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Error Correction Model for Predicting the Carbon Dioxide Emissions of a Coal-based High-income Economy

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Introduction

Oil shock of the 70s has been the major factor that caused structural breaks in the ever-increasing trend in carbon dioxide (CO_2) emissions experienced by high income economies such as United States, Japan, France and Austria (see, Unruh and Moomaw, 1998; Friedl and Getzner, 2003; Shanthini and Perera, 2006). The ever-increasing trend in the CO_2 emissions of Australia, despite it being a high income economy, remains relatively unaffected owing to perhaps its dependence on coal as fuel (BP, 2006; World Bank, 2007). This paper seeks to identify the effect the increasing income has upon the CO_2 emissions of Australia, particularly because it is one of the two countries that has defied the Kyoto Protocol (UNFCCC, 1997) that assigned mandatory greenhouse gas emissions limitations to the signatory nations.

Since both income and emissions data of Australia are trending non-stationary time series, an ordinary least square regression model developed based on this data can be spurious (Granger and Newbold, 1974). In this study, we show that there exists a cointegrating relationship between the income and emissions non-stationary time series, and thus the long term effect that income has on emissions can be captured using the error correction modeling approach proposed by Engle and Granger (1987).

Data analyses

The annual CO_2 emissions (denoted by CO_2) and the gross domestic product per capita (denoted by GDPpc) data for Australia used in this study, obtained from World Development Indicators (World Bank, 2007), are shown in Figure 1. The unit of CO_2 is Mt (mega tonnes = 10^9 kg) of CO_2 and that of GDPpc is thousands of constant 2000 US$. The time span used for modeling is 1960 to 1996, which makes available the emissions data from 1997 to 2003 for model validation.

The results obtained from regressing CO_2 on GDPpc, $\ln(CO_2)$ on ln(GDPpc) and $\ln(CO_2)$ on 1/ln(GDPpc) using the ordinary least square (OLS) procedure are given in Table 1. In all cases, the R^2 statistics are very high. The low values of Durbin-Watson (dw) statistics indicate the presence of serial correlation among the residuals of the respective regressions. The problem is, however, more than just the presence of auto-correlated residuals. It is the fact the time series considered are all nonstationary as revealed by the results of Augmented Dickey-Fuller (ADF) test carried out to test the presence of unit roots. Regressing one nonstationary time series on the other is known to give significant statistical correlation, such as high R^2, between the variables, even though the two variables may not be related at all.

In order to determine if there exists an equilibrium relationship between the nonstationary time series of our interest, i.e. if these series "move together" over time, we tested the residuals of the respective regression models shown in Table 1 for stationarity using the ADF test. The results showed that the residuals are stationary at the 5% level of significance for the first two regression models and at the 10% level of significance for the last regression model tabulated in Table 1. Therefore, we concluded that the respective time series are cointegrated, which is indeed a clear proof for the existence of an equilibrium, i.e. a long-term, relationship between the cointegrated time series (Engle and Granger, 1987; Stock and Watson, 1988).

Results: Error correction model

The error (or equilibrium) correction model (ECM) between two cointergrated first-difference stationary variables, y and x, could be written (Engle and Granger, 1987) as

$$\begin{aligned}\Delta y_t &= a + \sum_{i=1}^{m} b_i \Delta y_{t-i} + c_0 \Delta x_t \\ &\quad + \sum_{j=1}^{n} c_j \Delta x_{t-j} + dECT_{t-1} + \varepsilon_t\end{aligned} \qquad (1)$$

where y is CO_2 or $\ln(CO_2)$, x is GDPpc or ln(GDPpc) or 1/ln(GDPpc), and the error correction term *ECT*, expressed as

$$ECT_t = y_t - \text{slope} * x_t - \text{intercept},$$

is the residual of the cointegrating regression obtained using the OLS procedure. The respective slope and the intercept values could be obtained from Table 1. The coefficients of ECM in Eq. (1) estimated using the Engle Granger 2-Step Method (Engle and Granger 1987), and other relevant statistics are tabulated in Table 2.

Discussion

The coefficients of *ECT*, given by the values of *d* in Table 2, show that the error correction term in Eq. (1) has significant effect on the otherwise difference model in all three cases analysed. The AIC and BIC values of Table 2 make the Linear Model inferior to the Ln and the Inverse Models. Of these two, the Inverse Model is superior to the Ln Model since the Ln Model fails the tests for the normal distribution of the residuals (as testified by the P-values corresponding to the Shapiro-Wilk, Kolmogorov-Smirnov, Cramer-von Mises and Anderson-Darling tests). Moreover, the dw of the Inverse Model, being close to 2, also makes it clear that the Inverse Model is the model to be used for predicting the future CO_2 emissions in Australia.

Figure 2 shows the emissions predicted by the Inverse Model in comparison to the other two models and the actual emissions. The GDPpc value used for model prediction is the actual value until 2005 and after that it is generated using an annual GDPpc growth rate of 2.135%, which is the average growth rate for Australia during the period 1961 to 2005 (World Bank, 2007). The CO_2 value used for model prediction is the value predicted by the model considered, except for the 1960 value. Figure 2 shows that the long term predictions made using the Inverse Model trace the trend of the actual emissions much better than the other two models.

Conclusions

Australian carbon dioxide emissions has a long term tendency to keep growing with the GDP per capita growth in accordance with the relationship given by,

$$\begin{aligned}CO_2(t) &= 0.7183CO_2(t-1) \\ &\quad - 6.3233x(t) + 3.1635x(t-1) + 2.6860,\end{aligned}$$

where x = 1/ln(GDPpc), if there is a crisis in the oil supply or not. It is made possible owing to Australia being a heavy user of coal, which is available in abundance in her soil. In 2004, coal-based energy generation in Australia accounted for 44.6% of the total (BP, 2006) and coal-based electricity generation accounted for 79.3% of the total (WDI, 2007).

The model above, developed in this study, predicts that Australia would have a total of 440 Mt CO_2 emissions in 2012, whereas Kyoto Protocol allows only 294 Mt of emissions in 2012, which is 8% above the 1990 emissions level. This means, in 2012, Australia would be emitting 50% above the emissions allowed by the Kyoto Protocol in order to maintain its GDP per capita growth at a minimum of 2.135%. The strong link between the GDP per capita growth and the emissions as established in this study would probably explain why Australia rejected Kyoto Protocol.

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Table 1. Coefficients and other relevant statistics of the ECM

Model	R^2 (%)	Adj R^2 (%)	dw	Root MSE	AIC	BIC
CO_2 = 23.498 GDPpc -131.427	0.977	0.977	0.74	9.792	171	173
$Ln(CO_2)$ = 1.750 ln(GDPpc) + 0.645	0.984	0.983	0.93	0.047	-224	-222
Ln(CO2) = -11.217 [1/ln(GDPpc)] + 9.535	0.976	0.976	0.66	0.057	-210	-208

Note: P<.0001 for both the intercept and slope coefficients, and dw, MSE, AIC and BIC stand for Durbin-Watson, Mean Square Error, Akaike-Information Criterion and Schwarz Bayesian Information Criterion, respectively.

Table 2. Coefficients and other relevant statistics of the ECM

	Linear model: ECM with $y = CO_2$ and x = GDPpc	Ln model: ECM with $y = \ln(CO_2)$ and x = ln(GDPpc)	Inverse model: ECM with $y = \ln(CO_2)$ and x = 1/ln(GDPpc)
a, b_i, c_j of Eq. (1)	Set to 0 since the OLS estimates of them are not significant (i.e. P>0.05)		
C_0 of Eq. (1)	13.5916 (P < 0.0001)	1.0071 (P < 0.0001)	-6.3233 (P < 0.0001)
d of Eq. (1)	-0.3374 (P = 0.0059)	-0.4125 (P = 0.0019)	-0.2817 (P = 0.0136)
R^2; Adj R^2	0.461; 0.429	0.508; 0.479	0.452; 0.419
dw	1.695	1.649	1.821
F-valve	14.52 (P < 0.0001)	17.58 (P < 0.0001)	14.03 (P < 0.0001)
Root MSE	6.58173	0.03365	0.03552
AIC; BIC	137.6; 139.8	-242.3; -240.0	-238.4; -236.1
Chi-Square for heteroskedasticity	0.89 (P = 0.8270)	3.27 (P = 0.3513)	2.44 (P = 0.4862)
Shapiro-Wilk	P = 0.2325	P = 0.0309	P = 0.5158
Kolmogorov-Smirnov	P > 0.1500	P < 0.0100	P > 0.1500
Cramer-von Mises	P = 0.1325	P = 0.0144	P > 0.2500
Anderson-Darling	P = 0.1488	P = 0.0154	P > 0.2500

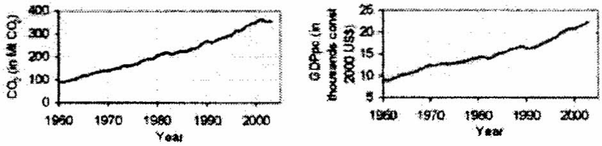

Figure 1. CO_2 emissions and GDP per capita time series of Australia from 1960 to 2003

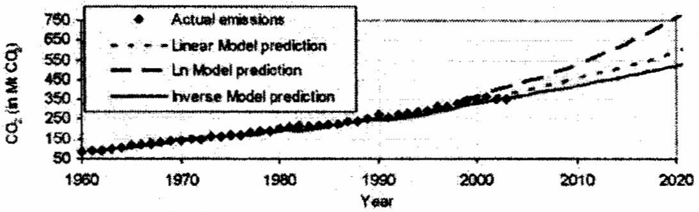

Figure 2. CO_2 emissions, actual and predicted