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A Study Investigating the Effects of Health and Energy Consumption on Economic Growth in the US by using the ARDL Bounds Testing and Variance Decomposition Approach

Hung-Ming Wu
Assistant Professor
Department of Public Finance and Taxation
Aletheia University No. 32, Zhenli Street, Tamsui Dist., New Taipei City, 25103
Taiwan, R.O.C.

Shu-Chin Su
Assistant Professor
Department of English
Aletheia University No. 32, Zhenli Street, Tamsui Dist., New Taipei City, 25103
Taiwan, R.O.C

Abstract

The purpose of this study was to explore the effects of energy consumption and health (with Life expectancy at birth as a proxy) on economic growth in the US using the neo-classical production function. The Autoregressive distributed lag (ARDL) bounded testing approach with additional variables (energy consumption and health) was used to investigate co integration during the period of 1960-2013 in the US. The Variance Decomposition approach was also used to check the robustness. The ARDL revealed a co integration relationship among energy consumption, health, capital and economic growth. The dimension of Energy consumption revealed only short-run impacts on economic development. Health had only long-run impacts on economic growth, while Capital had both short and long-run impacts. As a result, energy conservation policies can be implemented since energy consumption only displayed short- term effects on economic growth. It is suggested that the US government could boost economic growth by increasing budget levels directed at health

Keywords: ARDL; energy consumption; life expectancy; economic growth; Variance Decomposition

JEL Classifications: C5; Q43

1. Introduction

Anthropogenic global warming (AGW) has become a serious problem and issue for all the countries in the world. Using energy efficiently while protecting the environment is very important for future generations. The US needs to take the lead in this area, using its highly developed technology sector. The hypothesis of this study was that the health, energy consumption, and economic growth (income) may have been correlated to keep a good life for citizens. Therefore, the purpose of this study is to explore the relationship among health, energy consumption, and economic growth in a case of the US. The study used the ARDL approach in the neo-classical production function to find the effects of health and energy consumption on economic growth.

The relationship between energy consumption and economic growth has been discussed since the 1970s (Kraft & Kraft, 1978). Smyth and Narayan (2014), Ozturk (2010), and Payne (2010) further addressed the relationship between energy consumption and economic growth. They argued that previous studies had been conducted in different countries, in different time periods, or using different models; therefore, they obtained different results regarding the relationship between these two variables. Numerous studies discussing the relationship between health and economic growth were inconclusive. Some found a positive relationship between these two variables (Bloom, Canning & Sevilla, 2004; Gangadharan & Valenzuela, 2001; Preston, 1980), while Acemoglu and Johnson (2007) found no positive relationship between life expectancy and economic growth.

Some authors suggested an inverted-u shape relationship between health and economic growth, which would mean that low levels of effort expended increasing health, would increase economic growth, but the impact would become negative at higher levels (Kunze, 2014; An & Jeon, 2006).

This study was the first empirical study that used the variables (economic growth, capital, energy consumption, and health) with the advanced and well-established ARDL bounds testing approach (Pesaran, Shin & Smith, 2001) to investigate any long-term and short-term cointegration relationships among these variables in the US. In this study, variance decomposition was also used to check robustness (Lütkepohl, 2005).

2. Literature Review

In order to comprehend the impact of health and energy consumption on economic growth, this literature review focuses on two major foci of these past studies: the health- economic growth nexus and the energy consumption - economic growth nexus.

2.1. Health-Economic Growth Nexus

The relationship between health and economic growth was analyzed in recent years (Azam & Ahmed, 2015). Preston (1980) argued that there was a positive relationship between health and income. Gangadharan and Valenzuela (2001) used two-stage least squares model to explain the relationship between health, environmental quality and economic growth. They also claimed that a healthier labour force would increase productivity levels, and hence would generate better income levels and economic productivity. Bloom et.al (2004) estimated a production function for human capital which included two components (work experience and health). Their result showed that health had a positive and statistically significant relationship with aggregate output. The theoretical research of Kunze (2014) indicated that the relationship between life expectancy and economic prosperity depended on the intergenerational transfers of bequests. An and Jeon (2006) use panel data model and argue that population aging and economic growth have an inverted-U shape relationship

2.2. Energy Consumption- Economic Growth Nexus

In the early 1970s, Kraft and Kraft (1978) used the bivariate model to perform the original study of the energy-growth relationship. They reported a unidirectional causality relationship running from Gross National Product（GNP）to energy consumption but not vice versa. In the same bivariate models, other authors found that the relationship between energy use and income were inconclusive (Akarca & Long, 1980; Dagher & Yacoubian, 2012; Eden& Hwang, 1984). Since those bivariate models only used two variables, they might obtain biased results due to missing variable(s).

When the multivariate VAR model has been used, the authors found that energy consumption did affect economic growth (Ewing, Sari & Soytas, 2007; Stern, 1993). Soytas and Sari (2006) used the multivariate framework and found that the direction of causality seemed to differ across countries. In order to obtain long-run information, cointegration analysis was used. Stern (2000) extended his previous study by using the multivariate VAR model (Stern, 1993) in the US to do the cointegration analysis. He discovered that the energy consumption had a long-run relationship with output. On the other hand, Yu and Jin (1992) used the co integration test and claimed that energy consumption had no long-turn relationship with output in the US case. In order to test the short-turn and long-turn relationship between energy and output, Oh and Lee, (2004) used the vector error correction model (VECM) and found that there was a short-run relationship between energy and output but no long- term causal relationship. Shahiduzzaman and Alam, (2012) found a bidirectional causality between energy and output by using a VECM model. One weakness of the VECM model, however, is that all variables need to be the same order of integration and same lag-lengths. In order to avoid these issues, this study employed an ARDL model, which does not have the same restrictions on order of integration and lag-lengths.

Although some of studies have investigated the energy consumption- economic growth nexus and others investigated the health-economic growth nexus, very few studies have examined the relationship among energy consumption, health, and economic growth with a production function. Therefore, this study performed an in-depth empirical analysis of both the short-term and long-term impacts of energy consumption and health on economic growth in the US with a production function and an advanced methodology-ARDL bound testing procedure.

3. *Data and Methodology*

This study follows recent studies that use the energy consumption as one important production input (Ghali & El-Sakka, 2004; Lean and Smyth, 2014; Shahiduzzaman & Alam, 2012; Wu, 2015). Health is also considered as an important input of production (Bloom & Sevilla, 2004). According to the existing literature, the impact of energy consumption and health on economic growth is empirically described by the following model:

$$\ln y_t = \beta_0 + \beta_1 \ln k_t + \beta_2 \ln e_t + \beta_3 \ln life_t + \mu_t \qquad (1)$$

where *y* is GDP per capita at constant price (constant 2010 US$) (a proxy for economic growth), *k* is capital per capita (Gross fixed capital formation (constant 2010 US$), *e* is energy consumption in kg of oil equivalent per capita, *life* is health proxies by average life expectancy at birth, and μ_t is a term of stationary error. All variables are taken by the natural log (written by *ln*). All data were obtained from World Development Indicators (WDI, by the World Bank).

3.1 ARDL analysis

The autoregressive distributed lag model (ARDL) was used to test for co integration and to estimate long-run and short-run dynamics. The ARDL model offers an advantage when handling variables, in that the variables may include a mixture of stationary and non-stationary time-series, for example, integrated of order (1) or (0). Another advantage of the model was that it was easy to implement and interpret since it involved only a single-equation arrangement. A third advantage was that different variables of the model could be assigned different lag-lengths (Pesaran et al. 2001). In order to find the long-run and short- run relationship, the dynamic error correction model has been used, which derived by ARDL model. The model is presented as follows:

$$\begin{aligned}\Delta \ln y_t = \alpha_0 &+ \sum_{i=1}^{n1} \phi_i \Delta \ln y_{t-i} + \sum_{i=0}^{n2} \varphi_i \Delta \ln k_{t-i} + \sum_{i=0}^{n3} \gamma_i \Delta \ln e_{t-i} + \sum_{i=0}^{n4} \eta_i \Delta \ln life_{t-i} + \\ &\lambda_1 \ln y_{t-1} + \lambda_2 \ln k_{t-1} + \lambda_3 \ln e_{t-1} + \lambda_4 \ln life_{t-1} + \varepsilon_t \, * \qquad (2)\end{aligned}$$

Notes: * the equation is adjusted from Wu (2015), p4. Equation 3.

where ϕ ,φ,γ and η are short-run parameters and λ_1 toλ_4 are long-run parameters. To test co integration, the null hypothesis is set to H_0: $\lambda_1=\lambda_2=\lambda_3=\lambda_4=0$ against the alternative hypothesis H_1 is at least one of the λ's not zero. A rejection of the null hypothesis implies that the model has a long-run (co integration) relationship. Pesaran et al. (2001) provided the upper bounds and lower bounds on different numbers of variables to be the critical values. The upper bound (UB) was based on the assumption that all variables are I(1) and the lower bound (LB) applied if the series were I(0). An F-statistic above the UB indicates co integration. An F-statistic below the LB indicates that there was no co integration. If the F-statistic fell between the UB and LB, the test was inconclusive.

The Akaike Information Criterion (AIC) was used to select the orders of the lags for the specification in the ARDL model. AIC is a popular model selection criterion. Even though it has a risk of over-fitting the model, it would not under-fit. The lag length that minimizes AIC is then selected. After the suitable lag structure for Eq. (2) has been selected, Eq. (2) must be tested to ensure that its error term is serially independent. Then, the bounds test was used to test the model for whether there was a long-run relationship between these variables. If a long-run (co integration) relationship was observed, we could estimate the long-run model (levels model) and the short-run model (conventional error-correction model). If a long-run (co integration) relationship among these variables was identified, all of the first difference of the variables in the Eq. (2) were equal to zero, for example, $\Delta \ln y_t$ = $\Delta \ln k_t$ = $\Delta \ln ec_t$ = $\Delta \ln life_t$ = *0.* And the long-run model could be formulated as the following form:

$$\ln y_t = \delta_1 + \delta_2 \ln k_t + \delta_3 \ln ec_t + \delta_4 \ln life_t + \varepsilon_{1t} \qquad (3)$$

where the long-run coefficients δ_1=- α_0 /λ_1 ; δ_2 = -λ_2/λ_1 ; δ_3= -λ_3/λ_1 ; δ_4 = -λ_4/λ_1 , and ε_{1t} was the random error. In order to estimate the short-run relationship, the error correction model version model from the ARDL model in Eq. (2) was used as follows:

$$\Delta \ln y_t = \alpha_2 + \sum_{i=1}^{n1} \phi_{2i} \Delta \ln y_{t-i} + \sum_{i=0}^{n2} \varphi_{2i} \Delta \ln k_{t-i} + \sum_{i=0}^{n3} \gamma_{2i} \Delta \ln e_{t-i} + \sum_{i=0}^{n4} \eta_{2i} \Delta \ln life_{t-i} + \psi \mathrm{ECM}_{t-1} + \varepsilon_{2t} \qquad (4)$$

The coefficient of the error correction term (ECM_{t-1}) in Eq. (4) was the speed of adjustment from the short-run to the long-run, which was expected to be negative and statistically significant. The model was tested by the diagnostic tests that were serial correlation LM test for serial correlation, normality test for normality, autoregressive conditional heteroskedasticity test and white heteroskedasticity test for heteroskedasticity, and Ramsey RESET test for the functional form. Stability tests (cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMSQ)) were also used to test the goodness of fitting the ARDL model.

3.2. Variance Decomposition analysis

In this study, variance decomposition was used to check robustness. Variance decomposition analyzes the changes between the variables in unrestricted vector autoregressive model (VAR) (Lütkepohl, 2005). Observing changes in the prediction error for each variable and its variance from other variables revealed the relative strength of exogenous variables and fluctuations. Forecasts of error variance decompositions evaluated the contribution of each type of shock to forecast error variance. The variance decomposition computations helped assess how shocks to economic variables reverberated through a system.

4. *Empirical Results*

The ARDL model for empirical analysis was constructed using Eviews 9 econometric software. Since the ARDL model could only be used if the variables were integrated of I (0) or I (1) (Pesaran et al. 2001), unit root tests had to be used to make sure no variables were integrated of I(2) or higher. In Fig.1, the plots of the variables in this study were presented. They did not appear to be integrated of I (0). In order to make sure the variables were not equal or greater than I (2), the study used two popular unit root tests, the augmented Dickey-Fuller (ADF) (Dickey & Fuller, 1979) and Phillips–Perron (PP) (Phillips & Perron, 1988) tests. Table 1 presented the unit root tests results. All variables in the levels were almost not stationary but all variables integrated of order 1 or I (1) was stationary.

The bound test was used to evaluate co integration, as shown in Table 2. In the Table 2, the value of k (the number of all variables are k+1) was 3 in the model that the research used. The F-statistics of 11.88 was higher than the upper critical bound of 5.61(1% significance level), which indicated a long-run relationship among economic growth, energy consumption, health, and capital during 1960-2013 in the US. The ARDL (1, 4, 2, 3) model was selected by Akaike info criterion (AIC). The model could estimate the coefficients of the long-run relations and the short-run relations. Table 3 presented the estimated long- run coefficients and the short- run coefficients.

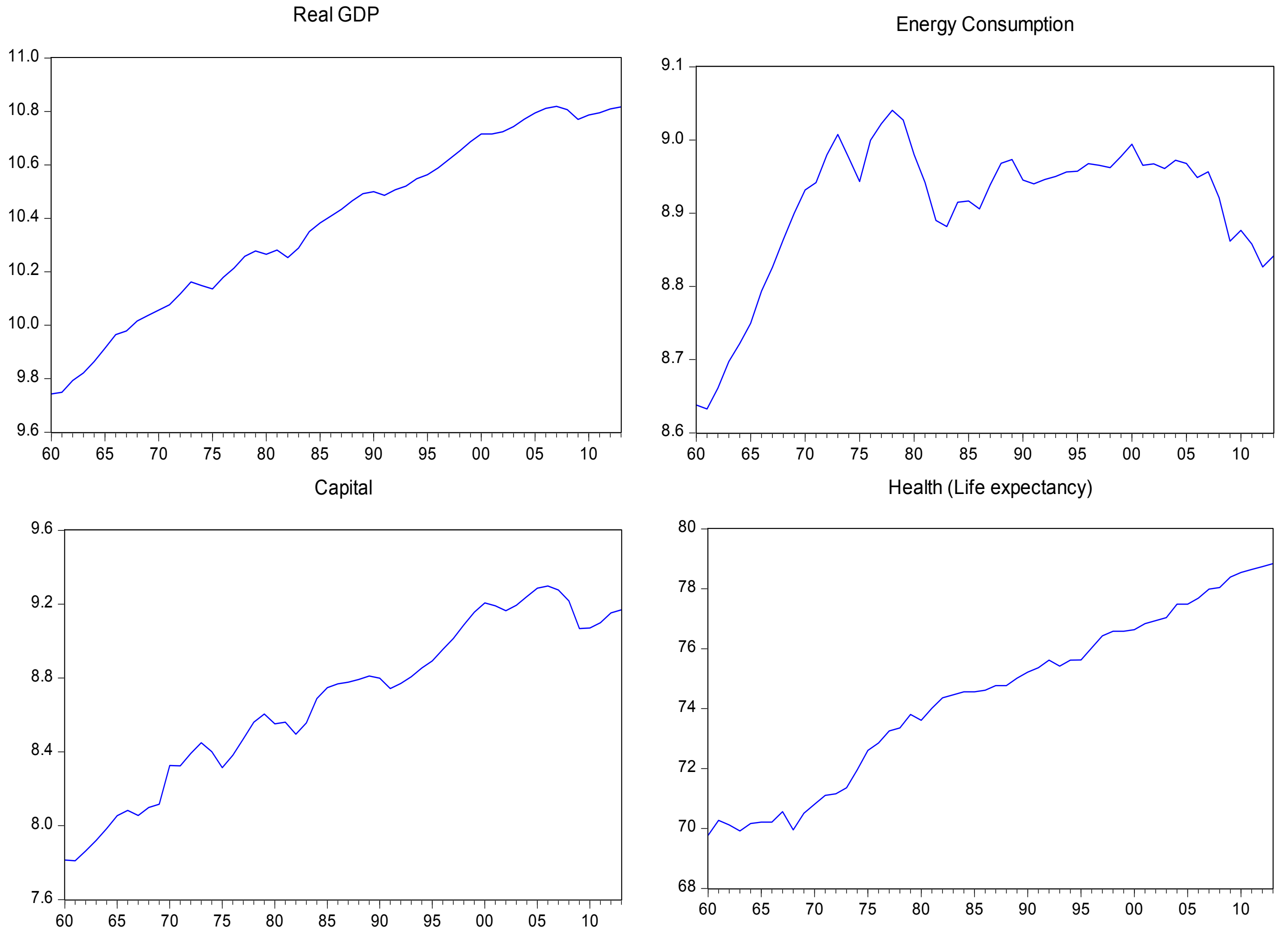


Figure 1: **Plots of variables**

Table 1: ***Unit Root Tests***

	ADF test		**PP test**	
	(t-Statistic)		(adjusted	t-Statistic)
		Level		
Variable	**Constant Without Trend**	**Constant With Trend**	**Constant Without Trend**	**Constant With Trend**
ln y	-2.75	-2.15	-3.09*	-1.03
ln k	-1.95	-2.48	-2.15	-1.60
ln e	-3.47	-2.68	-2.89	-1.85
ln life	-0.60	-1.83	-0.60	-1.79
	First Difference			
ln y	-5.17*	-5.82*	-5.15*	-5.73*
ln k	-5.38*	-5.61*	-5.17*	-5.54*
ln e	-4.57*	-5.37*	-4.51*	-5.42*
ln life	-8.55*	-8.46*	-8.46*	-8.38*
Notes: * denotes significance at the 5% level.				

Table 2: Results of Bounds Test

F-statistics	**k**	**Significance Level**	**Bound Critical values** I(0)	I(1)
11.88	3	1%	4.29	5.61
		5%	3.23	4.35
		10%	2.72	3.77

In Table 3, the long-run coefficient of energy consumption was -0.17 and was not significant (p value is 0.07 which is greater than 5%), all else being constant, which meant that a policy of conserving energy would not affect the US economic growth in the long run. The coefficient of health was 3.41 and is significant (p value close to 0) in the long run. This indicated that health did affect long-run economic growth. The coefficient of capital was 0.47 and was significant (p value close to 0). That is, a 1 per cent increase in capital increases economic growth by approximately 0.47 percent. Table 3 also showed the results obtained when the conventional error correction model was used to estimate the short-run relationship. It is suggested that the energy consumption had a short- run impact on economic growth because the coefficient (0.29) was positive and significant (p value close to 0). The coefficient of capital is 0.22 which meant that the result was positive and statistically significant. That is, capital positively affected economic growth. The coefficient of health was -0.17 and was not significant (p value is 0.60 which is greater than 5%). That indicated that health did not effect on economic growth in the short run. The coefficient of *ECM* (-0.26) was negative and it was very significant, which suggested that nearly 26% of any deviation from the long-run equilibrium was corrected within one year. The adjustment speed was fast.

Diagnostic tests of the model were performed to evaluate serial correlation (serial correlation LM), normality (normality test), heteroskedasticity (autoregressive conditional heteroskedasticity and white heteroskedasticity), and functional form (Ramsey RESET Test) in Table 3. The diagnostic test results suggested that there was no serial correlation, autoregressive conditional heteroskedasticity or White heteroskedasticity at the 5% significance level. The diagnostic test results also revealed on the normal residual terms. The Ramsey reset test suggested that the model appeared well specified.

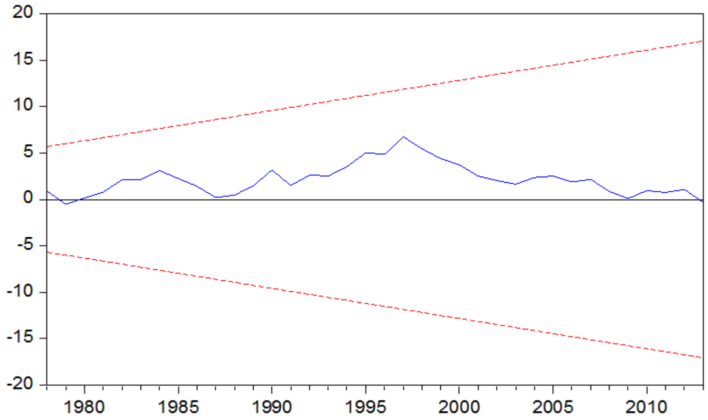
Table 3: ***Statistical Output for Long-run & Short-run Model and Diagnostic Tests***

	Long-run model coefficients	
Regressor	Coefficient	p-value
ln k	0.47	$<0.01^*$
ln e	-0.17	0.07
ln life	3.41	$<0.01^*$
	Short run model coefficients	
Regressor	Coefficient	p-value
constant	-1.76	$<0.01^*$
Δln k	0.22	$<0.01^*$
Δln e	0.29	$<0.01^*$
Δln life	-0.17	0.60
ECM	-0.26	$<0.01^*$
Diagnostic tests (p-value)		
Serial Correlation LM (0.63)		
Normality Test (0.31)		
ARCH Test (0.34)		
Heteroscedisticity Test (0.09)		
Ramsey RESET Test (0.6)		

Notes: * denotes significance at the 5% level.

The stability of the estimated model was tested by calculating the cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMSQ). Both these plots in Figs. 2 and 3 were in the critical bounds at 5% significance level, which indicated that the estimated model was stable in the research period.

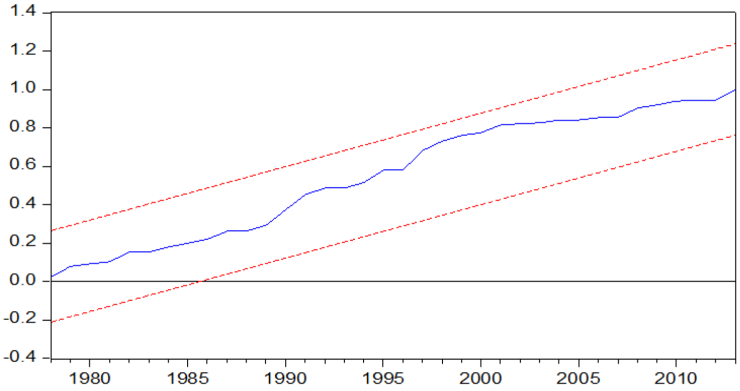
Plot of Cumulative Sum of Recursive Residuals



The straight lines represent critical bounds at 5% significance level

Figure 2: CUSUM plots for stability tests

Plot of Cumulative Sum of Squares of Recursive Residuals



The straight lines represent critical bounds at 5% significance level.

Figure 3: CUSUMSQ plots for stability test

Table 4 showed the result of variance decomposition. Unexpected changes exhibited by economic growth were about 86% self-explanatory, since energy consumption, capital, and health accounted for 6.8%, 5%, and 2.2%, respectively in the tenth period. Unexpected changes in energy consumption were 34% self-explanatory. These unexpected changes were far better explained by economic growth: economic growth, capital and health were 61.8%, 3.2% and 1%, respectively in the tenth period. When health exhibited unexpected changes, these were 81.6% self-explanatory; otherwise, economic growth had the greatest explanatory power: energy consumption, capital, and economic growth were 3.8%, 3.9% and 10.7%, respectively in the tenth period. From the results of the above, we found that the health and energy consumption had relationship with economic growth. The result of variance decomposition analysis was consistent with ARDL analysis.

Table 4: the result of Variance Decomposition

The Variance Decomposition (unit： %)

Variance Decomposition of DLY:					
Period	S.E.	DLY	DLK	DLE	DLLIFE
1	0.020234	100	0	0	0
2	0.022388	92.78793	0.918803	6.279668	0.013597
3	0.022975	88.65414	2.974848	6.375475	1.995535
4	0.023307	87.41696	4.208211	6.195966	2.178866
5	0.023324	87.28959	4.20567	6.256738	2.248003
6	0.023466	86.23733	4.739898	6.779688	2.243082
7	0.023517	85.9961	4.984281	6.775562	2.244061
8	0.023526	85.94236	5.037925	6.772907	2.24681
9	0.023569	85.95534	5.05114	6.754355	2.23916
10	0.023608	85.96433	5.042146	6.760899	2.232629
Variance Decomposition of DLE:					
Period	S.E.	DLY	DLK	DLE	DLLIFE
1	0.026111	67.31272	0.539545	32.14773	0
2	0.029256	63.88077	2.215166	33.89744	0.006632
3	0.029394	63.5714	2.322189	34.00566	0.100757
4	0.029755	62.87514	2.315748	34.50684	0.302278
5	0.0304	62.43883	2.800445	34.03152	0.729205
6	0.030626	61.70467	3.174581	34.20949	0.911264
7	0.030733	61.68443	3.17537	34.20815	0.932046
8	0.030785	61.72204	3.185662	34.16078	0.93152
9	0.030863	61.76592	3.179034	34.12036	0.934685
10	0.030909	61.75354	3.177138	34.13426	0.935061
Variance Decomposition of DLLIFE:					
Period	S.E.	DLY	DLK	DLE	DLLIFE
1	0.003118	6.980877	1.35002	0.41789	91.2512
2	0.003221	6.651994	2.06841	1.249013	90.03058
3	0.003322	8.37511	3.08198	1.386648	87.15626
4	0.003383	9.12257	3.30623	3.372081	84.19911
5	0.003396	9.25997	3.79949	3.36955	83.57098
6	0.003399	9.31464	3.80711	3.375458	83.50279
7	0.003426	10.2362	3.90050	3.667054	82.19624
8	0.003436	10.64664	3.89381	3.725785	81.73376
9	0.003439	10.65758	3.88969	3.77794	81.67478
10	0.003442	10.74663	3.89332	3.802858	81.55719
Cholesky Ordering: DLY DLK DLE DLLIFE					

5. Conclusions and Policy Implications

This study examined the impact of energy consumption, health, and capital on the US economic growth during 1960-2013. The ARDL bounds testing model was used in a neoclassical production function to identify short-run and long-run relationships among these variables. The variance decomposition approach was used to check robustness. The original contribution of this study was its use of ARDL bounds testing model and variance decomposition approaches in an empirical analysis of the impact of energy consumption and health on US economic growth. In conclusion, the research revealed a co integration relationship among energy consumption, health, capital and economic growth. Energy consumption displayed only a short-run impact on economic development. Health displayed only a long-run impact on economic development. Capital displayed both short and long-run impacts on economic development.

5.1. Implications for the US Government

The test suggests that energy consumption has a positive impact on economic growth in the short run. In the long run, it follows the neutrality hypothesis (Payne, 2010) in the US empirical study. This implies that energy conservation policy will not have long-run negative effects on the U.S. economic growth. The US may continue to develop energy efficient technologies while maintaining economic growth in the long run. Health positively affects economic growth in the long term but not in the short term. Therefore, the US government should pursue policies involving greater health investment to foster economic growth. Capital positively affects economic growth and is a very important input of economic growth both in the short run and long run. This follows production theory and implies that the US government should adopt a policy of encouraging capital investment to maintain economic growth.

5.2. Limitation and the Future Research of the Study

This study used time series data (annual data) for policy analyses of the US. The time series data is an effective tool for policy analyses of a single country but it cannot include all important variables (for example, openness, financial development, tourism and so on). That is because of restrictions on degree of freedom. For the future study, it is suggested that the researchers may use high-frequency data, for example, quarterly GDP data or industrial production index monthly data as an alternative to annual GDP. Or researchers may use Mixed-Data Sampling (MIDAS) (Ghysels, Sinko, & Valkanov, 2007) to conduct the policy analyses.

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