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LONG-RUN DETERMINANTS OF ATMOSPHERIC CO_2: GRANGER-CAUSALITY AND COINTEGRATION ANALYSIS

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Abstract: *Atmospheric concentrations of CO_2 grew annually 1.12 ± 0.48 parts per million (ppm) in 1958-1984, and 1.72 ± 0.54 ppm (mean ± standard deviation) in 1985-2009, so that the rate growth is growing itself. Natural phenomena that influence short-run changes in CO_2 atmospheric levels (through their influence on CO_2 emissions and sinks) are stationary processes that cannot explain the growth of CO_2 levels at an increasing rate. Cointegration tests show at a high level of statistical significance that the annual increase of CO_2 concentrations is roughly proportional to "human activities" as measured by the money value of the world economy and the size of the world population. We find that population and world GDP help to predict CO_2 concentrations, but CO_2 concentrations do not help to predict the other variables; that is, there is Ganger causality from population and world economic output to CO_2. Though the smallness of the time series involved and the theoretical and practical issues posed by cointegration allow only for a limited confidence in these results, they have obvious major implications. For business-as-usual conditions and a world economy growing annually 3.5%—the mean annual growth of the world economy since 1960—the required world population to maintain or reduce CO_2 levels would be 1.3 billion or less. For a world population of 7 billion as the present one, CO_2 atmospheric levels would decrease if the global economy contracted annually 24.5% or more.*

Keywords: climate change; CO_2 atmospheric concentrations; world economic growth; world population.

1. Introduction

Successive reports of the Intergovernmental Panel on Climate Change (IPCC) have highlighted the connection between human activity and climate change. In 2007 the IPCC asserted that most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas

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concentrations. In a recent testimony to the U.S. House of Representatives a prominent geoscientist explained that the “very likely” in this statement signifies a probability over 90% that the statement is correct (Santer, 2001). Similarly, conclusive evidence has accumulated during recent years, both at the national and global level, on the relation between increased output of goods and services (measured by gross domestic product, GDP) and growth of greenhouse gas emissions, especially CO_2 (Arrow et al., 1995; Quadrelli & Peterson, 2007; M. R. Raupach et al., 2007; Roca & Alcántara, 2001; Tol, Pacala, & Socolow, 2009). However, the main variable determining climate change is the atmospheric level of CO_2, which in turn is the result of emissions (mainly from burning fossil fuels) minus removals by natural sinks. Although there are studies that link the short-run evolution of CO_2 atmospheric concentrations with natural factors, to our knowledge there are no investigations that have attempted to explain the evolution of CO_2 concentrations by changes in the global economy. Almost 20 years ago (Nordhaus, 1994, p. 14) considered that there are “no well established relationships or empirical studies that can be drawn upon to represent the linkage between economic activity and climate change.” Regarding the relationship between CO_2 concentrations and world GDP, it seems as if this assertion were still valid.

To investigate the link between the world economy and climate change focusing on CO_2 atmospheric concentrations rather than CO_2 anthropogenic emissions is a better methodological choice because (a) concentrations and not emissions are the key variable impacting on climate change; and (b) because the *measurement* of atmospheric levels of CO_2 is much more accurate and reliable than the *estimation* of emissions (from statistics on fuel consumption, exports, imports, etc.), which is likely subject to considerable margins of error (Nordhaus, 1994, p. 27; Nisbet & Weiss, 2010).

There is considerable uncertainty on the short-run links and impacts of human activities in the atmospheric levels of CO_2. Between 20% and 35% of anthropogenic CO_2 emissions are thought to be sequestered by the oceans (Anonymous, 2009) which could account for the fact that despite continuing deforestation, the observed CO_2 increase in the atmosphere averaged over several years accounts for only about 56% of the fossil fuel input (Hansen, 2010). The general view in the geoscience community seems to be that short-run annual changes in atmospheric CO_2 are to a large extent determined by natural phenomena—volcanic eruptions and the climatic fluctuation known as *El Niño* Southern oscillation (ENSO) (Bacastow, 1976; R. K. Kaufmann & Stern, 1997; R. Kaufmann, Kauppi, & Stock, 2006; Le Quéré et al., 2009; Le Quéré, Raupach, Canadell, Marland, & Bopp, 2009; M. R. Raupach, Canadell, & Le Queré, 2008; Wignuth et al., 1994). However, natural scientists have also asserted that the global recession of 2007–2009 reduced CO_2 emissions and probably was also responsible for the 2009 annual increase in CO_2 atmospheric levels being quite low, though this was also attributed to a response to ENSO activity (Friedlingstein et al., 2010).

In this investigation we show that the world economic output (WGDP) and the world population are determinants of the *long-run* evolution of CO_2 atmospheric concentrations. Cointegration models show the annual growth of CO_2 concentrations is roughly proportional to the size of the world population and economic output. We show Granger tests that indicate causality from either world population or WGDP to CO_2 concentrations.

Our findings reduce the uncertainty in the links of the causal chain implied in global warming and they also allow for quantitative estimates of the required level of economic growth or size of the global population that would reduce CO_2 concentrations if business-as-usual (BAU) conditions are maintained. The results suggest that given BAU conditions as in the present, major contractions of the world economy, the world population, or both, would be needed for the stabilization of atmospheric CO_2.

In the next section we present the data and discuss the variables potentially determining the growth atmospheric CO_2 in the long-run. Section 3 presents the cointegration tests and section 4 the Granger-causality analysis. Section 5 discusses the results and concludes. An appendix provides details about the data.

2. Atmospheric CO2 and its potential explanatory factors

Throughout the period 1960–2009, CO_2 atmospheric levels grew 1.41 ± 0.59 ppm/year (mean ± standard deviation), but the rate of growth of CO_2 also increased from 1.12 ± 0.48 ppm/year in 1960–1984 to 1.72 ± 0.54 ppm/year in 1985–2009 (figure 1). The augmented Dickey-Fuller (ADF) test for unit roots indicates that CO_2 atmospheric levels are not a stationary series (table 1). When the series is differenced, the ADF results are very sensitive to the specifications of the test and in several specifications the hypothesis of a unit root cannot be rejected. When CO_2 levels are differenced twice, the ADF test rejects the null of unit roots in all specifications (table 1). So, it is clear that CO_2 atmospheric concentrations are not integrated of order zero, that is, I(0), but it is unclear if the series is I(1) or I(2).

A number of estimates of the world economic output (WGDP) and the world population are available (see appendix on data). According to World Bank estimates, WGDP measured in 2000 U.S. dollars increased almost six-fold from 7.3 trillion in 1960 to 40.4 trillion in 2008. Since 1960 to 2009 WGDP grew 0.59 ± 0.35 trillion dollars/year. Since the output of national economies grows in the long run at a more or less constant rate, the annual increase in WGDP also tends to be larger over time. According to the

World Bank series (figure 1), WGDP grew on average 0.46 ± 0.19 trillion/year before 1985 and 0.72 ± 0.43 trillion/year in 1985–2009 (with a big deviation from trend in the world recession of 2008–2009, when WGDP shrank by 0.85 trillion). ADF tests for unit roots indicate that, in levels, WGDP is not a stationary series. As in the case of CO_2 concentrations, ADF tests for WGDP in first differences are inconclusive, while in second differences the rejection of the null hypothesis of unit roots is robust to specifications of the test (table 1).

Estimates of the world population since the late 1950s indicate that it increased 70.1 ± 10.5 million/year before 1985 and 79.4 ± 4.8 million/year in 1985–2009. The annual net growth of the global population (figure 1) rose steeply from the late 1950s, reaching a peak in 1990, and decreasing slightly thereafter. Again, as with CO_2 concentrations and WGDP, results of the ADF test (table 1) are inconclusive. No clear evidence indicates whether world population as estimated for the last six decades is modeled best as an I(1) or an I(2) process.

3. Cointegration Analysis

Let C_t be the atmospheric concentration of CO_2 in parts per million (volume) at the end of year t. Then

$$C_t = V_t / A$$

where V_t is the volume of CO_2 present in the atmosphere at the end of year t and A is the total volume of the atmosphere, which we assume to be constant. Therefore $\Delta V_t = V_t - V_{t-1} = H_t + N_t$, that is, the annual increase in the volume of atmospheric CO_2 is equal to human emissions (H_t) plus net natural emissions (N_t). Since we don't know if nature is capturing or throwing CO_2 to the atmosphere, we can assume $N_t = B + S_t$, where B is a constant (which can be positive, negative, or zero) and S_t is a random variable normally distributed with mean zero. N_t will be negative if natural sinks of CO_2 predominate over CO_2 emissions to the atmosphere from permafrost, natural wildfires, etc.; if these natural emissions predominate on processes that capture atmospheric CO_2, N_t will be positive. From all the former,

$$C_t = (V_{t-1} + H_t + B + S_t) / A.$$

If emissions were proportional to world economic activity during year t, that is Y_t, and k is a proportionality constant, then $H_t = k \cdot Y_t$, and, therefore,

$$C_t = (V_{t-1} + k \cdot Y_t + B + S_t) / A.$$

That is,

$$C_t = V_{t-1}/A + (k/A) \cdot Y_t + B/A + S_t/A.$$

And, since V_{t-1}/A is C_{t-1}, we have that ΔC_t, the annual increase in concentrations, must be

$$\Delta C_t = (k/A) \cdot Y_t + B/A + S_t/A.$$

Let $k/A = \beta$, $B/A = \alpha$, and $S_t/A = \varepsilon_t$ is a random shock. Then we have

$$\Delta C_t = \alpha + \beta \cdot Y_t + \varepsilon_t. \qquad \text{[Eq.1]}$$

Eq. 1 can be interpreted as a cointegration equation of the annual increase in CO_2 concentrations and world economic output. If CO_2 concentrations grew annually in proportion to human (economic) activities (as suggested by figure 2, top panel), then ΔC_t would be cointegrated with Y_t . It might be, too, that CO_2 concentrations would grow in proportion to the size of world population (figure 2, bottom panel), or to the rate of expansion of the world economy, or to both human activity (or its rate of growth) and human numbers (or their rate of growth).

To explore all these possibilities, we computed models in which CO_2 concentration in first differences is regressed on (*i*) WGDP, (*ii*) WGDP per capita, (*iii*) world population, (*iv*) the rate of growth of WGDP, (*v*) the annual increase of world product per capita, or (*vi*) the annual increase of world population (table 2, models 1 to 6; figure 3, panels 1 to 5) or with a combination of the aforementioned variables (table 2, models 7 to 13, figure 3, panel 6). The Durbin-Watson *d* in these regressions is the cointegrating regression Durbin-Watson (CRDW) statistic. For a sample size of 50, the CRDW statistic has critical values of 0.69, 0.78, and 1.00 respectively for the 0.10, 0.05, and 0.01 levels of significance (Engle & Yoo, 1987). Since for all these models the values of the CRDW statistic are much greater than the CRDW critical values, the null hypothesis of no cointegration is rejected (at the 0.01 level of significance). The annual growth of atmospheric CO_2 looks therefore to be cointegrated with the size of both the global economy (and its rate of growth) and the world population (and its rate of growth). For a number of models, for instance the one in which dC is cointegrated with g (model 4 in table 4), the Durbin-Watson statistic is considerably lower than for the other equations. Moreover, the residuals of the cointegration equation (figure 3, panel 4) quite clearly reveal a pattern (a rising trend). We discovered the same pattern in the residuals in several of the cointegration models, those in which the CRDW statistic is not very far from 1.5. We believe these models provide much weaker evidence of cointegration than those in which CRDW values are close to 2.0 and residuals do not reveal any pattern (such as those in figure 3, except panels 4, 7, and 8).

In most formal definitions of cointegration (Engle & Granger, 1987; Gujarati, 2003; Hamilton, 1994), the cointegrating series must have the same order of integration so that a linear combination of them has a lower grade of integration. In the simplest case of two cointegrated series, they are both I(1) and there is a linear combination of the two which is a stationary I(0) series. However, as we explained before, the order of integration of CO_2 concentrations, WGDP, and world population that can be inferred from the ADF tests is ambiguous (table 1). For the three series in levels, the test results are all clearly compatible with unit roots, while for the series in second differences, the unit root null hypothesis is rejected under all assumptions and lags. However, when the series are in first differences, the ADF test results depend on the specifications of the test. For CO_2 concentrations in first differences, we can reject the hypothesis of a unit root under the specifications of unit root with drift or unit root with drift and deterministic time trend, but not assuming a unit root without drift ($P = 0.186$). For WGDP in first differences, the ADF test does not allow rejection of either a unit root without drift ($P = 0.019$) or a unit root with drift and trend ($P = 0.363$), while the result for the unit root with drift is in the range of marginal significance. Therefore, it seems that WGDP, CO_2, and population are not I(0) but each of them could be I(1) or I(2). On the other hand, a simple linear regression indicates that, in first differences, the three variables have a trend with a slope that is significantly different from zero ($\beta \pm SE[\beta]$ is 0.026 ± 0.004 for CO_2 concentrations, 0.010 ± 0.004 for WGDP, and 0.00031 ± 0.00007 for world population). Even world population in second differences has a linear negative trend (-0.00009 ± 0.00003), indicating that the annual increase of world population has been falling. The conclusion of all this is that in first differences CO_2 is likely I(1) and therefore the hypothesis that it might be cointegrated with trended variables such as WGDP or world population that are probably I(1) is possible and cannot be rejected a priori. For these reasons we tested the possibility of cointegration of CO_2 atmospheric concentrations in levels with WGDP, WGDP per capita, or world population. The CRDW statistic in these regressions is quite close to zero and therefore the null hypothesis of no cointegration is not rejected in any case (table 2). Moreover, the residuals in these regressions reveal obvious patterns incompatible with cointegration (figure 3, panels 7 and 8). Interestingly, in spite that we find the annual increase in CO_2 concentrations cointegrated with both WGDP and world population, these two variables do not appear to be cointegrated with each other (the CRDW statistic is 0.10).

Johansen cointegration tests for the former models produced similar results to those obtained from the simpler CRDW test.

Cointegration in general tries to answer the question of whether a regression in which variables have trends is or is not a spurious one. To answer that question, an examination of the residuals is an important tool. The residuals of regressions in which CO_2 in first differences is regressed on WGDP and world population are not at all suggestive that the regressions are spurious (the CRDW test is a way to quantify that).

Nevertheless, given the smallness of the sample (only 50 observations) and the considerable uncertainty about the ability of tests of unit roots and cointegration to produce reliable results (Cochrane, 1991; Perron, 1989; Romero-Ávila, 2008; Zivot & Andrews, 2002), we believe these cointegration relations must be considered tentative though likely. It might be that some of these series (as proposed by Perron for log-transformed GDP) have a trend and breaking points.

4. Granger Causality

Results of Granger-causality tests with series in first differences indicate that at the usual levels of statistical significance ($P < 0.05$) and for lags of one or few years (for long lags the test almost always produce very low P values) both WGDP and world population help to predict CO_2 atmospheric levels (tests A1 and B1 in table 4). In the other direction of causality, however, CO_2 levels help to predict neither WGDP nor world population (tests A2 and B2 in table 4). The results are therefore consistent with Granger-causation from

WGDP and world population to CO_2 atmospheric levels. (We also tested Granger causality between WGDP and world population, but *P* values are too large as to accept the hypothesis in any direction.)

5. Discussion and conclusions

A possible objection against our cointegration models is that they don't consider that the rate at which CO_2 is removed from the atmosphere may be proportional to the atmospheric level of CO_2. Since we model changes in the atmospheric concentration of CO_2 as the sum of anthropogenic emissions —proportional to WGDP— plus a stationary, normally distributed error term that represents net CO_2 emissions from biophysical processes, we might be setting a model in which the error term is correlated with the dependent variable. We believe this objection is not very plausible. If the errors in our cointegration equations were correlated with the dependent variable, that would show up in the examination of the residuals. However, the process of choosing a valid cointegration model implies, among other things, to discard those models in which there are patterns in the residuals. At a more basic level, there is considerable uncertainty about the degree in which the natural sinks of CO_2 depend on atmospheric concentrations. A recent investigation (Khatiwala, Primeau, & Hall, 2009) concluded that the rate of CO_2 uptake by the oceans has increased since preindustrial times and that this increase slowed between 2000 and 2008 while emission rates rose by a factor of three, so that more emissions are remaining in the atmosphere. This could be because as the ocean absorbs more CO_2 it becomes acidic and can hold less CO_2 (Anonymous, 2009). Moreover, ocean uptake of CO_2 is a sluggish process (Santer, 2001) and if emissions grow too rapidly, then the oceans cannot keep up.

In the past some analyses concluded controversially that the pace of economic growth does not affect the annual or cumulative flow of CO_2 emissions (Holtz-Eakin & Selden, 1995). We have shown evidence that rather shows the opposite. The main conclusion of our investigation is that in the long run and assuming the continuation of present BAU conditions, annual increases in atmospheric CO_2 will be proportional to "human activities" as indexed by the size of (a) the world economy in money terms (WGDP) and (b) world population. Obviously, the cointegration of annual increases of CO_2 concentrations with WGDP and world population have policy implications which are quite important and extremely thorny.

Among the models in which the annual increase in CO_2 concentrations is cointegrated with variables indexing human activities in terms of money (WGDP) and world population, it seems the best is the one in which the explanatory variables are world population and the rate of growth of WGDP. That model (model 9 in table 2, panel 6 in figure 3) has the greatest CRDW, and is also the one explaining the greatest proportion in the variation of CO_2 levels ($R^2 = 43\%$), with both explanatory variables being statistically significant.

The implication from that model, in which

$$\Delta C_t = -0.77 + 0.08 \cdot g_t + 0.39 \cdot P_t$$

(error term omitted), is that each extra percentage point in WGDP growth raises the annual increase in CO_2 concentrations by 0.08 ppm, while each extra billion people raises it by 0.39 ppm. Holding $\Delta C_t = 0$ we can compute the levels of world economic growth that—assuming BAU conditions—would lead to a reduction of CO_2 atmospheric levels. For an annual growth of WGDP at the mean of the past five decades, 3.5%, the required world population would be 1.3 billion or less. For zero economic growth, zero or decreasing atmospheric CO_2 would occur with a population below 2.0 million. For the world economy contracting at 2% per year, CO_2 levels would fall if world population were 2.4 billion or less. These are quite dismal conclusions, that, however, we cannot sustain with a high degree of confidence, not only because the shortness of the time series considered demands circumspection, but also because the ability of tests of unit roots and cointegration to produce reliable results is not beyond doubt. Only the passage of time and the availability of additional data will allow to confirm or reject with more confidence these relations.

APPENDIX

Data sources

All data used in the analysis (table 4) come from open access sources. CO2 atmospheric concentrations (in ppm by volume) are annual means computed from monthly atmospheric concentrations of CO_2 measured at Mauna Loa. These were obtained from the Earth's CO_2 Home Page (http://co2now.org), which reports data provided by the U.S. National Oceanic and Atmospheric Administration (NOAA). World GDP is in trillions of 2000 U.S. dollars, from the World Bank database (data.worldbank.org/). From the same database are the figures of world population, in billions (according to the World Bank database, these population figures are from the United Nations Population Division). We also analyzed shorter WGDP series from Maddison (Maddison, 2003) (to 2001 only), from the International Monetary Fund (1980–2007) and from the Department of Economic and Social Affairs of the United Nations (1970–2007), as well as annual estimates of the world population from Maddison (Maddison, 2003), and from the U.S. Census Bureau (USCB,). Using these alternative series, we obtained estimates of the change and evolution of the annual volume of the world economy and world population quite similar to those we presented here.

Figure 1. World population, mean atmospheric concentrations of CO_2, and world economic output, all series in year-to-year absolute growth

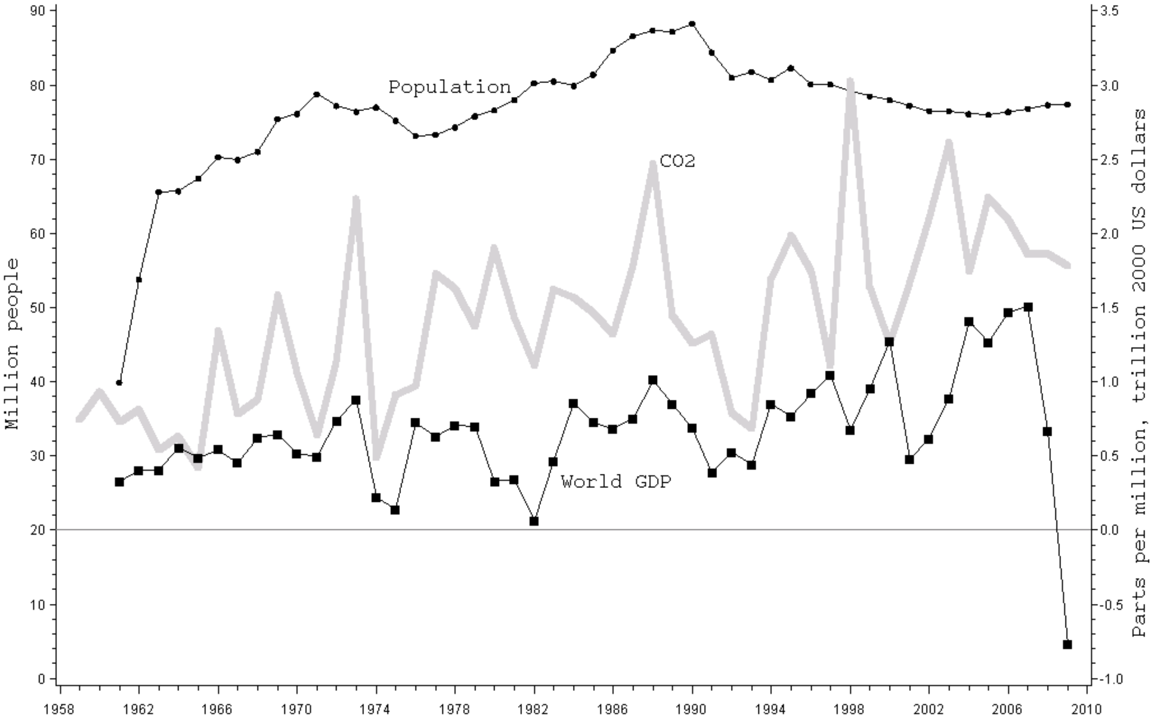
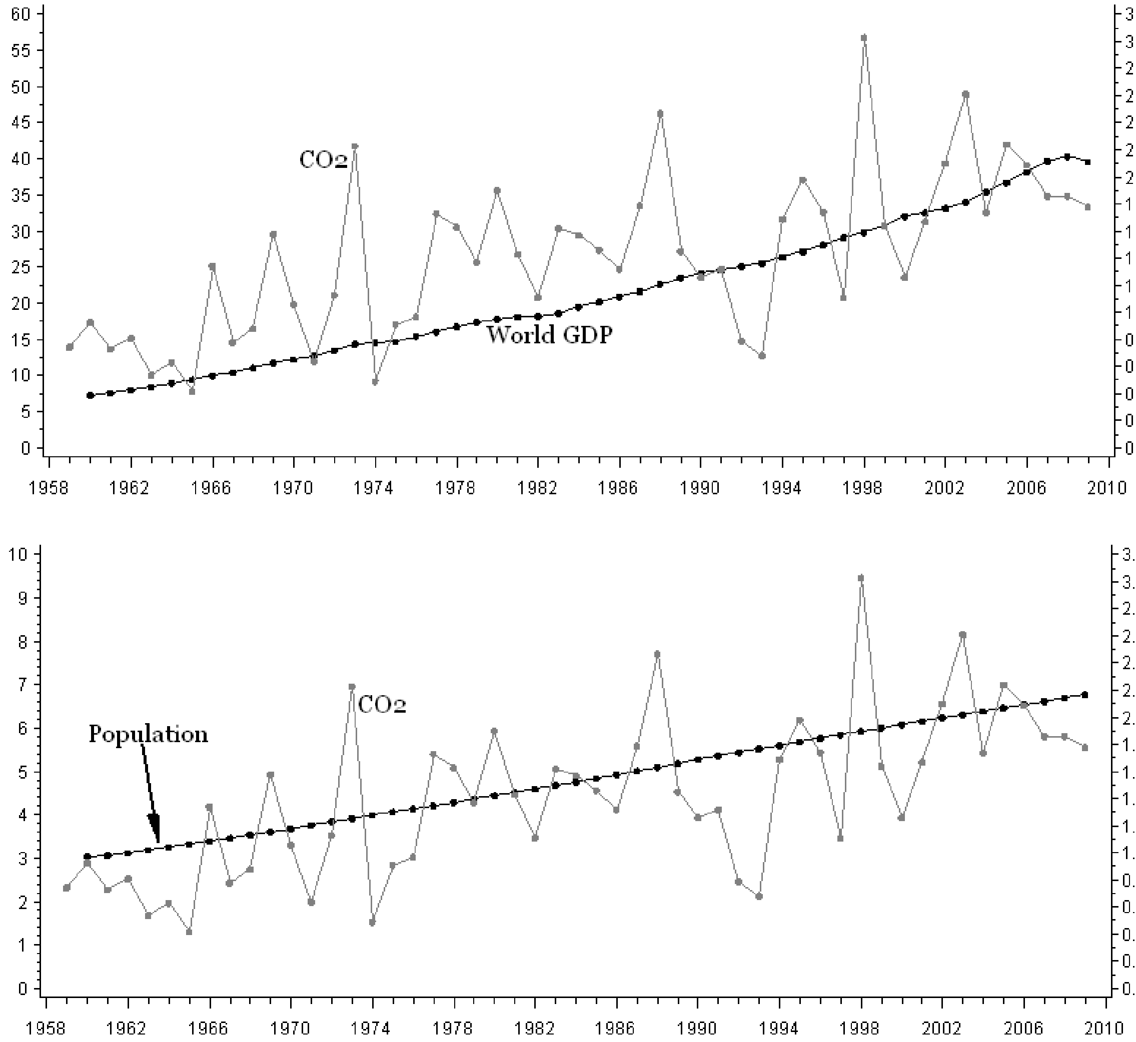


Figure 2. World GDP and world population compared with the annual increase in atmospheric concentrations of CO2



CO2 in ppm, right scales; world GDP in trillions of 2000 U.S. dollars; world population in billions, left scales.

Figure 3. Cointegration regressions and the corresponding plots of residuals versus time. *C* is CO2 atmospheric concentrations, *Y* is world economic output, *Ypc* is *Y* per capita, *g* is the annual rate of growth of *Y,* and *P* is world population. The lower-case d before a variable symbol indicates first differences, the *d* value (close to the right upper corner of each panel) is the Durbin Watson statistic. Standard errors in parenthesis below parameter estimates

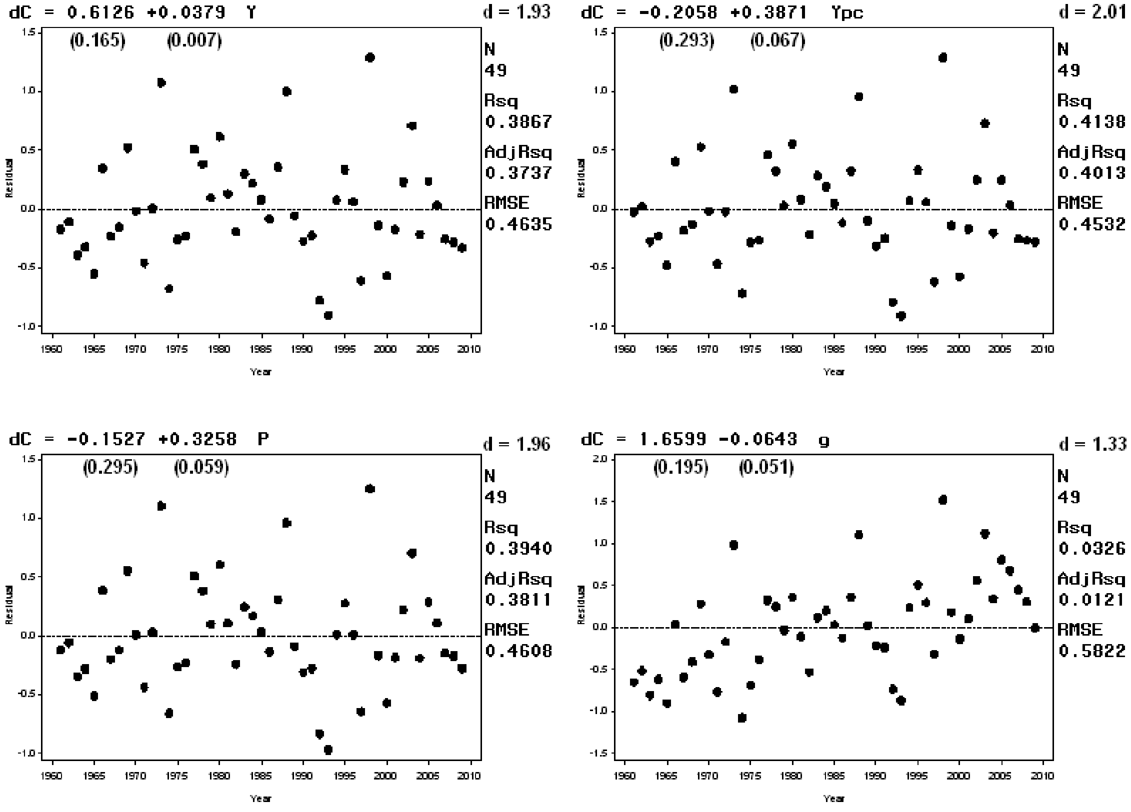


Figure 3 (Cont.).

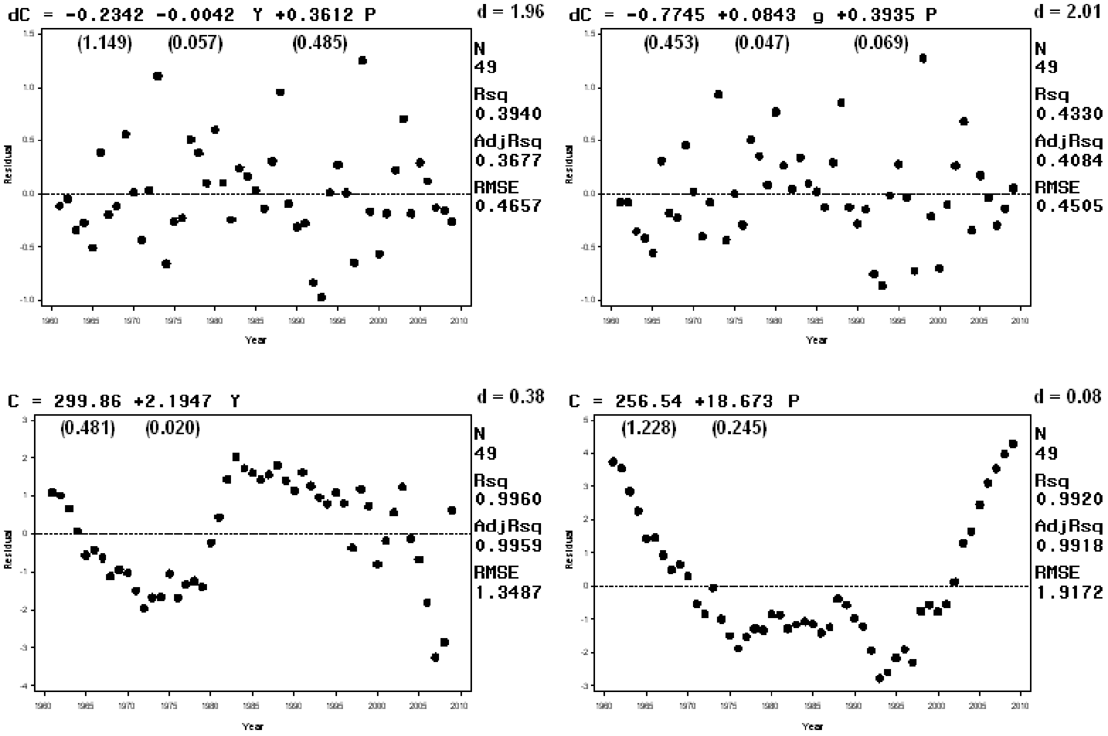


Table 1. P-values for the null hypothesis of a unit root in the augmented Dickey Fuller (ADF) test for stationarity.

	C	dC	d2C
Lag 0			
Unit root	1.000	0.186	< 0.001
Unit root with drift	1.000	0.001	< 0.001
Unit root with drift and trend	0.884	< 0.001	< 0.001
Lag 1			
Unit root	1.000	0.414	< 0.001
Unit root with drift	1.000	0.022	< 0.001
Unit root with drift and trend	1.000	< 0.001	< 0.001

	Y	dY	d2Y
Lag 0			
Unit root	1.000	0.119	< 0.001
Unit root with drift	1.000	0.074	< 0.001
Unit root with drift and trend	0.926	0.363	0.002
Lag 1			
Unit root	0.921	0.078	< 0.001
Unit root with drift	0.960	0.008	0.002
Unit root with drift and trend	0.336	0.019	0.011

	P	dP	d2P
Lag 0			
Unit root	1.000	0.940	< 0.001
Unit root with drift	1.000	< 0.001	< 0.001
Unit root with drift and trend	< 0.001	< 0.001	< 0.001
Lag 1			
Unit root	0.470	0.783	< 0.001
Unit root with drift	0.935	0.024	< 0.001
Unit root with drift and trend	0.927	0.162	< 0.001

C is CO2 concentrations, Y is world GDP and P is world population; d before the variable means first differences, d2 means second differences.

Table 2. CRDW tests for models in which the dependent variable is dC (CO2 concentrations in first differences). The null hypothesis of no cointegration is rejected in all cases (the critical value for the CRDW statistic is 1.00 for the 99% level of confidence)

	Explanatory	Effect estimates				CRDW
Model	variables	β	SE		R^2	statistic
1	Y	0.04	0.01	***	0.39	1.93
2	Ypc	0.39	0.07	***	0.41	2.01
3	P	0.33	0.06	***	0.39	1.96
4	g	-0.06	0.05		0.03	1.33
5	dY	0.58	0.21	**	0.14	1.49
6	dYpc	1.78	1.36		0.02	1.19
7	dP	27.83	9.76	**	0.15	1.42
8	Y	0.00	0.06		0.39	1.96
	P	0.36	0.49			
9	g	0.08	0.05	†	0.43	2.01
	P	0.39	0.07	***		
10	Y	0.03	0.01	***	0.40	1.98
	dP	8.88	9.35			
11	g	-0.02	0.05		0.15	1.45
	dP	26.55	10.56	*		
12	dY	0.26	0.18		0.42	2.06
	P	0.29	0.06	***		
13	dY	0.48	0.20	*	0.24	1.67
	dP	23.22	9.49	*		

Y = world economic output; Ypc = Y per capita; g = annual rate of growth of Y; P = world population; CRDW = cointegrating regression Durbin-Watson statistic. The lower case d before a variable indicates first differences. For each explanatory variable the parameter estimate (β) is followed by its standard error (SE) and the corresponding level of statistical significance († $P < 0.1$, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$).

Table 3. CRDW tests for models in which the dependent variable is CO_2 concentrations in levels.

Explanatory variable(s) included in the model	CRDW
Y	0.38
Ypc	0.21
P	0.08
g	0.34
d*Y*	0.15
d*Ypc*	0.01
d*P*	0.04
Y, P	0.43
g, P	0.11
Y, d*P*	0.40
g, d*P*	0.27
d*Y, P*	0.08
d*Y, dP*	0.14

Symbols as in table 1. Since the critical values for the CRDW statistic are respectively 0.69 and 0.78 for the 0.10 and 0.05 levels of significance, the hypothesis of no cointegration cannot be rejected in any case.

Table 4. *P* values for testing causality in the classical Granger test and in the asymptotically equivalent test (AET). $N = 53$ in all tests.

	Lags	Granger test	AET
Test A1 H_0: world population do not help to predict CO_2 levels	1	0.033	0.024
	2	0.140	0.105
	3	0.118	0.068
	4	0.150	0.073
	5	0.172	0.067
	7	0.113	0.013
	10	0.026	< 0.001
Test A2 H_0: CO_2 levels do not help to predict world population	1	0.459	0.442
	2	0.632	0.600
	3	0.519	0.449
	4	0.536	0.430
	5	0.526	0.377
	7	0.429	0.187
	10	0.475	0.091
Test B1 H_0: increase in world GDP does not help to predict increase in CO2 levels	1	0.010	0.006
	2	0.053	0.032
	3	0.175	0.113
	4	0.174	0.090
	5	0.116	0.036
	7	0.528	0.280
	10	0.194	0.007
Test B2 H_0: CO_2 levels do not help to predict WGDP	1	0.288	0.269
	2	0.172	0.133
	3	0.330	0.256
	4	0.305	0.198
	5	0.350	0.202
	7	0.333	0.115
	10	0.406	0.057
Test C1 H_0: world GDP does not help to predict world population	1	0.692	0.682
	2	0.478	0.437
	3	0.496	0.425
	4	0.179	0.094
	5	0.198	0.084
	7	0.173	0.032
	10	0.040	< 0.001
Test C2 H_0: world population does not help to predict WGDP	1	0.646	0.634
	2	0.623	0.590
	3	0.903	0.884
	4	0.628	0.534
	5	0.721	0.607
	7	0.940	0.873
	10	0.066	< 0.001

Table 5. Data used in the analyses

Year	CO2 atmospheric concentrations	World GDP	World population
1958	315.24		
1959	315.98		
1960	316.91	7.2757	3.0317
1961	317.64	7.6049	3.0716
1962	318.45	8.0082	3.1254
1963	318.99	8.4090	3.1910
1964	319.62	8.9664	3.2567
1965	320.04	9.4517	3.3241
1966	321.38	9.9944	3.3944
1967	322.16	10.4464	3.4643
1968	323.04	11.0706	3.5353
1969	324.62	11.7148	3.6107
1970	325.68	12.2340	3.6868
1971	326.32	12.7308	3.7656
1972	327.45	13.4651	3.8428
1973	329.68	14.3461	3.9192
1974	330.17	14.5663	3.9962
1975	331.08	14.7036	4.0714
1976	332.05	15.4279	4.1446
1977	333.78	16.0570	4.2179
1978	335.41	16.7616	4.2922
1979	336.78	17.4573	4.3680
1980	338.68	17.7852	4.4446
1981	340.11	18.1311	4.5226
1982	341.22	18.1913	4.6029
1983	342.84	18.6524	4.6834
1984	344.41	19.5102	4.7633
1985	345.87	20.2345	4.8447
1986	347.19	20.9199	4.9294
1987	348.98	21.6696	5.0160
1988	351.45	22.6814	5.1034
1989	352.90	23.5301	5.1906
1990	354.16	24.2164	5.2789
1991	355.48	24.6022	5.3633
1992	356.27	25.1285	5.4443
1993	356.95	25.5691	5.5261
1994	358.64	26.4202	5.6068
1995	360.62	27.1882	5.6891
1996	362.36	28.1097	5.7692
1997	363.47	29.1531	5.8493
1998	366.50	29.8264	5.9285
1999	368.14	30.7774	6.0070
2000	369.40	32.0484	6.0850
2001	371.07	32.5301	6.1622
2002	373.17	33.1453	6.2387
2003	375.78	34.0327	6.3152
2004	377.52	35.4438	6.3913
2005	379.76	36.7108	6.4673
2006	381.85	38.1781	6.5437
2007	383.71	39.6861	6.6205
2008	385.57	40.3519	6.6978
2009	387.35	39.5798	6.7752

See Appendix for details about sources and units.

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