International Journal of Energy Economics and Policy
Vol. 3, No. 3, 2013, pp.307-314
ISSN: 2146-4553
www.econjournals.com

Disaggregate Energy Consumption and Total Factor Productivity: A Cointegration and Causality Analysis for the Turkish Economy

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ABSTRACT: The aim of this study is to investigate the long and the short-run relationships between disaggregate energy consumption (i.e. alternative and nuclear, fossil and renewable) and total factor productivity growth in the Turkish economy for the period 1970-2011. To this end, ARDL bounds testing approach to cointegration and the Dolado and Lütkepohl's Granger causality analyses were employed. Results showed that disaggregate energy consumption is cointegrated to total factor productivity growth and there exists bi-directional causal relationships among the variables in consideration. Besides, findings revealed that the share of renewable energy consumption in total energy consumption is the only energy type which positively affects total factor productivity growth in the Turkish economy. This result implies that an improvement in the share of renewable energy consumption in total energy consumption is crucial for economic efficiency.

Keywords: Disaggregate energy consumption; Total factor productivity growth; Turkish economy
JEL Classifications: C33; O47; O50; Q20; Q30; Q40

1. Introduction

According to the growth accounting framework of Solow (1956, 1957), the total factor productivity is a central concept which represents the combination of advances in production technology and efficiency, and the growth of managerial skills. Thus, it has been generally assumed that the total factor productivity has an explanatory power on factors of production, and this assumption has been confirmed by many researches (Abramovitz, 1956; Kendrick, 1961; Denison, 1985; Jones, 1997; Miller and Upadhyay, 2000; Easterly and Levine, 2001; Jerzmanowski, 2007). In this regard, the link between the total factor productivity and economic growth has become a clear field in the literature of development economics.

Compared to the stylized facts about the concept of total factor productivity (Abramovitz, 1956; Solow, 1957), the total factor productivity and energy consumption nexus is a relatively new field of interest. In this context, due to the relationship between energy consumption and total factor productivity which was first introduced by Schurr (1983) and Jorgenson (1984), energy consumption positively contributes to total factor productivity, and disaggregating energy input into its components causes this contribution to vary based on the energy source in consideration (Hisnanick and Kymn, 1992; Chien and Hu, 2007; Turner and Hunley, 2011). In this sense, by disaggregating energy consumption into alternative and nuclear, fossil, and renewable energy components, this study aims at investigating the long and the short-run relationships between energy consumption and total factor productivity growth in the Turkish economy for the period 1970-2011.

The rest of the paper is organized as follows: Next section summarizes the literature and describes the novelty. Section 3 presents the data, methodology and results. Finally, Section 4 concludes.

2. Literature Review

Following the *growth*, *conservation*, *feedback* and *neutrality* hypotheses that explain the four possible links between energy consumption and economic growth (Ozturk, 2010; Payne, 2010), the literature of energy and growth nexus could be considered under three lines.

The first line includes studies which investigate the causal relationships between (dis)aggregate energy consumption and economic growth (Soytas and Sari, 2003; Lee, 2006; Lise and Montfort, 2007; Soytas *et al.*, 2007; Narayan and Smyth, 2008; Akinlo, 2008; Apergis and Payne, 2009a; Apergis and Payne, 2009b; Belloumi, 2009; Ozturk *et al.*, 2010; Apergis and Payne, 2010a; Belke *et al.*, 2011; Kaplan *et al.*, 2011; Eggoh *et al.*, 2011; Fuinhas and Marques, 2012; Apergis and Tang, 2013). The second line of the literature is composed of the studies which analyze the causal relationships between renewable energy consumption and economic growth (Chien and Hu, 2007; Sadorsky, 2009; Apergis and Payne, 2010b; 2010c; Apergis and Payne, 2011; Payne, 2011; Fang, 2011; Menegaki, 2011; Tiwari, 2011a). Finally, the third line covers the studies which aim at investigating the causal relationships between renewable and non-renewable energy consumption and economic growth (Ewing *et al.*, 2007; Payne, 2009; Apergis *et al.*, 2010; Bowden and Payne, 2010; Tiwari, 2011b; Tugcu *et al.*, 2012; Apergis and Payne, 2012).

Although it is not as substantial as the literature of energy consumption and economic growth nexus, the literature related to energy consumption and total factor productivity can be classified under two strands. The only paper which establishes the first strand of this literature is Hisnanick and Kymn (1992) that investigates the impact of energy consumption on total factor productivity growth in the US manufacturing sector for the period 1958-1985 by disaggregating energy consumption into petroleum and non-petroleum components. Results show that a decline in the energy intensity of production raises total factor productivity, and disaggregated energy component is the major factor behind the productivity fluctuation over the period in consideration.

Studies which analyze the relationship between efficiency in energy consumption and total factor productivity constitute the second strand of the literature. In this sense, Kelly *et al.* (1989) investigates the link between energy efficiency and productivity in the US for the period 1963-1985 and expresses that there is a positive direct relationship between energy efficiency and productivity. Adenikinju (1998) examines the impact of efficiency in energy consumption on productivity growth in Nigerian manufacturing sector for the period 1988-1990 and concludes that efficiency in energy consumption positively contributes to total factor productivity growth. Boyd and Pang (2000) evaluate the link between energy efficiency and productivity in the US for the period 1987-1995 and state that energy efficiency improvements depend on the total factor productivity growth. Finally, Worrell *et al.* (2003) review over 70 industrial case studies which are related to energy efficiency and productivity nexus and examine the effects of energy efficiency on total factor productivity in the US iron and steel industry. Results reveal that efficiency improvements in energy-use positively affect total factor productivity.

The present study differs from the previous studies in several aspects. The first, in order to investigate the long and the short-run relationship between disaggregate energy consumption and total factor productivity growth, this study employs Autoregressive Distributed Lag (ARDL) approach to cointegration developed by Pesaran *et al.* (2001) which is not sensitive to the order of integration of the variables in consideration. The second, since implication(s) inferred from empirical findings will not be valid in case of the unstable cointegration parameters, stability of the estimated cointegration parameters are checked by the parameter stability tests of Brown *et al.* (1975). The third, the present study adopts a Granger causality analysis which was modified by Dolado and Lütkepohl (1996) for testing the causal relationships between disaggregate energy consumption and total factor productivity growth. This causality approach overcomes the singularity problem which may result in non-standard limiting distributions based on the cointegration properties of the variables and on the nuisance parameters (Lütkepohl and Kratzig 2004). Finally the fourth, the relationship between disaggregate energy consumption and total factor productivity growth in the Turkish economy has never been studied before. Thus, this study aims to fulfill this gap and contribute to the empirical literature.

3. Data, Methodology and Results

3.1. Data

Data set includes the share of alternative and nuclear, fossil, and renewable energy consumption in total energy consumption, and the growth of total factor productivity in Turkey for the period 1970-2011. Following Hisnanick and Kymn (1992), Miller and Upadhyay (2000) and Jerzmanowski (2007), total factor productivity growth was calculated by estimating a growth equation and removing the growth effect of standard inputs (i.e. capital and labor) from the income growth. For this purpose, log-linear form of the classical Cobb-Douglas production function below was used:

$$\ln \mathrm{Y}_{\mathrm{i,t}} = \ln \mathrm{A}_{\mathrm{i,t}} + \alpha_i \ln C_{i,t} + \beta_i \ln L_{i,t} + \varepsilon_{i,t} \qquad (1)$$

where *Y* is real income, *C* is capital, *L* is labor, *A* is the exogenous rate of technological change and *ε* is the error term. *Y*, *C* and *L* are proxied by annual GDP per capita growth in constant 2000 US dollars, real gross fixed capital formation growth in constant 2000 US dollars, and the growth of total labor force, respectively. Data for energy consumption was obtained from World Bank, World Development Indicators database, whereas others were attained from OECDStat.

After estimating and subtracting from both sides of Eq. (1), the contribution of traditional inputs to growth is formulated in the following manner:

$$\ln \hat{\mathrm{Y}}_{\mathrm{i,t}} - (\alpha_i \ln \hat{C}_{i,t} + \beta_i \ln \hat{L}_{i,t}) - \hat{\varepsilon}_{i,t} = \ln \hat{\mathrm{A}}_{\mathrm{i,t}} \qquad (2)$$

Accordingly, since elasticities of capital and labor (i.e. *α* and *β*) are equal to the observed income shares, total factor productivity growth is equal to an approximation of the left hand side variables of Eq. (2). Thus the exogenous rate of technological change can also be defined as total factor productivity growth for each country.

$$\ln \hat{\mathrm{A}}_{\mathrm{i,t}} = \mathrm{TFP}_{\mathrm{i,t}} \qquad (3)$$

where TFP is the growth of total factor productivity.

3.2. Unit root

Although the ARDL framework does not require pre-testing for the order of integration, the Augmented Dickey-Fuller (ADF) and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests were employed in order to determine the order of integration of the variables. Findings in Table 1 reveal mixed results about the stationary of the variables in consideration. Thus the ARDL approach seems to be the right choice for investigating the cointegration relationship.

Table 1. Unit root

	H_0: Series contain a unit root		H_0: Series do not contain a unit root	
	ADF		KPSS	
Variables	constant	constant+trend	constant	constant+trend
TFP	-0.697 (0.83)	-2.867 (0.18)	0.796	***0.057
AN	-1.730 (0.40)	-2.142 (0.50)	**0.676	**0.206
FOS	-1.957 (0.30)	-3.359 (0.07)	0.805	***0.068
RNW	1.525 (0.99)	-0.937 (0.94)	0.799	**0.183
ΔTFP	-6.991 (0.00)	-6.900 (0.00)	***0.051	***0.049
ΔAN	-6.846 (0.00)	-6.923 (0.00)	0.213	**0.201
ΔFOS	-6.210 (0.00)	-6.115 (0.00)	***0.161	***0.059
ΔRNW	-6.354 (0.00)	-7.020 (0.00)	*0.354	***0.051

[a] Δ is the first difference operator and numbers in parenthesis are *p*-values.

[b] *** significant at 1% level; ** significant at 5% level; * significant at 10% level.

3.3. Cointegration

For analyzing the cointegration relationship, this study employs the Autoregressive Distributed Lag approach (i.e., the bounds testing approach) to cointegration developed by Pesaran *et al.* (2001). In this regard, the ARDL representation of the model which examines the long-run relationship between disaggregate energy consumption and total factor productivity growth is formulated in the following manner:

$$\Delta TFP_t = a_0 + \sum_{i=1}^{p} a_{1i}\Delta TFP_{t-i} + \sum_{i=0}^{p} a_{2i}\Delta AN_{t-i} + \sum_{i=0}^{p} a_{3i}\Delta FOS_{t-i} + \sum_{i=0}^{p} a_{4i}\Delta REN_{t-i} + \theta_1 TFP_{t-1} + \theta_2 AN_{t-1} + \theta_3 FOS_{t-1} + \theta_4 REN_{t-1} + u_t \quad (4)$$

where *TFP* is the total factor productivity growth, *AN*, *FOS*, and *REN* is the share of alternative and nuclear, fossil, and renewable energy consumption in total energy consumption, respectively. Δ is the difference operator, *p* is the lag length, and *u* is serially uncorrelated error term. All variables are in natural logarithms.

The ARDL procedure involves two stages. In the first stage, the null hypothesis of no-cointegration (H_0: $\theta_1=\theta_2=\theta_3=\theta_4=0$) is tested against the alternative hypothesis of cointegration (H_1: $\theta_1\neq0, \theta_2\neq0, \theta_3\neq0, \theta_4\neq0$). Testing cointegration relationship is based on the F-statistic. Since the asymptotic distribution of this F-statistic is non-standard irrespective of whether the variables are *I(0)* or *I(1)*, Narayan (2005) tabulated two sets of critical values which are appropriate for the studies with small sample size ranging from 30 to 80 observations. In this sense, one set assumes that all variables are *I(0)* and other set assumes that all variables are *I(1)*. This provides a bound covering all possible classifications of the variables. If the calculated F-statistic lies above the upper level of the bound, the H_0 is rejected, supporting cointegration relationship. If the calculated F-statistic lies below the lower level of the bound, then the H_0 cannot be rejected, indicating lack of cointegration.

Once a long-run relationship is established, the second stage of the ARDL procedure is to estimate the error-correction model (ECM) from the Eq. (4). The ECM can be written as follows:

$$\Delta TFP_t = \alpha + \sum_{i=1}^{p} \omega_k TFP_{t-i} + \sum_{i=0}^{p} \lambda_k AN_{t-i} + \sum_{i=0}^{p} \delta_k FOS_{t-i} + \sum_{i=0}^{p} \beta_k REN_{t-i} + \varpi EC_{t-1} + u_t \quad (5)$$

where ϖ is the error correction parameter and *EC* is the residual obtained from the Eq. (4).

Since cointegration among variables does not ensure the stability of the parameters, one should provide that the cointegration parameters are stable over the time. In this regard, cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) tests for parameter stability developed by Brown *et al.* (1975) are widely utilized with the ARDL modeling framework. These tests are based on the recursive regression residuals. The CUSUM and CUSUMSQ statistics are updated recursively and plotted against the break points of the model. If the plot of these statistics falls inside the critical bounds, one can decide that the estimated coefficients are stable over the time.

Findings of the cointegration analysis presented in Table 2 indicate the first that disaggregate energy consumption and total factor productivity growth are cointegrated over the long-run. Second, either in the long or in the short-run the share of alternative and nuclear, and fossil energy consumption in total energy consumption negatively affects total factor productivity growth in the Turkish economy. On the other hand, one percent increase in the share of renewable energy consumption in total energy consumption raises total factor productivity growth by 0.818% and 0.663% in the long and in the short-run, respectively. Besides, diagnostics and stability tests show that there is no statistical failure of the estimated ARDL model.

3.4. Causality

The existence of a cointegration relationship among variables indicates a possible causality in at least one direction (Engle and Granger, 1987). In this sense, a recent Granger causality analysis developed by Dolado and Lütkepohl (1996) (henceforth, DL) was employed for testing the causal relationships. The main advantage of this analysis is to deal with the singularity problem of classical Granger causality test. The classical Granger causality analysis requires carrying out zero restrictions on VAR coefficients using familiar $\chi2$ or F-test based on the Wald principle. However, the presence of *I(1)* variables in the VAR model may cause non-standard asymptotic distributions. Particularly, Wald test for Granger causality may result in non-standard limiting distributions based on the cointegration properties of the system and possibly on nuisance parameters. The DL causality analysis overcomes this problem by adding an extra lag to the true order of the VAR model. The testing procedure involves two steps. The first, a $VAR_{(p)}$ is determined by a model selection criterion such as Schwarz Bayesian Criterion. Second, a $VAR_{(p+1)}$ is estimated and then the standard Wald test is applied on the first *p* lags. Dolado and Lütkepohl (1996) called this new statistics as modified Wald statistic which is asymptotically distributed as chi-square.

Table 2. Cointegration

	Dependent variable: TFP
Panel A: Cointegration Tests	
F-stat	4.74
Error Correction Parameter	-0.810 (0.00)
Panel B: Long-run Parameters	
Constant	-8.415 (0.01)
AN	-0.294 (0.01)
FOS	-2.100 (0.00)
REN	0.818 (0.00)
Panel C: Short-run Parameters	
Constant	-6.816 (0.01)
AN	-0.238 (0.00)
FOS	-1.701 (0.01)
REN	0.663 (0.00)
Panel D: Diagnostic Checking	
Adjusted-R^2	0.96
Serial Correlation[a]	0.387 (0.53)
Heteroscedasticity[b]	2.469 (0.11)
Functional Form[c]	3.923 (0.04)
Normality[d]	0.995 (0.60)
Panel E: Stability Tests	
CUSUM	S
CUSUMQ	S

The critical values for F-stat are (2.93-4.02) for 10 percent, (3.54-4.80) for 5 percent, and (5.01-6.61) for 1 percent level of significance. The critical values are obtained from Case III in Narayan (2005: 1988).
a: The Breusch–Godfrey LM test statistic for no serial correlation.
b: The White's test statistic for homoscedasticity.
c: The Ramsey's Reset test statistic for regression specification error.
d: The Jarque–Bera statistic for normality
Numbers in parenthesis are *p*-values.
S refers to a stable model.

The test results showed in Table 3 indicate the validity of the bi-directional causal relationships between disaggregate energy consumption and total factor productivity for all three cases. Considering the short and the long-run estimates of the ARDL model, it can be concluded that the direction of causality from *AN* and *FOS* to *TFP* is negative, whereas *REN* has a positive causal impact on *TFP* in the Turkish economy.

Table 3. Causality

H_0: No causality	(p+1)	MWALD	Decision
AN does not cause TFP	2	16.676 (0.00)	Reject
TFP does not cause AN	2	10.068 (0.00)	Reject
FOS does not cause TFP	2	14.205 (0.00)	Reject
TFP does not cause FOS	2	18.218 (0.00)	Reject
REN does not cause TFP	2	12.140 (0.00)	Reject
TFP does not cause REN	2	33.379 (0.00)	Reject

The Schwarz Bayesian Criterion was used to determine the optimal lag length.
Numbers in parenthesis are *p*-values.

4. Conclusion

In this study, the short and the long-run relationships between disaggregate energy consumption and total factor productivity growth in the Turkish economy was investigated by using annual data covering the period 1970-2011. To this end, the bounds testing approach to cointegration by Pesaran *et al.* (2001) and a modified Granger causality analysis by Dolado and Lütkepohl (1996) were employed.

Results show that disaggregate energy consumption and total factor productivity growth are cointegrated, and either in the long or in the short-run an increase in the share of alternative and nuclear, and fossil energy consumption in total energy consumption decreases the growth of total factor productivity, whereas an increase in the share of renewable energy consumption in total energy consumption raises the total factor productivity growth. In addition, causality analysis proved that there exists a bi-directional causality between disaggregate energy consumption and total factor productivity growth in the Turkish economy.

Findings of the present study are consistent with Hisnanick and Kymn (1992) and imply a policy that the share of renewable energy consumption in total energy consumption of Turkey should be improved, if it is intended to benefit from energy consumption not only as a factor of production but also a positive externality that strengthens the growth performance of the economy by its positive effects on the total factor productivity.

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