promote technological advancement in energy-saving measures is in line with the theoretical justifications for price-induced technological innovation (Hicks, 1932).

Human capital promotes firms' capacity to absorb knowledge and is favorable to the creation of new knowledge (Cohen & Levinthal, 1990). The coefficient of human capital is positive and significant in all models. These results are consistent with Dakhli and De Clercq (2004), confirms that human capital is an important driving force of technological innovation. Since, individuals with greatest educational skills use their human capital to advance technology if they have proper access to the educational resource. They are most likely responsible for the advancement of technology.

Table 3: Linkages Between Energy Price and Technological Innovation (Developing Countries)

Variables	Panel(a): Base Line Results				Panel(b): Interaction Results			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	POLS	FE	RE	Sys GMM	POLS	FE	RE	Sys GMM
Lag TECH	0.525***	0.393***	0.523***	0.397***	0.558***	0.429***	0.556***	0.418***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
EP	0.031*	0.159***	0.183	0.058*	0.207***	0.517***	0.202***	0.265***
	(0.061)	(0.001)	(0.338)	(0.088)	(0.002)	(0.000)	(0.002)	(0.002)
HC	0.426*	1.552*	0.301***	0.719**	2.00***	2.974**	1.960***	2.506***
	(0.055)	(0.059)	(0.002)	(0.049)	(0.000)	(0.017)	(0.000)	(0.003)
EP*HC	-	-	-	-	-0.240***	-0.458***	-0.241***	-0.300***
					(0.002)	(0.000)	(0.002)	(0.003)
FDI	0.095*	0.083***	0.081	0.119**	0.040	0.025*	0.034***	0.073*
	(0.067)	(0.000)	(0.122)	(0.013)	(0.431)	(0.075)	(0.000)	(0.087)
IMP	0.119***	0.078*	0.125***	0.123**	0.0798***	0.0919*	0.105***	0.139***
	(0.001)	(0.072)	(0.000)	(0.038)	(0.002)	(0.089)	(0.002)	(0.009)
GDP	-0.024	-0.025	-0.026	-0.021***	-0.004	-0.097*	-0.025***	-0.076***
	(0.607)	(0.621)	(0.582)	(0.006)	(0.102)	(0.089)	(0.003)	(0.009)
MANUF	0.0369	0.052*	0.033**	0.042	0.036	0.055*	0.034	0.0436
	(0.108)	(0.095)	(0.036)	(0.155)	(0.108)	(0.074)	(0.119)	(0.160)
Constant	0.421	31.9077*	-4.388	0.404	-0.076	4.98	-4.5913	-0.352
	(0.359)	(0.062)	(0.645)	0.584	(0.903)	(0.868)	(0.629)	(0.630)
No of Observations	1319	1319	1319	1319	1276	1276	1276	1276
No of countries	44	44	44	44	44	44	44	44
No of Instruments	-	-	-	11	-	-	-	37
F-Stat	-	45.32***	-	549.55***	-	46.55***	-	557.17***
		(0.000)		(0.000)		(0.000)		(0.000)
AR(2)	-	-	-	0.49	-	-	-	0.23
P-value				(0.622)				(0.820)
Hansen	-	-	-	5.25	-	-	-	25.39
P-value				(0.155)				(0.607)
Hausman	-	193.37***	-	-	-	148.30***	-	-
P-value		(0.000)				(0.000)		
Bruesch-Pagan	-	-	175.22***	-	-	-	210.93***	-
LM			(0.000)				(0.000)	

Note: The estimation results of pooled OLS, fixed effect, random effect, and system GMM estimation are represented by POLS, FE, RE, and Sys-GMM. Brackets surround the p-value, which is * p<0.1, ** p<0.05, and *** p<0.01. The null hypothesis is that there is no autocorrelation, and the second degree of residual autocorrelation is revealed by the AR(2) test. The purpose of the Hansen test is to determine if an instrumental variable is effective, considering that instrumental variables are valid as the null hypothesis.

Technological innovation is not only determined by factors that are directly associated with the generation of new research and development and educational experience but also by the institutional and economic structure of the country (Furman et al., 2002; Varsakelis, 2006). We have added foreign direct investment, which is an important economic element of the innovative structure of a country. The results show a strong positive and significant relationship between FDI and technological innovation. Since the entry of foreign firms is accompanied by a transfer of technology and knowledge into the host economy, FDI is an important source of access to resources and technology for some countries (Anwar & Sun, 2014). Along with FDI, import-related spillovers also play a very important role in determining technological innovation. The results confirm a positive and significant relationship between imports and technological innovation. Through import, companies can interact with foreign production technologies and production methods. With the introduction of new technologies, companies can benefit from significant technological spillovers and acquire new skills by increasing their capacity for regional innovation processes (Shang et al., 2022).

The findings also point to a strong and favorable association between innovation activity and economic growth rates. The sign of the first order coefficient of economic growth is negative and significant. This suggests that until the level of economic development reaches the turning point, the higher the level of advancement of the economy, the less favorable it is for the firm to adopt the innovation process. When the level of regional economic growth exceeds the turning point, the process of technological innovation also increases with the increase in the level of economic growth. Since then, most countries have been implementing broad economic development strategies, which involve expanding the production process by investing in a variety of factors of production to increase economic growth and reduce interest in technological innovation. However, the extended economic growth pattern is not sustainable once a country's level of economic development reaches a certain level. Under extensive economic development, enterprises will focus on technological innovation. From this point, the degree of economic development will begin to have a beneficial effect by promoting the development of innovation (Liu et al., 2020).

4.2 Conditional Analysis

We take the partial derivative of equation 4 to assess the moderating role of human capital in the link between energy price and technological innovation.

$$\frac{\partial TECH}{\partial EP} = 0.265 - 0.300HC \quad (6)$$

From equation 6 it is clear that the partial derivative β_1 and β_3 are opposite in signs. This explains why human capital and technological innovation have an inverse association with partial increases in energy prices. Results confirm that energy price and human capital are substitutes in explaining the relationship with technological innovation. In this study, conditional analysis is used to access the conditional effect of energy price on technological innovation at three different levels of percentiles of human capital. The conditional impact of human capital is displayed in Table 4 at the 25th, 50th, and 75th percentiles.

Table 4: Conditional Analysis (Developing Countries)

	POLS	FE	RE	Sys-GMM
HC at the 25th percentile	-0.250***	-0.358***	-0.257***	-0.306***
	(0.003)	(0.004)	(0.002)	(0.005)
HC at the 50th percentile	-0.355***	-0.560***	-0.0364***	-0.438***
	(0.002)	(0.001)	(0.002)	(0.004)
HC at the 75th percentile	-0.444***	-0.730***	-0.453***	-0.550***
	(0.002)	(0.001)	(0.002)	(0.000)

Notes: Levels of significance ***, **, * are 1, 5, & 10%. The 25th, 50th, and 75th percentiles are P25, P50, and P75, respectively. P-values are listed in brackets.

Regarding human capital, results show significant negative signs at low, medium, and high percentiles. Over percentiles, the coefficient's magnitude is decreasing. Overall, conditional effects findings show that energy prices have a detrimental effect on technological innovation at different levels of human capital. It might be the cause of highly educated workers not always contributing to the innovation process. Nazarov and Akhmedjonov (2012) measure that people with a university education have little or no impact on a company's capacity to announce new technologies. This is because innovation in some economies is dependent more on acquiring than developing new technologies. As a result, employers need workers with highly specialized technical skills rather than those with more general (academic) knowledge. Indeed, in the present context, higher educational institutes are not as established as those in advanced countries. They are unable to provide individuals with the abilities needed to meet the level of human capital demanded by businesses.

Table 5 describes the linkages betwene energy price and technological innovation for 37 developed coutries. Panel (a) displays the findings of the influence of energy price on technological innovation, without considering the moderating role of human capital. These results are based on POLS, FE, RE and System GMM are presented in columns 1, 2, 3, and 4. On the other hand, panel (b) shows the moderating role of human capital that influence price and technology. These results including interaction terms are presented in panel (b) in columns 5, 6, 7 and 8.

Table 5: Linkages Between Energy Price and Technological Innovation (Developed Countries)

Variables	Panel(a); Base Line Results				Panel(b); Interaction Results			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	POLS	FE	RE	Sys GMM	POLS	FE	RE	Sys GMM
Lag TECH	0.572***	0.460***	0.571***	0.452***	0.570***	0.458***	0.569***	0.448***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
EP	0.028	0.301***	0.034***	0.051*	0.345*	0.761***	0.335*	0.501*
	(0.108)	(0.000)	(0.006)	(0.087)	(0.053)	(0.002)	(0.060)	(0.074)
HC	0.438	1.535	0.580*	0.453	1.65**	3.157**	1.727**	2.234*
	(0.133)	(0.152)	(0.063)	(0.214)	(0.025)	(0.020)	(0.020)	(0.087)
EP*HC	-	-	-	-	-0.278*	-0.458**	-0.265*	-0.398*
					(0.074)	(0.049)	(0.090)	(0.091)
FDI	0.095*	0.073*	0.043	0.048***	0.029	0.025*	0.034***	0.048
	(0.067)	(0.078)	(0.241)	(0.004)	(0.417)	(0.075)	(0.000)	(0.347)
IMP	0.119***	0.065*	0.125***	-0.058	0.021***	0.074**	0.0216	-0.0734
	(0.001)	(0.069)	(0.000)	(0.905)	(0.002)	(0.041)	(0.484)	(0.999)
GDP	-0.024	0.013**	0.023	0.031	-0.021	0.0154	-0.023	0.021
	(0.607)	(0.021)	(0.408)	(0.532)	(0.453)	(0.635)	(0.421)	(0.591)
MANUF	0.0369	0.081***	0.037*	0.054**	0.0342	0.081***	0.034	0.0584*
	(0.108)	(0.001)	(0.086)	(0.038)	(0.108)	(0.001)	(0.119)	(0.070)
Constant	0.421	64.268***	13.409	1.502**	-0.216	52.47***	10.936	-0.352
	(0.359)	(0.000)	(0.166)	(0.036)	(0.792)	(0.006)	(0.264)	0.630
No of Observations	1109	1109	1109	1109	1109	1109	1109	1109
No of countries	37	37	37	37	37	37	37	37
No of Instruments	-	-	-	37	-	-	-	37
F-Stat	-	45.32***	-	549.55***	-	46.55***	-	557.17***
		(0.000)		(0.000)		(0.000)		(0.000)
AR(2)	-	-	-	-0.55	-	-	-	-0.54
P-value				(0.584)				(0.586)
Hansen	-	-	-	30.87	-	-	-	28.28
P-value				(0.372)				(0.503)
Hausman	-	146.81***	-	-	-	150.56***	-	-
P-value		(0.000)				(0.000)		
Bruesch-Pagan LM	-	-	433.22***	-	-	-	412.30***	-
			(0.000)				(0.000)	

Note: The estimation results of pooled OLS, fixed effect, random effect, and system GMM estimation are represented by POLS, FE, RE, and Syst GMM. Brackets surround the p-value, which is * p<0.1, ** p<0.05, and *** p<0.01. The null hypothesis is that there is no autocorrelation, and the second degree of residual autocorrelation is revealed by the AR(2) test. The purpose of the Hansen test is to determine if an instrumental variable is effective, considering that instrumental variables are valid as the null hypothesis.

After determining the impact of energy price on technological innovation for the case of developing countries, we have found almost similar results as for developed countries. This implies that energy price and human capital are significant determinant of technological innovation for both the developed and developing countries. We have also determined the partial derivative to assess the moderating role of human capital in the link between energy price and technological innovation.

$$\frac{\partial TECH}{\partial EP} = 0.501 - 0.398HC \qquad (7)$$

From equation 7 it is clear that the partial derivative $\beta_1$and β_3 are opposite in signs. These results like developing countries implies that energy price and human capital are substitutes in explaining the relationship with technological innovation. The conditional impact of human capital is displayed in Table 6. at the 25th, 50th, and 75th percentiles.

Table 6: Conditional Analysis (Developed Countries)

	POLS	**FE**	**RE**	**Sys GMM**
HC at the 25th percentile	-0.460*	-0.495***	-0.431***	-0.650***
	(0.092)	(0.004)	(0.002)	(0.009)
HC at the 50th percentile	-0.546*	-0.628***	-0.512***	-0.772*
	(0.089)	(0.001)	(0.002)	(0.096)
HC at the 75th percentile	-0.616*	-0.738***	-0.579***	-0.873*
	(0.087)	(0.001)	(0.002)	(0.095)

Notes: Levels of significance ***, **, * are 1, 5, & 10%. The 25th, 50th, and 75th percentiles are P25, P50, and P75, respectively. P-values are listed in brackets.

5. CONCLUSION AND POLICY RECOMMENDATIONS

This study determines the impact of energy price on technological innovation by using the data set of developed and developing countries covering the period from 1990 to 2019. Further, this study also explores moderating role of human capital in the relationship between energy price and technological innovation. This study addressed this relationship for developed and developing countries, by applying POLS, FE, RE and System GMM.

The fact that technological development speeds up economic progress cannot be ignored. This is because technological advancement has played a significant role in improved productivity. This paper uses patent data to determine the driving forces behind technological innovation. It adds to the literature on the induced innovation hypothesis by considering energy price as a significant factor of technological innovation. In addition to that, it takes into account the usefulness of existing technology and absorptive capacity. Additionally, this study aims to find out more about how human capital moderates the link between energy prices and technological innovation. The earlier studies are questioned based on controversial findings between energy prices and technological innovation. This study offers empirical support in favor of the technology-push and induces innovation hypothesis.

Following are prime conclusions: First, energy price plays a positive and significant role in boosting the level of technologies. Second, the moderating role of human capital confirms that energy price and human capital are substitutes in explaining the relationship with technological innovation. Third, our findings support the notion that the advancement of technological innovation is positively influenced by the state of current knowledge. As benefits from technological improvements cannot be exclusively claimed by innovators. The knowledge already at hand enables researchers to do so at a lower cost and with less risk than earlier inventors. Finally, our findings support the idea that countries with significant human capital might benefit from knowledge spillovers, primarily by adopting advanced technologies.

In terms of policy implication, this study implies that countries require great financial support because promoting technological innovation is an expensive investment. Investors might also view information generated outside the boundaries of the business as a viable replacement for internal innovation efforts. This study evaluated the performance of developed and developing countries. Future research, however, can clarify the relationship between energy prices, technology, and human capital by undertaking within-country analyses to determine the effects of certain national characteristics. We employed HDI, which might not be an accurate indicator of the growth of human capital. Future studies might look into a measure that may also include other aspects of human capital at the national level, such as experience, skills, attributes, and behaviors. It should be noted that the only available policy variables in this work are the price of energy and technological advancement. Yet, environmental taxes, discharge fees, total quantity controls, and other factors also have an impact on the advancement of energy technology innovation. In addition, we use the total number of patents in this study to represent the degree of technological innovation. We do not take into account the heterogeneity between various patents, despite the fact that the patent number has been shown to be a good indicator of the extent of technological innovation. As a result, there is still much to be learned and more research in these areas is required.

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