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ECONOMIC DIMENSIONS OF CO_2 TREATY PROPOSALS

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ABSTRACT

The Montreal Protocol on CFC control used positive growth rates for developing countries and negative growth rates for industrial countries. However, the treaty appears to fail on two criteria: effectiveness in reducing global CFCs, and equity between developing and industrialized countries. Seven possible treaty proposals to control CO_2 emissions are evaluated here. Growth rate proposals fail on effectiveness or equity criteria. Complex proposals link policies in population growth, economic development, world energy taxation, and forestation. These complex proposals appear to be effective and equitable, and can defer or avoid CO_2 doubling.

> I don't accept being transformed into a doorman of a zoo for the Americans. (Não aceito ser transformado mem porteiro de jardim zoolõgico para os americanos.)
>
> --Elton Rohnelt, Brazilian adventurer, discussing rainforest policy.[1]

I. INTRODUCTION

The structure of the Montreal Protocol on chlorofluorocarbons (CFCs) raises interesting general issues about the framing of international agreements on pollution control. The two major problems with the Protocol can be generalized in a manner relevant to future carbon dioxide (CO_2) treaties. The first problem is effectiveness. The 1987 Protocol did not attain sufficient reduction in CFCs to avert major upper-atmosphere ozone loss and consequent skin cancer. Recent discussion has focused on complete CFC prohibition.

The second unresolved problem is equity. As formulated, developing countries were restricted to 0.3 kg per capita after 1997.[2] However, the Western industrialized countries were to make a 50% rollback from unspecified benchmark levels.[3] This might have left Western consumers, for example, with a 1 kg per capita limit. This is one of the reasons that countries such as China and India refused to sign the Protocol.

Analyzing the CFC Protocol suggests three criteria for evaluating treaty proposals. A first criterion is effectiveness. A proposal should have some significant impact on deferring a doubling of CO_2 concentration. For this paper, 550 ppm CO_2 is taken as a reference point defining a value equal to 200% of the preindustrial level of the 1860s.

A second criterion is equity in a political context. This is important if the cooperation of developing nations is expected. Without such cooperation, any treaty would be ineffective. The relative impact on industrialized and developing countries must be such that neither group holds a permanent advantage in per capita use, and the levels of developing country per capita use must approach the industrialized group levels.

The third criterion is economic feasibility. The proposal must be implemented at an economic cost which is acceptable to the world's citizens. This criterion is harder to specify, although extremes of infeasibility can be given. For example, a prohibition on vehicles would be economically costly and not feasible. A second infeasible example, a mitigation method, might be to send missile loads of trees into deep space. With our present level of understanding, the first two criteria (effectiveness and political equity) may be more easily applied to possible proposals, and they are given the greater emphasis in this paper.

II. THE BIOCARBON MODEL

The model used in determining the approximate doubling date is based on an airborne fraction model.[4] It relates future levels of atmospheric CO_2 to current levels plus a percentage of future emissions from both biotic sources and fossil fuel use:

$$(1) \qquad CO_2(t+1) = A * CO_2(t) + [0.4721 * AF * Emit(t)].$$

$CO_2(t+1)$ is the atmospheric concentration of CO_2 in year t+1 in parts per million (ppm); A is a decay factor associated with ocean absorption that allows for a preindustrial equilibrium for atmospheric CO_2[5]; AF is the airborne fraction (0.5), the percent of carbon released in year t that remains in the atmosphere; and Emit(t) is the emission of carbon in year t in billion metric tons. The emission of carbon for any year depends on annual contributions from deforestation and on the quantity of fossil fuels used. Estimates of the current annual amount released from deforestation range from 0.6 to 2.6 gigatons per year.[6] A value of 1.0 gigaton per year is assumed in this model.

A multiplicative function is used to calculate future energy demand for each specified region in any year, t:

$$(2) \qquad Q(t) = aP(t)^b I(t)^c N$$

where P refers to the price of the fuel type, b is the price elasticity of demand, I is per capita income, c is income elasticity of demand, and N is world population.[7]

III. GROWTH RATE CONTROL POLICIES

Seven possible initiatives are examined (Table 1). The proposals focus on agreements on fossil fuel use and tree planting. Certainly, policies emphasizing renewable energy and nuclear energy are of interest but outside the domain of this paper. From this point, the term "energy" will be used to mean "fossil fuel energy." For example, when reference is made to the 0.6% annual reduction in world per capita energy use, it means, in this context, a reduction in the total energy content of petroleum, natural gas, and coal on a per capita basis. It is assumed that countries would agree to certain goals and be responsible for achieving them.

The first case assumes a continuation of the present reduction in world per capita energy use with increasing world population. In the six years from 1980 to 1986, this has declined from 57.5 MBtu (million Btu) per capita to 55.5 MBtu, as shown in Table 2. The immediate cause has been the industrial world's 0.5% annual decline which has partially offset the developing world's annual increase in per capita use. However, developing country population growth interacts with growth in per capita use. Current rates of population growth (2%) and per capita energy use (1.7%) define a 3.7% growth rate in aggregate energy use by developing countries.[8] Consequently, continuing the current reduction in per capita energy use in the industrial world is associated with an overall 1.8% increase in aggregate world energy consumption.[9] The result is a CO_2 doubling in

TABLE 1

Seven Possible Treaty Initiatives

Number	Possible Treaty Initiative
#1	Continue current reduction in industrial country per capita energy[1] use.
#2	Restrict all energy types to 1% growth.
#3	Industrial per capita energy use constant, developing countries rise to this.
#4	No growth in total energy use.
#5	Reduced developing country population growth and increased income growth, energy taxation.
#6	Same as #5, but 2.5 million acres forested annually.
#7	Same as #5, but 10 million acres forested annually.

TABLE 2

Growth in World Energy, Population and Per Capita Use in Q or MBtu

1980 to 1986

	All Industrialized Countries	All Developing Countries	World Total or Average
Total Energy, Q			
1986	201.7	69.0	270.7
1980	198.7	55.2	253.9
Growth rate	0.25%	3.79%	1.07%
Total population, billions			
1986	1.192	3.684	4.876
1980	1.139	3.275	4.414
Growth rate	0.76%	1.98%	1.67%
Per Capita Energy, MBtu			
1986	169.2	18.7	55.5
1980	174.5	16.9	57.5
Growth rate	-0.51%	1.70%	-0.59%
Per Capita Income, 1986 $			
1986	$10,988	$571	$3,118
1980	$10,131	$565	$3,033
Growth rate	1.36%	0.18%	0.46%

Sources are World Bank (1988); United Nations (1988); Pollard (1988).

seventy years.[10] (See Table 3.) In a similar case (not shown), the same increase in CO_2 is provided by rising coal and natural gas use while petroleum consumption declines.[11] We must conclude that simply continuing the industrial world's decline in per capita energy use would not be an effective policy since it leads to an early doubling of atmospheric CO_2 levels.

The second proposal allows for a uniform 1% annual increase in aggregate energy consumption for each country. This defers CO_2 doubling further into the future, to 2079. On the criterion of political equity, this proposal fails because it lowers the ratio of per capita energy use between developing and industrial countries. In 2036, the ratio would be 6:100. In 1986, it was a higher 11:100. The reason this happens is, of course, the higher population growth in developing countries. With current population growth rates, the 1% energy growth proposal would mean a 1% annual decline in per capita developing country use and a 0.2% increase in industrial country per capita use.

A third potential initiative recognizes the need for developing country growth in per capita use and allows it to grow to the current industrial level of 169.2 MBtu per capita over the next century while holding industrial use constant.[12] After fifty years, energy use rises to an aggregate 721 Q (quadrillion Btu). Although this policy is appealing in terms of equity (the per capita ratio is 26:100 in 2036), it actually leads to an earlier CO_2 doubling compared to case #1.

TABLE 3
Summary of Growth Rate Policies at 2036[ii]

Case	Per Capita Growth in Energy Use	Future Per Capita Energy, 50 years, MBtu	Future Total Energy, Q (and growth)	Year of CO_2 Doubling
#1. Continue current reduction in industrial per capita use.			(+1.8%)	2059
Developing Countries	+1.7%	43.4	426.5	
Industrial Countries	-0.5%	131.0	228.1	
World Total or Average	1.8%	56.6	654.7	
#2. Restrict all energy types to 1% aggregate growth.			(+1.0%)	2079
Developing Countries	-1.0%	11.6	113.5	
Industrial Countries	+0.2%	190.5	331.7	
World Total or Average	-0.7%	38.5	445.2	
#3. Developing countries rise to industrial level, 169.2 MBtu.			(+2.0%)	2056
Developing Countries	+1.7%	43.4	426.5	
Industrial Countries	0.0%	169.2	294.6	
World Total or Average	+2.0%	62.5	721.1	
#4. No growth in aggregate energy.			(0.0%)	2151
Developing Countries	-1.9%	7.0	69.0	
Industrial Countries	-0.8%	115.9	201.7	
World Total or Average	-1.7%	23.4	270.7	

A fourth possibility considers no growth in total energy. This is effective, deferring the doubling date until the twenty-second century, in 2151. However, it fails on the equity criterion since it results in a per capita use ratio of 6:100, lower than the current ratio.

IV. COMPLEX CONTROL POLICIES

Some other approach is needed. The last three options combine economic and social policy with forestation. The major problem with the preceding four cases is the high population growth and low income growth in developing countries. Total GNP growth in developing countries has recently slightly exceeded that in industrial countries (2.2% versus 2.1%), both defining a world average of 2.1%. However, population growth was quite different: 2.0% versus 0.8%. Consequently, per capita income growth was only 0.2% in developing countries.

This problem is further complicated by the geoeconomic differences in the developing country group. China and Indochina experienced a healthy 9.1% per capita income growth and a 1.3% population growth.[13] In contrast, the rest of the developing world experienced a decline of 1.1% in per capita income while its population grew at 2.3%. As a group, one-half of the world's population experienced declining per capita incomes.

One remedy would be domestic and international policies which reduce population growth and increase per capita income growth. This means capital investment growth, employment and output growth, and declining birth rates and population growth.[14] Assume, for the purpose of this study of CO_2, that population growth can be reduced to 0.8% and developing country income growth increased to 2.2%. Also assume a growth in energy prices of 2% annually.

The results here are encouraging. The doubling year for CO_2 is postponed to 2309, three centuries into the future. Figure 1 shows the CO_2 paths for policy #5 and selected other cases. This policy does best of the first five options on the effectiveness criterion. For political equity, it has a slowly rising ratio of developing country to industrialized country energy use, reaching 13:100 in 2036. (See Table 4.)

Case #6 adds 2.5 million acres of new forest annually to policy #5. Note in Figure 1 that CO_2 asymptotically approaches the doubling benchmark. case #7 assumes 10 million acres annually of new forest. Here, CO_2 concentration declines after 250 years. Given the current world forest cover of 7.3 billion acres,[15] policy #6 adds 0.034 of 1% of this annually, and policy #7 adds 0.14 of 1% annually.

Assume that the forestation costs are $1,000 per acre.[16] This defines annual cost of $2.5 billion for policy #6 and $10 billion for policy #7. Also assume that the 2% annual price increase is divided equally between taxation and revenue for producers. The energy tax is 4¢/MBtu in the first year, collecting $10 billion. In ten years, it reaches 42¢/MBtu and collects $110 billion in revenue, despite falling energy use.

Figure 1. Policy Results

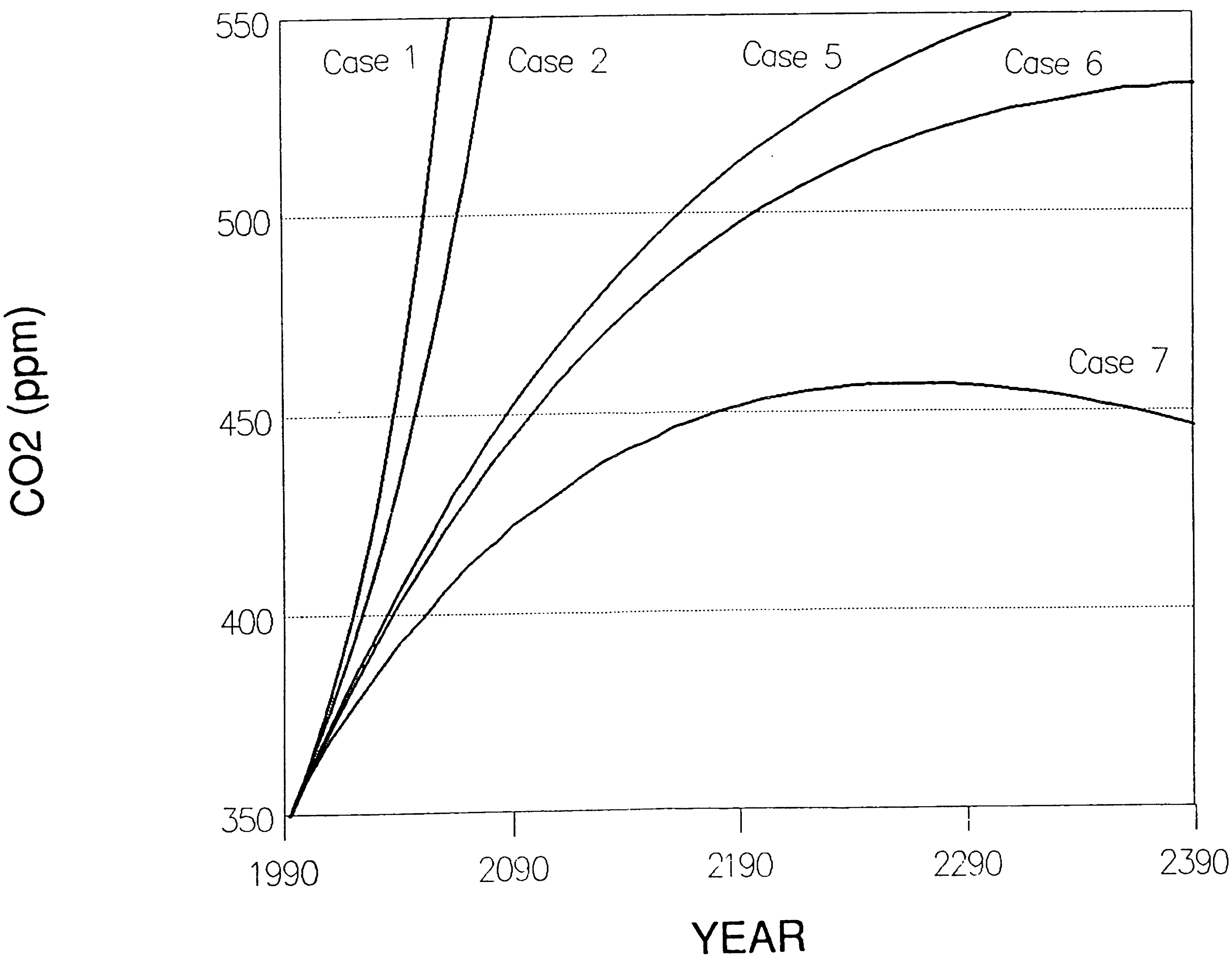

TABLE 4

Summary of Economic Policies at 2036

Case	Per Capita Growth in Energy Use	Future Per Capita Energy, 50 years, MBtu	Future Total Energy, Q (and growth)	Year of CO_2 Doubling
#5. Reduce population growth, increase developing country income, 2% price growth with one-half as taxation.			(-0.4%)	2309
Developing Countries	-0.9%	12.0	117.8	
Industrial Countries	-1.3%	89.0	154.9	
World Total or Average	-1.2%	30.8	223.8	
#6. Same as #5, but add 2.5 million forest acres annually.			(-0.4%)	never
Developing Countries	"	"	"	
Industrial Countries				
World Total or Average				
#7. Same as #5, but add 10 million forest acres annually.			(-0.4%)	never
Developing Countries	"	"	"	
Industrial Countries				
World Total or Average				

The forestry program would require maintaining the currently forested acreage and setting aside additional amounts for intensive cultivation and biomass recycling. After 400 years, world forest cover would increase 14% in policy #6 and 55% in policy #7. If the biomass is used for energy, it can be substituted for or added to fossil energy use.

A world forestry policy might meet the equity criterion. The incidence of an energy tax would be primarily upon industrial countries, and the forestation expenditures could be directed predominately toward the developing countries.

The results in cases #5, #6, and #7 depend on several assumptions. The price elasticity is -1, the income elasticity is +0.5, and the population elasticity is +1.[17] For world energy use to decline, it is necessary that

$$(3) \qquad |\eta_p r_p| > \eta_i r_i + \eta_n r_n.$$

The left side is the absolute value of the product of price elasticity and price growth. The right side is the sum of elasticity and growth terms for per capita income (subscript i) and total population (subscript n). For world energy use to decline, it is necessary for the left side of Equation (3) to exceed the right side. It is the product of price elasticity and price growth which is important. For example, with a price growth of 2% and a -1 elasticity (or a 4% price growth and a -0.5 elasticity), CO_2 concentration does not double with the forestry program. (See Figure 1 and Table 4.)

V. CONCLUSION

The results here suggest several avenues of future analysis with respect to possible treaties. First, it appears that energy growth rate policies alone are unlikely to satisfy both the effectiveness and political equity criteria. Any proposed treaty that would be effective would not be acceptable to developing nations.

Second, elevated per capita income growth rates in developing countries are necessary to provide for a slow increase in the ratio of per capita energy use between developing and industrial countries. Generally, development economists have concluded that population growth and per capita income growth are competitive. Therefore, it follows that developing countries should be considering population policies which enhance income growth. Reduced world population growth is also necessary to reduce aggregate energy demand.

Taxation, beginning at 4¢/MBtu, would initially provide $10 billion annually for a forestry program of the same magnitude. If the tax rises, additional international funds would be available for investment in developing countries' infrastructure or commerce, and for renewable energy, conservation, or nuclear research and development. For example, if one-half of a 2% annual energy price increase were to be an international tax, an amount on the order of $110 billion would be available in 1996,[18] and energy prices would be 22% higher.

The exploratory results here suggest that CO_2 doubling can be deferred with international policies that are effective and politically equitable. These CO_2 policies probably require international policies in macroeconomics, population, energy taxation, and forestry.

APPENDIX TABLE A1

World Population and Income[iii]

1986

	Industrialized Market-Economy Countries	Developing Countries	Soviet-Eastern Europe Group	China and Indochina	World Totals
Population, millions	760.7	2535.6	431.7	1148.3	4876.3
Annual Population Growth Rate, 1980-86	0.8%	2.3%	0.8%	1.3%	1.7%
Per Capita Income, US $	$13,767	$713	$7482	$258	$3242
Annual Change, Per Capita Income, 1980-86	+1.0%	-1.1%	+1.3%	+9.1%	+1.8%

Sources are World Bank (1988); United Nations (1988); Pollard (1988).

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NOTES

* Professor of Resource Economics and Research Assistant, Department of Agricultural Economics, Cornell University. The assistance of Wendy Bacon is appreciated. Presented at the Western Economics Association International Annual Meeting, June 1989.

1. Veja (5 July 1989, p. 109). Translation by Steven Kyle.

2. Montreal Protocol (1987, Article 5). About 10.6 ounces per capita.

3. Montreal Protocol (1987, Article 2, Section 4).

4. This is a modified version of models that appeared in National Academy of Sciences (1983) and Mintzer (1987). See Drennen and Chapman (1989) for complete discussion. Methane, ozone, nitrous oxides, and chlorofluorocarbons also contribute to global warming. During the period 1975-85, these non-CO_2 gases contributed approximately 50% of the total heating (Ramanthan 1988, pp. 293-99). However, since CO_2 remains the primary contributor, and since policies directed at curbing fossil fuel use would also reduce some of the other greenhouse gases, such as nitrous oxides, this paper focuses on reducing CO_2. If CFCs are prohibited, then CO_2 will become an even larger component of greenhouse gases.

5. The decay factor value is 0.99900618.

6. Trabalka (1985, pp. 113-115).

7. Use of this equation ignores the possibility of fuel switching. For the scenarios discussed here, this causes little problem since price increases and taxes are uniformly applied to all fossil fuels.

8. Formally, the interaction is multiplicative: 3.7% = (1 + 2%)(1 + 1.7%) - 1. (Rounding error causes this value to differ by 0.0009 from the Table 2 value.)

9. Total world energy use in 2035 in this case equals (3.684*(1.02)**50)*(18.7*(1.017)**50 + (1.192*(1.008)**50)*(169.2*(0.995)**50) = 654.7 Q. The other cases are defined analogously.

10. Estimated with our Biocarbon model (Drennen and Chapman 1989).

11. Natural gas increases at 1.6%, coal at 3%, and petroleum declines at 0.4%.

12. Increase the developing country per capita use at 1.7% annually to 169.2 MBtu by 2117.

13. See Appendix Table A1.

14. Chapter 5 in World Bank (1984) gives a useful discussion of the interaction between income and population growth.

15. International Institute for Environment and Development and World Resources Institute (1986) and Trabalka (1985, p. 123). Summarized in Drennen and Chapman (1989, p. 24).

16. Assumes a growth ratio of six tons per acre per year; cost estimates includes site preparation, weed control, planting costs, land rental costs, fertilizer, harvesting, and removal of trees from the site. Based on estimates from Perlack and Ranney (1987, pp. 224-29). Also assumes the use of Short Rotation Intensive Culture (SRIC) which utilizes fast-growing trees on managed plantations. In this scenario, the trees grow for twenty-five years before harvesting for use as a fuel substitute or for other uses which preferably do not result in a return of the carbon to the atmosphere.

17. In Bohi's review of energy demand elasticities, the median price elasticity of energy use sectors is -1.1 (Bohi 1981).

18. In ten years, the tax would be 42¢/MBtu, equivalent to 5¢ per gallon of gasoline. Current average price is about $3.80 per MBtu, based upon U.S. data.

i. "Energy" refers here to fossil-fuel energy only: petroleum products including natural gas liquids, natural gas, and coal.

ii. Percents rounded to nearest tenth.

iii. The industrialized countries consist of North America, Western Europe, Japan, Australia, and New Zealand. The developing countries consist of Latin America, Africa, and Asia outside the China and Soviet Group. The Soviet-Eastern Europe group includes Cuba and Mongolia. Indochina (Laos, Kampuchea, and Vietnam) is assumed to have the same per capita income as China. All data are for 1986 or 1980-86. Income figures are gross domestic product for all regions except the Soviet-Eastern Europe Group, which are GNP.

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