Revisiting Energy Consumption and GDP: Evidence from Dynamic Panel Data Analysis

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Abstract

In recent years the issues of energy consumption and economic development have become the concern of many parties, particularly policy makers. The empirical outcomes of previous studies examining the relationship between energy consumption and economic growth have been inconclusive and conflicting due to different sample periods, variables used, countries studied and econometric techniques employed. Utilising dynamic panel data GMM-system estimator on datasets of selected 23 countries across 12 years ranging from 2000-2011, this paper shows evidence of uni-directional causality between energy consumption and GDP. In energy consumption model, the GDP is found to significantly determine energy consumption, whereas in the GDP model, energy consumption has however less significant effect on GDP. Energy price and investment are the other important determinants of energy consumption and income, respectively.

***Keywords*: Energy consumption; Economic growth; Panel Data Analysis; System GMM**

1. Introduction

Classical and neoclassical economists made specific comments about the significance of nature and environment, but did not include them in their exposition of theories. Environmental economics attempts to promote economic growth of nations with least environmental damage. Classical and neoclassical school of thoughts underestimated the environmental issues of production and consumption, since these issues merely viewed as social issues. When the environmental goods get transferred into economic goods, the problems of environmental damage crop up, and therefore the need to interact with economic principles. Therefore, a study of environmental economics calls for a detailed understandings about various environmental factors, their influence in the economy, their functions upon the environment, and their impacts upon the life of the people of the present and future.

In general, there are four views exist regarding the causal relationship between energy consumption and economic growth. The first view argues that economic development and growth affects energy use rather than vice versa. The second view stressed the importance of considering energy as an essential factor of production in addition to capital, labor and materials. Thus, energy is necessary for growth. The third view contends that both energy consumption and economic growth cause each other. The fourth view argues that there is no relationship between energy consumption and economic growth. In other words, both energy

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consumption and economic growth are neutral with respect to each other.

Huang *et al.* (2008) has provided an excellent review of previous literatures on the relationship between GDP growth and energy consumption. From the studies as early as in 1978 by Kraft and Kraft (1978) to the latest evidence by Lee and Chang (2007) before when Huang *et al.*'s study is conducted, and they summarise the results in Table 1 of their paper[†]. A quick glance of Table 1 reveals a rather mixed or inconclusive evidence of causality between GDP or income and energy consumption.

The most recent study related to energy consumption and economic growth is conducted by Shabaz *et al.* (2013). The paper analyses the relationship between economic growth, energy consumption and carbon emissions for a period of 1980-2010 in case of Romania. They employed the ARDL bounds testing approach to investigate the long run cointegration. This study confirms long run relationship between economic growth, energy consumption and energy pollutants.

Ouedraogo and Diarra (2010) stress that a country that is energy dependent (a county in which causality runs from energy consumption to growth) will have a cautious energy policy because any negative shock on energy supply will have effects on economic growth. On the other hand, in an economy where energy consumption is determined by economic growth (a country in which the direction of causality runs from economic growth to energy consumption) an energy conservation policy have very little effect on economic growth.

Our paper revisits the relationship and would like to test the direction of causality between energy consumption and GDP after controlling the additional variables commonly found to determine the energy consumption and GDP. The reminder of the paper is structured as follows: the next section describes the data and methodology. Section 3 presents and explains the empirical results. The final section provides conclusions.

2. Data Sources, Framework, and Methodology

The data for this study covers 23 countries and a period of 12 years from 2000-2011. Data on energy consumption and energy prices are obtained from the U.S. Energy Information Administration (EIA, 2012). The data on real GDP per capita, population and gross capital formation are taken from World Development Indicator (World Bank, 2012). The energy consumption model for this study is represented in the following equations:

$$EC_{it} = \alpha EC_{it-1} + \beta_1 GDP_{it} + +\beta_2 EP_{it} + \beta_3 POP_{it} + v_i + \varepsilon_{it} \qquad (1)$$

Where EC = energy consumption measured by kilograms (kg) of oil equivalent of energy use per capita
GDP = real GDP per capita in US dollars based on the 2000 constant price
EP = energy price in U.S. dollars per gallon, including taxes
POP = population (millions)

The presence of the lagged dependent variable EC_{it-1} in the model indicates the dynamic nature of energy consumption which explains the interdependent energy consumption across periods. Ones would expect naturally a production process would require stable and continuous level of energy consumption. In other words the level of energy consumption would normally follow the similar pattern of the previous period consumption. Similarly, the overall energy consumption by the end-user is assumed to invariably

[†] For the sake of brevity, we omitted the Table 1 by Huang *et al.* (2008) from this paper. Please refer page 43 of Huang *et al.* paper for more details of the energy consumption and economic growth studies and the studies' respective findings covered by their study.

follow the similar pattern without sudden shocks. GDP_{it} is real GDP per capita which is the variable of interests whose relationship previously shown in the literature review to be yet inconclusive. The other variables namely EP_{it}, energy price, and POP_{it}, population, are the control variables which have been shown to influence the energy consumption. Price of energy would determine the energy consumption (energy demand) negatively and population size is expected to have effect of energy consumption. The effect could either be positive or negative depending on the energy conservation policy that is normally implemented subsequent to the excess energy consumption which either could have positive or negative response by the population. Population would normally be thought to have positive relationship to energy consumption, but if population increase results in more people adopting efficient use of energy, we could see a negative relationship between population and energy consumption.

The second model is the GDP model adapted from Solow neoclassical model, augmented with energy consumption as the variable of interest, in addition to the steady state parameters, i.e., population and investment proxied by gross fixed capital formation:

$$GDP_{it} = \alpha GDP_{it-1} + \beta_1 EC_{it} + + \beta_2 CAP_{it} + \beta_3 POP_{it} + v_i + \varepsilon_{it} \tag{2}$$

where GDP = real GDP per capita in US dollars based on the 2000 constant price
EC = energy consumption measured by kilograms (kg) of oil equivalent of energy use per capita
CAP = gross capital formation to reflect the level of investment
POP = population (millions)

In this study, we employ a relatively new and advanced estimation method namely system GMM to estimate an energy consumption and the GDP model as in Equation (1) and (2). System GMM is developed by Arellano and Bover (1995) and Blundell and Bond (1998) and the method is considered more superior than difference GMM. Bond *et al*. (2001) argue this method is able to correct unobserved country heterogeneity, omitted variable bias, measurement error, and potential endogeneity that frequently affect growth estimation.

This technique combines in a system the relevant regressions expressed in first-differences and in levels. First-differencing checks for unobserved heterogeneity and omitted variable bias, as well as for time-invariant component of the measurement error. It also corrects endogeneity bias (time-varying component) via instrumenting the explanatory variables. Instruments for differenced equations are obtained from values (levels) of explanatory variables lagged at least twice, and instruments for levels equations are lagged differences of the variable. Estimating two equations in a system GMM reduced potential bias and imprecision associated with a simple first-difference GMM estimator (Arrellano and Bover, (1995), Blundell and Bond (1998))[‡]. Alonso-Borrego and Arellano (1999), and Blundell and Bond (1998) point out that when explanatory variables are persistent over time, lagged levels of these variables make weak instruments for regression in differences, and instrument weakness in turn influences the asymptotic and the small-sample performance of the difference estimator. Asymptotically, variance of the coefficients will rise, and in small

[‡] See Arellano and Bover (1995) and Blundell and Bond (1998) for more detailed explanation of the dynamic panel system GMM, its moment conditions and stationarity assumptions which shown to outperform difference GMM and static panel model such as Fixed effect and Pooled OLS.

sample, Monte Carlo experiments show that weak instruments can produce biased coefficients.

Consistency of the GMM estimator depends on the validity of the instruments. As suggested by Arellano and Bond (1991), Arellano and Bover (1995), and Blundell and Bond (1998), two specification tests are used. Firstly, Sargan/Hansen test of over-identifying restrictions which tests for overall validity of the instruments and the null hypothesis is that all instruments as a group are exogenous. The second test examines the null hypothesis that error term ε_{it} of the differenced equation is not serially correlated particularly at the second order (AR2)[§] Ones should not reject the null hypothesis of both tests.

For additional robustness check, as far as the results are concerned, we also estimate Equation (1) and (2) using cross sectional (Pooled Ordinary Least Square- Pooled OLS) and panel fixed effect methods.

3. Estimation Results and Discussion

As shown in Table 1 below, Real GDP per capita emerges the significant determinant of energy consumption at 1% level across all estimation techniques with the exception of Pooled OLS. Since the system GMM is superior estimator, it can be inferred that for every 1% change in income, energy consumption would increase by about 6%. The significance of energy price at 1% level in all four estimation techniques is not unexpected and the negative sign is naturally in line with the theory that shows negative relationship between price and demand of energy. The lagged energy consumption coefficient too is significant at 1% level arguably vindicating the assumption of dynamic nature of the energy consumption.

The instruments validity and reliability are indicated by the serial correlation tests (AR(1) and AR(2)) and the Hansen test. P-value of AR tests indicates the presence of serial correlation at first order but not at second order. As explained in footnote 3 earlier, the differenced in error term is probably serially correlated at first order even though the original error is not. Meanwhile, the Hansen test shows that we are unable to reject the null hypothesis of overall exogeneity of the instruments used in the estimation of dynamic system GMM.

Table 1: Energy consumption estimation against GDP

	Pooled OLS	Fixed effect	Difference GMM	System GMM
Constant	0.334***	2.739		0.420
	(0.093)	(2.333)		(0.263)
Lagged energy consumption	0.959***	0.591***	0.366***	0.924***
	(0.034)	(0.095)	(0.119)	(0.036)
Energy price	-0.080**	-0.578***	-1.103***	-0.222***
	(0.040)	(0.084)	(0.208)	(0.043)
Real GDP percapita	0.020	**0.133*** **	**0.269*** **	**0.057*** **
	(0.025)	**(0.025)**	**(0.044)**	**(0.019)**
Population	-0.003	0.019	-0.173	0.003
	(0.003)	(0.154)	(0.296)	(0.007)
Observations	246	246	223	246
R-squared	0.997	0.998		
Adj. R-squared	0.997	0.998		
Number of countries			23	23
No. of instruments			17	30
AR1 p-value			0.046	0.029
AR2 p-value			**0.538**	**0.293**
Hansen p-value			0.150	0.589

Note: Dependent variable is energy consumption. All variables are in natural log. Robust standard errors in parentheses. ***, ** and * indicate the coefficients are significant are 1%, 5% and 10% respectively.

[§] By construction, the differenced error term is probably serially correlated at first-order even if the original error is not. While most studies that employ GMM dynamic estimation report the test for first order serial correlation, some do not.

Table 2: GDP estimation against energy consumption

	Pooled OLS	Fixed effect	Difference GMM	System GMM
Constant	-0.138	-16.907***		-0.515
	(0.173)	(4.683)		(0.364)
Lagged GDP	0.991***	0.828***	0.779***	0.993***
	(0.012)	(0.035)	(0.083)	(0.016)
Energy consumption	0.002	**0.170****	**0.550****	0.014
	(0.017)	**(0.085)**	**(0.228)**	(0.042)
Capital Formation	0.101***	0.231***	0.285*	0.181***
	(0.034)	(0.079)	(0.143)	(0.028)
Population	-0.002	0.954***	0.998	-0.002
	(0.004)	(0.277)	(0.743)	(0.007)
Observations	246	246	223	246
R-squared	0.996	0.996		
Adj. R-squared	0.996	0.996		
Number of code			23	23
No. of instruments			17	30
AR1 p-value			0.020	0.008
AR2 p-value			**0.001**	**0.000**
Hansen p-value			0.091	0.608

Dependent variable is Real GDP percapita. All variables are in natural log. Robust standard errors in parentheses. ***, ** and * indicate the coefficients are significant are 1%, 5% and 10% respectively.

In the GDP model, as presented in Table 2, energy consumption have positive significance effect on income but only in fixed effect and difference GMM models, but not in Pooled OLS and system GMM, and the level of significance is somewhat smaller at 5% (recall that income significantly determined energy consumption at 1% level). Since the system GMM is the superior estimator, we conclude that the causality between GDP and energy consumption is uni-directional i.e. income significantly causes an increase in the level of energy consumption. The significant of lagged income indicate the dynamic nature of the GDP but the sign is positive which could be the outcome of regression of the GDP in level and not in growth. Meanwhile, the investment effect on GDP is evidenced by the significance of capital formation variable coefficients at 1% confidence level which is in accordance with the theory.

The regression of real GDP percapita over energy consumption and other control variables however has statistical issues as the system GMM estimator is shown to have serial correlation at both first and second order correlation. Notwithstanding that, the instruments on overall are exogenous as shown by the p-value of Hansen test of 0.608.

4. Conclusions

Utilising dynamic panel data GMM, the present study examines the energy consumption and GDP relationship based on two models namely energy consumption model and the GDP model. The results from the first model show that real GDP per capita is the significant determinant of energy consumption, whereas the second model indicates that energy consumption has less explanatory power on real GDP percapita. This implies that the causality runs from real GDP percapita to energy consumption and not the other way around. The policy implication of this findings is that the policy makers must cautiously implement economic development policies which aim to promote more endavours towards environmental friendly energy use and thereore reducing harm from such economic development strategies. Expressed differently, policy makers should promote strategies with greater emphasis given to environmental considerations in their development strategies as a precaution to global warming, climate change and sustainable development issues.

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