

Polynomial Cointegration Tests of the Anthropogenic Theory of Global Warming

Michael Beenstock¹ and Yaniv Reingewertz¹

¹*Department of Economics, The Hebrew University, Mount Scopus, Israel.*

We use statistical methods designed for nonstationary time series to test the anthropogenic theory of global warming (AGW). This theory predicts that an increase in atmospheric greenhouse gas concentrations increases global temperature permanently. Specifically, the methodology of polynomial cointegration is used to test AGW when global temperature and solar irradiance are stationary in 1st differences, whereas greenhouse gas forcings (CO₂, CH₄ and N₂O) are stationary in 2nd differences. We show that although greenhouse gas forcings share a common stochastic trend, this trend is empirically independent of the stochastic trend in temperature and solar irradiance. Therefore, greenhouse gas forcings, global temperature and solar irradiance are not polynomially cointegrated, and AGW is refuted. Although we reject AGW, we find that greenhouse gas forcings have a temporary effect on global temperature. Because the greenhouse effect is temporary rather than permanent, predictions of significant global warming in the 21st century by IPCC are not supported by the data.

While most of the scientific research into the causes of global warming has been carried out using calibrated general circulation models, since 1997 a new branch of scientific inquiry has developed in which hypotheses of climate change are tested by the method of cointegration^{i,ii,iii,iv,v,vi,vii,viii}. These cointegrated models putatively confirm that an increase in the radiating forcing of greenhouse gases permanently raises global temperature.

The method of cointegration is designed to test hypotheses with time series data that are non-stationary to the same order, and to avoid the pitfall of spurious regression.^{ix} The order of non-stationarity refers to the number of times a variable must be differenced (d) to render it stationary, in which case the variable is integrated of order d , or $I(d)$. We confirm previous findings^{ii,iii,v,vi,ix} that the radiative forcings of greenhouse gases (CO_2 , CH_4 and N_2O) are stationary in second differences (i.e. $I(2)$) while global temperature and solar irradiance are stationary in first differences (i.e. $I(1)$).

Normally, this difference would be sufficient to reject the hypothesis that global temperature is related to the radiative forcing of greenhouse gases, since $I(1)$ and $I(2)$ variables are asymptotically independent.^x An exception, however, arises when greenhouse gases, global temperature and solar radiation turn out to be polynomially cointegrated.^x In polynomial cointegration the greenhouse gases that are stationary in second differences must share a common stochastic trend, henceforth the "greenhouse trend", that is stationary in first differences. If this "greenhouse trend" exists and if it is cointegrated with global temperature and solar irradiance, we may conclude that greenhouse gases are polynomially cointegrated with global temperature and solar irradiance.

The fact that greenhouse gases are $I(2)$ variables has been completely overlooked by some who by default treated them as $I(1)$ variables.ⁱ Others noticed that they are $I(2)$ variables, but inappropriately used standard cointegration tests instead of polynomial cointegration tests.^v Still others used polynomial cointegration tests designed for situations where all, instead of just some of the variables are $I(2)$,^{vi} and some ignore the issue altogether^{xi, xii}.

We show that when these shortcomings are corrected, there is no evidence relating global warming in the 20th century to the level of greenhouse gases in the long run. We show that although greenhouse gases share a common stochastic trend, this "greenhouse trend" is not cointegrated with global temperature and solar irradiance. Therefore greenhouse gas forcings do not polynomially cointegrate with global temperature and solar irradiance. Consequently, the putative evidence in favor of the anthropogenic theory of global warming turns out to be spurious.

Although we do not find permanent effects of greenhouse gas forcings on global temperature, we find that they have temporary, or short-term, effects. This means that an increase in CO_2 emissions only has a temporary warming effect. We show that previous investigators have confused the temporary with the permanent. This means, crucially, that a doubling of greenhouse gas forcings does not permanently increase global temperature. The policy implications of this temporary greenhouse effect are obviously much less serious than had the effect been permanent.

The Time Series Properties of Greenhouse Gas Concentrations

Our data have been used in several recent studies, and come from NASA GISS.^{xiii,xiv} We classify these variables in terms of their order of integration (d) using various unit root tests. Since these tests are known to have low power we prefer not to rely on any single test. In Table 1 we provide details of the classification procedure for the radiative forcing of CO_2 (rfCO_2). Test 1 shows that according to all three test statistics rfCO_2 is not trend stationary. Test 2 shows that according to the PP statistic rfCO_2 is marginally difference stationary, but the KPSS and ADF statistics clearly reject this hypothesis. Test 3 establishes that the 2nd difference of rfCO_2 is stationary according to all three test statistics. Finally, a direct estimate of d using the fractional unit root method^{xv} gives a value of 1.56 to d which provides independent evidence that rfCO_2 is $I(2)$.

Table 1 here

We also check whether rfCO_2 is $I(1)$ subject to a structural break. A break in the stochastic trend of rfCO_2 might create the impression that $d = 2$ when in fact its true value is 1. We apply the test suggested by Clemente, Montanas and Reyes (1998) (CMR).^{xvi} The CMR statistic (which is the ADF statistic allowing for a break) for the first difference of rfCO_2 is -3.877. The break occurs in 1964, but since the critical value of the CMR statistic is -4.27 we can safely reject the hypothesis that rfCO_2 is $I(1)$ with a break in its stochastic trend.

We have applied these test procedures to the variables in Table 2. It turns out that the radiative forcings of all three greenhouse gases are $I(2)$. Global temperature and solar

irradiance, however, are I(1). The test proposed by Dickey and Fuller (1981) rejects trend stationarity in favor of difference stationarity for global temperature and solar irradiance. Also, the CMR tests indicate that structural breaks do not affect the classifications of d reported in Table 2.

Table 2 here

A Greenhouse Trend?

Since the radiative forcings of greenhouse gases are I(2) they cannot be cointegrated with global temperature, which is I(1). If, however, these greenhouse gas forcings cointegrate into an I(1) variable they might be polynomially cointegrated with temperature and solar irradiance. The OLS estimate of the cointegrating vector for $rfCO_2$, $rfCH_4$ and rfN_2O is:

$$rfCO_2 = 10.927 + 0.0466rfCH_4 + 10.1346rfN_2O + g \quad (1)$$

Sample: 1850 – 2006 $se = 0.032$ $\bar{R}^2 = 0.9941$

where g denotes the residual. We use cointegration test statistics to estimate the order of integration of g (d_g) in equation (1). According to Haldrup (1994) the critical value for the cointegration test statistic at $p = 0.05$ is -3.86. If $d_g = 2$ the greenhouse gases are not cointegrated. The test statistics indicate that we can reject the hypothesis that d_g is 2 or 0 but we cannot reject the hypothesis that $d_g = 1$:

$$d_g = 0: ADF_4 = -1.332 \quad PP = -1.53 \quad KPSS = 0.721$$

$$d_g = 1: ADF_4 = -4.248 \quad PP = -12.779 \quad KPSS = 0.134$$

The fact that $d_g = 1$ means that the three greenhouse gases share a common stochastic trend, the "greenhouse trend", which we represent by g , and which is non-stationary.

Polynomial Cointegration Test

Since global temperature, solar irradiance and g are $I(1)$ variables, we specify these variables in levels in equation (2). We specify greenhouse gas forcings in first differences since their order of integration is 2. The OLS estimate of the relationship between global temperature and solar irradiance and the differences in greenhouse gas forcings is:

$$T = 13.903 + 1.498S + 10.057\Delta rfCO_2 + 36.882\Delta rfN_2O - 41.5\Delta rfCH_4 + 0.268g \quad (2)$$

$$\text{Sample: } 1880 - 2000 \quad s = 0.1509 \quad \bar{R}^2 = 0.5875$$

$$ADF_4 = -5.062 \quad PP = -7.018 \quad KPSS = 0.304$$

Equation (2) indicates that global temperature varies directly with solar irradiance and with the first differences of $rfCO_2$ and rfN_2O as well as the levels of these forcings via g . However, it varies inversely with the first difference of $rfCH_4$. This difference between methane and other greenhouse gases has been noted by others.^{vi} According to Haldrup (1994) the critical value ($p = 0.05$) of the cointegration statistic to test for polynomial cointegration is about -5.2. The critical value of the cointegration test statistic due to MacKinnon (1991) is -4.534. The ADF statistic for the residuals of

equation (2) is therefore marginal, but the PP and KPSS statistics clearly indicate that equation (2) is polynomially cointegrated.

We cannot use t – tests or F – tests to carry out specification tests of equation (2) since the parameters estimates have non-standard distributions. To test for the statistical significance of individual variables or groups of variables, we re-estimate equation (2) without these variables. If as a result equation (2) ceases to be cointegrated this means that the omitted variables are statistically significant. For example, omitting g has almost no effect on the cointegration test statistics ($ADF_4 = -4.930$, $PP = -6.995$, $KPSS = 0.303$), which suggests that g is not statistically significant in the cointegrating vector. If, in addition, the first differences of greenhouse gas forcings are omitted, the cointegration test statistics deteriorate considerably ($ADF_4 = -3.038$, $PP = -5.398$ and $KPSS = 0.503$). This shows that the first differences of greenhouse gases are empirically important but not their levels. The most important variable is solar irradiance. Dropping this variable, but retaining the first differences of the greenhouse gas forcings, adversely affects all three cointegration test statistics ($ADF_4 = -2.203$, $PP = -6.326$ $KPSS = 1.0$). As noted, a number of studies^{ii,v,ix} recognize that greenhouse gases are I(2) variables, but their cointegration tests are incorrect. To explore the implications of this oversight we reconstruct their model estimated over 1880 - 2000:

$$T = -18.05 + 1.06rfCO_2 + 0.66S - 1.89rfCH_4 + 0.71rfN_2O \quad (3)$$

$$\bar{R}^2 = 0.6829 \quad se = 0.132 \quad ADF_4 = -4.76 \quad PP = -7.73 \quad KPSS = 0.11$$

Equation (3) seems to be cointegrated according to cointegration test statistics designed for I(1) variables. It implies that a doubling of atmospheric $rfCO_2$ raises global

temperature by almost 4 degrees. According to Haldrup (1994) the left hand side variable in equation (3) should be I(2) rather than T which is I(1). Making this simple correction by specifying rfCO₂, an I(2) variable, on the left hand side instead of T (see equation (4)) radically weakens the cointegration test statistics:

$$\text{rfCO}_2 = 11.92 + 0.03T - 0.12S + 0.15\text{rfCH}_4 + 9.36\text{rfN}_2\text{O} \quad (4)$$

ADF₄ = -2.22 instead of -4.76 and PP = -2.72 instead of -7.77. Haldrup's (1994) critical value of the cointegration test statistic when there are three I(2) variables and two I(1) variables is about -4.25. Therefore equation (4) is clearly not polynomially cointegrated, and the conclusions of these studies regarding the effect of rfCO₂ on global temperature are incorrect and spurious.

Error Correction

Cointegration implies error correction.^{xvii} We report the error correction model (ECM) for global temperature since this is the main variable of interest here. This model uses the residuals (u) from equation (2) estimated without g, because g is not statistically significant. Its dynamic specification is estimated using the general-to-specific methodology.^{xviii}

$$\Delta T_t = 0.005 - 0.138\Delta T_{t-2} - 0.196\Delta T_{t-3} + 0.71\Delta^2 S_t + 4.72\Delta^3 \text{rfCO}_{2t} \quad (5)$$

$$(0.05) \quad (1.71) \quad (2.51) \quad (2.09) \quad (4.08)$$

$$+ 29.74\Delta^2 \text{rfN}_2\text{O}_{t-2} - 0.50u_{t-1}$$

$$(2.41) \quad (6.38)$$

$$R^2 \text{ adj} = 0.379 \quad \text{se} = 0.12 \quad \text{DW} = 1.98 \quad \text{LM} = 4.36$$

In equation (5) the change in temperature varies directly with the 3rd difference in rfCO₂ and the twice lagged 2nd difference in rfN₂O. It also varies directly with the 2nd ("seasonal") difference of solar irradiance - $\Delta_2^2 S_t = \Delta S_t - \Delta S_{t-2}$. It does not depend at all on methane. There is evidence of 2nd and 3rd order negative autoregression in the change in temperature. Finally, the error correction coefficient is very significant and is equal to a half. This means that when the temperature deviates from its equilibrium as determined in equation (2) about half of the deviation is corrected within a year. These estimated speeds of adjustment are orders of magnitude more rapid than their calibrated counterparts obtained from general circulation models^{xix}, but are similar to those obtained from time series models^{v,vi}. The Durbin Watson (DW) and lagrange multiplier (LM) statistics for serial correlation in the residuals indicate that the dynamic specification of equation (5) is appropriate.

We use equations (2) and (5) to simulate the effect on global temperature of a permanent increase in the variables in Table 3. Both solar irradiance and rfCO₂ have pronounced short-term effects. Importantly, however, the long-run effect of rfCO₂ in levels is zero. If instead of a permanent increase in its level, the *change* in rfCO₂ were to increase *permanently* by 1 w/m², global temperature would eventually increase by 0.54 C. If the level of solar irradiance were to rise permanently by 1 w/m², global temperature would increase by 1.47 C. Table 3 shows that most of these effects occur within 5 years.

Table 3 here

Decomposing the Causes of Global Warming in the 20th Century

We use equation (2) to calculate the contributions to global temperature change during the 20th century. Results are reported in Table 4.

Table 4 here

Between 1880 and 2000 global temperature rose by 0.54 degrees Celsius of which 0.48 occurred since 1940. Equation (2) attributes 0.4 of this to solar irradiance and the balance to greenhouse gas forcings. Table 4 shows, however, that since 1940 greenhouse gas forcing have made a larger contribution to global warming than before, and solar irradiance a smaller one. This creates the misleading impression that the level of greenhouse gas forcings have been the main cause of global warming in the 20th century. However, our results clearly indicate that it is not the level of greenhouse gas forcings that matters, but the change in the level. During 1880-1940 the level of greenhouse gas forcing increased, but the change in the level decreased. This is why Table 4 implies that greenhouse gas forcings reduced global temperature before 1940.

During the second half of the 20th century greenhouse gas forcings accelerated due in particular to increased carbon emissions. Our model predicts that this effect will be temporary unless these forcing continue to accelerate. Since carbon emissions depend

on the level of global economic activity, this continued acceleration would unreasonably imply faster economic growth in the 21st century than in the 20th. Our results also imply that cutting carbon emissions will only induce a short-term reduction in global temperature, leaving no long run effect.

Robustness Checks

We carry out a number of different types of robustness check. We test for finite sample bias in equation (2). We use alternative cointegration methodologies to estimate equation (2). Finally, we use new data on solar irradiance that have recently become available.^{xx}

Our polynomial cointegration tests are designed for asymptotic situations. Even though the data span 130 years there may nevertheless be finite sample bias, especially if error correction is slow. Since equation (5) indicates rapid error correction, finite sample bias is unlikely to be large. We use the 3-stage procedure suggested by Engle and Yoo (1987) to test for finite sample bias. Since the p-value of the F – statistic for the 3rd stage (for which equation (5) is the 2nd stage) is 0.48, we may reject the hypothesis of finite sample bias.

Next, we use DOLS^{xxi} rather than OLS to estimate equation (2). The cointegration test statistics slightly improve, e.g. $ADF_4 = -6.43$ instead of -5.31 and the parameter estimates are slightly different. However, the conclusion that greenhouse gases do not polynomially cointegrate with global temperature and solar irradiance is robust. Another method of polynomial cointegration is proposed by Johansen.^{xxii,xxiii} This method differs

conceptually in the way the $I(2)$ variables are treated. In Haldrup's method the levels of the $I(2)$ variables are assumed to "cointegrate down" to an $I(1)$ variable such as g in equation (1). In Johansen's method the first differences of the $I(2)$ variables are assumed to "cointegrate down" into an $I(0)$ variable. This induces a deterministic time trend in the relationship between the levels of the $I(2)$ variables. It assumes therefore that there is an independent time trend in one of the greenhouse gas forcings, which is incompatible with greenhouse gas theory. In any case, in contrast to equation (1), we do not find that the first differences in the greenhouse gas forcings unambiguously cointegrate down as expected. Therefore, we do not think that Johansen's method of polynomial cointegration is appropriate in this context.

Finally, we have estimated equation (2) using revised and extended (to 2006) data for solar irradiance.^{xx} Prior to 1980 these data were based on various proxy measures. Data since 1980 are based on instrumental measures from satellites. Whereas the data in NASA GISS used 15 years of satellite data, the revised data use 26 years. We note that the revised data behave differently to the original in that the ratio of revised to original decreases during 1850 to 1950 but increases subsequently. Also, surprisingly, the revised series is not cointegrated with the original. We have focused on the original data since these were used by others who claimed that global temperature is cointegrated with solar irradiance and greenhouse gas forcings.

When we use the revised data, equation (2) ceases to be cointegrated. This happens because, as noted, the revised data are quite different to the original. The revised data confirm that greenhouse gas forcing do not polynomially cointegrate with global temperature. However, they also reject the hypothesis that global temperature varies

directly with the change in greenhouse gas forcings, and indeed, that solar irradiance is a driver of climate change.

Conclusion

We have shown that greenhouse gas forcings do not polynomially cointegrate with global temperature and solar irradiance. Therefore, previous claims that carbon emissions permanently increase global temperature are false. Although we find no permanent effect of greenhouse gas forcings on global temperature, there appears to be a temporary, or short-term, effect. We show that this temporary effect can easily be mistaken for a permanent one. Polynomial cointegration tests show that the putative permanent effect is induced by the spurious regression phenomenon. Because the effect is temporary, recent global warming should be interpreted as a short-term response to increased carbon emissions, which is expected to be reversed in the future.

Table 1. The Order of Integration of rfCO₂: 1850 -2006

Test	d	Root	Trend	ADF	DW	PP	KPSS
1	0	1.02	Yes	7.37	1.04	4.41	0.81
2	1	0.93	No	-1.38*	1.99	-3.25	2.66
3	2	-0.35	No	-17.88	2.21	-20.86	0.03

The null hypothesis in the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) test is that there is a unit root in the variable. The null hypothesis in the KPSS test due to Kwiatkowski, Phillips, Schmidt and Shin (1992) is that there is no unit root in the variable. PP uses the Newey-West bandwidth default of 4 lags and KPSS uses a bandwidth of 3 lags. Asterisked ADF statistics include 4 augmentations. In tests 2 and 3 the critical values for ADF and PP at $p = 0.05$ are -2.886 and for KPSS 0.463. In test 1 these critical values are -3.442 and 0.146 respectively.

Table 2. Orders of Integration

Series	d	Years
rfCO ₂	2	1850-2006
Temperature	1	1880-2006
Solar irradiance	1	1850-2000
rfCH ₄	2	1850-2006
rfN ₂ O	2	1850-2006

rfCH₄ is the radiative forcing of methane. rfN₂O is the radiative forcing of nitrous oxide.

Table 3. Impulse Responses

Year	rfCO ₂	Solar Irradiance	ΔrfCO ₂
1	0.253	0	0.2525
2	-0.110	1.44	0.1425
3	0.163	0.75	0.3051
4	0.082	0.91	0.3870
5	0.074	1.00	0.4614
6	-0.051	1.35	0.4563
7	0.014	1.37	0.471
∞	0	1.47	0.539

Notes: The table shows the impulse responses of global temperature (degrees Celsius) with respect to permanent changes of 1 watt per square meter in the variables.

Table 4. Contributions to Global Warming in the 20th Century

	1940-2000	1880-2000
Solar irradiance	0.17	0.40
rfCO ₂	0.20	0.09
rfCH ₄	0.11	0.03
rfN ₂ O	0.002	0.03
Total	0.48	0.54
Change in temperature	0.43	0.54

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