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Article

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Time-frequency Relationship between Innovation and Energy Demand in Pakistan: Evidence from Wavelet Coherence Analysis

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ABSTRACT

This study examines the empirical relationship of innovation and energy demand by wavelet transform context. This innovative technique allowed the decomposition time-series of different time-frequency domains. The continuous wavelet and the wavelet coherence power spectrum is adopted in this study. The relationship between innovation and energy is investigated by using the annual data of Pakistan, from 1997 to 2016 by using three proxies of innovation which includes research and development expenditures, high technology exports, and the number of registered patent by residents. The overall results of the wavelet coherency propose that the measures of innovation are beneficial to bring change in the demand of energy in Pakistan in the long-run period. Furthermore, the results suggested that the technology-oriented innovations have reached to the level of bringing a notable reduction in the level of energy consumption in Pakistan.

Keywords: Technology Innovation, Energy, Wavelet Coherence, Continuous Wavelet Transform
JEL Classifications: O33, K32, P18

1. INTRODUCTION

The ability of individuals to enhance, modify, organize and manage the innovative ways of the corporate process is linked to the phenomenon of entrepreneurship. Businesses nowadays rely on the advanced tools and cohesive technological efforts to upgrade their prospects of exclusivity. The level of innovation is crucial to augment the ability of entrepreneurs in excelling their long-run potentials. Similarly, entrepreneurs are said to have the capacity to identify the potentials of viable inventions having the tendency to allocate the capital, talent & resources in a way that can transform the invention into a sustainable innovation (Audretsch et al., 2002). On an aggregate level, countries with technical expertise tend to enhance the level of developments with improved business operations by redefining the conventional practices of performing business. Thus the country's level of innovation is regarded as a predecessor of advanced business practices, exceptional goals, and redefined sustainable objectives.

On the other hand, the modern world is changing the view profit-oriented approach towards the eco-friendly modes of business developments. The role of energy in this regard is crucial to address the issue of high energy dependence resulting in the negative influence on the environment. The emphasis in recent era is inclined towards achieving sustainable development by focusing on ways in which the negative effects of business and economic operations can be curtailed. The technological innovations are also linked to high levels of energy dependence. The excessive energy consumption in the process of innovation can bring negative consequences to the environment and hinder the process of sustainable development. Similarly, if the renewable resources of energy can be utilized in the process of technological advancement, it can bring positivity in the environment. Nonetheless, the major contribution of energy consumption in the process of innovation cannot be ignored.

Pakistan is among the developing nation which is included in the group of "Next Eleven" countries. The set of economies in "Next

Eleven" are identified for having the capability of being in the World largest economies (Grant, 2011). The prospect of Pakistan's economic progress is enhanced especially after the mass project of China-Pakistan Economic Corridor. The upsurge investment and economic activities as a result of CPEC also instigated the need for innovation across the country. Similarly, the willingness of countries to be the part of CPEC also insist Pakistan embrace modernizations with innovative operations. In acquiescence to the excessive energy demand, the country has increased the investment in the energy sector from 2015 to 2017 by 35%. Similarly, the focus of government has also shifted towards increasing the knowledge paradigms by particularly focus on higher education with the motive of bringing technical expertise via education sector into economic activities. The benefits of awareness regarding the effect of technologies on energy consumption are also vital to recognize both present and future projections of energy dependence (Popp, 2001). Likewise, the importance of technology also lies in bringing energy efficient solutions to the process of business and economic expansion. In order to develop the energy-efficient solutions, industries are required to setup energy-advanced machinery. Therefore, the objective of the present study is to analyze the role of innovation in influencing energy consumption in Pakistan. The uniqueness of our study is attributed in examining the highly debatable issue of innovations in enhancing the level of the energy dependence of the countries. Furthermore, the exclusivity of our approach also outspreads in deploying the numerous measures of innovation. Therefore, the present research used the three core measures of innovation in Pakistan including high-tech exports, research and development on technology and patents application by residents.

The main aim of the study is to discover the contribution of innovation in affecting the energy consumption of Pakistan. Therefore the present research examine the causal connection between technology innovation and energy demand in Pakistan and suggests efficient guidelines to the policymakers. Focusing to these main aims, the following techniques have applied. Primarily, the present research uses the continuous wavelet transform to examine the connection among technology and energy demand. Along with this, the present research apply two cross-wavelet tools that are continuous wavelet power spectrum and wavelet coherence. The innovative approach that we have utilized in the present study is unique to identify the time frequency associations. Particularly, the exclusivity of continuous wavelet transforms is to classify the causality at multiple events. Moreover, the current study examines the cyclical and anti-cyclical relationship between innovation and energy demand. The unique association lacks to be identified in past studies. In this regard, the present study not only pioneers in addressing the relationship between innovation and energy but also attempts to analyze the time-frequency causal effects among the time series at various measure.

The present study is therefore motivated to contribute in many ways. First, in analyzing the crucial relationship of innovation with energy consumption. Second, in identifying the various measures of innovation. Unlike the conventional setup of bi-variate investigations, the present study does not depend on single measure of innovation but seeks to expand the analysis by studying three important aspects of a country's innovation i.e., Research and development expenditures, the exports of high technologies by the country and number of Patent applications by the residents of Pakistan. In addition, the study instead of relying on the old fashioned methodologies, applied the advanced approach of Wavelet Analysis. Furthermore, after appraising the prospect of Pakistan for being the potential part in Next Eleven, the educational inquiry in assessing the role of country's innovation towards energy consumption would help the policy makers to craft the necessary policies in the energy-innovation domain.

The rest of the study is structured as follows: Sections two sheds lights on the critical empirical studies related to the field of innovation and energy. Section three presents the basic understanding of the methodologies applied in the current study. This is followed by section four that displays the data analysis and results of the investigation. Lastly, section five concludes the research findings and suggests the critical implications of the association between energy and innovation for the case of Pakistan.

2. LITERATURE REVIEW

The studies in the literature that analyze the energy innovation domains focus more on how energies can be used in enhancing the level of innovations and how the level of innovations can be utilized in increasing energy conservation (Haseeb, 2018; Hasan, 2017; Bayat et al., 2017; Anwana and Akpan, 2016; Haseeb et al., 2017; Zhang, 2017; Manaf and Ibrahim, 2017; Lopez-Morales et al., 2017; Zarra-Nezhad et al., 2016; Okpiliya et al., 2016; Zomorrodi and Zhou, 2016; Haseeb et al., 2014; Ekong and Akpan, 2014). Therefore, very little attention is paid to how innovations are related to energy consumption. The theoretical link between energy consumption and innovation suggest that innovation can bring both the positive and negative effects on energy consumption. If the level of innovations focused on the energy-efficient technologies, it will bring positive results to the level of consumption. The use of renewable energies is also critical in diversifying the dependence of a country in the process of energy consumption. Similarly in the absence of focus on efficient use of energy, the high level of innovations can enhance the country's dependence on energy consumption.

Popp (2001) undermining the role of innovation in influencing energy prices studies the connection between the Patent data of United States with energy prices. The study utilized the data from the period of 1970–1994. Focusing on the prices of energy-efficient innovations, the findings of the study stated that energy prices along with the level of educational quality are significant to increase the level of innovation in the country. However, when the level of educational quality is removed from the analysis, the results suggested that energy prices adversely affect the level of innovations. Another interesting study in this regard is provided by Herring and Roy in 2007. The study analyzes the connection between the level of innovation, energy effectiveness, and energy consumption. The findings of the study conclude that adoption of energy efficient technologies does influence the level of energy consumption in short run but the in long-run, the level of reduction is outpaced by high growth and as a result, increased the level of energy consumption. Similar conclusions are made in the study of Alfredsson (2004) that stress on the view that green consumption is not related to bringing positive effects to the quality of the environment.

Berndt et al. (1993) also analyze the relationship between technology and energy. The study evaluates the trans-log cost functions in the manufacturing industry for manufacturing industries of United States, Canada, and France. The outcomes of the study establish that change in technologies results in improved savings in both fuels and electricity consumptions. In a similar context, Mountain et al. (1989) also discover the role of technological inventions in Ontario manufacturing industries. The results of the study highlight that level of technology augments the utilization of natural gas. More recently, Elliott et al. (2017) adopted the distinctive approach in examining the association between energy consumption and technologies. The study focuses on the mobile technologies particularly focusing on Samsung Galaxy Note to analyze its role in energy consumption. The study applied the quantitative methodology by gathering data from the mixed approach of interviews, experiments and questionnaires to analyze the battery consumption of Android smartphones. The results of the analysis suggest that user practice is a significant factor to influence energy consumption of smartphone technologies.

Using a panel approach, Álvarez-Herránz et al. (2017) investigate the relationship between energy-efficient technologies with the environment. The study tests the environment Kuznets curve in 28 Organization for Economic Co-operation and Development (OECD) countries. The authors used annual data from the time period from 1990 to 2004. Using public budget in energy research development and demonstration along with green house gas emissions, the findings of the study analyze how energy innovation contributes to reducing energy intensity and environmental pollution. The outcome of the study concludes that energy efficient technology has insignificant effects in improving environmental quality. In a similar aspect, Andreoni and Levinson (1998) the association between innovations in technologies, energy consumptions, growth and environmental degradation depends on the technical effect. The authors suggest that increased investment in innovation aids in decreasing level of pollutions. The study further establishes that higher level of income in economies resulted in higher energy consumption and declines the level of degradation through the level of innovations (Abidin and Haseeb, 2015; 2018; Abidin et al., 2015).

Balsalobre et al. (2015) also utilized the panel approach and study the association between energy-oriented research development and demonstration (RD and D) and energy intensity. The study examines 28 OECD countries from the period of 1994–2010. The results of the study reveal that energy innovations reduce harmful gasses and thus diminish the negative effect of energy intensity. The authors further suggest that focus on energy RD and D policies can aid to decline the level of energy intensity and improves the quality of the environment. Similar findings are reported in the studies of Alcantara and Duro, 2004; Dowlatabadi and Oravetz, 2005; that suggests that energy intensity involves higher energy consumption and therefore declines quality of the environment.

In addition, Bointner (2014) analyzes the contribution of innovation in energy industries of fourteen IEA countries. The outcome of the investigations comprehended that public research and development are positively linked to the promotion of market diffusion of niche technology and subsequently underlies the capability to result in a breakthrough of the respective technology. Furthermore, Li and Lin (2016) investigate the relationship of energy prices on energy technology patents in thirty provinces of China. The study used data from the time period of 1999–2013 and applied the statistical technique of Fully Modified Ordinary Least Square in order to check the long-run coefficient of the variables. The results of the study stated that energy prices decrease the level of energy technology patents in China.

3. METHODOLOGY

The datasets utilized in the current study comprises of annual observation of technology innovation. In the current study, we used three proxies of technology innovation including (i) high technology exports (amount in U$) (ii) investment in research & development (percentage of GDP) and (iii) number patents registered by a resident of the country. The data of energy is measured as the total energy consumption (in the form of Mtoe). All the data is collected during the period of 1997–2016 from World Development Indicators (World Bank official website). The annual series is then transformed into quarterly series by a quadratic match-sum technique. This way also creates modifications for cyclical deviations in the data when the data are transformed from low frequency into a high frequency by reducing the point-to-point data variations (Cheng et al., 2012; Sbia et al., 2014; Shahbaz et al., 2017). The data is transformed into the logarithmic difference series to get the return-series with the view of making our results reliable.

3.1. A Short Note on Wavelet

3.1.1. Continuous wavelet transform

Consequent wavelet transform $W_x(m,n)$ is one that is attained to analyze the defini∈te wavelet ψ (.) in contradiction of the time sequence $x(t) \in L^2(R)$, i.e.,

$$W_x(m,n) = \int_{-\infty}^{\infty} x(t) \frac{1}{\sqrt{n}} \bar{\psi}\left(\frac{t-m}{N}\right) dt$$

Continuous Wavelet transform has the potential to decompose the time series and impeccably regenerate the subsequent time series $x(t) \in L^2(R)$:

$$x(t) = \frac{1}{C_\psi} \int_{-\infty}^{\infty} \left[\int_{-\infty}^{\infty} W_x(m,n) \psi_{m,n}(t) du \right] \frac{dn}{N^2}, N > 0$$

Besides, this distinctive technique foster the influence of the observed sequence in time,

$$\| x \|^2 = \frac{1}{C_\psi} \int_0^{\infty} \left[\int_{-\infty}^{\infty} | W_x(m,n) |^2 \, dm \right] \frac{dn}{N^2}$$

Therefore, in the present empirical investigation, we relate the abovementioned features to the wavelet coherence in order to enumerate the degree of the inherent link of the studied innovation and energy time series framework.

3.1.2. Wavelet coherence

If the motive of the analysis is to study the relationship of the two-time series in a bi-variate arrangement in the time frequency event, the methodology of wavelet coherence is best suited. The approach of wavelet coherence inclines to classify regions for time-frequency breach. In doing so, the observed series of time transform concurrently, however, do not fundamentally retain the substantial shared power. Mentioned below is the equation for adjusted coefficient of wavelet coherence as identified by Torrence and Webster (1999):

$$R^2(m,n) = \frac{|N(N^{-1}W_{xy}(m,n))|^2}{N(N^{-1}|W_x(m,n)|^2)N(N^{-1}|W_y(m,n)|^2)}$$

The association of local linear in the abovementioned method amongst the stationary series of bi-variate variables is present at every dimension. Also the association is consistent to the squared correlation coefficient in linear regression. In the meantime, the conjectural distribution for the wavelet coherence is not recognized, therefore in the present investigation, this is done by utilizing the method of Monte Carlo procedure.

4. DATA ANALYSIS AND DISCUSSION

Displayed in Table 1 are the outcomes of unit root techniques utilized in the present study. They include the analysis of Augmented Dicky & Fuller (1979) and Phillips & Perron (1988). The purpose of the mentioned unit root analyses is to evaluate the stationary attributes within the time-series variables of the study i.e., innovation and energy. The results of unit root therefore suggested that both the variables are non-stationary at the level but gain the stationarity at first difference. The findings in this way comprehend that innovation and energy do not encompass the issue of unit root.

The continuous wavelet analysis is relatively easily translated as it offers more observable and apparent frequency evidence. Consequently, to establish the findings of the wavelet transform, continuous wavelet analysis in analyzing the association between research and development and energy consumption is used. Figure 1 displays the continuous wavelet power spectrum in the two series.

4.1. Continuous Wavelet and Wavelet Coherence Results (R&D-ENC)

The result of continuous wavelet power spectrum offers the variance effects of the variables in three domains of time, frequency and color code. Displayed in Figure 1 are the results of R&D and ENC in possible time-frequency correlation. The findings suggest that the variance of R&D are strong in the short-run from the period of 2001–2004. As for medium-run, the strong variance of the variable is identified in the period of 1999–2005. Furthermore, the intensity of the variance can be identified from the color range from the side bars. In this context, the results can also interpret that the variation in R&D are higher in short run having dark red color but relatively lower in the medium-run as the cluster color code is changed to orange-red.

Likewise, the results for energy consumption is displayed on the right of Figure 1. The findings suggest that the variance of ENG are strong in the short-run from the period of 2006–2008. As for medium-run, the strong variance of the variable is identified in the period of 2004–2009. Furthermore, in order to identify the intensity of the variance, the results suggest that similar to R&D the variation of ENG are also higher in short run having dark red color than in the medium-run for having orange red color.

The results of wavelet coherence between research and development and energy consumption are presented in Figure 2. In short run (0–4 period), we have two substantial clusters of red color. During the year 1997–1999, we have an arrows right side upward which means both the variable are in-phase and have a cyclic effect in which ENC is leading (energy consumption has a causal influence on R&D). Furthermore, during the time period of 2007–2010, we have arrows are right side upwards and also right side downward indicating that both variables are in phase and having a cyclic effect on each other (R&D and ENC has a bi-directional causal relationship with each other). In the period of 16–32, we have a single cluster in which all arrows are right side upwards which are clearly indicating that both variables are in-phase and having cyclic effect in which energy consumption is leading. In summary, the results of wavelet coherence confirm that R&D and ENC have a bi-directional causal relationship with each other in short run and a uni-directional causal relationship where ENC is leading. However, no evidence of a causal relationship in a medium run period.

4.2. Continuous Wavelet and Wavelet Coherence Results (TEXPT-ENC)

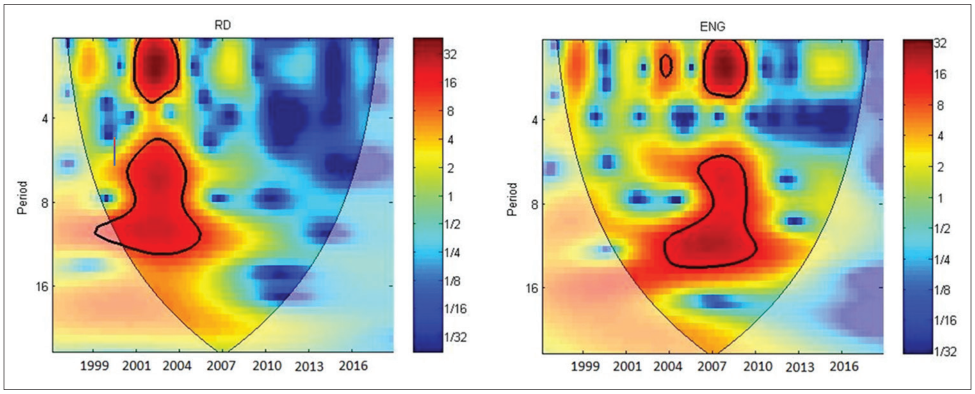
Displayed in Figure 3 are the results of TEXPT and ENC in possible time-frequency correlation. The findings suggest that the variance of TEXPT are strong in the short-run in the period of 2000. As for medium-run, the strong variance of the variable is identified in the period of 1999–2001. However, the longest

Table 1: Stationary test results

Variables	Augmented Dickey-Fuller				Phillips-Perron			
	I (0)		I (1)		I (0)		I (1)	
	C	C&T	C	C&T	C	C&T	C	C&T
R&D	−1.83	−1.65	−3.46	−3.53	−0.96	−0.60	−3.32	−3.883
TEXPT	−1.002	−2.175	−5.263	−5.228	−0.792	−1.002	−5.246	−5.210
PAT	−1.806	−1.502	−4.941	−4.905	−1.240	−2.310	−4.912	−4.876
ENC	−2.021	−1.587	−4.290	−4.458	−1.446	−0.740	−4.204	−4.377

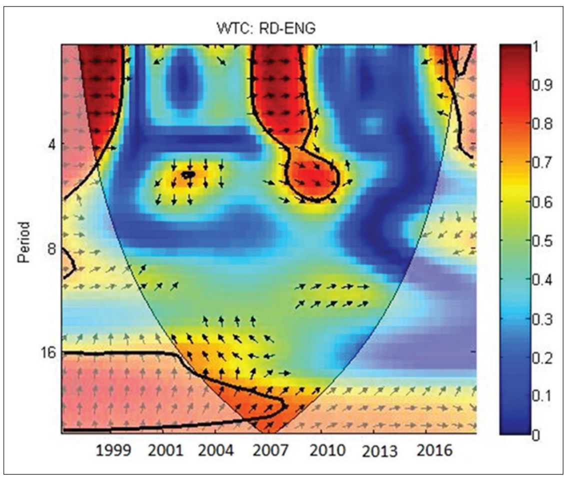
The critical values for ADF and PP tests with constant (c) and with constant and trend (C&T) 1%, 5% and 10% level of significance are−3.596, −2.931, −2.604 and −4.194, −3.522, −3.219 respectively. Source: Authors’ estimation

Figure 1: Continuous wavelet power spectra of R&D and ENC



Source: The thick black contour represents the 5% significance level against the red noise. The color code for power ranges from blue (low power) to red (high power)

Figure 2: Wavelet Coherence power spectra of R&D-ENC



Source: The thick black contour represents the 5% significance level against the red noise. The color code for power ranges from blue (low power) to red (high power)

variance in the time-series of TEXPT is seen in the long-run particularly from the period of 2000–2006. Furthermore, the intensity of the variance suggest that the variation in TEXPT are higher in short run having dark red color but relatively lower in the medium-run as the cluster color code is changed to orange-red. However, the highest intensity of the variance is seen in the long-run for having the dark red color.

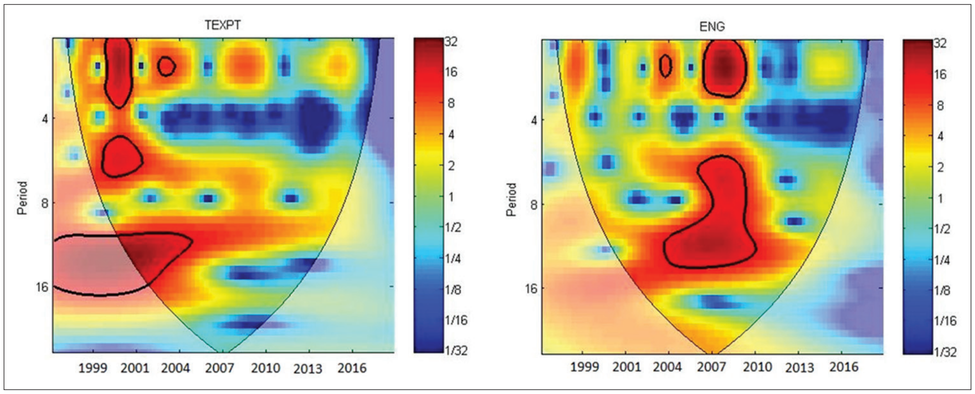
As for the results of energy consumption, the variance is seen both in short run and middle to upper long-run period. The findings suggest that the variance of ENG are strong in the short-run from the period of 2006–2008 and from 2004 to 2009 in medium to long run. Furthermore, for the intensity of the variance, the results suggest that similar to R&D the variation of ENG are also higher in short run having dark red color than in the medium-run for having orange red color.

The results of wavelet coherence between research and development and energy consumption are presented in Figure 4. In short run (0–4 period), we have three considerable groups of red color. During the year 1997–1999, we have an arrows right side upward which means both the variable are in-phase and have a cyclic effect in which ENC is leading (energy consumption has a causal influence on high technology exports). Furthermore, during the time period of 2002–2010, we have arrows are left side upwards indicating that both variables are out phase and having anti-cyclic effect in which TEXPT is leading (TEXPT has a negative causal relationship with each ENC). Moreover, during 2013–2016, the majority of the arrows are right side upward indicating that both variables are in-phase and have a cyclic effect in which energy is leading (ENC has a causal influence over TEXPT). In the period of 4–8 weeks, we have a single cluster in which all arrows are left side upwards and left side downward which are clearly indicating that both variables are out-phase and having anti-cyclic effect in which both variables are leading. Technical speaking, the results of wavelet coherence confirm that TEXPT and ENC have a bi-directional causal relationship with each other in the medium run and a uni-directional causal relationship where ENC is leading in a short run time period. Though, we found no evidence of a causal relationship in a long and very long run period.

4.3. Continuous Wavelet and Wavelet Coherence Results (PAT-ENC)

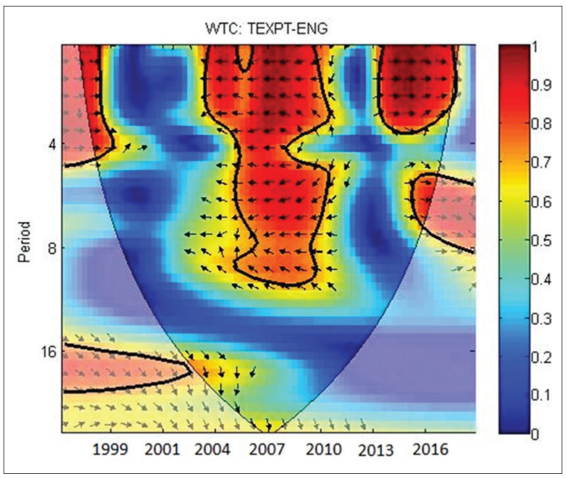
The outcomes of continuous wavelet transform between patents and energy consumption are shown in Figure 5. It pretty obvious that both series of PAT and ENC retain fluctuating characteristics in numerous time-frequency domains. The outcomes of PAT establishes a quite noteworthy variance in the time series. The short run variance for PAT is seen during the period of 2004–2007. As for medium run, the PAT series has not shown any stable variance However, in the long-run, the variable identified the strong variance from the 2001 to 2008. Along with this, the variation in PAT is high in the short run as the small clusters having dark red color but low in the long-run as the cluster having orange-red color. Furthermore, the results show that ENC. The findings suggest that the variance of ENG are strong in the short-run from the period of 2006–2008 and from 2004 to 2009 in medium to long run. Furthermore, for the intensity of the variance, the results suggest that similar to R&D the variation of ENG are also higher in short run than in medium to long run. In brief, the results of continuous wavelet transform suggested that these outcomes recommend that the variance in PAT and ENC are confidently occurring in the short and medium to long run period as well.

Figure 3: Continuous wavelet power spectra of TEXPT and ENC



Source: The thick black contour represents the 5% significance level against the red noise. The color code for power ranges from blue (low power) to red (high power)

Figure 4: Wavelet Coherence power spectra of TEXPT-ENC



Source: The thick black contour represents the 5% significance level against the red noise. The color code for power ranges from blue (low power) to red (high power)

The results of wavelet coherence between patents and energy consumption are displayed in Figure 6. In short run (0–4 period), we have two significant groups of red color. During the year 2008–2009, we have an arrows left side upward which means both the variable are out-phase and have an anti-cyclic effect in which patents are leading (patents has a causal influence on energy consumption). Furthermore, during the time period of 2011–2016, we have arrows are right side upwards indicating that both variables are in phase and having cyclic effect in which ENC is leading (ENC has a positive causal relationship with PAT). In the period of 4–8 weeks, we have a single cluster during 2001–2009 in which all arrows are left side downwards and which are clearly indicating that both variables are out-phase and having anti-cyclic effect in which ENC leading. Finally, in 8–16 week period, during 2000–2010 we found a visible cluster in which all arrows are left side upward which indicating that both variables are out phase and having anti-cyclic effect in which patents are leading (patent has negative causal relationship on energy consumption in Pakistan).

Technically speaking, the results of wavelet coherence confirm that PAT and ENC have a bi-directional causal relationship with each other in short run and a uni-directional causal relationship where ENC is leading in medium run time period. However, we found an evidence of a uni-directional causal relationship in a long and very long run period where causality is running from patens to energy consumption in Pakistan.

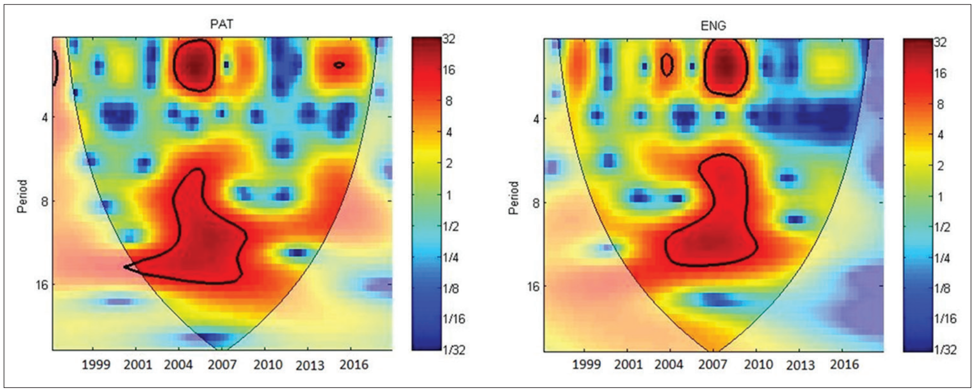
5. CONCLUSION AND RECOMMENDATION

Despite of the proliferation of existing literature with studies focusing on the relationship among technology innovation and energy, outcomes are rather mixed. Moreover, previous studies have also used classical analysis methods such as autoregressive models, linear models or cointegration models which are prone to the problems of non-stationary time series. We have used the wave-like oscillation transmute structure to investigate the association among technology innovation and energy in Pakistan. We have employed continuous wavelet power spectrum, and wavelet coherence power spectrum investigation to examine the association among technology innovation (using three different proxies) and energy by considering monthly samples for the period of 1997(1)–2016(4).

Our findings of unit root tests by using ADF and PP shows no issue of data stationary at first level. For all four studied variables, we have observed a substantial variance in the small and medium run. Moreover, the outcomes of wavelet coherence confirm that R&D and ENC have a bi-directional causal relationship with each other in short run and a uni-directional causal relationship where ENC is leading. However, no evidence of a causal relationship in a medium run period.

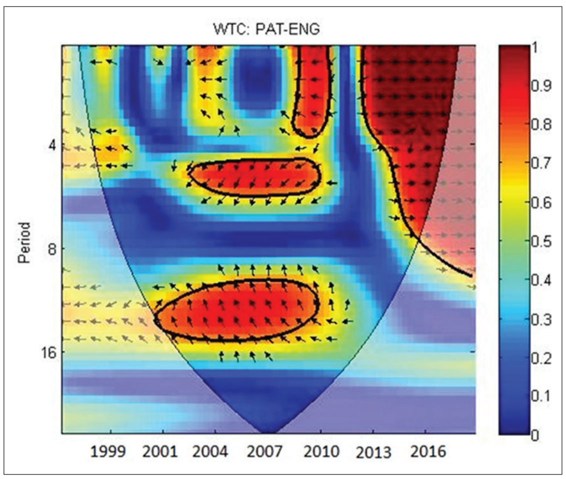
In addition, the results of wavelet coherence confirm that TEXPT and ENC have a bi-directional causal relationship with each other in the medium run and a uni-directional causal relationship where ENC is leading in a short run time period. Though, we found no evidence of a causal relationship in a long and very long run period. Lastly, the results of wavelet coherence confirm that PAT and ENC have a bi-directional causal relationship with each other in short run and a uni-directional causal relationship where ENC is leading in medium run time period. However, we found an evidence of a uni-directional causal relationship in a long and

Figure 5: Continuous wavelet power spectra of PAT and ENC



Source: The thick black contour represents the 5% significance level against the red noise. The color code for power ranges from blue (low power) to red (high power)

Figure 6: Wavelet coherence power spectra of PAT-ENC



Source: The thick black contour represents the 5% significance level against the red noise. The color code for power ranges from blue (low power) to red (high power)

very long run period where causality is running from patens to energy consumption in Pakistan. Although this study identifies the limitation of bivariate technique, in the further studies scholars may use a multivariate technique to re-examine the connection. This study can be done in the future with nexus of any other economic variable for instance, foreign direct investment, import and export of oil and tourist arrivals which can be acceptable on hypothetical views in the economic framework.

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