Quadrilateral Causal Analysis of Economic Growth in India

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2015

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Abstract

Following the economic growth pattern of India, continuous fossil fuel consumption is deteriorating the air quality by CO_2 emission. This issue also directs towards the problem of energy efficiency. An error correction model has been formulated for fossil fuel consumption, energy efficiency, economic growth, and CO_2 emission for India (1971-2010). We conclude that economic growth pattern is causing energy efficiency and it is driven by established missing feedback link of Environmental Kuznets Curve (EKC).

Keywords: CO_2 emission, economic growth, Environmental Kuznets Curve, energy efficiency, India

1. Introduction

Indian growth history has been fairly a grown up subject matter of interest for researchers across the world. Since 1971, India is experiencing an elevated decadal average growth rate. Beginning with a decadal average of 3.08% in 1971-80, the gross domestic product (GDP) has ascended to 5.57% in 1980-2000 and 7.47% in 2001-10. Enabler of this significant growth is the energy consumption, which was evident in the form of electrical power consumption (Ghosh, 2002). During 1971-2010, fossil fuel energy consumption of India has gone up to more than two and half times. It can be said that this intensification in electrical power consumption has heightened the economic growth. Indian economic growth and energy consumption follow a causal relationship, which says that energy consumption is the reason behind economic growth of India (Cheng, 1999). Within the boundary of this established causal association, we will consider only the one segment of energy consumption, i.e. the fossil fuel energy consumption.

However, certainly there is shadow beneath the lamp. Elevated fossil fuel based energy consumption has also heightened the level of emission in the environment (Pek, 2014). Majority of the power utilized in economic development is power generated from fossil fuels. During 1971-2010, amount of fossil fuel consumption as a fraction of total power consumption has almost doubled. This has resulted in huge level of Carbon Dioxide (CO_2) emission in the atmosphere. During 1971-2010, CO_2 emission has gone up from 205,869.05 kilo tons in 1971 to 1,979,424.60 kilo tons in 2010, i.e. nearly an increase of 9.61 times. Consequently, the amplified utilization of fossil fuel, which is facilitating the economic growth of India, is as well worsening the atmosphere. Nevertheless, this phenomenon is quite understandable for the case of India, as for a developing nation, attracting more investment and employment of the same is endowed with more importance than the environmental protection (Acharyya, 2009). This underestimation of environmental damage can in turn bring harm to the economic growth. Nevertheless, the amount of combustible energy waste has been reducing, which signifies the enhanced energy efficiency in India, which has been catalyzed by public-private partnership (Sinha-Khetriwal et al., 2005). On one hand, when gradually rising fossil fuel energy consumption is affecting the environment, then on the other hand, rising ecological awareness is lowering the amount of energy waste (Rahmawati, 2013). They sound to be contradictory, but for India, it is a fact.

This argument can be put forward in terms of Environment Kuznets Curve (EKC) hypothesis. In accordance with this hypothesis, inverted U-curve association subsists between environmental degradation and economic growth for developing nations (Panayotou, 1993). Interaction between economic growth and environmental degradation leads to reduction of the latter one after certain level of the former one. Divergence among researchers exists on the subject of the turnaround point of the EKC (Abdou and Atya, 2013; Dinda, 2004; 2014). In spite of this, EKC hypothesis confirms one thing that a causal association exists between economic growth and environmental degradation. This causal relation can be unidirectional or bidirectional in nature. Based on this foundation, it can be stated that, in order to scrutinize the sustainability of economic growth of any nation, it is needed to discover the direction of this causality.

Hence, while assessing the growth trajectory of India, it is needed to establish a directional causal relationship among fossil fuel consumption, economic growth, CO_2 emission, and energy waste. In the existing body of knowledge, there are only a handful number of studies, which focus on the Granger causal association between income expansion and environmental degradation. Studies have been taken up in the United States (Soytas et al., 2007) and China (Zhang and Cheng, 2009). However, these studies are mainly focused on the unidirectional relationships. In both of the aforementioned studies, Granger's causality test using the augmented VAR approach has been employed. In this paper, we intend to investigate about the causal association among fossil fuel consumption, economic growth, CO_2 emission, and energy waste, keeping in mind the sustainability aspect of the economic growth, which India is achieving.

2. Econometric Methodology

In this section, we will discuss about the econometric methodologies applied to look into the association between fossil fuel consumption, energy consumption, economic growth, and CO_2 emission. To start with, we should check the integration characteristics of the data. For this purpose, unit root tests have been applied. If variables in the dataset are I(1) in nature, then cointegration test is used to look into the long run equilibrium association among them. Based on the findings of aforementioned test, order of integration will be found, and that will ensure the applicability of error correction model (ECM), based on which directions of causality among the variables are found. In the subsequent sections, we will discuss these methodologies one by one.

2.1 Investigation for Integration

In most of the cases, time series economic data exhibits non-stationary nature, as their central tendencies are found to be upwards over a long period. However, in order to investigate the considerable long run association among the variables, carrying out non-stationarity test becomes essential. This test primarily focuses on order of integration, at which point considered variables become stationary in nature. The test is carried out on the level data, and subsequently on differentiated forms of the variables. For this purpose, we will apply augmented Dickey-Fuller test (Dickey and Fuller, 1981), Phillips-Perron test (Phillips and Perron, 1988), and Kwiatkowski-Phillips-Schmidt-Shin test (Kwiatkowski et al., 1992). These three tests will be conducted for checking the serial correlation, heteroscedasticity, and deterministic trend present in variables under consideration. Following are the test statistics considered for each of the cases:

Augmented Dickey-Fuller (ADF) test: $\left(\frac{\sigma^2}{\lambda^2}\right)^{1/2} .t_{\pi=0} - \frac{1}{2}\left(\frac{\lambda^2-\sigma^2}{\lambda^2}\right)\left(\frac{T.SE(\pi)}{\sigma^2}\right)$ (1)

Phillips-Perron (PP) test: $T\pi - \frac{1}{2}\left(\lambda^2-\sigma^2\right)\left(\frac{T^2.SE(\pi)}{\sigma^2}\right)$ (2)

Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test: $\left(T^{-2}\sum_{t=1}^{T} S_t^2\right) / \lambda^2$ (3)

Where, $\sigma^2 = \lim_{T\to\infty} T^{-1}\sum_{t=1}^{T} E\left[u_t^2\right]$ (4)

$$\lambda^2 = \lim_{T\to\infty} \sum_{t=1}^{T} E\left[T^{-1}S_t^2\right] \quad (5)$$

$$S_t = \sum_{t=1}^{T} u_t \quad (6)$$

2.2 Investigation for Cointegration

Cointegration is an econometric methodology to investigate the subsistence of long run equilibrium association among variables. This is imperative from an algebraic perspective, as progression of the variables over a long timeframe adjusts the inconsistencies being appeared along the shorter durations. In accordance with Dickey et al. (1991), if the cointegrated association among variables is not present or weak in nature, then probability of existence of variability in their long-term movement is very high. In view of the existence of this cointegrated association among variables, conducting a regression analysis becomes significant. However, for any number of non-stationary time series variables to be cointegrated, it is imperative for their linear combination to be stationary in nature (Engle and Granger, 1987). However, it is seemingly not appropriate to stick to a methodology, which is capable of analyzing the cointegrated association between only two variables. That is the reason behind our preference of the cointegration testing methodology by Johansen and Juselius (1990) over the one that of by

Engle and Granger (1987), as scope of our analysis is not confined by bivariate nature of analysis. Trace and maximum eigenvalue statistics are the two major components of this cointegration analysis (Johansen, 1988; 1991). We will discuss about both of these two statistics.

Consider Y_t as an (n X 1) vector of I(1) integrated variables and ε_t as an (n X 1) vector of error terms. Then the vector autoregressive model (VAR) of order N can be expressed as per the following:

$$\Delta Y_t = \mu + \Pi \Delta Y_{t-1} + \sum_{i=1}^{N} \Gamma_i \Delta Y_{t-i} + \varepsilon_t \quad (7)$$

Where, $\Pi = \sum_{i=1}^{N} A_i - \mathrm{I}$ (8)

$$\Gamma_i = -\sum_{j=i+1}^{N} A_j \quad (9)$$

Precisely, $\prod$ contains the information about coefficients, which determine the nature of long run association among variables under consideration. Rank of this matrix, which determines number of cointegrating vectors among variables, is calculated through two statistics, namely trace and maximum eigenvalue. The trace test embarks upon the null hypothesis of having cointegrating vectors equal to the rank of the matrix (say r) aligned with the alternate hypothesis of having cointegrating vectors of number n (< r). In case of the maximum eigenvalue test, it embarks upon null hypothesis of having cointegrating vectors equal to the rank of the matrix (= r) against the alternative hypothesis of having cointegrating vectors exactly one more than the rank of the matrix (= r + 1). The test statistics are as per the following:

Trace statistics (JJ_T) = $-T \sum_{i=r+1}^{n} \ln(1-\eta)$ (10)

Maximum eigenvalue statistics (JJ_{ME}) = $-T \ln(1-\eta_{r+1})$ (11)

Where, η = i^{th} principal canonical correlation

2.3 Investigation for Causality Association

In this section, we will make use of Granger causality test (Granger, 1969) to investigate the causal association encompassing parameters, namely fossil fuel consumption, energy consumption, economic growth, and CO_2 emission for India. The quadrivariate Granger causality test based on error correction model (Toda, Phillips, 1993) can be formulated in the following manner:

$$\begin{bmatrix} \Delta \ln FF_t \\ \Delta \ln EW_t \\ \Delta \ln EG_t \\ \Delta \ln CE_t \end{bmatrix} = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix} + \begin{bmatrix} b_{11,1} & b_{12,1} & b_{13,1} & b_{14,1} \\ b_{21,1} & b_{22,1} & b_{23,1} & b_{24,1} \\ b_{31,1} & b_{32,1} & b_{33,1} & b_{34,1} \\ b_{41,1} & b_{42,1} & b_{43,1} & b_{44,1} \end{bmatrix} \begin{bmatrix} \Delta \ln FF_{t-1} \\ \Delta \ln EW_{t-1} \\ \Delta \ln EG_{t-1} \\ \Delta \ln CE_{t-1} \end{bmatrix} + \ldots$$
$$+ \begin{bmatrix} b_{11,n} & b_{12,n} & b_{13,n} & b_{14,n} \\ b_{21,n} & b_{22,n} & b_{23,n} & b_{24,n} \\ b_{31,n} & b_{32,n} & b_{33,n} & b_{34,n} \\ b_{41,n} & b_{42,n} & b_{43,n} & b_{44,n} \end{bmatrix} \begin{bmatrix} \Delta \ln FF_{t-n} \\ \Delta \ln EW_{t-n} \\ \Delta \ln EG_{t-n} \\ \Delta \ln CE_{t-n} \end{bmatrix} + \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \end{bmatrix} \left[ECT_{t-1} \right] \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \end{bmatrix} \quad (12)$$

Where, FF stands for fossil fuel consumption, EW stands for energy waste, EG stands for economic growth, and CE for CO_2 emission. ECT_{t-1} is the lagged error correction term, and ε_1, ε_2, ε_3, and ε_4 are reciprocally exclusive white noise residuals.

Fossil fuel energy consumption as a percentage of total energy consumption is used as a proxy measure for fossil fuel consumption (FF), combustible waste as a percentage of total energy is used as a proxy measure for energy waste (EW), GDP is used as a proxy measure for economic growth (EG), and CO_2 emission from fossil fuel consumption is used as a proxy measure for CO_2 emission (CE). The annual data from 1971 to 2010 has been taken from the World Bank database. No major structural breaks are found for any of the four variables under consideration.

3. Analysis

Analysis of collected data starts with checking the stationarity nature of variables under consideration, for which unit root tests have been conducted. The results of unit root test are recorded in Table 1. It can be visualized that the level data does not show any indications of stationarity, which confirms existence of unit roots in all the four variables under consideration. Subsequently, we moved towards differencing them and conducting unit root tests on the differentiated variables. It is evident from the results that all the four variables are showing stationary nature after first differentiation. This result also confirms that the variables are I(1) in nature.

Table 1: Unit root test results

		ADF	*PP*	*KPSS*
Level				
Intercept	FF	-1.033828	-0.988481	0.759594
	EW	2.078668	1.983462	0.773819
	EG	0.501026	0.383000	0.769768
	CE	-0.699015	-0.753285	0.779263
Intercept and Trend	FF	-0.642654	-0.824338	0.159340
	EW	-2.744440	-2.744440	0.129813
	EG	-0.822281	-1.177163	0.109605
	CE	-1.685673	-1.685673	0.163886
First Difference				
Intercept	FF	-2.674129[b]	-5.501225[a]	0.243062
	EW	-5.320134[a]	-5.314678[a]	0.411684
	EG	-5.492174[a]	-5.583894[a]	0.201027
	CE	-6.523463[a]	-6.522925[a]	0.131064
Intercept and Trend	FF	-5.598336[a]	-5.585270[a]	0.146613
	EW	-5.759701[a]	-5.754942[a]	0.130744
	EG	-5.468922[a]	-5.505470[a]	0.173178
	CE	-6.481731[a]	-6.480215[a]	0.076280

[a] Value at 1% significance level
[b] Value at 5% significance level

Once it has been established that the variables are integrated of order one, it is needed to test the cointegration association between them. The cointegration testing methodology by Johansen and Juselius (1990) have been applied on the variables. The results are recorded in

Table 2. The results show that a brawny long run association subsists among the variables. Null hypotheses of having no cointegrating vectors have been rejected by both the statistics, and they show that two cointegrating vectors are present between the variables. Based on these results, we can proceed for further analysis.

Table 2: Cointegration test results

Trace test				*Maximum Eigenvalue test*			
Null	*Alternate*	JJ_T	*Critical Value*	*Null*	*Alternate*	JJ_{ME}	*Critical Value*
$r \leq 0$	$r > 0$	52.11154[a]	40.17493	$r \leq 0$	$r = 1$	25.97830[a]	24.15921
$r \leq 1$	$r > 1$	26.13324[a]	24.27596	$r \leq 1$	$r = 2$	15.25316	17.79730
$r \leq 2$	$r > 2$	0.168605	4.129906	$r \leq 2$	$r = 3$	0.168605	4.129906

[a] Value at 1% significance level
"r" symbolizes the number of cointegrating vectors

As we have seen the being of cointegration vectors among variables under consideration, we can proceed to formulate the ECM. The results of causality test are recorded in Table 3. Lag length selection criterion are provided in Table 4. Sequential modified LR test statistic (each test at 5% level), final prediction error, Akaike information criterion, Schwarz information criterion and Hannan-Quinn information criterion have been used for this purpose. We can see that bidirectional causality exists between growth in fossil fuel consumption and economic growth, and growth in fossil fuel consumption and CO_2 emission. Apart from these two, unidirectional causality exists from economic growth to growth in energy waste.

Table 3: Causality test results

	Independent Variable				*Error Correction Term*
Dependent Variable	ΔFF	ΔEW	ΔEG	ΔCE	
ΔFF	-	1.874914	5.491500[c]	16.64088[a]	0.026368[a]
ΔEW	1.192637	-	8.083179[b]	1.392324	0.009243[a]
ΔEG	5.886544[c]	4.151562	-	1.267882	0.140973[a]
ΔCE	7.698427[b]	1.851769	3.358084	-	-0.008365[a]

[a] Value at 1% significance level
[b] Value at 5% significance level
[c] Value at 10% significance level

Deductions: ΔEG => ΔFF, ΔCE => ΔFF; ΔFF => ΔEG; ΔFF => ΔCE; ΔEW <= ΔEG

Table 4: Lag length selection results

Lag	*LogL*	*LR*	*FPE*	*AIC*	*SC*	*HQ*
0	142.6689	NA	5.30e-09	-7.703831	-7.527884	-7.642420
1	357.3252	369.6858	8.60e-14	-18.74029	-17.86056*	-18.43324
2	378.3599	31.55201*	6.74e-14*	-19.01999*	-17.43647	-18.46730*
3	391.1091	16.29068	8.86e-14	-18.83939	-16.55209	-18.04106
4	409.4867	19.39855	9.38e-14	-18.97148	-15.98039	-17.92751

LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

Existence of the causal associations become significant from economic policy based decisions. Bidirectional causal association between economic growth and growth in fossil fuel consumption narrows down the findings by Paul and Bhattacharya (2004). However, the second bidirectional causal association needs serious attention. As economy grows at a sturdy pace, urbanization sets in, and it requires a rapid transformation in urban infrastructure. In order to supplement the growth in urbanization, rapid transformation in urban infrastructure was required, and that was supported by augmented fossil fuel energy consumption. However, due to rapid growth in fossil fuel consumption, negative environmental impact took place in the form of rising CO_2 emission. However, EKC hypothesis answers to the other direction of causal association. Rise of CO_2 emission in the environment catalyzes less usage of fossil fuel. From policymaking perspective, change in India's energy usage pattern signifies this association, as renewable energy source has been almost 30% of the entire energy production in India by the end of 2010 (Natarajan and Kanmony, 2014). This result is an extension of the findings by Sinha and Mehta (2014), Sinha and Bhattacharya (2014), Sinha (2015), in terms of specifying the missing feedback link in EKC hypothesis.

When we look at the unidirectional causal association from economic growth to growth in energy waste, again the answer comes from EKC hypothesis. With rise in income, comes the awareness, which enables citizens to keep themselves refrained from environmental endangering activities, like combustible energy wastage (Grossman and Krueger, 1995). Focusing on this direction of causality can assist policymakers to achieve the EKC turnaround point for India.

Graphical reconfirmation of the aforementioned results has been provided as generalized impulse responses (Figure 1). Results of impulse response functions endow us with additional impending towards established causal associations among the variables. To set off this study, it is imperative to look into the long-run stability of the associations among the variables. For this purpose, we have carried out a series of diagnostic tests to check serial correlation (LM test), heteroscedasticity (White test) and stability test (Ramsey RESET test). The results those are recorded in Table 5, confirm the constancy of the model analyzing the associations among fossil fuel consumption, energy waste, economic growth and CO_2 emission. Largely, the study divulges that although fossil fuel based energy-led economic growth poses a serious threat to environmental aspects by rising CO_2 emission, consequential rising social development aspects alongside the economic growth increases awareness among the citizens, which in turn reduces the wastage of energy and environmental degradation, following the trajectory of EKC.

Table 5: Diagnostic test results

Variables	R^2	*Adj.* R^2	*LM*	*White*	*Ramsey RESET*
FF	0.991558	0.990855	15.97802[a]	3.936801[a]	119.1980[a]
EW	0.979841	0.978161	52.36818[a]	13.39543[a]	945.3439[a]
EG	0.969700	0.967175	17.29865[a]	5.513543[a]	12.98833[a]
CE	0.996203	0.995887	10.18507[a]	4.438088[a]	20.69747[a]

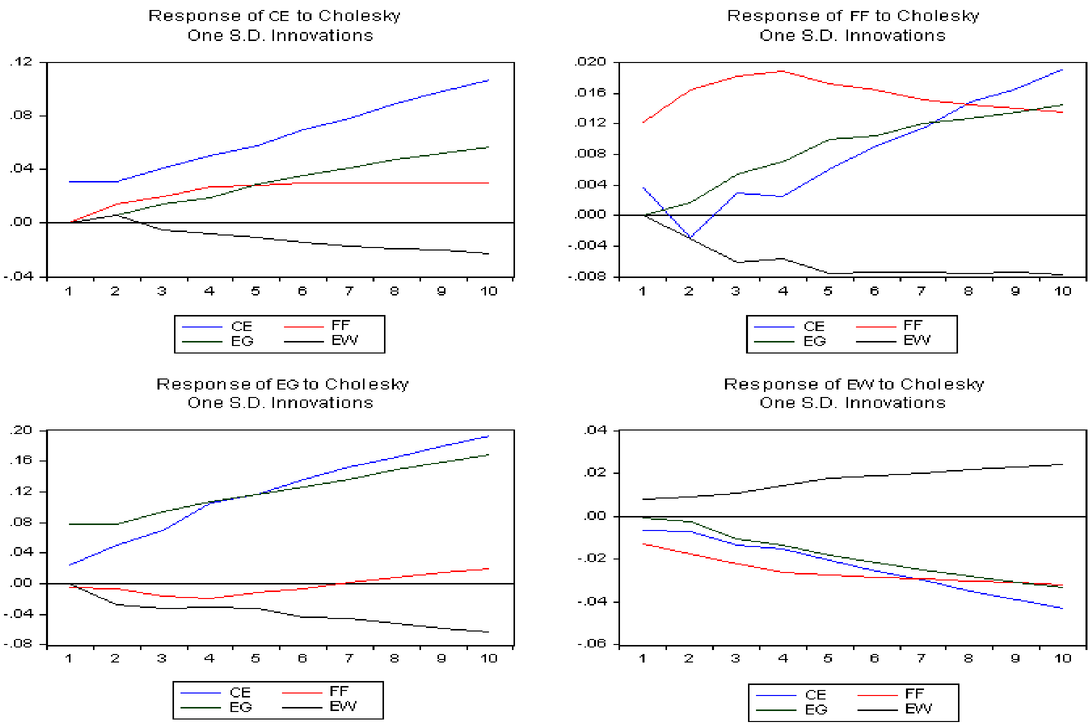

Figure 1: Generalized Impulse Responses

4. Conclusion

The study investigates about the long-run causal associations among fossil fuel consumption, energy waste, economic growth and CO_2 emission, considering the statistics for India during 1971-2010. The econometric analysis of the data substantiates the following findings:

First, the considered variables are showing stationarity after first differentiation, and they are first order integrated.

Second, long run equilibrium associations among the variables are ensured by two cointegrating vectors.

Third, the econometric model shows bidirectional causal association between growth in fossil fuel consumption and economic growth, and growth in fossil fuel consumption and CO_2

emission. Apart from these two, unidirectional causality exists from economic growth to growth in energy waste.

This study by far concludes that devoid of a social development perspective, a sustainable development objective can never be attained, as it acts as a mediating feature between environmental aspects and economic aspects in the EKC hypothesis. While focusing on policy decisions regarding economic growth, leaving apart the environmental and social aspects always poses a serious threat towards the sustainable development objective, which is not desirable for a developing nation like India. This issue has been addressed by the established directional causal associations among fossil fuel consumption, energy waste, economic growth and CO_2 emission.

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