Modelling the Causal Relationship Between Energy Consumption and GDP in New Zealand, Australia, India, Indonesia, the Philippines and Thailand

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Abstract: A number of industrialized and developing countries agreed to the terms of the Kyoto protocol to conserve energy and reduce emissions. The close relationship between energy consumption and real GDP growth suggests that energy conservation policies are likely to affect real GDP growth. In this paper, the possible impact of energy conservation policies on the New Zealand economy is examined and compared with Australia and developing Asian economies. Causality between energy consumption and GDP in New Zealand is investigated as is the causal relationship between GDP and various disaggregate energy data (coal, natural gas, electricity, oil). It appears that energy conservation policies will not have significant impacts on real GDP growth in industrialized countries such as New Zealand and Australia compared to some developing economies.

Key words: Energy Consumption; GDP; Granger Causality

1. INTRODUCTION

Since the seminal papers by Granger [1969] and Sims [1972], causality tests applied to the energy sector have steadily increased. Recent papers applying causality methods include, Asafu-Adjaye, [2000], Stern [2000] and Sadorsky [2000].

The interest in applying such methods to the energy sector continues in part because current results are, as Asafu-Adjaye [2000] states, "mixed" or "conflicting" due to the differences in econometric methodology used and possible problems caused by non-stationary data. This paper investigates the causal relationship between energy consumption and GDP in New Zealand, Australia and 4 Asian countries.

2. THE EXISTING LITERATURE

The majority of the studies on the relationship between energy consumption and the level of economic development relate to the US, with a number of other studies considering various Asian economies. The issue studied relates typically to the impact of energy conservation on GDP growth. Figure 1, below shows there is a relationship between world energy demand and world real GDP, the issue is whether it is a causal one.

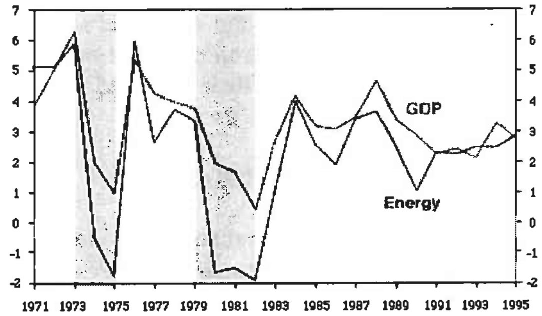

Figure 1. Relationship between world energy demand and world real GDP.

While most of the studies outlined in the introduction mainly consider a bivariate approach, Asafu-Adjaye [2000] uses a trivariate approach to study causality between GDP and energy consumption in India and three Asian countries: Indonesia, Philippines and Thailand. He found that for India and Indonesia, there is unidirectional link from energy to income, while for Thailand and Phillipines, there is bidirectional causality between energy and income.

Stern [2000], analysed causality between GDP and energy use in the US economy after World War II using a multivariate approach. He added labour and capital input and time trend as additional variables. The time trend was added to capture the exogenous effect of new technology. Stern measured energy input differently using a quality-adjusted index because, he argued, this would take into account the effect of energy quality on energy consumption. He also used divisia aggregation index of energy content (BTU) in energy aggregate final energy consumption of coal, natural gas, petroleum, electricity power and biofuels and found there is cointegration between GDP, capital, labour and energy. He concluded that, with a dynamic multivariate cointegration analysis approach, energy is significant, in the Granger causality sense, in explaining GDP (p.280).

A closely related study by Engsted and Bentzen [1993], estimated the relationship for Denmark using annual data for the period 1948-1990. The main variables were energy consumption, the real price of energy, and real GDP. All variables appear to be non-stationary and cointegration and error-correction methods were applied. All estimated parameters have the expected signs and magnitudes, and no evidence is found of a structural break in energy demand caused by the increases in real energy prices since 1973/1974.

The previous studies used aggregate economic data. An argument was made by Fouquet et. al. [1997] for the use of more disaggregate industry level data. Hence they study the long run relationship between energy consumption and sectoral economic activity. They found that all, but the iron and steel industry, are expected to increase their rate of energy consumption to the year 2000.

3. DATA AND METHODOLOGY

The New Zealand and Australian data were taken the International Energy Agency (IEA) energy database and comprise annual data, 1960-1999, for total final energy consumption and also coal, oil, gas, electricity used. The data for electricity and fuel prices, the price of other goods proxied by CPI, as well as real GDP (PPP adjusted) were also from the IEA database. All data were transformed to natural logarithms.

4. TESTING FOR CAUSALITY

The Engle-Granger [1987] Representation Theorem establishes the relationship between cointegration and causality. Dependant on the order of integration 3 approaches can be used to establish the direction of causality. In addition, the Toda and Yamamoto [1995] approach can be used when the order of integration is ambiguous. An important first stage in the process is thus to establish the order of integration and cointegration.

The hypothesis of non-causality can be tested in 3 ways depending on the order of integration. If the variables are I(1) and cointegrated, causality can be tested using the levels of the variables as in equations (1) and (2) below where the null-hypothesis of non-causality relates to the significance of φ and γ.

$$LX_t = \alpha + \sum_{i=1}^{k} \zeta_i LX_{t-i} + \sum_{j=1}^{l} \varphi_j LY_{t-j} + \varepsilon_t \quad (1)$$

$$LY_t = \psi + \sum_{i=1}^{k} \chi_i LY_{t-i} + \sum_{j=1}^{l} \gamma_j LX_{t-j} + \eta_t \quad (2)$$

Alternatively, if the variables are I(1) and cointegrated, the variables can be first-differenced and the error-correction (ECM) term from the cointegrating regression added as in equations (3) and (4). In this case, as well as the significance of φ and γ, the significance of ξ and ϕ can establish the direction of causation.

$$\Delta LX_t = \alpha + \sum_{i=1}^{k} \zeta_i \Delta LX_{t-i} + \sum_{j=1}^{l} \varphi_j \Delta LY_{t-j} + \xi ECM_{t-1} + \varepsilon_t \quad (3)$$

$$\Delta LY_t = \psi + \sum_{i=1}^{k} \chi_i \Delta LY_{t-i} + \sum_{j=1}^{l} \gamma_j \Delta LX_{t-j} + \phi ECM_{t-1} + \eta_t \quad (4)$$

If the variables are I(1) and not cointegrated, the variables must be rendered stationary by differencing, as in (3) and (4) above, but the test of causality does not include the ECM-terms as (5) and (6) below show:

$$\Delta LX_t = \alpha + \sum_{i=1}^{k} \zeta_i \Delta LX_{t-i} + \sum_{j=1}^{l} \varphi_j \Delta LY_{t-j} + \varepsilon_t \quad (5)$$

$$\Delta LY_t = \psi + \sum_{i=1}^{k} \chi_i \Delta LY_{t-i} + \sum_{j=1}^{l} \gamma_j \Delta LX_{t-j} + \eta_t \quad (6)$$

In addition to the Engle and Granger approach, we also used the Toda and Yamamoto [1995] method to verify if our results still hold. The Toda and Yamamoto approach involves using levels of the variables as in equations (7) and (8) even though the variables may be individually non-stationary.

$$LX_t = \alpha + \sum_{i=1}^{m} \beta_i LX_{t-i} + \sum_{j=1}^{n} \gamma_j LY_{t-j} + u_t \quad (7)$$

$$LY_t = a + \sum_{i=1}^{q} b_i LY_{t-i} + \sum_{j=1}^{r} c_j LX_{t-j} + v_t. \quad (8)$$

The initial lag lengths m, n, q and r are chosen using the Akaike Information Criteria. The initial lag lengths are augmented with an extra lag depending on the likely order of integration of the series LX_t and LY_t. If LX_t and LY_t are I(1) then one extra lag is added to each variable in equations (7) and (8). Wald/LM tests are then used to test causality direction. For example, in equation (7), the lags of LY_t, excluding the extra lag added to capture maximum order of integration, are tested for their significance. If the null hypothesis that the lags are jointly equal to zero is accepted, then LY_t does not cause LX_t in equation (7). Testing for the joint significance of LX_t, excluding the extra lag added, in equation (8) allows for testing uni-directional or bi-directional causality.

5. EMPIRICAL RESULTS

The first stage involves establishing the order of integration of the annual, New Zealand, data. Table 1 presents the results of the unit root tests for the two variables total final energy consumption (tfc) and GDP, as well as energy disaggregated into coal, gas, electricity and oil energy consumption, 1960-1999. The null of non-stationarity can not be rejected for any of the variables at the 95% significance level.

The variable tfc includes both household and commercial energy consumption. As it is possible that GDP will be to be affected by the level of commercial energy consumption we also used commercial energy consumption. This variable is represented by the variable "ind" in Table 1 and is also I(1).

Table 1. Unit Root Tests.

Variable	Levels	First Difference	Critical Values	Lags
Coal	-2.2	-4.56	3.53	1
Gas	-2.79	-3.13	2.94	2
Electricity	-1.64	-4.25	3.53	1
Oil	-2.54	-5.64	3.53	1
Tfc	-3.24	-3.66	3.53	2
Ind	-2.98	-4.77	3.53	1
Gdp	-2.72	-3.84	3.53	1

Given the variables are I(1), we then tests for bivariate cointegration as the second stage using the Johansen [1991] approach. The results are presented as Table 2.

For all the variables, the null hypothesis of no cointegration was not rejected. Thus, although the variables were found to be I(1), they are not cointegrated. The null of no cointegration was also not rejected for the relationship between real GDP and oil, gas, electricity and coal energy consumption. We also tested the relationship between real GDP and commercial energy consumption and found that they are not cointegrated.

Because all the variables, except electricity, were I(1) but not cointegrated, we transform the variables by taking their difference to induce stationarity and test for Granger causality using equations (3) and (4) without adding an error correction term.

Table 2. Testing for bivariate cointegration between variables and real GDP, 1960-1999.

Var.	Max. Eigen.	Trace	CV (eigen)	CV (trace)	H_0	H_1	VAR
coal	9.3	14.4	19.2	25.7	R = 0	r = 1	1
	5.1	5.1	12.3	12.3	r <= 2	r = 2	
gas	15.8	20.2	19.2	25.7	R = 0	r = 1	1
	4.4	4.4	12.3	12.3	r <= 2	r = 2	
elec	14.6	23.0	19.2	25.7	R = 0	r = 1	2
	8.2	8.3	12.3	12.3	R <= 2	r = 2	
Oil	15.7	22.0	19.2	25.7	R = 0	r = 1	1
	6.2	6.2	12.3	12.3	r <= 2	r = 2	
Tfc	11.6	19.9	19.2	25.7	R = 0	r = 1	1
	8.2	8.2	12.3	12.3	r <= 2	r = 2	
Ind	13.3	21.4	19.2	25.7	R = 0	r = 1	1
	8.0	8.0	12.3	12.3	r <= 2	r = 2	

Max. eigen denotes maximum eigenvalue statistic; Trace is trace statistic, VAR denotes order of the VAR.

Table 3 shows that for there is statistical independence between oil, gas, coal consumption and real GDP supporting the neutrality hypothesis in the literature.

However, when we test Granger causality between commercial/industrial energy consumption and real GDP, we found that there is uni-directional link from real GDP to commercial/industrial energy consumption. Also, we found that there is uni-directional link from real GDP to total final energy consumption (tfc).

Table 3. Test of bivariate causality, differenced data, not cointegrated, 1960-1999.

Dep	ΔGDP	Δcoal	ΔGDP	Δgas	ΔGDP
Ind	Δcoal	ΔGDP	Δgas	ΔGDP	Δoil
k		1		1	
l		2		2	
r	1		2		3
s	2		2		1
LM test	0.40	2.25	0.64	1.48	5.52
Prob.	(0.81)	(0.32)	(0.72)	(0.47)	(0.13)
LR*	0.40	2.32	0.65	1.51	5.99
Prob.	(0.81)	(0.31)	(0.72)	(0.47)	(0.11)
F-stat	0.18	1.07	0.28	0.68	1.87
Prob.	(0.83)	(0.35)	(0.75)	(0.51)	(0.15)
Conc.	ΔCoal $\nRightarrow$ ΔGDP	ΔGDP $\nRightarrow$ Δcoal	Δgas $\nRightarrow$ ΔGDP	ΔGDP $\nRightarrow$ Δgas	Δoil $\nRightarrow$ ΔGDP

Table 3 (cont.). Test of bivariate causality, differenced data, not cointegrated, 1960-1999.

Dep.	Δoil	ΔGDP	Δind	ΔGDP	Δtfc
Indt.	ΔGDP	Δind	ΔGDP	Δtfc	ΔGDP
k, l	1,1		1,2		1,1
r,s		2,2		2,1	
LM test	0.88	3.32	12.3**	1.07	6.45**
Prob.	(0.34)	(0.18)	(0.00)	(0.58)	(0.01)
LR*	0.89	3.49	15.1**	1.08	7.10**
Prob.	(0.34)	(0.17)	(0.00)	(0.58)	(0.00)
F-stat	0.82	1.57	8.36**	0.49	7.20**
Prob.	(0.37)	(0.22)	(0.00)	(0.61)	(0.01)
Conc.	ΔGDP ⇏ Δoil	Δind ⇏ ΔGDP	**ΔGDP** ⇒ **Δind**	Δtfc ⇏ ΔGDP	**ΔGDP** ⇒ **Δtfc**

Note: k, l, r and s are the lags. Δ denotes a first difference, ⇏ denotes 'not-causal', ⇒ denotes 'causal'.

To consider the robustness of these results we use the Toda and Yamamoto [1995] approach. The results using this approach for New Zealand are presented as table 4.

Table 4. Test of bivariate causality, Toda and Yamamoto approach, 1960-1999.

Dep	Coal	GDP	Gas	GDP	Oil
Ind.	GDP	Coal	GDP	Gas	GDP
m,n	1,1		2,2		1,1
q,r		2,1		3,2	
LM test	1.25	0.06	2.88	0.11	0.80
Prob.	(0.26)	(0.97)	(0.08)	(0.94)	(0.36)
Conc.	GDP ⇏ Coal	Coal ⇏ GDP	GDP ⇏ Gas	Gas ⇏ GDP	GDP ⇏ Oil

Dep	GDP	GDP	Ind	GDP	Tfc
Ind.	Oil	ind	GDP	Tfc	GDP
m,n	1,1		2,2		1,1
q,r		1,1		2,2	
LM test	2.23	0.26	13.1**	1.74	5.3**
Prob.	(0.33)	(0.60)	(0.00)	(0.42)	(0.02)
Conc.	Oil ⇏ GDP	ind ⇏ GDP	**GDP** ⇒ **ind**	Δtfc ⇏ ΔGDP	**ΔGDP** ⇒ **Δtfc**

Note : m, n, q and r are the number of lags.

The causality results using the log levels of the variables in the Toda and Yamamoto approach are qualitatively the same as the results from the Engle and Granger approach. That is, there is unidirectional Granger causality from real GDP to industrial energy consumption and from real GDP to total final energy consumption.

6. COMPARISONS WITH OTHER COUNTRIES

We also compare our results with studies of developing countries, in particular, four Asian economies and Australia. The results for the four Asian economies, India, Indonesia, Thailand and The Philippines are summarised in Table 5.

Table 5. Results from 4 Asian economies

	SR effects		
Country/dependent variable	Δyt	Δent	Δpt
India			
Δy	-	8.14**	1.01
Δen.	0.18	-	0.08
Δpt.	0.39	0.07	-
Indonesia			
Δy.	-	0.81	1.68
Δen.	0.87	-	0.63
Δpt.	1.06	0.81	-
Thailand			
Δyt.	-	11.3***	0.26
Δent.	9.66***	-	5.22**
Δpt.	0.40	9.02***	-
Phillipines			
Δyt.	-	2.66**	21.6***
Δent.	2.98**	-	0.00
Δpt.	10.6***	0.21	-

EC-error correction term in the error correction model. Significance at the ***1% level, the ** 5% level and * 10% level. Statistics is Wald's F-statistics. *Δy* = first difference of real GDP. *Δen* = first difference of commercial energy. *Δpt* = first difference of energy price. *Source:* Asafu-Adjaye [2000].

	Source of causation:			
	ECT only	Δent	Δpt	Δyt
Country/dependent variable		ECT	ECT	ECT
	t-ratio	Wald F-statistics		
India				
Δy.	-2.85	4.09**	4.63	-
Δen.	-1.01	-	0.77	0.83
Δpt.	-0.41	0.11	-	0.20
Indonesia				
Δy.	-2.08**	2.19	2.40	-
Δen.	1.83	-	1.68	1.70
Δpt.	-2.83**	4.00**	-	4.67*
Thailand				
Δyt.	-0.54	9.98***	0.20	-
Δen.	-2.84***	-	6.55**	16.9*
Δpt.	-3.48***	7.48***	-	6.60*
Phillipines				
Δyt.	-1.16	-1.43	14.4***	-
Δent.	-2.16	-	2.38	6.14*
Δpt.	-1.43	1.05	-	8.51*

The results for these developing Asian economies show either unidirectional link from energy to income as it is for India and Indonesia or birectional Granger causality as it is for Thailand and the Phillipines.

Glasure and Lee [1997] examined Granger causality for two Asian tigers South Korea and Singapore. Using an error correction model, they found there established bi-directional causality for energy consumption and income for both countries. They suggested that their results may be due to "some indigenous oil production, coupled with easy access to crude oil from Malaysia, energy consumption and the level of economic activity."(p.24).

In addition to the four Asian developing economies, we also tested for Granger-causality between total final energy consumption and real GDP, industrial energy consumption and real GDP and energy disaggregated into coal, electricity and gas for Australia. Table 6 presents the results of the integration properties of the variables. The null of non-stationarity of each of the variables, in their log levels, was not rejected. However, after first differencing, each of the variables became stationary as in column three of Table 6. All the variables therefore are individually I(1).

Table 6. Unit root test for some energy variables for Australia.

Variable	Levels	First Difference	Critical Values	Lags
Coal	-1.07	-4.69	3.53	1
Gas	-1.48	-3.74	3.53	1
Electricity	-1.97	-4.13	3.53	1
Tfc	-2.41	-4.07	3.53	1
Ind.	-2.20	-4.44	3.53	1
Gdp	-2.76	-5.26	3.53	0

Ind = Industrial final energy consumption.

We then test for the cointegration properties of each of the variables using Johansen's maximum likelihood approach. Table 7 presents the results. Industrial energy consumption and real GDP are not cointegrated. However, total final energy consumptions, total electricity consumption cointegrate with real GDP.

For the variables that did not cointegrate (gas, coal and total industrial energy demand) we take their difference to induce stationarity and test for Granger-causality using equations (5) and (6). The results are presented as Table 8. For the variables that cointegrate (electricity and tfc) we added an ECM term lagged one period as in equations (3) and (4).

Table 7. Testing for bivariate cointegration bet. the relevant variables and real GDP, 1960-1999.

Var.	Max. Eigen.	Trace	CV (eigen)	CV (trace)	H_0	H_1	VAR
coal	7.8	12.1	19.2	25.7	R = 0	r = 1	1
	4.2	4.2	12.3	12.3	r <= 2	r = 2	
gas	17.7	28.6*	19.2	25.7	R = 0	r = 1	2
	10.8	10.8	12.3	12.3	r <= 2	r = 2	
elec	44.2*	48.6*	19.2	25.7	R = 0	r = 1	1
	4.4	4.4	12.3	12.3	r <= 2	r = 2	
Tfc	23.1*	27.6*	19.2	25.7	R = 0	r = 1	1
	4.5	4.5	12.3	12.3	r <= 2	r = 2	
Ind	6.9	12	19.2	25.7	R = 0	r = 1	1
	5.1	5.1	12.3	12.3	r <= 2	r = 2	

Max. eigen denotes maximum eigenvalue statistic; Trace is trace statistic, VAR denotes order of the VAR. * denotes test significant at 95% level.

Table 8. Test of bivariate causality, differenced data, not cointegrated, without ECM for coal, gas and ind, but cointegrated, with ECM for elec and tfc, 1960-1999.

Dep Ind.	ΔGDP ΔCoal	ΔCoal ΔGDP	ΔGDP ΔGas	ΔGas ΔGDP	ΔGDP ΔElec.
k		2		1	
l		3		2	
r	1		2		3
s	2		2		1
ECM coeff.	-	-	-	-	0.18
LM test	1.86	8.84**	0.64	0.76	5.52
Prob.	(0.17)	(0.03)	(0.72)	(0.18)	(0.13)
LR*	0.16	10.1**	0.65	0.54	5.99
Prob.	(0.68)	(0.01)	(0.72)	(0.25)	(0.11)
F-stat	0.07	3.25**	0.28	0.86	1.87
Prob.	(0.78)	(0.03)	(0.75)	(0.98)	(0.15)
Conc.	ΔCoal ⇏ ΔGDP	**ΔGDP** ⇒ **ΔCoal**	Δgas ⇏ ΔGDP	ΔGDP ⇏ ΔGas	ΔElec. ⇏ ΔGDP

Dep Indt	ΔElec. ΔGDP	ΔGDP ΔInd.	ΔInd. ΔGDP	ΔGDP ΔTfc	ΔTfc ΔGDP
k, l	1,1		2,2		1,1
r, s		3,2		2,1	
ECM	0.16	-	-	0.26	0.38
LM test	11.9**	3.32	0.49	1.07	13.65**
Prob.	(0.00)	(0.18)	(.48)	(0.58)	(0.01)
LR*	14.4**	3.49	0.22	1.08	17.17**
Prob.	(0.00)	(0.17)	(0.63)	(0.58)	(0.00)
F-stat	15.7**	1.57	0.79	0.49	19.55**
Prob.	(0.00)	(0.22)	(0..37)	(0.61)	(0.01)
Conc.	**ΔGDP** ⇒ **ΔElec.**	ΔInd. ⇏ ΔGDP	ΔGDP ⇏ ΔInd.	ΔTfc ⇏ ΔGDP	**ΔGDP** ⇒ **ΔTfc**

The results show there is unidirectional Granger causality from real GDP to coal, electricity and total final energy consumption for Australia. For the rest of the relationships tested, we found neither bi-directional or unidirectional link between real GDP and coal, gas and industrial energy demand.

We also used the Toda and Yamamoto [1995] approach to ascertain if the previously produced results using the standard Engle-Granger approach hold. The results presented as Table 9 show that the two approaches produce qualitatively similar results.

Table 9. Toda and Yamamoto [1995] causality test results.

Dep. / Indp.	GDP / coal	coal / **GDP**	GDP / gas	Gas / GDP	GDP / Elec.
m, n		1,1		3,1	
q, r	1,1		2,1		1,2
ECM coeff.	-	-	-	-	0.18
LM test	0.05	5.20**	0.24	2.97	5.52
Prob.	(0.82)	(0.02)	(0.61)	(0.05)	(0.13)
Conc.	Coal $\nRightarrow$ GDP	**GDP $\Rightarrow$ coal**	gas $\nRightarrow$ GDP	GDP $\nRightarrow$ gas	Elec. $\nRightarrow$ GDP

Dep / Indp.	Elec. / GDP	GDP / Ind.	Ind. / GDP	GDP / Tfc	Tfc / GDP
m, n	1,1		1,3		1,1
q, r		1,1		2,1	
ECM coeff.	0.16	-	-	0.26	0.38
LM test	10.5**	1.38	7.6	3.1	15.78**
Prob.	(0.01)	(0.24)	(0.06)	(0.21)	(0.00)
Conc.	**GDP $\Rightarrow$ Elec.**	Ind. $\nRightarrow$ GDP	GDP $\nRightarrow$ Ind.	Tfc $\nRightarrow$ GDP	**GDP $\Rightarrow$ Tfc**

7. CONCLUSIONS

The paper reports tests for Granger causality using New Zealand, Australian, and four Asian countries data. Issues in the literature were discussed and application of the standard Granger causality method and Toda and Yamamoto's [1995] approach were used to study the energy-GDP relationship. In this study, we found evidence of a unidirectional link from real GDP to aggregate final energy consumption and unidirectional link from real GDP to industrial and commercial energy consumption in New Zealand. Similar relationships were found for Australia. In the case of the 4 Asian economies considered, India, Indonesia, Thailand and The Philippines, a unidirectional link from energy to income was established for India and Indonesia and a bi-directional link for Thailand and The Philippines.

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