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CO2 emissions, nuclear energy, renewable energy and economic growth in the US

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\textbf{A B S T R A C T}

This study explores the causal relationship between carbon dioxide (CO2) emissions, renewable and nuclear energy consumption and real GDP for the US for the period 1960–2007. Using a modified version of the Granger causality test, we found a unidirectional causality running from nuclear energy consumption to CO2 emissions without feedback but no causality running from renewable energy to CO2 emissions. The econometric evidence seems to suggest that nuclear energy consumption can help to mitigate CO2 emissions, but so far, renewable energy consumption has not reached a level where it can make a significant contribution to emissions reduction.

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1. Introduction

It is now widely recognised that unless drastic actions are taken to reduce global warming, the world could be heading not only towards reduced growth but also more importantly towards environmental disaster (Stern, 2007; Adamantiades and Kessides, 2009; DeCanio, 2009; Reddy and Assenza, 2009). Stern (2007) estimates that the economic impact of global warming could reduce global GDP by as much as 25%, while greenhouse gas mitigation would cost about 1% of the global GDP. Equally, the energy security problem facing energy-importing countries is also daunting (Hedenus et al., 2010). The high degree of concentration of energy supply sources in the volatile region of the Middle East, where over 68% of oil reserves are located clearly involves risks for the US in terms of the reliability of its supply of energy needs (Gnansounou, 2008).

The environmental challenge facing the US including many other imported-energy-dependent countries is how to increase sectoral energy supplies to produce more secure and cheap energy, and at the same time, how to reduce greenhouse gas emissions (GHG). Any attempt at dealing with global warming requires finding sources of energy alternatives to fossil fuels. Both renewable (hydro, wind, solar, biomass and geothermal) and nuclear energy sources are believed to provide some solutions to the problems of energy security and climate change. Like many other countries, as part of its strategy of increasing energy security and dealing with global warming, the US is investing in nuclear and renewable energy not only to reduce dependence on imported oil but also to increase the supply of secure energy, to minimize the price volatility associated with oil imports and to reduce greenhouse gas emissions (Toth and Rogner, 2006; Vaillancourt et al., 2008; Adamantiades and Kessides, 2009). The advantage of using nuclear and renewable energy has also become even more pressing as a result of the Kyoto Agreement that requires signatories to cut back substantially on their emissions of CO2 in order to reduce global warming (Becker and Posner, 2005). The Kyoto Protocol places an obligation on all signatories to ensure that GHG emissions in 2012 are not greater than the total of such emissions in 1990. The possible avenues for reduction in GHG emissions include the use renewable and nuclear sources of energy. Many believe that both renewable and nuclear energies, as virtually carbon free energy sources, could provide a major solution to global warming and energy security (Elliot, 2007 and Ferguson, 2007). It is therefore not surprising to see that these serious concerns over rising fossil fuel prices, energy security, and greenhouse gas emissions have brought the importance of both renewable and nuclear energies to the forefront of the wider issue of the energy debate (Adamantiades and Kessides, 2009). Even countries that were sceptical in the past about nuclear energy are now showing a keen interest in developing nuclear energy as a means of diversifying energy...
supplies, improving energy security, and as a means of providing a low-carbon energy alternative to fossil fuels (International Energy Agency, IEA, 2008; Adamantiades and Kessides, 2009; Wolde-Rufael, 2010). Unlike in the past, there are now some concrete proposals within the US to build new nuclear energy plants, and the prospects of expanding renewable energy are also looking more viable than assumed earlier (Patleve et al., 2009).

It is claimed that the operation of nuclear plants worldwide makes a significant contribution to the mitigation of GHG emissions where currently nuclear plants save some 10% of CO2 emissions from world energy use (Adamantiades and Kessides, 2009). According to the Nuclear Energy Agency (2002), over the past 40 years nuclear power plants have already played a major role in lowering the amount of greenhouse gases produced by the electricity sector in OECD countries. It is further claimed that without nuclear power, the OECD power plant emissions of carbon dioxide would have been about one-third higher than what they are at present. Estimates made by the Nuclear Energy Agency (2002) also suggest that nuclear plants save annually some 1200 million tonnes of carbon dioxide, or about 10% of total CO2 emissions from energy use in OECD countries. Moreover, the European Union (2006) also believes that Europe would not have been able to make any significant impact on reducing CO2 emissions without relying on nuclear energy. However, sceptics warn that while the combination of several factors mentioned above makes nuclear energy a creditable alternative source of energy and one of the potential panaceas for greenhouse gas reduction, its enormous risks are also equally substantial (Toth and Rogner, 2006; Elliot, 2007, Ferguson, 2007; World Energy Council, 2007; Squassoni, 2009; Adamantiades and Kessides, 2009; Wolde-Rufael, 2010).

While there have been numerous studies that have investigated the causal relationship between energy consumption and economic growth, and between energy consumption and pollutant emissions [see, Dinda, 2004; Chontanawat et al., 2008; Ferguson, 2007], to the knowledge of the present authors, there seems to be no empirical evidence. Summary and concluding remarks are presented in Section 4.

2. Data and methodology

The empirical evidence presented in this paper is carried out using the Toda and Yamamoto (1995, here after TY) version of the Granger non-causality test. This approach fits a standard vector auto-regression model on levels of the variables (not on their first differences) that give allowances for the long-run information often ignored in systems that require first differencing and pre-whitening (Clarke and Mirza, 2006; Rambaldi and Doran, 2006). The TY procedure employs a modified Wald test (MWALD) 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 artifically augment the correct order, k, by the maximal order of integration, say dmax. Once this is done, a (k+dmax)xihar order of VAR is estimated and the coefficients of the last lagged dmax vectors are ignored (see Caporale and Pittis (1999)). As we are more interested in the relationship between CO2 emissions, nuclear energy consumption and renewable energy consumption, the equations corresponding to each of these dependent variables are presented below

\[\ln C_t = \alpha_0 + \sum_{i=1}^{k} \alpha_i \ln C_{t-i} + \sum_{j=1}^{d_{max}} \beta_j \ln N_{t-j} + \sum_{j=1}^{d_{max}} \gamma_j \ln Y_{t-j} + \sum_{j=1}^{d_{max}} \delta_j \ln R_{t-j} + \epsilon_t\]

(1)

\[\ln N_t = \alpha_0 + \sum_{i=1}^{k} \alpha_i \ln N_{t-i} + \sum_{j=1}^{d_{max}} \beta_j \ln N_{t-j} + \sum_{j=1}^{d_{max}} \gamma_j \ln Y_{t-j} + \sum_{j=1}^{d_{max}} \delta_j \ln R_{t-j} + \sum_{j=1}^{d_{max}} \phi_j \ln Y_{t-j} + \sum_{j=1}^{d_{max}} \psi_j \ln R_{t-j} + \zeta_{t-j} + e_{t}\]

(2)

\[\ln Y_t = \alpha_0 + \sum_{i=1}^{k} \alpha_i \ln Y_{t-i} + \sum_{j=1}^{d_{max}} \beta_j \ln Y_{t-j} + \sum_{j=1}^{d_{max}} \gamma_j \ln N_{t-j} + \sum_{j=1}^{d_{max}} \delta_j \ln R_{t-j} + \sum_{j=1}^{d_{max}} \phi_j \ln N_{t-j} + \sum_{j=1}^{d_{max}} \psi_j \ln Y_{t-j} + \zeta_{t-j} + \tau_{t-j} + \upsilon_{t-j} + \omega_{t-j} + \eta_{t}\]

(3)

Where \(\ln C_t\) is the log of CO2 emissions (measured in kt of oil equivalent), \(\ln R_t\) is the log renewable energy consumption (measured in billion Btu); \(\ln N_t\) is the log nuclear energy consumption (measured in billion of Btu) and \(\ln Y_t\) is the log of real GDP (proxy for economic growth). All data are annual for 1960–2007. Real GDP at 2000 constant prices and CO2 emissions are taken from the World Bank, World Development Indicators, 2008. Nuclear energy consumption and renewable energy consumption are from the online database of the US Energy Information Administration. Following Apergis and Payne (2010) and Sadorsky (2009), renewable energy consumption includes net geothermal, solar, wind, and wood and waste electric power consumption (Energy Information Administration, 2009a, 2009b). We include real GDP because both real GDP and CO2 emissions are found to be important drivers of renewable energy consumption (Sadorsky, 2009; Apergis and Payne, 2010). Per-capita income is also the most important determinant of CO2 emissions. There is

The rest of the paper is organised as follows: in Section 2 we present the data and methodology followed in Section 3 by the empirical evidence. Summary and concluding remarks are presented in Section 4.
also evidence of a bi-directional causality between nuclear energy consumption and economic growth (Apergis and Payne, in press).

From (1), nuclear energy consumption (\(ln(N_t)\) Granger causes \(CO_2\) emissions (\(ln(C_t)\) if \(\beta_{11} \neq 0\), while Granger causality from renewable energy consumption (\(ln(R_t)\) to \(CO_2\) emissions (\(ln(C_t)\)) implies \(\pi_{11} \neq 0\). Similarly, in (2) \(CO_2\) emissions (\(ln(C_t)\) Granger causes nuclear energy consumption (\(ln(N_t)\) if \(\delta_{11} \neq 0\), while renewable energy consumption (\(ln(R_t)\) Granger causes nuclear energy consumption (\(ln(N_t)\) implies \(\pi_{11} \neq 0\). In (3) \(CO_2\) emissions (\(ln(C_t)\) Granger causes renewable energy consumption (\(ln(R_t)\) if \(\theta_{11} \neq 0\), while nuclear energy consumption (\(ln(N_t)\) Granger causes renewable energy consumption (\(ln(R_t)\) implies \(\phi_{11} \neq 0\).

3. Empirical evidence

Before conducting any causality testing it is important to determine the order of integration of the series (\(d_{\text{max}}\)) and the optimal lag length \(k\) [in Eqs. (1)–(3)], in order to avoid any spurious causality or spurious absence of causality (Clarke and Mirza, 2006). Using several unit root tests, we found that all series were \(I(1)\) [results available from the authors]. In selecting the optimal lag length, we followed Lütkepohl’s (1993:306) procedure where he suggests linking the lag length (\(mlag\)) and number of endogenous variables in the system (\(m\)) to the sample size (\(T\)) according to the formula \(m_{\text{mlag}}=T^{0.25}\) (Könya, 2004). Following Hatemi-J and Iranoudost (2000) a combination of AIC, Schwarz’s Bayesian criterion (SBC), likelihood ratio (LR) test, and diagnostic testing are used to select the number of lags required in each case. If two different orders of lags are obtained by the AIC and the SBC criteria, we applied the LR test to choose one of these two orders of lags (Pesaran and Pesaran, 1997). We then checked to see whether the chosen lag order passes some diagnostic tests. If not, we increased the order of lag successively until the diagnostic tests showed better results when we tested the reliability of our models by applying a number of diagnostic tests, including tests of autocorrelation, normality and heteroscedasticity. In general, we found no evidence of serious violation of all the above tests. Table 1 presents results of selecting the optimal lag length.

Results of Granger causality test are presented in Table 2. The table shows that there was a unidirectional Granger causality running from nuclear energy consumption to \(CO_2\) emissions without feedback. The coefficients of the lagged nuclear energy consumption variable were negative implying that nuclear energy consumption helps to reduce \(CO_2\) emission. In contrast, we found no causality running from nuclear energy consumption to \(CO_2\) emissions but we found the opposite unidirectional causality between nuclear energy consumption and economic growth (Apergis and Payne, in press). From (1), nuclear energy consumption (\(ln(N_t)\) Granger causes \(CO_2\) emissions (\(ln(C_t)\) if \(\beta_{11} \neq 0\), while Granger causality from renewable energy consumption (\(ln(R_t)\) to \(CO_2\) emissions (\(ln(C_t)\)) implies \(\pi_{11} \neq 0\). Similarly, in (2) \(CO_2\) emissions (\(ln(C_t)\) Granger causes nuclear energy consumption (\(ln(N_t)\) if \(\delta_{11} \neq 0\), while renewable energy consumption (\(ln(R_t)\) Granger causes nuclear energy consumption (\(ln(N_t)\) implies \(\pi_{11} \neq 0\). In (3) \(CO_2\) emissions (\(ln(C_t)\) Granger causes renewable energy consumption (\(ln(R_t)\) if \(\theta_{11} \neq 0\), while nuclear energy consumption (\(ln(N_t)\) Granger causes renewable energy consumption (\(ln(R_t)\) implies \(\phi_{11} \neq 0\).

Table 1

<table>
<thead>
<tr>
<th>Lags</th>
<th>Log-likelihood</th>
<th>AIC</th>
<th>SBC</th>
<th>LR Test</th>
<th>Adjusted LR Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>392.74</td>
<td>336.74</td>
<td>286.12</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>2</td>
<td>361.43</td>
<td>321.43</td>
<td>285.30</td>
<td>CHSQ(16)=62.60(0.00)</td>
<td>CHSQ(16)=43.13(0.00)</td>
</tr>
<tr>
<td>1</td>
<td>351.45</td>
<td>327.45</td>
<td>305.77</td>
<td>CHSQ(32)=82.56(0.00)</td>
<td>CHSQ(32)=56.88(0.00)</td>
</tr>
</tbody>
</table>

AIC=Akaike information criterion and SBC=Schwarz Bayesian criterion. The figures in bold are the values of the statistics for the optimal lags for the various tests.
Table 2
Granger causality test

<table>
<thead>
<tr>
<th>Direction of causality</th>
<th>$\chi^2$ (Chi-squared)</th>
<th>p-value</th>
<th>$\Sigma$ of the lagged coefficients of the causing variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>from ln $N_t$ to ln $C_t$</td>
<td>7.075</td>
<td>0.070*</td>
<td>-0.046</td>
</tr>
<tr>
<td>from ln $C_t$ to ln $N_t$</td>
<td>3.174</td>
<td>0.366</td>
<td>-0.186</td>
</tr>
<tr>
<td>from ln $R_t$ to ln $C_t$</td>
<td>1.495</td>
<td>0.683</td>
<td>-0.032</td>
</tr>
<tr>
<td>from ln $C_t$ to ln $R_t$</td>
<td>14.758</td>
<td>0.002***</td>
<td>0.541</td>
</tr>
<tr>
<td>from ln $Y_t$ to ln $C_t$</td>
<td>8.221</td>
<td>0.042***</td>
<td>0.142</td>
</tr>
<tr>
<td>from ln $C_t$ to ln $Y_t$</td>
<td>12.059</td>
<td>0.007***</td>
<td>2.999</td>
</tr>
<tr>
<td>from ln $R_t$ to ln $N_t$</td>
<td>6.297</td>
<td>0.098*</td>
<td>0.396</td>
</tr>
<tr>
<td>from ln $N_t$ to ln $R_t$</td>
<td>5.635</td>
<td>0.131</td>
<td>0.123</td>
</tr>
<tr>
<td>from ln $Y_t$ to ln $N_t$</td>
<td>5.381</td>
<td>0.146</td>
<td>0.265</td>
</tr>
<tr>
<td>from ln $N_t$ to ln $Y_t$</td>
<td>1.715</td>
<td>0.634</td>
<td>0.000</td>
</tr>
<tr>
<td>from ln $R_t$ to ln $Y_t$</td>
<td>8.289</td>
<td>0.040**</td>
<td>-0.331</td>
</tr>
<tr>
<td>from ln $R_t$ to ln $Y_t$</td>
<td>4.554</td>
<td>0.208</td>
<td>0.482</td>
</tr>
</tbody>
</table>

Notes: *** and * denote significant levels at 1%, 5% and 10%, respectively.

Table 3
Generalized forecast error variance decomposition.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Horizon</th>
<th>CO2 emissions</th>
<th>Nuclear energy consumption</th>
<th>Renewable energy consumption</th>
<th>GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2 emissions</td>
<td>1</td>
<td>92.7</td>
<td>16.9</td>
<td>19.0</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>89.2</td>
<td>19.8</td>
<td>19.4</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>90.1</td>
<td>18.5</td>
<td>18.9</td>
<td>6.6</td>
</tr>
<tr>
<td>Nuclear energy consumption</td>
<td>15</td>
<td>90.3</td>
<td>18.4</td>
<td>18.9</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>17.6</td>
<td>95.5</td>
<td>19.9</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>17.7</td>
<td>88.8</td>
<td>17.6</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>17.8</td>
<td>88.4</td>
<td>17.5</td>
<td>6.8</td>
</tr>
<tr>
<td>Renewable energy consumption</td>
<td>1</td>
<td>29.3</td>
<td>22.3</td>
<td>79.0</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>27.9</td>
<td>25.1</td>
<td>72.1</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>27.7</td>
<td>25.0</td>
<td>71.4</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>27.7</td>
<td>25.0</td>
<td>71.4</td>
<td>5.8</td>
</tr>
<tr>
<td>GDP</td>
<td>1</td>
<td>5.5</td>
<td>0.5</td>
<td>0.4</td>
<td>92.1</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>6.6</td>
<td>1.6</td>
<td>3.9</td>
<td>87.3</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>7.2</td>
<td>1.9</td>
<td>4.4</td>
<td>86.1</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>7.3</td>
<td>1.9</td>
<td>4.5</td>
<td>85.9</td>
</tr>
</tbody>
</table>

Notes: Unlike the orthogonalised case, the row values for the generalized decompositions do not sum up to 100. The generalized version gives an ‘optimal’ measure of the amount of forecast error variance decomposition for each series (see Payne, 2002; Sari and Soyta, 2007).

Table 2 also indicates that there was also a bi-directional causality running between GDP and CO2 emissions. This implies that it may not be possible to reduce CO2 emissions without sacrificing economic growth. This result may give credence to those who support the view that combating global warming would be a burden for the US national economy. Our finding contrasts with the no causality found by Soyta et al., (2007) between CO2 emissions and GDP in the US. In relation to nuclear energy consumption and economic growth, we found no causality running in any direction between nuclear energy consumption and GDP. This is consistent with the findings of Payne and Taylor (in press) but contrary to Apergis and Payne (in press) and Wolde-Rufael and Menyah (forthcoming) who found a bi-directional causality between nuclear energy consumption and economic growth for a panel of sixteen countries. However, unlike the no causality found by Bowden and Payne (forthcoming) between GDP and renewable energy consumption, we found a unidirectional causality running from GDP to renewable energy consumption. Our results are however in line with Sadorsky (2009) who found real income to be an important driver of renewable energy consumption in G-7 countries. Our results are, however, not in line with Apergis and Payne (in press) who found a bi-directional causality between renewable energy consumption and economic growth in a panel of OECD countries. We also found a unidirectional causality running from renewable energy consumption to nuclear energy consumption.

The causality test presented above indicates only Granger causality within the sample period and does not allow us to gauge the relative strength of the Granger causality among the series beyond the sample period (Payne, 2002; Shan, 2005). Thus, to complement the above causality test, we applied the generalized impulse response approach proposed by Pesaran and Shin (1998) that does not require orthogonalization of shocks and is invariant to the ordering of the variables in the VAR (Payne, 2002). Hence, we decomposed the forecast error variance of CO2 emissions into proportions attributed to shocks in all variables in the system including itself by estimating the non-augmented VAR (k lags only). By doing so, we can provide an indication of the Granger causality test beyond the sample period.

As can be seen from Table 3, the forecast error variance of nuclear energy consumption explains more than 18% of the forecast error variance of CO2 emissions. Similarly, the forecast error variance of renewable energy consumption explains more than 19% of the forecast error variance of CO2 emissions. In contrast, the forecast error variance of GDP explains not more than 7% of the forecast error variance of CO2 emissions. As can be seen from Table 3, renewable energy consumption explains around 19% of the forecast error variance of nuclear energy consumption. On the other hand, nuclear energy consumption explains around 25% of the forecast error variance of renewable energy consumption. This may suggest that there is a bi-directional causality between nuclear energy consumption and renewable energy consumption. What does this mean in policy
terms? As can be seen from Table 3, GDP does not seem to contribute much either to the forecast error variance of nuclear energy consumption or to renewable energy consumption.

4. Concluding remarks

The environmental challenge facing many countries including the US is how to balance sectoral energy supplies in order to produce more secure and cheap energy, and at the same, to reduce greenhouse gas emissions (GHG). By applying Granger causality test for the US for the period 1960–2007, this paper tested the hypothesis that nuclear energy consumption and renewable energy consumption help to reduce CO₂ emissions. The empirical evidence indicates a unidirectional negative causality running from nuclear energy consumption to CO₂ emission without feedback implying that nuclear energy consumption can help to reduce CO₂ emissions. In contrast, we found no causality running from renewable energy consumption to CO₂ emissions but we found a unidirectional causality running from CO₂ emissions to renewable energy consumption. The evidence seems to indicate that the US can reduce its CO₂ emissions by increasing nuclear energy consumption. The concrete proposals to build more nuclear plants may be justified not only to increase energy supply and energy security, but also to increase the capacity of the US to reduce CO₂ emissions. Future research should investigate the experience of other countries individually and collectively through panel cointegration analysis.

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The Times, Saturday August 01 2009 Clean Energy: U.S. Lags in Research and Development.


