Available online at www.sciencedirect.com
SCIENCE DIRECT®
Energy Economics 26 (2004) 69–75
Energy Economics
www.elsevier.com/locate/eneco

# Disaggregated industrial energy consumption and GDP: the case of Shanghai, 1952–1999

Yemane Wolde-Rufael*

*Equalities Unit, London Borough of Camden, Town Hall, Judd Street, London WCIH 9JE, UK*

**Abstract**

This paper investigates the causal relationship between various kinds of industrial energy consumption and GDP in Shanghai for the period 1952–1999 using a modified version of the Granger (1969) causality test proposed by Toda and Yamamoto (J. Econ. 66 (1995) 225). The empirical evidence from disaggregated energy series seems to suggest that there was a uni-directional Granger causality running from coal, coke, electricity and total energy consumption to real GDP but no Granger causality running in any direction between oil consumption and real GDP.


*JEL classifications:* Q43

*Keywords:* Energy; GDP; Causality; Lag-augmented VAR; Shanghai

## 1. Introduction

Over the past few years the relationship between energy consumption and economic growth has been studied extensively using modern advances in time series econometrics of cointegration and causality. The empirical evidence is mixed ranging from bi-and uni-directional causality to no causality. For instance, Cheng (1999) finds no Granger causality running from energy consumption to economic growth in the case of India, while Masih and Masih (1996) and Asafu-Adjaye (2000) find uni-directional Granger causality running from energy consumption to income for the same country, India. Uni-directional Granger causality running from energy consumption to economic development was found in the case of Brazil and Japan

*Tel.: +44-207-974-1997; fax: +44-207-974-5947.
*E-mail address:* yemane.wolde-rufael@camden.gov.uk (Y. Wolde-Rufael).

0140-9883/04/$ - see front matter 
PII: S0140-9883(03)00032-X

by Cheng (1997, 1998) and in the case of France, West Germany, Japan and Turkey by Soyta and Sari (in press). An opposite uni-directional Granger causality running from GDP to energy consumption was found by Cheng and Lai (1997) for Taiwan. However, this contrasts with the bi-directional causality found for Taiwan by Masih and Masih (1997), Glasure et al. (2000), Yang (2000) and Chang et al. (2001). This type of conflicting evidence was also found in the case of Korea where Masih and Masih (1997), Glasure and Lee (1997) and Glasure (2002) found a bi-directional causality running between energy consumption and GDP, while Soyta and Sari (in press) found causality running from GDP to energy consumption. Bi-directional causality running between energy consumption and GDP were also found for Argentina by Soyta and Sari (in press), for Greece by Hondroyianais et al. (2002), for Philippines and Thailand by Asafu-Adjaye (2000) and for Pakistan by Masih and Masih (1996). No causality was found in the case of Mexico and Venezuela by Cheng (1997) and for Canada, UK and USA by Soyta and Sari (in press).

These conflicting evidences have major implications for energy policy. If there is a uni-directional causality running from energy to GDP, reducing energy consumption may lead to a fall in income, but if there is an inverse relationship, energy conservation would not cause an adverse effect on economic growth. On the other hand, if there is a negative causality running from employment to energy, total employment can rise if energy conservation is implemented (Asafu-Adjaye, 2000). Similarly, if there is uni-directional causality running from energy consumption to income, reducing energy consumption could lead to fall in income or employment. In contrast, if there is no causality in any direction between energy consumption and income, reducing energy use may not affect income and energy conservation policies may not affect economic growth (Asafu-Adjaye, 2000; Cheng, 1998).

The purpose of this paper is not to resolve these conflicting evidences but to add to the debate by examining the causal relationship between various forms of energy consumption and GDP in the case of Shanghai, the richest and fast growing city in China with a per capita income of $3720 compared to the national average per capita income of $780 (Statistical Yearbook of Shanghai, 2000). This paper argues that the empirical finding cited above using the conventional $F$-statistic for testing Granger non-causality between energy consumption and GDP may not be valid as the test does not have a standard distribution when the time series data are integrated (see Toda and Yamamoto, 1995, hereafter TY). Therefore, the modest contribution of this paper is to use a Granger no-causality test that does not require the integration and cointegration properties of the system.

The paper is organised as follows. In Section 2 we briefly outline the methodology and data. The empirical evidence is presented in Section 3. Some concluding remarks are outlined in Section 4.

## 2. Methodology and data

This paper attempts to extend the energy–income nexus by undertaking causality tests using a modified version of the Granger causality test proposed by TY as elaborated and expanded by Rambaldi and Doran (1996), Zapata and Rambaldi (1997) and Shan and Tian (1998). When time series data are integrated, TY have shown that the conventional $F$-statistic for Granger non-causality test is not valid as the test does not have a standard distribution (Caporale and Pittis, 1999; Giles and Mizra, 1998). The approach proposed by TY is to employ a modified Wald (MWALD) test for restriction on the parameters of the VAR ($k$) where $k$ is the lag length of the system. The basic idea of the TY approach is to artificially augment the correct order, $k$, by the maximal order of integration, say $d_{\max}$. Once this is done, a $(k+d_{\max})$th order of VAR is estimated and the coefficients of the last lagged $d_{\max}$ vectors are ignored (Caporale and Pittis, 1999). Therefore, in order to apply the TY approach, we need to know the true lag length ($k$) and the maximum order of integration ($d_{\max}$) of the series under consideration. The novelty of the TY procedure is that it does not require pre-testing for the cointegrating properties of the system and thus avoids the potential bias associated with unit roots and cointegration tests (Zapata and Rambaldi, 1997; Shan and Tian, 1998).[1] The test has an asymptotic $\chi^2$ distribution when a VAR $(k+d_{\max})$ is estimated. This ensures that the usual test statistic for Granger causality has the standard asymptotic distribution where valid inference can be made. The test (MWALD) statistic is valid regardless of whether a series is $I(0)$, $I(1)$ or $I(2)$, non-cointegrated or cointegrated of an arbitrary order 'so long as the order of integration of the process does not exceed the true lag length of the model' (TY, p. 225).[2]

To undertake TY version of the Granger non-causality test, we represent the GDP-energy model in the following VAR system:

$$Y_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} Y_{t-i} + \sum_{j=k+1}^{d_{\max}} \alpha_{2j} Y_{t-j} + \sum_{i=1}^{k} \phi_{1i} E_{it-i} + \sum_{j=k+1}^{d_{\max}} \phi_{2j} E_{it-j} + \lambda_{1t} \quad (1)$$

$$E_{it} = \beta_0 + \sum_{i=1}^{k} \beta_{1i} E_{it-i} + \sum_{j=k+1}^{d_{\max}} \beta_{2j} E_{it-j} + \sum_{i=1}^{k} \delta_{1i} Y_{t-i} + \sum_{j=k+1}^{d_{\max}} \delta_{2j} Y_{t-j} + \lambda_{2t} \quad (2)$$

where $E_{it}$ $(i=1,2,3,4,5)$ is the log of total energy, coal, coke, electricity and oil consumption and $Y_t$ is the log of real GDP deflated by the overall consumer price index as GDP deflator was not available. All the data are annual and were taken from the Statistical Yearbook for Shanghai, 2000. From Eq. (1), Granger causality from $E_{it}$ to $Y_t$ implies $\phi_{1i} \neq 0 \ \forall_i$; similarly in Eq. (2), $Y_t$ Granger causes $E_{it}$, if $\delta_{1i} \neq 0 \ \forall_i$.

[1] Another novelty of the TY approach is that Zapata and Rambaldi (1997) have made the procedure easy to apply using several of the available econometric packages using a Seemingly Uncorrelated Regression (SUR).

[2] For the shortcomings of the TY approach, see Kuzozumi and Yamamoto (2000). According to them, when 'we have a small sample, the asymptotic distribution may be a poor approximation to the distribution of the test statistic' (p. 212); but the approach is less distorted than others and may be preferable when the sample size is small.

Table 1
Tests for unit roots

| Series | KPSS test | | $ADF^{GLS}$ test |
|---|---|---|---|
| | $\eta_{\mu}$ | $\eta_{r}$ | |
| CC | 0.942*** | 0.103 | −2.6799 (2) |
| ΔCC | 0.253 | 0.074 | −4.7467*** (2) |
| EE | 1.026*** | 0.234*** | −1.8605 (3) |
| ΔEE | 0.450** | 0.080 | −5.1784*** (3) |
| KK | 0.939*** | 0.174** | −1.5037 (3) |
| ΔKK | 0.386** | 0.107 | −4.9936*** (2) |
| OO | 0.863*** | 0.260*** | −0.6090 (1) |
| ΔOO | 0.571** | 0.073 | −6.9149*** (1) |
| TT | 1.025*** | 0.186** | −1.8605 (3) |
| ΔTT | 0.336 | 0.083 | −5.1783*** (3) |
| YY | 1.061*** | 0.107 | −2.9448 (2) |
| ΔYY | 0.262 | 0.125** | −4.8483*** (2) |

*Note:* ***, ** and * denote significant at the 1, 5 and 10% confidence levels, respectively. Optimum lags are in parenthesis. For the KPSS test, the truncated lags were selected according to lag = Integer*[$4(T/100)^{1/4}$] where $T$ = the number of observations; while for the $ADF^{GLS}$ (Elliot et al., 1996, see Maddala and Kim, 1998) test, the lags were selected according to the AIC. $\eta_{\mu}$ and $\eta_{r}$ tests refer to level and trend stationary, respectively, against the alternative of a unit root.

## 3. Empirical evidence

The first step in testing for Granger causality is to establish the order of integration ($d_{max}$) of the series under consideration. As there are many controversies surrounding these tests, our strategy is to compare results obtained from several of these tests and examine whether the preponderance of the evidence makes a convincing case for stationarity or non-stationarity. These tests were carried out using the Augmented Dickey-Fuller, the augmented Weighted Symmetric (tau) test, Phillips and Perron (1989), Kwiatkowski et al. (1992), Zivot and Andrews (1992) and the relatively more powerful unit root test due to Elliot et al. (1996).[3] Results of some of these unit root tests are presented in Table 1. For the levels of the series, we cannot reject the null hypothesis of non-stationarity; but for the first difference of the two series, we reject the null hypothesis of non-stationarity at the conventionally accepted critical values.

The second step in testing for causality is to determine the optimal lag in the model. There are several approaches, for instance, Lütkepohl (1993, p. 306) suggests linking the lag length ($m_{lag}$) and number of endogenous variables in the system ($m$) to a sample size ($T$) according to the $m \times m_{lag} = T^{1/3}$ formula. In our case with $T$ = 48, $k$ was initially set to 4 and we used the AIC, SBIC and the adjusted LR (likelihood ratio) criteria to determine the order of the VAR (Enders, 1995). The adjusted LR criterion seems to select $k=4$, while the AIC selected $k$ between 4 and 2, but the SBIC selected $k$ between 2 and 1. When there is a conflict between the

[3] For an excellent summary of all these tests, see Maddala and Kim (1998).

Table 2
Granger non-causality test

| Direction of causality | | Significance of the -value of the MWALD statistic | | |
|---|---|---|---|---|
| From | To | (3) | (4) | (5) |
| CC | YY | 0.00***[a] | 0.00*** | 0.00*** |
| YY | CC | 0.19[a] | 0.25 | 0.29 |
| EE | YY | 0.19 | 0.00*** | 0.00***[a] |
| YY | EE | 0.11 | 0.42 | 0.31[a] |
| KK | YY | 0.00*** | 0.00***[a] | 0.00*** |
| YY | KK | 0.25 | 0.77[a] | 0.09** |
| OO | YY | 0.95[a] | 0.61 | 0.63 |
| YY | OO | 0.11[a] | 0.17 | 0.58 |
| TT | YY | 0.01*** | 0.00***[a] | 0.00*** |
| YY | TT | 0.43 | 0.89[a] | 0.65 |

*Note:* CC, EE, KK, OO, TT and YY are the logs of coal, electricity, coke, oil, total energy consumption and real GDP, respectively. A trend term was included in all the equations to capture the deterministic trend. The number in parenthesis denotes the length of the VAR $(k+d_{max})$. ***, ** and * denote significant at the 1, 5 and 10% levels, respectively.

[a] Denotes the selected optimum lag.

AIC and BIC, we apply the LR test to choose the optimal lag. However, given the uncertainty with the lag length and given that Granger causality is sensitive to the lag length and also to the test the robustness our results, the tests were carried out by varying $k$ from 4 to 2. For the optimal $k$ selected, the residuals were also checked for white noise using the Box-Pierce $Q$-Statistic and other mis-specification tests (Enders, 1995).

Having established the integration properties of the series and the length of the VAR, we can now apply the TY approach. Results of these causality tests are presented in Table 2. As can be learned from the significance of the $\rho$-values of the MWALD statistic, there is a uni-directional Granger causality running from coal, coke, electricity and total energy consumption to GDP but no causality running in any direction between oil consumption and GDP. Our results are in sharp contrast to that found for Taiwan by Yang (2000), where he found bi-direction causality between GDP and total energy, coal and electricity and a uni-directional causality running from GDP to oil consumption.

Since, Granger causality is sensitive to the number of lags chosen, we have also used different lag structures to ensure that the results are not sensitive to the choice of the lag length. These tests indicate that the results are robust to $k$ ranging from 2 to 4.

## 4. Concluding remarks

In this paper a modified version of the Granger causality test due to Toda and Yamamoto (1995) was applied to investigate the causal relationship between several disaggregated categories of energy consumption and GDP in Shanghai for the period 1952–1999. This paper finds that there was an uni-directional Granger causality running from coal, coke, electricity and total energy consumption to GDP, but no Granger causality running in any direction between oil consumption and GDP. These results indicate that reducing energy consumption may lead to a fall in income, but as these results may suffer from the omission of other relevant variables, future research should attempt to incorporate more relevant variables in the analysis.

## References

Asafu-Adjaye, J., 2000. The relationship between energy consumption, energy prices and economic growth: time series evidence from Asian developing countries. Energy Econ. 22, 615–625.

Caporale, G.M., Pittis, N., 1999. Efficient estimation of cointegrating vectors and testing for causality in vector autoregressions. J. Econ. Issues 13, 3–35.

Chang, T.S., Fang, W., Wen, L., 2001. Energy consumption, employment, output and temporal causality: evidence from Taiwan based on cointegration and error-correction modelling techniques. Appl. Econ. 33, 1045–1056.

Cheng, B.S., 1997. Energy consumption and economic growth in Brazil, Mexico and Venezuela: a time series analysis. Appl. Econ. Lett. 4, 671–674.

Cheng, B.S., Lai, T.W., 1997. An investigation of co-integration and causality between energy consumption and economic activity in Taiwan. Energy Econ. 19, 435–444.

Cheng, B.S., 1998. Energy consumption, employment and causality in Japan: a multivariate approach. Indian Econ. Rev. 33, 19–29.

Cheng, B.S., 1999. Causality between energy consumption and economic growth in India: an application of cointegration and error-correction modelling. Indian Econ. Rev. 34, 39–49.

Enders, W., 1995. Applied Econometric Time Series. Wiley, New York.

Giles, J.A., Mizra S., 1998. Some pre-testing issues on testing for Granger non-causality, econometric working papers, EWP 9914. Department of Economics, University of Victoria, Canada.

Glasure, Y.U., Lee, A., 1997. Cointegration, error-correction and the relationship between GDP and energy: the case of South Korea and Singapore. Resour. Energy Econ. 20, 17–25.

Glasure, Y.U., Angirasa, A., Lee, A., 2000. The impact of money supply and government spending on economic development and energy: the Taiwan experience. J. Energy Dev. 24, 55–64.

Glasure, Y.U., 2002. Energy and national income in Korea: further evidence on the role of omitted variables. Energy Econ. 24, 355–365.

Hondroyianais, G., Lolos, S., Papapetrou, E., 2002. Energy consumption and economic growth assessing the evidence from Greece. Energy Econ. 24, 319–336.

Kuzozumi, E., Yamamoto, T., 2000. Modified lag augmented autoregressions. Econ. Rev. 19, 207–231.

Lütkepohl, H., 1993. Introduction to Multiple Time Series. Springer, Berlin.

Maddala, G.S., Kim, I., 1998. Unit Roots, Cointegration and Structural Change. Cambridge University Press, Cambridge.

Masih, A.M.M., Masih, R., 1996. Energy consumption, real income and temporal causality: results from a multi-country study based on cointegration and error-correction modelling techniques. Energy Econ. 18, 165–183.

Masih, A.M.M., Masih, R., 1997. On the temporal causality between energy consumption, real income and prices: some evidence from Asia energy dependent NICs based on a multi-country study based on cointegration and error-correction modelling techniques. J. Policy Model. 19, 417–440.

Rambaldi, A.N., Doran H.E., 1996. Testing for Granger non-causality in cointegrated system made easy, working papers in econometrics and applied statistics, no. 88, Department of Econometrics, University of New England.

Shan, J., Tian, G.G., 1998. Causality between exports and economic growth: the empirical evidence from Shanghai. Aust. Econ. Pap. 37, 196–202.

Soyta, U., Sari R., Energy consumption and GDP: causality relationship in G-7 countries and emerging markets, Energy Economics, in press.

Toda, H.Y., Yamamoto, Y., 1995. Statistical inference in vector autoregressions with possibly integrated process. J. Econ. 66, 225–250.

Yang, H.-Y., 2000. A Note on the causal relationship between energy and GDP in Taiwan. Energy Econ. 22, 309–317.

Zapata, H.O., Rambaldi, A.N., 1997. Monto Carlo Evidence on Cointegration and Causation. Oxford Bull. Econ. Stat. 59, 285–298.