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The voluntary provision of a pure public good? Another look at CFC emissions and the Montreal Protocol

By Ulrich J. Wagner

The Earth Institute at Columbia University, 2910 Broadway, MC 3277, New York, NY 10025, USA, e-mail: ulrich.wagner@columbia.edu

Based on their finding of a positive and nearly linear relationship between GNP and reductions of chlorofluorocarbon (CFC) emissions in the run-up to the Montreal Protocol, Murdoch and Sandler (1997) have argued that the treaty's initial emission targets were consistent with voluntary provision of abatement rather than cooperative behavior. This paper documents that their analysis relies on largely imputed emission data that overstate emission reductions compared to emission data that countries reported to UNEP. The imputation procedure appears to induce a spurious positive correlation between income and CFC reductions. In a replication of the econometric analysis using UNEP data, the hypothesis of a positive and linear relationship between the two variables is rejected. These findings call for a more cautious interpretation of emission targets set by the Montreal Protocol and alert researchers to important limitations of a data set that has been widely used in empirical studies of this treaty.

JEL classifications: H41, D62, Q20.

1. Introduction

James Murdoch and Todd Sandler (1997), henceforth referred to as MS, study reductions in the emissions of chlorofluorocarbons (CFC) between 1986 and 1989. Because of their potential to deplete stratospheric ozone, CFCs were regulated under the Montreal Protocol on Substances that Deplete the Ozone Layer, a multilateral treaty that was negotiated in 1987 and entered into force in 1989. MS regard CFC abatement by individual countries during this time period as the voluntary provision of a global public good and advocate the view that cutbacks would have occurred even in the absence of the treaty. They support this claim with the finding of a positive and nearly linear relationship between income and CFC reductions in least squares regressions that control for other country characteristics.

The article by MS has been widely cited as evidence that the initial version of the Montreal Protocol did not prescribe abatement beyond voluntary levels.[1] This paper re-examines the emission data set used by MS and shows that the large share of imputed observations severely limits its value for the purposes of their analysis. Furthermore, the paper replicates the empirical analysis by MS using self-reported data on CFC emissions published by UNEP (2006). The replication exercise provides ample evidence for rejecting the hypothesis of a positive and linear relationship between income and emission abatement.

The structure is as follows. Section 2 summarizes the analysis by MS. Section 3 points out problems related to the emission data set they use and replicates the analysis with an alternative data set. Section 4 concludes.

2. Voluntary provision of CFC abatement

MS model reductions of CFC consumption at the country level as the voluntary provision of a pure public good, as analysed in Bergstrom *et al.* (1986), Andreoni (1988), and Cornes and Sandler (1996). Country i maximizes a quasi-concave, strictly increasing utility function subject to a budget constraint and spillovers from other countries' abatement:

$$\max_{y_i, G}\left\{U(y_i, G; \Theta)\,|w_i + pG_{-i} = y_i + pG\,;\, G \geq G_{-i}\right\} \tag{1}$$

where y_i and $G = \sum_j g_j$ denote consumption of a private and a pure public good (CFC abatement), respectively, w_i denotes income and p is the relative price of a marginal unit of a public good in terms of private consumption. Θ is a parameter vector or index measuring country-specific tastes. MS posit that country i's level of CFC abatement in non-cooperative Nash equilibrium is given by

$$g_i^* = \begin{cases} w_i/p - w^*(p, \Theta)/p & \text{if } w_i > w^*(p, \Theta), \\ 0 & \text{if } w_i \leq w^*(p, \Theta). \end{cases} \tag{2}$$

They emphasize the model's prediction that CFC cutbacks in countries with positive residual income $w_i - w^*$ are linearly increasing in income.

Based on this theory, MS estimate the equation

$$g_i = \beta_0 + \beta_1 w_i + \Theta_i' \gamma + \epsilon_i \tag{3}$$

using absolute reductions of CFC emissions between 1986 and 1989 as the dependent variable (*DEMIT*) and dropping all countries that expanded their consumption of CFCs during this time ($g_i < 0$). Table 1 reproduces the results from their Table 3 (Murdoch and Sandler, 1997, p. 345). The most striking result from these regressions is that the effect of gross national product in 1985 (GNP85) is positive and explains 94% of the variation in emission cutbacks *DEMIT*. Adding population in

[1] As of October 2007, the Social Sciences Citation Index lists 45 academic journal articles citing MS (see, e.g., Na and Shin, 1998; Sigman, 2002; Beron *et al.*, 2003; Lange and Vogt, 2003; Murdoch *et al.*, 2003; Auffhammer *et al.*, 2005; Auffhammer and Steinhauser, 2007). A search with google scholar returns links to more than a hundred scholarly papers.

Table 1 OLS estimates by Murdoch and Sandler (1997)

	DEMIT						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
GNP85	1.649	1.643	1.633	1.612	1.609	1.611	1.608
	(0.052)**	(0.051)**	(0.051)**	(0.050)**	(0.051)**	(0.053)**	(0.054)**
GASTIL		−0.152		−0.136		−0.138	
		(0.073)*		(0.071)		(0.075)	
FREE			1.296		1.170		1.179
			(0.674)		(0.677)		(0.708)
PFREE			−0.422		−0.080		−0.076
			(0.848)		(0.856)		(0.868)
L2				−1.568	−1.312	−1.560	−1.308
				(0.634)*	(0.693)	(0.645)*	(0.706)
L3				−1.680	−1.744	−1.675	−1.742
				(1.083)	(1.096)	(1.094)	(1.107)
POP85						0.0002	0.0001
						(0.0023)	(0.0023)
Constant	1.061	2.050	0.559	2.712	1.213	2.713	1.203
	(0.323)**	(0.568)**	(0.526)	(0.602)**	(0.598)*	(0.608)**	(0.642)
*R*2	0.94	0.95	0.95	0.95	0.95	0.95	0.95
	p-values for H_0: homoskedastic error terms						
White	0.000	0.012	0.019	0.142	0.182	0.001	0.000

Note: $N=61$. Standard errors in parentheses; *significant at 5%; **significant at 1%. Murdoch and Sandler report *t*-statistics instead of standard errors and do not report results from heteroskedasticity tests. The last rows report *p*-values for White's test of the hypothesis that the error term is homoskedastic.

1985 (POP85) and dummy variables for political freedom and civil liberties (FREE and P(artly)FREE) as well as for geophysical position in the tropics (L2) and in the Southern hemisphere (L3) raises the R^2 by a mere 1%. Except for GASTIL in column (2) and L2 in columns (4) and (6), none of the coefficients on the additional variables is significant at the 5% level.

Furthermore, MS estimate a particular Box-Cox transformation of eq. (3)

$$g_i = \beta_0 + \beta_1\left[(w_i^{\lambda} - 1)/\lambda\right] + \Theta_i'\gamma + \epsilon_i \tag{4}$$

in order to test if the model is linear in GNP, as predicted by the theory in eq. (2). The test is based on the transformation parameter λ and rejects linearity if the estimate $\hat{\lambda}$ is significantly different from 1. While linearity is rejected for the full sample of 61 countries, MS report that linearity cannot be rejected when three large countries – the USA, the USSR, and China – are dropped from the sample. They 'feel some confidence in stating that the 'true relationship' between income and voluntary contributions is nicely approximated by the linear specification' (MS, p. 346).

MS interpret the finding of a positive and nearly linear relationship between emission reductions and GNP as being more consistent with a non-cooperative model than with a cooperative model of public good provision. To further support this view, they point out that the sample average CFC reduction of 41% by 1989 was close to the 50% mandated only until 1999, and emphasize that substantial cutbacks were made by both member and non-member states, as well as by developing countries that were exempt from any emission cutbacks under a 10-year 'grace period'.

3. Voluntary provision revisited

3.1 Data issues

MS compute their dependent variable *DEMIT* as the difference in consumption of CFC in 1986 and 1989, as reported by the World Resources Institute (WRI) in two volumes of its 'World Resources' report (World Resources Institute, 1990, 1992). A fundamental problem with using this data set for regression analysis arises from the fact that WRI imputed consumption data for most of the 145 countries in their sample on the basis of very scant information about actual consumption. More specifically,

> 'it used data on 1986 per capita production/use from 18 countries and the European Community (EC) to peg consumption in other similar countries. . . . Consumption data for the EC, as reported by the EC and UNEP, were allocated to each member country in proportion to its share of the total EC population' (World Resources Institute, 1990, p.354).

Further, WRI 'used data on 1986 per capita production/use from 47 countries and the European Community (EC) to peg consumption in other similar countries, and updated these estimates using consumption data for 15 countries plus the EC in 1989' (World Resources Institute, 1992, p.354).

While not entirely self-explanatory, these quotes from the publications' data appendices provide some clues regarding the scale and nature of the imputation process. An immediate implication is that consumption data for most of the 145 countries were imputed: Since WRI used actual observations from 15 countries in 1986 and 18 countries in 1989, it follows that there are at most 15 countries for which *DEMIT* is based on actual observations only. Put differently, for 46 (75%) or more of the 61 abatement observations used by MS, one or both of the underlying emission values were imputed.

With respect to the specifics of the imputation process, WRI is explicit about allocating total EC consumption to individual member states in proportion to their population. This results in a correlation coefficient between *DEMIT* and POP85 of 0.9997 in EC countries. Unfortunately, the explanation of the imputation rule for non-EC countries given in the 'World Resources' reports is less precise and WRI is currently unable to further clarify this matter.[2]

Nonetheless, two clues can be gleaned from the above quotes. First, imputed values of per capita CFC use in 1986 were based on actual values in

[2] E-mail correspondence with Amy Cassara at WRI, January 31 and February 12, 2007.

'similar countries'. Second, values imputed for 1989 were based, to a large extent, on per capita use in 1986. The almost perfect correlation between *DEMIT* and GNP85 in non-EC countries (the coefficient is 0.9878) thus raises the concern that the classification into 'similar countries' – and hence the choice of which values to impute – was guided by comparisons of GNP across countries. In this case, the strong positive correlation between GNP and CFC reductions is spurious and should be interpreted as an artefact of WRI's imputation procedure rather than the outcome of a non-cooperative game.

3.2 Evidence from self-reported emission data

In view of the shortcomings of the WRI data, this section re-evaluates the predictions of the non-cooperative model using a novel abatement measure based on the variable 'Consumption of Ozone-Depleting Substances – Chlorofluorocarbons' from the United Nations Environmental Programme (UNEP, 2006). 'Consumption' is calculated as the residual of production plus imports minus exports of controlled substances and is taken from annual reports that member states of the Montreal Protocol are required to file with the treaty secretariat. This variable appears appropriate for the voluntary provision model because it adds up emissions of all five CFCs that were regulated under the Montreal Protocol and weights them by their relative ozone-depleting potential (ODP).[3] A measure of CFC abatement, 'ΔCFC' in thousands of ODP-weighted tons, is obtained by subtracting consumption in 1989 from its 1986 value.

An inspection of the data reveals large differences between this abatement measure and the *DEMIT* variable used by MS. Table 2 displays summary statistics for both data sets and several subsamples of interest. Panel A summarizes the distribution of *DEMIT* for all 61 countries in MS while panel B summarizes the distribution of ΔCFC for all 160 countries available in the UNEP data set. Panel B shows that only 59 countries reduced their consumption of CFCs between 1986 and 1989. The average reduction of 675 tons in those countries is much lower than the 4,265 tons reported by MS. The unconditional mean of CFC abatement is negative.

Panel C of Table 2 compares the distribution of both variables in the intersection of 46 countries contained in both data sets, henceforth referred to as the joint sample.[4] For 27 out of 46 countries in the joint sample, positive values of *DEMIT* are not confirmed in the UNEP data set. 25 countries expanded their consumption between 1986 and 1989, including the United States, Spain,

[3] The weights for each of the CFCs (CFCl3, CF2Cl2, C2F3Cl3, C2F4Cl2, C2F5Cl) are listed in Annex A of the 1987 treaty and range from 0.6 to 1.0. Article 3(a)(i) of the Montreal Protocol stipulates that member states must weight CFC reductions by these factors before aggregating across substances. The weights are also relevant for non-member states in that their private benefit from abating a substance depends on its ozone-depleting potential.

[4] The 15 missing countries are Afghanistan, Belgium, Denmark, France, East Germany, West Germany, Greece, Iraq, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, and the United Kingdom.

Table 2 Descriptive Statistics for *DEMIT* and ΔCFC

	N	Mean	Std. Dev.	Median	Min	Max
A. Murdoch and Sandler (1997) data set						
DEMIT	61	4.265	10.056	0.888	0.023	67.4
B. UNEP data set						
ΔCFC	160	−0.230	2.865	0	−28.475	3.937
$\Delta CFC > 0$	59	0.675	0.927	0.280	0.0001	3.937
$\Delta CFC \leq 0$	101	−0.759	3.433	−0.008	−28.475	0
C. Joint sample						
DEMIT	46	3.630	10.996	0.473	0.023	67.4
ΔCFC	46	0.055	2.219	−0.008	−11.579	3.937
$\Delta CFC > 0$	19	1.306	1.081	1.115	0.004	3.937
DEMIT if $\Delta CFC \leq 0$	27	3.454	12.873	0.325	0.023	67.4
$\Delta CFC \leq 0$	27	−0.824	2.402	−0.052	−11.579	0
D. UNEP sample used for replication						
ΔCFC	125	−0.338	3.224	−0.000	−28.475	3.937
$\Delta CFC > 0$	43	0.758	1.004	0.328	0.0001	3.937
$\Delta CFC \leq 0$	82	−0.913	3.797	−0.008	−28.475	0

Note: DEMIT and ΔCFC measure abatement, i.e. the negative of the change in emissions.

the Netherlands, China, Indonesia, Chile, Israel, and others. An additional 51 countries not used in MS reported increases in CFC use to UNEP, most notably Japan and India.[5]

The magnitude of these discrepancies is highlighted by the largest value of *DEMIT*, a 67,400 ton reduction in CFC consumption attributed to the United States, who actually reported an 11,579 ton increase in consumption during this period to UNEP. To put this into perspective, UNEP (2006) estimates aggregate global abatement between 1986 and 1989 at 40,930 tons. Similar differences reaching thousands of tons in magnitude were found for countries such as the USSR/Russian Federation, China, Nigeria, Canada, Indonesia, and others. Along with the truncation at zero this explains why the sample distribution of *DEMIT* is shifted to the right and much more dispersed compared to the distribution of ΔCFC.

Overall, the self-reported data on CFC consumption from UNEP do not suggest that – as MS argue when rejecting a cooperative model – countries rushed to meet and exceed emission targets before the Montreal Protocol went into force. A replication of the econometric analysis in MS can help to clarify whether their conclusions – drawn on the basis of a largely imputed data set – are supported by self-reported emission data.

[5] A referee pointed out that the UNEP data may overstate consumption by counting inventories. This is a valid concern, but since it equally applies to the WRI data it is unlikely to drive the large discrepancies between the two abatement measures.

3.2.1 *Replication in the joint sample* It is instructive to first perform the replication exercise on the joint sample. This will provide a useful benchmark to assess whether differences in results between the original analysis and the replication are driven by differences in the emission data or merely by differences in country coverage across data sets.

Table 3 displays OLS estimates for all seven specifications considered in MS using all 46 countries in the joint sample. The dependent variables in columns (a) and (b) are *DEMIT* and ΔCFC, respectively. The estimates for *DEMIT* are very similar to those obtained in the larger sample of 61 countries reported in Table 3, implying that sample selection is not a concern. In particular, the positive and highly significant coefficient estimate for GNP85 of 1.6 is confirmed throughout.[6]

By contrast, the coefficient estimate drops to −0.2 when ΔCFC is the dependent variable and is statistically significant at the 5% level or better. What is more, the results in columns (6b) and (7b) show a negative and significant coefficient for population. Clearly, the negative coefficient on GNP85 is not consistent with the voluntary contribution model.[7] The coefficient remains negative when the sample is restricted to the subset of 19 countries that reported positive abatement to UNEP.[8]

To sum up, when the econometric analysis in MS is replicated with UNEP abatement data from countries contained in both data sets to control for sample selection, the hypothesis of a positive and linear relationship between abatement and national income must be rejected.

3.2.2 *Replication in the full sample* For an additional validity check of the conclusions drawn by MS it is enlightening to replicate their analysis using as many observations in the UNEP (2006) data set as possible.

To this end, the emission data were merged with data on country characteristics from different sources: GDP (in current US$) and population were obtained from the World Bank (2007), GASTIL, PFREE, and FREE were constructed based on raw data from Freedom House (2006), and data on country latitude were taken from the World Fact Book (CIA, 2007). All dummy variables were constructed exactly as described in Table 1 of Murdoch and Sandler (1997, p. 340). Time-varying covariates were evaluated for the year 1985.

The merged data set comprises 125 countries. Summary statistics for ΔCFC in this sample are reported in panel D of Table 2. A comparison with panel B of the same table shows that the sub-sample used for regression analysis is quite

[6] Since White's test rejects the hypothesis of homoskedastic residuals in most columns of table 1, the coefficient estimates in all other linear regressions are reported with robust standard errors.

[7] Maximum likelihood estimates of the Box-Cox transform (4) did not converge due to the small size of the joint sample.

[8] The coefficient on GNP85 for this subset ranges from −0.02 to −0.08, but asymptotic inference seems inappropriate in view of the extremely small number of observations. The results are available upon request.

Table 3 Comparison of OLS estimates in a joint sample of countries

	(1)		(2)		(3)		(4)		(5)		(6)		(7)	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
GNP85	1.615	−0.228	1.614	−0.228	1.610	−0.228	1.597	−0.239	1.597	−0.239	1.597	−0.204	1.597	−0.205
	(0.061)**	(0.079)**	(0.059)**	(0.085)*	(0.062)**	(0.088)*	(0.065)**	(0.086)**	(0.065)**	(0.086)**	(0.067)**	(0.091)*	(0.070)**	(0.096)*
GASTIL			−0.024	−0.037			−0.025	−0.039	−0.025	−0.039	−0.025	0.019		
			(0.088)	(0.089)			(0.090)	(0.094)	(0.090)	(0.094)	(0.094)	(0.086)		
FREE					0.080	0.580							0.056	0.130
					(0.660)	(0.635)							(0.704)	(0.599)
PFREE					−0.427	0.491							−0.279	0.372
					(0.678)	(0.546)							(0.640)	(0.482)
L2							−0.842	−0.500	−0.842	−0.500	−0.842	−0.781	−0.782	−0.828
							(0.618)	(0.495)	(0.618)	(0.495)	(0.652)	(0.422)	(0.644)	(0.372)*
L3							−0.636	−0.449	−0.636	−0.449	−0.637	−0.625	−0.655	−0.645
							(0.580)	(0.600)	(0.580)	(0.600)	(0.598)	(0.639)	(0.617)	(0.620)
POP85											−0.000	−0.005	−0.000	−0.005
											(0.001)	(0.001)**	(0.001)	(0.001)**
Const.	0.485	0.499	0.656	0.762	0.575	0.158	1.162	1.080	1.162	1.080	1.162	1.035	1.025	1.035
	(0.244)	(0.207)*	(0.523)	(0.625)	(0.563)	(0.424)	(0.595)	(0.703)	(0.595)	(0.703)	(0.602)	(0.699)	(0.864)	(0.464)*
R^2	0.98	0.48	0.98	0.48	0.98	0.49	0.98	0.49	0.98	0.49	0.98	0.60	0.98	0.60

Note: $N = 46$. Robust standard errors in parentheses; *significant at 5%; **significant at 1%. Dependent variable is *DEMIT* in (a) columns and ΔCFC in (b) columns.

representative of the full sample of 160 countries, since the main summary statistics and the share of positive observations in both data sets are very similar.

The results of a linear regression of all 125 available observations for ΔCFC on country characteristics are displayed in panel A of Table 4. The estimates are qualitatively similar to those obtained in the much smaller joint sample (reported in the (b) columns of Table 3). The coefficient on GDP is estimated at −0.5 and statistically significant at the 5% level for all specifications not including population. When population is included, the coefficient on GDP declines to −0.4 and becomes insignificant. The coefficient on population is estimated at −0.003 and is statistically significant at the 5% level or better.

The negative coefficient on GDP is inconsistent with the voluntary contribution model, which also postulates that abatement is a linear function of GDP. Panel B of Table 4 reports selected parameters from a maximum likelihood estimation of the Box-Cox transform (4). The parameter λ is precisely estimated at 0.7. In contrast to findings by Murdoch and Sandler (1997, Table 2 on p. 343) there is no evidence of an increase in λ as more country characteristics are added to the regression equation. Furthermore, a likelihood ratio test rejects the linearity hypothesis in all columns at the 1% significance level. The coefficient on GDP remains negative and more than doubles in magnitude in the non-linear specification.[9] In sum, the hypothesis of a positive and linear relationship between abatement and GDP must be rejected on the basis of results obtained in a comprehensive sample of self-reported emission data.

Table 5 replicates the results from the previous table when the sample is limited to positive abatement as in MS. This leaves 43 observations for estimation. Linear regressions in panel A show a positive coefficient on GDP of 0.7 in column (1), less than one half of what MS find. The coefficient declines to 0.5 as more covariates are added and becomes statistically insignificant in columns (3) to (7) when more than two regressors are included in the regression equation. In panel B, the parameter λ of the Box-Cox transform is estimated at 0.3 and is statistically significant at the 5% level. The coefficient increases slightly from 0.28 to 0.30 as more covariates are included but the change is not statistically significant and the parameter remains far below 1. A likelihood ratio test rejects linearity ($\lambda = 1$) for all specifications at the 1% significance level.

In sum, the replication exercises do not provide evidence for the voluntary contribution model. The relationship between income and abatement is found to be negative and/or statistically insignificant in most specifications. A positive relationship does arise when all non-positive observations are dropped from the UNEP data. However, the positive relationship becomes insignificant when more than one

[9] No standard errors are reported for this coefficient because λ drops out when GDP is excluded from the estimation equation. Hence, λ is not identified in the constrained model of a likelihood ratio test of significance.

Table 4 Estimation results, UNEP data

	ΔCFC						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
A. Linear model							
GDP	−0.455	−0.460	−0.465	−0.454	−0.458	−0.432	−0.436
	(0.227)*	(0.227)*	(0.227)*	(0.226)*	(0.227)*	(0.229)	(0.229)
GASTIL		−0.025		−0.022		−0.016	
		(0.041)		(0.041)		(0.040)	
FREE			0.288		0.280		0.171
			(0.428)		(0.442)		(0.428)
PFREE			−0.412		−0.397		−0.357
			(0.490)		(0.515)		(0.518)
L2				0.198	0.256	0.136	0.183
				(0.554)	(0.575)	(0.546)	(0.572)
L3				0.771	0.649	0.678	0.586
				(0.686)	(0.648)	(0.694)	(0.656)
POPULATION						−0.003	−0.003
						(0.001)**	(0.001)*
Constant	0.032	0.246	0.087	0.044	−0.126	0.123	0.017
	(0.164)	(0.419)	(0.111)	(0.699)	(0.454)	(0.700)	(0.441)
R-squared	0.38	0.38	0.38	0.38	0.38	0.39	0.40
B. Box-Cox model							
GDP	−0.996	−1.039	−1.037	−1.094	−1.078	−1.027	−1.019
λ	0.687	0.679	0.684	0.660	0.668	0.678	0.684
	(0.082)**	(0.080)**	(0.080)**	(0.081)**	(0.081)**	(0.089)**	(0.089)**
$p\ [\lambda=1]$	0.004	0.003	0.003	0.002	0.003	0.007	0.008

Note: $N=125$. Robust standard errors in parentheses. *significant at 5%; **significant at 1%. Significance levels for the GDP coefficient in panel B are not reported since λ is not identified in the constrained model.

additional explanatory variables is included. Finally, the hypothesis that abatement is linear in GDP is rejected for all specifications at the 1% significance level.

4. Concluding remarks

In a widely cited article, Murdoch and Sandler (1997) argue that cutbacks in emissions of chlorofluorocarbons (CFC) that occurred between the negotiation of the Montreal Protocol and its entry into force are more consistent with non-cooperative Nash behavior of countries than with cooperative behavior. This paper shows that the qualitative and quantitative evidence that MS present to support their view relies on largely imputed emission data from the World Resources Institute (1990, 1992) which overstate emission reductions and appear to induce a spurious positive correlation between income and CFC cutbacks. The critical importance of imputed values for the results is revealed by a replication of the econometric analysis in MS using data on CFC consumption that countries reported to the UNEP Ozone Secretariat (UNEP, 2006): No robust positive

Table 5 Estimation results with positive abatement, UNEP data

	$\Delta CFC > 0$						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
A. Linear model							
GDP	0.733	0.682	0.644	0.577	0.552	0.480	0.462
	(0.323)*	(0.331)*	(0.327)	(0.307)	(0.300)	(0.441)	(0.433)
GASTIL		−0.020		−0.009		−0.016	
		(0.028)		(0.027)		(0.029)	
FREE			0.358		0.144		0.217
			(0.308)		(0.320)		(0.335)
PFREE			0.188		0.323		0.317
			(0.369)		(0.355)		(0.367)
L2				−0.486	−0.538	−0.551	−0.582
				(0.262)	(0.244)*	(0.324)	(0.287)
L3				0.293	0.315	0.242	0.261
				(0.310)	(0.341)	(0.293)	(0.341)
POPULATION						0.004	0.004
						(0.008)	(0.008)
Constant	0.436	0.621	0.331	0.819	0.666	0.890	0.657
	(0.141)**	(0.292)*	(0.149)*	(0.325)*	(0.268)*	(0.369)*	(0.266)*
R-squared	0.28	0.29	0.30	0.36	0.37	0.36	0.37
B. Box-Cox model							
GDP	0.597	0.582	0.572	0.562	0.554	0.680	0.682
λ	0.276	0.270	0.269	0.278	0.283	0.293	0.301
	(0.116)*	(0.121)*	(0.122)*	(0.129)*	(0.132)*	(0.113)*	(0.116)*
$p\ [\lambda = 1]$	0.000	0.000	0.000	0.001	0.001	0.001	0.001

Notes: $N = 43$. Robust standard errors in parentheses; *significant at 5%; **significant at 1%. Significance levels for the GDP coefficient in panel B are not reported because λ is not identified in the constrained model.

relationship between income and emission reductions is found and the hypothesis of linearity is rejected. Furthermore, the paper documents large discrepancies between the WRI and UNEP emission data sets and shows that the differing econometric results are driven by those discrepancies and not by differences in country coverage. The fact that most empirical studies of the Montreal Protocol use the WRI data set – including a seminal article by Congleton (1992) and more recent work by Mason and Swanson (2003) and Beron *et al.* (2003) – emphasizes the need to make researchers aware of its important limitations.

It bears noting that the replication exercise serves the single purpose to illustrate the impact of the imputation procedure on the statistical results. Even with perfectly accurate emission data it remains a formidable task to test a model of non-cooperative against one of cooperative behavior. To see this, notice that the test devised by MS will not statistically reject any type of country behavior that exhibits a positive and linear relationship between income and the provision of abatement. A great many behavioral assumptions other than voluntary contributions pass this basic test – including full cooperation.[10] Moreover, it seems compelling to require that a framework for testing these behavioral assumptions allow for both positive and negative values of abatement. Since CFC consumption is a global public bad, strategic interaction in the provision game need not be limited to positive contributors. It is this 'leakage' problem that explains why the initial parties to the Protocol sought to increase participation by offering side payments to developing countries under the London Amendments to the Protocol (Benedick, 1998; Barrett, 2001).

On a final note, while the evidence presented by Murdoch and Sandler cannot be regarded as conclusive, their seminal contribution is to bridge the gap between empirical research and a vast game theoretical literature on international environmental treaties started by Hoel (1991); Carraro and Siniscalco (1993), and Barrett (1994).[11] This literature builds on the notion that, in order to fully understand and evaluate global environmental treaties such as the Montreal Protocol, it is crucial to account for strategic interaction between countries. Only recently have economists begun to take up this idea by incorporating game theoretical concepts in empirical analyses of the Montreal Protocol (Beron *et al.*, 2003; Auffhammer *et al.*, 2005; Wagner, 2007) and other environmental treaties (Bui, 1998; Murdoch *et al.*, 2003). This new line of research is important as it helps to enrich our understanding of international cooperation not only in the environmental domain but also in the many other domains of international politics that involve transboundary externalities.

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[10] Under full cooperation – characterized by maximization of the sum of utilities in eq. (1) – individual provision levels are increasing in income, thus generating a positive coefficient estimate in eq. (3). It is easily verified that this relationship will also be linear if, for example, utility functions in eq. (1) take the form $U(y_i, G; \Theta) = (1-\theta_i)\ \ln(y_i) + \theta_i\ \ln(G)$.

[11] See Wagner (2001) for a survey.

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