Coal Consumption and Economic Growth Revisited: Structural Breaks, Cointegration and Causality Tests for Pakistan

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Abstract

A global profusion of coal provides many countries with opportunities for economic growth. The direction of causality between coal consumption and economic growth is useful for policy making, however, existing empirical evidence have failed to reach a consensus. This paper examined the liaison between coal consumption and economic growth for Pakistan over the period 1971-2009. The endogenous two-break *LM* unit test, derived in Lee and Strazicich (2003), is used to assess the order of integration of the variables and structural breaks in the data series. Application of the Autoregressive Distributed Lag (*ARDL*) bounds test reveals a cointegrating relationship between real income, real capital stock, labour and coal consumption, and further application of General to Specific (*GETS*), Engle and Granger (*EG*), Stock Watson's Dynamic Ordinary Least Squares (*DOLS*) and Phillip Hansen's Fully Modified Ordinary Least Squares (*FMOLS*) methods show statistical robustness of the estimates. The elasticity with respect to coal consumption is positive and significant. The Vector Error Correction Model (*VECM*) based Granger causality test is also applied for both short-and long-run situations.

Keywords: Coal consumption; economic growth; cointegration; Granger causality
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1. Introduction

The preference for coal still remains in the present day because it is the most dependable and coherent source of energy. The availability of coal in profusion makes it cost effective amongst the remnant fuels. The mounting prices of petroleum and natural gas products has made coal more competitive in the global market and importantly policy makers are now interested on the relationship between coal consumption and economic growth. The impact of coal consumption on economic growth is observed to be directly or indirectly through the use of capital and labour in the production process. The direction of causality between coal consumption and economic growth has four estimable strands. First, if the causal relation is running from coal consumption to economic growth then energy (coal) conservation policies may be harmful for economic growth. Secondly, if the causal relationship is from economic growth to coal consumption then conservation hypothesis postulates that coal consumption is determined by economic growth. To this end, energy conservation policies do not influence economic growth.

Thirdly, the bi-variate causal relation between coal consumption and economic growth implies that energy conservation policies may retard economic growth and also fluctuations in economic growth may distort the consumption of coal. Fourthly, it is also plausible to attain no causal relation between coal consumption and economic growth. However, other findings on this relationship are also possible. For instance, Apergis and Payne (2010a & b) asserted that the inefficient and extreme usage of coal has adversely affected economic growth. Similarly, Wolde-Rufael (2010) argued that use of coal is becoming inefficient which seems to contribute more in the growth of carbon dioxide emissions due to flexibility in environmental laws. Further, Hu and Lin (2008) posit that asymmetric tests are necessary to analyse the liaison between coal consumption and economic growth.

Pakistan has received relatively less attention in the energy and growth literature. It is a developing Asian country with a per capita income (*GDP*) of US$650 in 2008 and its rate of unemployment is estimated to be around 14 per cent.[2] The average rate of growth of per capita income from 1971 to 2009 is enormously low (nearly 1 percent). The Pakistan economy has suffered from decades of internal political disputes and economic instabilities. The oil price shocks, devaluations of Pakistani rupee, natural disasters etc. have also created drawbacks to the macroeconomic performance of the economy. Such major events in Pakistan must be associated with structural changes in the domestic economy which should be addressed in the cointegration analysis; the failure to accommodate structural changes could result in attaining biased cointegration results. This article utilises the production function framework to examine the impact of coal consumption on economic growth in Pakistan over the period 1971-2009. Our empirical methodology is based on Pesaran et al.'s (2001) Autoregressive Distributed Lag model (*ARDL*) as well as Lee and Strazicich's (2003) tests for structural breaks in the data series. Application of Vector Error Correction Model (*VECM*) based Granger causality methods are undertaken to test for causality between the variables. Furthermore, long run estimates are compared with other time series techniques (including London School of Economics Hendry's General to Specific (*GETS*), Stock and Watson's Dynamic Ordinary Least Squares (*DOLS*),

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[2] These facts have been extracted from the World Development Indicators (2010).

Engle and Granger two step method (*EG*) and Phillip and Hansen's Fully Modified Ordinary Least Squares (*FMOLS*)) to identify the consistency of estimates across time series methods.

The outline of this paper is as follows. Section 2 briefly reviews a few recent empirical works on coal consumption and economic growth in developing countries. Section 3 presents the model specification and methodology. In Sections 4 and 5, empirical results and conclusions are detailed, respectively.

2. Brief Review of Time Series Studies

A number of recent time series studies have analysed the relationship between coal consumption and economic growth for developing countries, for instance see Yang (2000a & b), Lee and Chang (2005) and Hu and Lin (2008) for Taiwan, Sari and Soytas (2004) for Turkey, Wolde-Rufael (2004 & 2010) respectively for Shanghai and six countries, Fatai et al. (2004) for six countries, Yoo (2006) for Korea, Zhang and Li (2007), Yuan et al. (2008) and Liu et al. (2009) for China, Zahid (2008) for four Asian countries, Jin-ke et al. (2008 & 2009) for five countries, Khan and Ahmed (2009) for Pakistan and Ziramba (2009) for South Africa. Table 1 summarises the main findings of these empirical works.

The Case of Pakistan

The empirical evidence is limited regarding the causality relationship between coal consumption and economic growth in Pakistan. Zahid (2008) applied Error Correction Model (*ECM*) to examine the relationship between coal consumption and economic growth in Pakistan, India, Sri Lanka, Bangladesh and Nepal over the period 1973-2003. Using Toda and Yamamoto (1995) Granger causality tests, they found uni-directional causality running from coal consumption to economic growth only in Pakistan. Recently, Khan and Ahmed (2009) examined the demand for energy at disaggregate level (gas, electricity and coal) for Pakistan over the period 1972-2007. Their results based on the VAR Granger causality suggest that both real income and domestic price level causes coal consumption in the short run. Furthermore, a few empirical studies related to Pakistan have focused on other sources of energy and energy consumption at aggregate level, for instance see Masih and Masih (1996), Aqeel and Butt (2001), Siddiqui (2004), Khan and Qayyum (2009) and Chary and Bohara (2010).[3] Aqeel and Butt (2001) attained a uni-directional causality from economic growth to petroleum consumption and electricity consumption to economic growth. No causality was found between gas consumption and economic growth. In an interesting study, Masih and Masih (1996) examined the link between energy consumption and economic growth for six Asian countries including Pakistan. They found a bi-directional causality between energy consumption and economic growth in Pakistan.

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[3] Siddiqui (2004) found that electricity and petroleum products are useful for economic growth in Pakistan. Using the *ARDL* technique, Khan and Qayyum (2009) found that income and prices are important determinants of electricity consumption. More recently, Chary and Bohara (2010) asserted that there exists a bi-directional causality between energy consumption and economic growth in Pakistan.

Table 1. Time Series Studies on Coal Consumption and Economic Growth in Developing Countries

Authors	Countries	Sample Period	Methodology	Variables	Cointegration	Causality
Yang (2000a)	Taiwan	1954-1997	EG	Coal Consumption; Real GNP per capita	No	Y→ CO
Yang (2000b)	Taiwan	1954-1997	EG	Coal Consumption; Real GDP	No	Y↔ CO
Sari and Soytas (2004)	Turkey	1960-1999	GC; VARGFEVD	Coal Consumption; Real GDP; Employment	N.A	Y × CO
Wolde-Rufael (2004)	Shanghai	1952-1999	GC	Coal Consumption; Real GDP	N.A	Y← CO
Fatai et al. (2004)	Australia; New Zealand	1960-1999	JML; EG	Coal Consumption; Real GDP; Consumer prices	No	Y × CO
	India; Indonesia				No	Y ← CO
	Philippines; Thailand				No	Y↔ CO
Lee and Chang (2005)	Taiwan	1954-2003	JML	Coal Consumption; Real GDP per capita	Yes	Y↔ CO
Yoo (2006)	Korea	1968-2002	JML	Coal Consumption; Real GDP	Yes	Y↔ CO
Zhang and Li (2007)	China	1980-2004	ECM	Coal Consumption; Real GDP	Yes	Y↔ CO
Hu and Lin (2008)	Taiwan	1982.I-2006.IV	Hansen-Seo	Coal Consumption; Real GDP	Yes	Y↔ CO
Yuan et al. (2008)	China	1963-2005	JML; VARGFEVD	Coal Consumption; Real GDP; Capital; Labour	Yes	Y↔ CO
Jin-ke et al. (2008)	China; Japan	1980-2005	EG	Coal Consumption; Real GDP	Yes	Y→ CO
	India; South Korea; South Africa				Yes	Y × CO
Zahid (2008)	Pakistan	1973-2003	ECM; GC	Coal Consumption; Real GDP per capita	Yes	Y ← CO
	India; Bangladesh; Nepal				No	Y × CO
	Sri Lanka				Yes	Y × CO
Khan and Ahmed (2009)	Pakistan	1972-2007	JML	Coal Consumption per capita; real GDP per capita; Consumer prices	Yes	Y→ CO
Ziramba (2009)	South Africa	1980-2005	ARDL; GC	Coal Consumption; Industrial Production; Employment	No	Y × CO CO→ L
Liu et al. (2009)	China	1978-2007	EG	Coal Consumption; Real GDP	No	Y→ CO
Jin-ke et al. (2009)	USA	1980-2005	EG	Coal Consumption; Real GDP	No	N.A
	Japan; China				Yes	Y→ CO
	India; South Africa				Yes	Y × CO
Wolde-Rafael (2010)	China; Korea	1965-2005	GC VARGFEVD	Coal Consumption; Real GDP; Real Gross Capital Formation; Employment	N.A	Y→ CO
	India; Japan				N.A	Y ← CO
	South Africa; USA				N.A	Y↔ CO

Notes: Y, CO and L represent economic growth, coal consumption and labour force. The uni-directional causality from economic growth to coal consumption is indicated by Y→ CO, from coal consumption to economic growth by Y ← CO, bi-directional causality between coal consumption and economic growth by Y↔ CO and no causal relation between both variables by Y × CO. NA represents not applied. In methodology column EG, GC, VARGFEVD, JML, ECM, ARDL means respectively Engle and Granger, Granger causality, Vector Autoregression Generalized Forecast Error Variance Decomposition, Johansen's Maximum Likelihood, Error Correction Model and Autoregressive Distributed Lag techniques.

The Case of Other Developing Countries

There are several empirical studies that have examined the relationship between coal consumption and economic growth for developing countries and yet there seems to be no consensus regarding the direction of causality between these two variables. For instance, Wolde-Rufael (2004) found uni-directional causality running from coal consumption to economic growth for Shanghai as did Fatai et al. (2004) for India and Indonesia and Wolde-Rufael (2010) for India. However, some empirical studies found uni-directional causality running from economic growth to coal consumption, for instance see Yang (2010a) for Taiwan, Jin-ke et al. (2008 & 2009) and Liu et al. (2009) for China and Wolde-Rufael (2010) for China and Korea. Further, bi-directional causality between coal consumption and economic growth was attained by Yang (2000b), Lee and Chang (2005) and Hu and Lin (2008) for Taiwan, Fatai et al. (2004) for Philippines and Thailand, Yoo (2006) for Korea, Zhang and Li (2006) and Yuan et al. (2008) for China and Wolde-Rufael (2010) for South Africa. On contrary, it is also observed that there is no causality between the two variables, for instance see Sari and Soytas (2004) for Turkey, Jin-ke et al. (2008) for India, South Korea and South Africa, Zahid (2008) for India, Bangladesh, Nepal and Sri Lanka, Ziramba (2009) for South Africa and Jin-ke et al. (2009) for India and South Africa. For more details of these studies in relation to their sample periods, methodology, variables and cointegration results; see Table 1.

Empirical Issues

Two important points must be stressed pertaining to the empirical studies on coal consumption and economic growth. First, country specific time series studies on this subject are limited for some developing countries, for instance, only two studies (Zahid, 2008; Khan and Ahmed, 2009) exists for Pakistan. Second, most studies used standard time series methods but failed to consider structural changes in the data series. For example, economic reforms, political disputes, natural disasters, oil price shocks, financial crises etc. must be associated with structural changes in the Pakistan economy. The failure to accommodate structural changes could result in attaining misleading results. Therefore in this article we utilise the production function framework to analyse the impact of coal consumption on economic growth in Pakistan over the period 1971-2009. The structural breaks in the data series are examined with the Lee and Strazicich (2003) method.

3. Specification and Methodology

Specification and Data

Recently, many empirical studies used the production function framework to analyse the relationship between energy consumption and economic growth (for example see Stern, 2000; Ghali and El-Sakka, 2004; Beaudreau, 2005; Sari and Soytas, 2007; Lee and Chiang, 2008; Yuan et al., 2008; Wolde-Rufael, 2008). Following these empirical studies, we utilise the conventional neo-classical production model where labour, capital and coal consumption are treated as separate factor inputs.

$$Y_t = f(K_t, L_t, CO_t) \quad (1)$$

where Y is real GDP, K is real capital stock, L is employment and CO is coal consumption. The log linear specification of the above is as follows:

$$\ln Y_t = \beta_0 + \beta_1 \ln K_t + \beta_2 \ln L_t + \beta_3 \ln CO_t + \varepsilon_t \quad (2)$$

The *iid* error term is denoted by ε. The elasticity of capital stock, employment and coal consumption are denoted by β_1, β_2, and β_3, respectively. We used annual data for Pakistan for the period 1971 to 2009. Data was obtained from Economic Survey of Pakistan (2009-10) and the World Development Indicators (2010).

Lee and Strazicich (2003) Tests

Lee and Strazicich (2003) proposed *LM* unit root tests that allows for two structural breaks. The two breaks in the *LM* unit root tests are endogenously determined and can be explained using two models viz., model A and model C. These models are based on alternative assumptions about structural breaks, for instance model A allows for two shifts in the intercept and model C includes two shifts in the intercept and trend. Models A and C with structural breaks are specified as follows:

$$\text{Model A: } Z_t = [1, t, D_{1t}, D_{2t}]' \quad (3)$$
$$(D_{jt} = 1 \text{ for } t \geq T_{Bj} + 1, j = 1, 2, \text{and } 0 \text{ otherwise})$$
$$\text{Model C: } Z_t = [1, t, D_{1t}, D_{2t}, DT_{1t}, DT_{2t}]' \quad (4)$$
$$(DT_{jt} = t - T_{Bj} \text{ for } t \geq T_{Bj} + 1, j = 1, 2, \text{and } 0 \text{ otherwise})$$

The break date is denoted by T_{Bj}. The null and alternative hypothesis of models A and C, respectively, are given by equations (5) and (6) as follows:

$$H_0 : y_t = \mu_0 + d_1 B_{1t} + d_2 B_{2t} + y_{t-1} + \nu_{1t}; \quad (5)$$
$$H_1 : y_t = \mu_1 + \gamma t + d_1 D_{1t} + d_2 D_{2t} + \nu_{2t};$$

$$H_0 : y_t = \mu_0 + d_1 B_{1t} + d_2 B_{2t} + d_3 D_{1t} + d_4 D_{2t} + y_{t-1} + \nu_{1t}; \quad (6)$$
$$H_1 : y_t = \mu_1 + \gamma t + d_1 D_{1t} + d_2 D_{2t} + d_3 DT_{1t} + d_4 DT_{2t} + \nu_{2t};$$

where $B_{jt} = 1$ for $t = T_{Bj} + 1, j = 1, 2,$ and 0 otherwise. The stationary error terms are represented by ν_{1t} and ν_{2t}. The *LM* unit root test statistic is attained by estimating the following regression:

$$\Delta y_t = \delta' \Delta Z_t + \phi \overline{S}_{t-1} + \mu_t \quad (7)$$

where $\overline{S}_t = y_t - \overline{\psi}_x - Z_t\overline{\delta}$, t=2,....,T; the regression of Δy_t provides estimates of $\overline{\delta}$; $\overline{\psi}_x = y_1 - Z_t\overline{\delta}$ and the first observations of y_t and Z_t are y_1 and Z_1 , respectively. The *LM* test statistics are given by $\overline{\tau}$ which is the test statistic for testing the unit root null hypothesis that ϕ=0. The optimal lag length is selected by observing the significance of the *t*-statistic on the last lag. Initially we allocated a maximum lag length of 8 periods. The break dates are determined where the *LM* test statistic is the minimum. Note that Lee and Strazicich (2004 & 2003) have tabulated the critical values for this test.

ARDL Tests

We utilise the *ARDL* bounds testing approach to examine the relationship between coal consumption and economic growth.[4] The *ARDL* approach entails estimation of the following unrestricted error correction models:

$$\Delta \ln Y_t = a_{oY} + \sum_{i=1}^{n} b_{iY}\Delta \ln Y_{t-1} + \sum_{i=0}^{n} c_{iY}\Delta \ln K_{t-1} + \sum_{i=0}^{n} d_{iY}\Delta \ln L_{t-1} + \sum_{i=0}^{n} e_{iY}\Delta \ln CO_{t-1} + \sigma_{1Y}\ln Y_{t-1} + \sigma_{2Y}\ln K_{t-1} + \sigma_{3Y}\ln L_{t-1} + \sigma_{4Y}\ln CO_{t-1} + \varepsilon_{1t} \quad (8)$$

$$\Delta \ln K_t = a_{oK} + \sum_{i=1}^{n} b_{iK}\Delta \ln K_{t-1} + \sum_{i=0}^{n} c_{iK}\Delta \ln L_{t-1} + \sum_{i=0}^{n} d_{iK}\Delta \ln Y_{t-1} + \sum_{i=0}^{n} e_{iK}\Delta \ln CO_{t-1} + v_{1K}\ln K_{t\text{-}1} + v_{2K}\ln Y_{t\text{-}1} + v_{3K}\ln L_{t\text{-}1} + v_{4K}\ln CO_{t\text{-}1} + \varepsilon_{1t} \quad (9)$$

$$\Delta \ln L_t = a_{oL} + \sum_{i=1}^{n} b_{iL}\Delta \ln L_{t-1} + \sum_{i=0}^{n} c_{iL}\Delta \ln K_{t-1} + \sum_{i=0}^{n} d_{iL}\Delta \ln Y_{t-1} + \sum_{i=0}^{n} e_{iL}\Delta \ln CO_{t-1} + \varpi_{1L}\ln L_{t\text{-}1} + \varpi_{2L}\ln Y_{t\text{-}1} + \varpi_{3L}\ln K_{t\text{-}1} + \varpi_{4L}\ln CO_{t\text{-}1} + \varepsilon_{1t} \quad (10)$$

$$\Delta \ln CO_t = a_{oCO} + \sum_{i=1}^{n} b_{iCO}\Delta \ln CO_{t-1} + \sum_{i=0}^{n} c_{iCO}\Delta \ln K_{t-1} + \sum_{i=0}^{n} d_{iCO}\Delta \ln Y_{t-1} + \sum_{i=0}^{n} e_{iCO}\Delta \ln L_{t-1} + \phi_{1CO}\ln CO_{t\text{-}1} + \phi_{2CO}\ln Y_{t\text{-}1} + \phi_{3CO}\ln K_{t\text{-}1} + \phi_{4CO}\ln L_{t\text{-}1} + \varepsilon_{1t} \quad (11)$$

where ln is the natural log and Δ is the first difference operator. As stated in Pesaran et al. (2001), the *ARDL* procedure includes two steps. First, tests for cointegration between the variables are performed. The *F* tests are employed to test for the existence of cointegrating relationships. In case where a long run relationship is attained, the *F* test dictates which variable should be normalized. Explicitly, the null hypothesis of no cointegration amongst the variables in equation (8) is $(H_0 : \sigma_{1Y} = \sigma_{2Y} = \sigma_{3Y} = \sigma_{4Y} = 0)$ tested against its alternative hypothesis $(H_1 : \sigma_{1Y} \neq \sigma_{2Y} \neq \sigma_{3Y} \neq \sigma_{4Y} \neq 0)$ which is referred to as $F_Y(Y|K, L, CO)$. Similarly, in equation (9)

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[4] Generally the *ARDL* method does not require testing for integrated properties of the variables, however, we did conducted unit root tests because we have also used other time series methods in which pre-testing of the variables are necessary.

where K is the dependent variable, the null hypothesis of no cointegration is $(H_0: v_{1K} = v_{2K} = v_{3K} = v_{4K} = 0)$ against the alternative $(H_1: v_{1K} \neq v_{2K} \neq v_{3K} \neq v_{4K} \neq 0)$, which is referred to as $F_K(K|Y,L,CO)$. However, in equations 10 and 11 the null hypotheses of no cointegration among the variables are $(H_0: \varpi_{1L} = \varpi_{2L} = \varpi_{3L} = \varpi_{4L} = 0)$ and $(H_0: \phi_{1CO} = \phi_{2CO} = \phi_{3CO} = \phi_{4CO} = 0)$ respectively, tested against the alternative $(H_1: \varpi_{1L} \neq \varpi_{2L} \neq \varpi_{3L} \neq \varpi_{4L} \neq 0)$ and $(H_1: \phi_{1CO} \neq \phi_{2CO} \neq \phi_{3CO} \neq \phi_{4CO} \neq 0)$, denoted as $F_L(L|Y,K,CO)$ and $F_{CO}(CO|Y,K,L)$, respectively.

Pesaran and Pesaran (1997) have reported two sets of critical values (*CVs*) where one set is calculated assuming that all variables included in the *ARDL* model are *I*(1) and the other is estimated assuming the variables are *I*(0). If the computed *F* values fall outside the inclusive band, a conclusive decision could be drawn without knowing the order of integration of the variables. Secondly, a further two-step procedure to estimate the model is performed. In the first step of the second stage, the Akaike Information Criteria (*AIC*) or the Schwarz Bayesian Criteria (*SBC*) can be used to determine the orders of the lags in the *ARDL* model. The second step entails estimating the long run coefficients and the error correction model (*ECM*) of the chosen *ARDL* model.

VECM Granger Causality

The existence of cointegration implies Granger causality though it does not indicate the direction of causality. To facilitate an analysis of the direction of causality the Johansen's *VECM* method is employed to assess the causality direction. This requires estimating the following models:

$$\Delta \ln Y_t = \upsilon + \sum_{i=1}^{n} \theta_i \Delta \ln Y_{t-1} + \sum_{i=1}^{n} k_i \Delta \ln K_{t-1} + \sum_{i=1}^{n} \delta_i \Delta \ln L_{t-1} + \sum_{i=1}^{n} \sigma_i \Delta \ln CO_{t-1} + \pi_1 ECT_{t-1} + \varepsilon_{1t} \quad (12)$$

$$\Delta \ln K_t = \upsilon + \sum_{i=1}^{n} k_i \Delta \ln K_{t-1} + \sum_{i=1}^{n} \beta_i \Delta \ln Y_{t-1} + \sum_{i=1}^{n} \varphi_i \Delta \ln L_{t-1} + \sum_{i=1}^{n} \delta_i \Delta \ln CO_{t-1} + \pi_2 ECT_{t-1} + \varepsilon_{2t} \quad (13)$$

$$\Delta \ln L_t = \upsilon + \sum_{i=1}^{n} \delta_i \Delta \ln L_{t-1} + \sum_{i=1}^{n} \gamma_i \Delta \ln Y_{t-1} + \sum_{i=1}^{n} \varpi_i \Delta \ln K_{t-1} + \sum_{i=1}^{n} \theta_i \Delta \ln CO_{t-1} + \pi_3 ECT_{t-1} + \varepsilon_{3t} \quad (14)$$

$$\Delta \ln CO_t = \upsilon + \sum_{i=1}^{n} \sigma_i \Delta \ln CO_{t-1} + \sum_{i=1}^{n} \rho_i \Delta \ln Y_{t-1} + \sum_{i=1}^{n} \psi_i \Delta \ln K_{t-1} + \sum_{i=1}^{n} \lambda_i \Delta \ln L_{t-1} + \pi_4 ECT_{t-1} + \varepsilon_{4t} \quad (15)$$

where the lagged error correction term derived from the long run cointegrating relationship is represented by ECT_{t-1}. The serially independent random errors are $\varepsilon_{1t}, \varepsilon_{2t}, \varepsilon_{3t}$ and ε_{4t} which have zero means and finite covariance matrices. The optimal lag lengths are selected using the *SBC* Criterion. The results for causality are obtained by regressing the respective dependent variables against past values of both itself and other variables. Note that the *VECM* provides results not only for long run causality but also for short run causality depending upon the significance of coefficient of *ECTs* and coefficient of lagged terms of independent variables.

4. Empirical Results

Lee and Strazicich (2003) Tests

The *ARDL* technique does not entail testing the integrated properties of the variables, nevertheless, we applied the endogenous two break minimum *LM* unit root tests proposed by Lee and Strazicich (2003) to ensure robustness of our results. Table 2 presents the *LM* unit root tests based on models A (two breaks in the intercept) and C (two breaks in the intercept and trend). The test statistics of the *LM* unit root tests for the four variables (real income, real capital stock, labour and coal consumption) do not exceed the critical values in absolute terms and therefore the unit root null cannot be rejected at 5% level. The *t*-statistics for break dates are not reported however they are significant at conventional levels. Both the models provided fairly consistent break dates and these are expected for this economy. For instance, since 2000 Pakistan implemented a number of economic reforms and also experienced political turmoil and destructive natural disasters. Further, break dates in mid 1980s and late 1990s are also reasonable because Pakistan deregulated her financial market during 1980s and later in 1990s the Asian financial crises reduced the economic activity. Thus it is worth noting that the conventional unit root tests which do not consider structural breaks could result in misleading inferences regarding the order of integration of the variables and their cointegrating relationships.

Table 2. Two-break minimum *LM* unit root test

	Model A		Model C	
Variables	Test Statistic	Break Dates	Test Statistic	Break Dates
ln*Y*	-2.187 [5]	1985; 2002	-1.363 [2]	2000; 2002
ln*K*	-3.036 [7]	2002; 2003	-2.477 [4]	1986; 2002
ln*L*	-1.736 [5]	1984; 2005	-3.768 [3]	2000; 2005
ln*CO*	-2.140 [6]	1998; 2000	-3.011 [2]	2002; 2003

The 5% critical values for Models A and C are -3.842 and -5.286, respectively. The number in [] indicates the optimal number of lagged first-differenced terms included in the unit root test to correct for serial correlation. The critical values are taken from Lee and Strazicich (2004 and 2003).

Cointegration Tests

The *ARDL* technique is applied to test for cointegration between the variables in equations (8) to (11). This determines whether a long run relationship exists between real income, real capital stock, labour and coal consumption. The optimal lag order is selected following the minimum values of both *AIC* and *SBC* criterion. Both indicated a lag length of 2 periods. The existence of a cointegrating relationship between the variables is tested with the *F* test. First, when *Y* is the dependent variable, the computed *F* statistic (6.236) is greater than the upper bound of the 95 percent critical value (4.378) resulting in the rejection of the null hypothesis of no cointegration. However, when *K, L, CO* are selected as endogenous variables, the computed *F* statistics (3.004, 1.258 and 2.064, respectively) are lower than the critical value thus accepting the null hypothesis of no cointegration. Explicitly, these results imply that there is a long run relationship when real income is the dependent variable and real capital, labour and coal consumption are explanatory variables.

Long- and Short-run Estimates

The *ARDL*, *GETS*, *DOLS*, *EG* and *FMOLS* cointegrating equations are reported in Table 3.[5] The five estimation techniques provided consistent estimates and reveal that coal consumption is positively linked with real income in Pakistan over this time period. The crucial coefficients viz., ln*K*, ln*L* and ln*CO* are statistically significant at 5 per cent level. The estimates of coal consumption imply that 1% increase in coal consumption leads to an increase in real income of between 0.11% to 0.14 %. The impact of capital and labour on real income is also positive and statistically significant at 5 percent level. The capital share of output is between 0.35 to 0.37 and this is not significantly different from its stylised value of one third. The labour share of output is also reasonable (between 0.67 to 0.76).

Table 3. Alternative Long-run Estimates

	ARDL	GETS	DOLS	EG	FMOLS
Constant	0.357 (7.46)*	3.275 (1.68)**	3.470 (2.01)*	1.730 (1.87)**	6.257 (4.01)*
ln*K*	0.359 (3.55)*	0.350 (4.30)*	0.356 (2.99)*	0.372 (2.49)*	0.361 (3.13)*
ln*L*	0.724 (2.03)*	0.711 (5.88)*	0.755 (4.07)*	0.666 (2.47)*	0.704 (2.23)*
ln*CO*	0.122 (2.68)*	0.135 (4.35)*	0.126 (2.66)*	0.105 (3.64)*	0.120 (2.97)*

Absolute *t*-statistics are reported in parenthesis underneath the estimates. Significance at 5% and 10% levels are denoted by * and **.

Our implied long run estimates are comparable to Yuan et al. (2008) for China. However, our results contrast with those provided by Apergis and Payne (2010a and b) where they utilised panel data estimation methods and found significant negative impact of coal consumption on economic growth for *OECD* countries and emerging market economies.

The short run results are reported in Table 4. It is observed that coal consumption has a significant positive impact on economic growth in the short run. Similar inferences could also be drawn for capital and labour on economic growth. Importantly, the estimate of the lagged error term (ECM_{t-1}) has the expected negative sign and is significant at 5% level. This corroborates the established long run relationship among the variables. The ECM_{t-1} serves as the negative feedback mechanism and implies that departures from equilibrium in the previous period are reduced by about 20% in the subsequent period. The adjusted R^2 is reasonable and the diagnostic tests imply that there is no serial correlation, functional form misspecification, non-normality and heteroscedasticity in the residuals. Further, the stability tests of cumulative sum (*CUSUM*) and cumulative sum of squares (*CUSUMSQ*) have also been used to investigate the stability of long-

[5] For more details on the application of these time series methods; see Kumar et al. (2010a and 2010b).

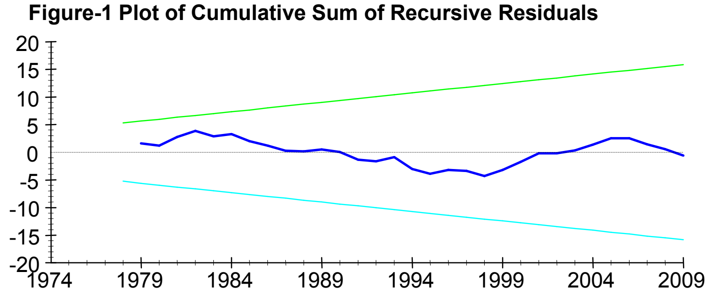
and short-run parameters. To this end, the *CUSUM* and *CUSUMSQ* tests revealed that our selected *ARDL* model is stable; see Figures 1 and 2.

Table 4. ARDL Short-run Estimates

Variables	Coefficients
Constant	6.825 (1.72)**
$\Delta\ln CO_t$	0.167 (3.77)*
$\Delta\ln K_t$	0.259 (2.13)*
$\Delta\ln L_t$	0.903 (4.05)*
ECM_{t-1}	-0.199 (6.11)*
Adjusted R^2	0.732
SEE	0.011
$\chi^2(sc)$	0.005 [0.99]
$\chi^2(ff)$	9.620 [0.38]
$\chi^2(n)$	0.102 [0.95]
$\chi^2(hs)$	0.482 [0.49]

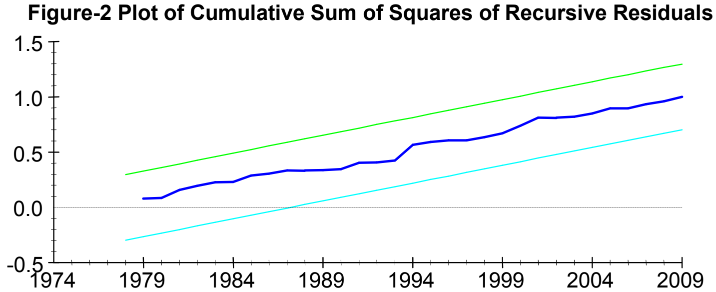
Notes: Absolute *t*-ratios are in the parentheses below the coefficients; *p*-values are in the square brackets for the X^2 tests. Significance at 5% and 10% level, respectively, denoted by * and **.

Figure-1 Plot of Cumulative Sum of Recursive Residuals



The straight lines represent critical bounds at 5% significance level

Figure-2 Plot of Cumulative Sum of Squares of Recursive Residuals



The straight lines represent critical bounds at 5% significance level

Granger Causality Tests

The Granger causality tests highlight the direction of causality among the variables viz., income, capital, labour and coal consumption. This is useful for policy makers to formulate appropriate policies related to energy and development. We utilised the *VECM* based Granger causality tests for both short-and long-run situations. The long run causality among the variables is indicated by the significance of the estimate of one period lagged error correction term (ECT_{t-1}). The joint significance *LR* test of the lagged explanatory variables signifies the short run causality. The results are reported in Table 5.

Table 5. Results of Granger Causality Tests

Dependent Variable	F-statistics				ECT_{t-1}
	$\Delta \ln Y_t$	$\Delta \ln CO_t$	$\Delta \ln K_t$	$\Delta \ln L_t$	
$\Delta \ln Y_t$	-	0.002 [0.00]*	0.401 [0.04]*	0.967 [0.03]*	-0.126 [0.00]*
$\Delta \ln CO_t$	0.257 [0.00]*	-	0.871 [0.65]	1.026 [0.12]	-0.252 [0.15]
$\Delta \ln K_t$	0.769 [0.43]	0.572 [0.59]	-	1.147 [0.15]	-0.109 [0.24]
$\Delta \ln L_t$	0.354 [0.21]	0.493 [0.47]	0.012 [0.66]	-	-0.199 [0.30]

Note: The *p*-values are reported in the square parenthesis. * denotes significance at 5% level.

In the short run, capital, labour and coal consumption are statistically significant at the 5% level in the income equation. However, all estimates are insignificant when coal consumption, capital and labour are dependent variables, except income in coal consumption equation. These results imply bi-directional Granger causality between income and coal consumption in the short run. Moreover, there is uni-directional causality in the short run from capital and labour to income.

In contrast, the long run results of the Granger causality test imply that capital, labour and coal consumption Granger causes income in the long run. Note that the estimate of ECT_{t-1} is significant at the 5% level with the expected negative sign in the income equation. These findings are comparable to Masih and Masih (1996) for Pakistan, Lee and Chang (2005) for Taiwan and Yuan et al. (2008) for China. However, Zahid (2008) found that uni-directional causality exists from coal consumption to economic growth for Pakistan, which seems to contrast with our findings.

5. Conclusion

In this article, we examined the relationship between coal consumption and economic growth for Pakistan using the production function framework. The endogenous two break minimum *LM* unit root tests indicated that the level variables are non-stationary and provided fairly consistent break dates that highlight structural changes in this economy in early 2000s, late 1990s and mid 1980s. These break dates may signify a number of events related to Pakistan economy, for instance, economic reforms, Asian financial crises, destructive natural disasters, political instabilities etc. The *ARDL* bounds test technique was utilised to test for cointegration among the variables and to estimate the cointegrating equations. These results suggest that there is a cointegrating relationship between real income, real capital stock, labour and coal consumption. To confirm the robustness of the results, we also used *GETS*, *EG*, *DOLS* and *FMOLS* techniques. All five methods of estimation provided consistent results regarding the impact of coal consumption on economic growth with coal consumption elasticities ranging between 0.11 to 0.14. This implies that a 1% increase in coal consumption leads to a 0.11-0.14% increase in the income. The elasticity with respect to capital and labour are also reasonable and close to their stylised values of one third and two third, respectively.

Further, the *VECM* based Granger causality tests were used to confirm the causality direction between the variables. These tests provide useful insights for policy related to energy (coal) conservation and economic growth. In the short run, we find that there exists bi-directional Granger causality between income and coal consumption and uni-directional causality from capital and labour to income. However, the long run Granger causality tests reveal that capital, labour and coal consumption Granger causes income in the long run. These results imply that energy (coal) conservation policies may retard economic growth and also fluctuations in economic growth may distort the consumption of coal. Therefore, there is need to explore new sources of coal that must be safe, clean and cheaper in the country.

This study by no means settles the concerns surrounding the use of coal in relation to its impact on economic growth and the environment. Future research can be pursued along several avenues. First, the incorporation of carbon dioxide emissions within the modeling of the coal consumption–growth nexus may provide further insights on the environmental consequences of coal usage. Secondly, the examination of the coal consumption–growth relationship within a non- linear framework could be informative; for instance threshold cointegration analysis of coal-consumption and growth as suggested by Hu and Lin (2008). Thirdly, future empirical works could allow for structural breaks in the cointegrating equation of coal consumption; for example see Gregory and Hansen (1996a and 1996b).

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