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M. L. Livingston

R. S. Risser

H. von Witzke

THE DETERMINANTS OF INTERNATIONAL POLLUTION: EMPIRICAL EVIDENCE FROM CO_2 EMISSIONS

M.L. Livingston,*
R.S. Risser,†
H. von Witzke‡

I. INTRODUCTION

The prospect of global climate change has caught the world's attention. Global warming refers to potential climate changes caused by increasing concentrations of greenhouse gases in the atmosphere. The changes may impact agricultural production, raise sea levels and trigger additional climate change that could devastate the environment. While

* Associate Professor, Department of Economics, and Director, International Trade and Relations, University of Northern Colorado. B.S., Utah State University; M.S., University of Arizona; Ph.D., Colorado State University.

† Commodity Analyst, Louis Dreyfus Corporation, Wilton, CT. B.S., University of Delaware; M.S., University of Minnesota.

‡ Associate Professor, Department of Agricultural and Applied Economics, University of Minnesota. Ph.D., University of Goettingen, Germany.

the actual extent and incidence of any change is uncertain, the sheer volume of literature on the topic over the past decade indicates the seriousness of the issue. The issue is nowhere near resolution, and as a result, "global warming promises to be one of the central environmental issues of the nineties."[1]

The four major greenhouse gases include CO_2, methane (CH_4), chlorofluorocarbons (CFC's), and nitrous oxide (N_2O). Together, the four major gases account for over 90 percent of all heat trapping.[2] Global warming presumably results as the concentrations of greenhouse gases in the atmosphere increase. CO_2 emissions are of special interest here because any attempt to prevent the accumulation of greenhouse gases must focus on CO_2. CO_2 accounts for more than 50 percent of the heat trapping potential of all gases, and over 80 percent of CO_2 results from burning fossil fuels. Since the sources are manmade, reductions may be possible.

The potential for global warming due to the accumulation of greenhouse gases poses special problems for analysis. First, global warming is a form of international pollution. Accordingly, nation-states cannot reduce pollution unilaterally. By the same token, individual nations are able to impose some of the costs of greenhouse gas emissions on other states. Some form of international agreement is necessary to successfully reduce the likelihood of global warming, and as a result, both economic and political incentives are at issue.

The second problem for analysis revolves around uncertainty concerning the amount, timing and impact of warming. Given current trends in emissions, atmospheric CO_2 will likely double by the middle of the next century. Based on simulation runs of general circulation models, the best scientific estimates place warming due to the doubling between 1.5 and 4.5 C.[3] The timing of any warming is also uncertain. The slow warming of the ocean delays the effects of CO_2 emissions. Models that take into account ocean mixing rates predict a delay of ten to one hundred years. CO_2 in the air today may contribute to warming many years into the future, whether or not any new carbon is added.

The extent and timing of warming are debatable, but the effects that warming will have are even less certain. Global warming could speed

1. CHRISTOPHER FLAVIN, *Slowing Global Warming* STATE OF THE WORLD 17 (1990).

2. ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT, ENVIRONMENTAL INDICATORS, (1991) [hereinafter OCED 1991].

3. DONALD J. WUEBBLES & JAE EDMONDS, U.S. DEP'T OF ENERGY, A PRIMER ON GREENHOUSE GASES (1988).

desertification and shorten or lengthen growing seasons, shifting the distribution of productive agricultural lands. Global warming could increase sea volume through thermal expansion. Rising ocean levels would destroy wetlands and threaten all low lying regions, including many coastal cities. Climate change could also cause the extinction of animal and plant species unable to adapt or move with the changing environment. Violent weather, including tornadoes and hurricanes, could become more frequent.[4]

Given the unanswered questions surrounding global warming, and that CO_2 is an international pollutant with economic and political dimensions, what are the prospects for international agreement on CO_2 reductions? What factors determine the extent to which individual nations are willing to reduce emissions? What factors are most important in explaining continued pollution of this type? The objective of this article is to explore these questions both conceptually and empirically.

The format of the paper is as follows. In the next section, a conceptual model is introduced that integrates concepts of political economy and transboundary pollution. In section III, existing evidence on CO_2 emissions by OECD nations is examined using regression analysis. Factors that have significant power in explaining increases or decreases in emissions are identified. Finally, the empirical results are interpreted in the context of the conceptual model. Implications are explored concerning the likely path of future CO_2 emissions and the prospects for international agreements.

II. A Political Economic Model of International Pollution

The global qualities of CO_2 emissions introduce at least three problems into the theoretical framework. First, the theory needs to capture the idea that any single nation "exports" some of the effects of CO_2 emissions and "imports" some of the effects imposed by other nations. Second, the framework must be flexible enough to allow for the many uncertainties associated with CO_2 emissions. Finally, the theory must address the fact that different nations, in determining their CO_2 emissions, face different political and economic incentives.

Recent attention to "political economy" and "public choice" in economics refers to the application of a simple set of economic principles to

4. Joel Darmstadter & Jae Edmonds, *Human Development and Carbon Dioxide Emissions: The Current Picture and the Long Term Prospects*, GREENHOUSE WARMING: ABATEMENT AND ADAPTATION 35 (Norman J. Rosenberg et al. eds., 1989).

political decisions. The basic idea is that the objective of a policy maker is to maximize his or her utility, which is assumed to be dependent on political support. In this regard, the policy maker must consider and balance the political support (benefits) and political resistance (costs) a particular regulatory decision will produce.[5]

This article focuses on policymakers in several nations facing the question of CO_2 emission policy. In each country, the policymaker can limit CO_2 emissions with a policy instrument. The policymaker selects a level of policy to maximize his political support. In other words, in considering a policy which would reduce carbon dioxide emissions, the policymaker will examine the expected marginal political support received (support for abatement) as well as the marginal political support lost (support for supply of emissions). The policymaker will issue regulations or agreements to reduce emissions only when the support for abatement dominates the support for continued emissions.

Since global warming is a function of global carbon dioxide emissions, unilateral abatement is a largely ineffective option for a single nation. A multilateral agreement to reduce emissions to a mutually beneficial level is necessary. This agreement is feasible if the group of nation-states as a whole realizes net benefits. When nations are not homogeneous (i.e., experience differing benefits and costs at a given level of abatement), nations that stand to gain must compensate nations that will experience losses. Correlative to less homogeneity of the countries involvedis a greater need for compensation for reaching international agreement.

The political economic framework is instructive in examining the political incentives facing nations who are contemplating regulation of carbon dioxide emissions. Certainly, there are specific political and economic pressures bearing on individual nations. The following paragraphs outline, in the context of CO_2 emissions, the factors which may influence support for supply (an increase in emissions associated with less regulation) and support for abatement (a decrease in emissions associated with stronger regulation).

A. *Factors Affecting Support for Abatement*

Three information factors may produce divergence in desired emissions between nations. First, the amount of warming from CO_2 is unknown. Second, the timing of the warming may be delayed up to 100

5. Harald von Witzke & Marie L. Livingston, *Staff Paper*, PUBLIC CHOICE IN INTERNATIONAL POLLUTION P90-15 (1990).

years.[6] Third, the economic impacts of any warming are uncertain. As people in each nation evaluate the threat they perceive given these uncertainties, the result is likely to be varying support for abatement functions.

One factor in the abatement function may reflect the expected warming in each country. The estimated range of between 1.5 to 4.5 C leaves considerable room for differences of opinion. Presumably a more alarmist nation leaning toward the 4.5 figure would demand a lower global emission level than a nation whose policymakers are convinced that an increase of 1.5 C would not be critical.

The time delay between CO_2 emissions and the resulting global warming magnifies the differences in support for abatement among nations. Many of the benefits from reducing CO_2 emissions will accrue to future generations while costs are born by the present population. Different countries will apply different discount rates to these future gains, with the rate determined by the return on competing investments. Investment in preserving species, ecosystems or wildlife areas may be a substitute for reducing CO_2 emissions. Particularly in lower income countries, investment in development may realize higher and more immediate economic gains than the alternative investment in CO_2 emission reduction.

A fundamental set of factors affecting the support for CO_2 abatement relate to the expected economic cost resulting from global climate change. Climate change would likely impose costs on farming, forestry, water resources, recreation and coastal based sectors of the economy. Natural landscapes and marine ecosystems may also be victims of climate change which may not be salvageable at any cost.[7] Of all these sectors, changes in agriculture and rises in sea levels will likely produce the largest economic costs.

Therefore, variables which reflect climate prone resource endowments, such as income from agriculture and susceptibility to sea level change may affect support for carbon dioxide abatement. One only need recognize the uneven distribution of threatened agricultural and coastal resources to conclude that support for abatement is bound to vary between countries. Of course, losses will be mitigated to the extent research and technology allow adaptation.[8]

6. Stephen H. Schneider & Norman J. Rosenberg, *The Greenhouse Effect: Its Causes, Possible Impacts, and Associated Uncertainties*, GREENHOUSE WARMING: ABATEMENT AND ADAPTATION 7 Norman J. Rosenberg et al. ed. 1989).

7. Gjerrit P. Hekstra, *Sea Level Rise: Regional Consequences and Responses*, GREENHOUSE WARMING: ABATEMENT AND ADAPTATION 53, (Norman J. Rosenberg et al. ed. 1989).

8. It is possible for individual nations to expect net economic gains from warming if large

There are other variables which may influence emissions, having nothing to do with uncertainty per se. In general, environmental quality is thought to be a "normal" economic good, meaning that as income increases, so does the demand for environmental amenities. Therefore, one may expect, *ceteris paribus*, higher income countries to demonstrate greater support for pollution abatement. Some indication of the general level of environmental awareness among a nation's population may also be a good predictor of the level of support for abatement in a particular country.

Ironically, the amount of CO_2 pollution "imported" (imposed by other countries), may also increase the support for abatement within the country itself.[9] Pollution from the outside essentially increases the cost of environmental damage at every level of domestic emissions, and therefore increases the incentive for emission reduction, even on a unilateral basis.

The primary political factor affecting the support for abatement is the ability of interested parties to organize and transform their economic and environmental interests into political power. The size and concentration of the group in addition to the average per capita gains to be realized, will affect its ability to organize.[10] Since the beneficiaries of reductions in global warming are widely dispersed and uncertain about the gains to be realized, political power may be difficult to achieve for this group.

B. *Factors Affecting Support for Supply*

Support for a continued supply of carbon dioxide emissions usually varies between nations. The primary benefit of carbon dioxide emissions is associated with productive activities that require energy and thus produce carbon dioxide emissions. Every nation to undergo development thus far has illustrated that higher GNP's lead to more CO_2. Therefore, energy requirement factors, technology factors and energy availability factors may all affect the support for emission supply.

Differing endowments of fossil fuels will likely bias a nation's tolerance for CO_2 emissions. Reduced CO_2 emissions implies lower demand for fossil fuels and lower income for countries rich in these fuels. A

areas of previously inhospitable land become suitable for agriculture or recreation. This analysis assumes the expected impacts of climate change to be negative, ruling out the possibility of policies that encourage pollution in anticipation of future economic gain.

9. *See supra* note 5.

10. MANCUR OLSON, THE LOGIC OF COLLECTIVE ACTION (1965).

country with substantial coal or oil reserves would have stronger support for CO_2 than a country with lower resources.

The nature of technology used by a particular nation determines the fuel mix needed to generate the energy requirement. As concern about carbon dioxide emissions increases, demand for fuel efficient automobiles, less fossil fuel intensive technologies and alternative energy sources should grow. The presence or absence of fossil fuel intensive technologies and alternative energy sources available to a nation may help explain differences in CO_2 emissions levels.

Variables such as population, and predominant industries may also affect support for emissions. Even assuming constant per capita income, one would expect higher population to yields a higher level of CO_2 emissions. Population promises to be an important factor increasing CO_2 emissions. The number or proportion of individuals in an economy that earn incomes in energy intensive industries may also be a factor in determining support for continued emissions.

The degree to which carbon dioxide is "exported" to other nations may also increase the support for emission supply. The ability to shift costs of productive activity onto others essentially increases the benefit of energy using activities to the domestic country. It has been shown many times that this kind of "externality," whereby costs are shifted to parties other than the decision maker yields the incentive to overproduce.[11] In the context of many nations facing similar incentives, a classic "prisoner's dilemma" is likely to result.[12]

Again, the ability of groups with an interest in continued CO_2 emissions to organize in a politically effective manner will affect the incentives policymakers face. Because the beneficiaries of continued carbon dioxide emissions tend to be more concentrated than the sufferers of the same, and because existing producer and labor organizations are available to galvanize support, one would expect these groups to be better able to translate economic concerns into political action.

III. Empirical Evidence from CO_2 Emissions

A. *Estimation Methodology*

The empirical study is designed to examine existing data on CO_2

11. William J. Baumol & Wallace Oates, The Theory of Environmental Policy (1988).
12. Marie L. Livingston & Harald von Witzke, *Institutional Choice in Transboundary Pollution* 3 Soc'y & Natural Resources 159 (1990).

emissions using regression analysis. Regression analysis is used to determine the degree to which selected independent variables have power to explain variation in a particular dependent variable. Ordinary least squares (OLS) regression is an econometric method for fitting an equation to a set of data. OLS calculates the best linear unbiased estimates of the equation parameters when the errors (estimated values minus actual values) are independent and are identically distributed with a constant variance.[13] In this case, the goal is to isolate variables which are significant in explaining 1) pressure to continue or increase emissions and 2) pressure to decrease CO_2 emissions by a subset of nations.

Identifying explanatory variables should give several insights into the supply and abatement functions. First, the existence of common supply or abatement variables can be established. Failing to find significant abatement variables may indicate that specific factors do not influence the level of emissions. A lack of significant supply or abatement variables could also indicate that variables differ between countries. The factors that determine pollution in a specific country may be largely independent of the factors for other countries. If, however, significant variables are found, specifying these common determinants should provide insight into how emissions may change as economic and political circumstances change.

The twenty four OECD countries prove to be a logical and practical choice for study.[14] In 1988 OECD nations together accounted for more than 44 percent of world CO_2 emissions. Therefore OECD reductions would translate into substantial global reductions.[15] Among the countries there are similarities both in development and in political systems. These similarities suggest that support for supply and support for abatement functions composed of a few common significant variables may exist.

Fortunately, the OECD publication *Environmental Indicators* reports CO_2 emissions (the dependent variable) in tons of carbon per capita

13. Additional econometric methods were use to analyze the data: Two, Stage Least Squares was used to test possible correlation between variables which would result in correlated errors and biased estimates. No significant bias was found. Three, Stage Least Squares was used to solve the abatement and supply equations simultaneously, correcting parameter estimate for interaction between variables. Most of the resulting parameters were insignificant, possibly due to insufficient sample size.

14. The twenty four OECD nations studied are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, and the United States.

15. OCED 1991.

for 20 of the OECD nations.[16] The independent, explanatory variables were obtained from a variety of published sources.[17] Missing data for some countries resulted in fewer usable observations for some variables. The sample size of seventeen countries yielded the best fitting regression equations.

The first regression focuses on the factors explaining increase in the supply of emissions. Treating CO_2 as endogenous and a linear function of the supply variable vector X, the following equation is estimated using ordinary least squares (OLS):

$$(1)\ COTWO = \hat{\lambda}_0 + \hat{\lambda}_1 x_1 + \ldots + \hat{\lambda}_k x_k$$

The k variables in X determine the physical supply of CO_2. Any x_j, ($j = 1,2,\ldots,k$) that, when increased, leads to a higher CO_2 output in all of the i countries, should have a significant coefficient μ_j, interpreted as the change in CO_2 for a marginal change in x_j. For x_j's specific to a minority of the countries the coefficient μ_j will not significantly differ from zero.

The second step is to chose the common significant abatement variables from the *l* variables in the abatement variable vector, relating to the pressure to decrease emissions. The equation is of similar form, and parameters are again estimated with OLS:

$$(2)\ COTWO = \hat{\mu}_0 + \hat{\mu}_1 y_1 + \ldots + \hat{\mu}_l y_l$$

The independent abatement variables, Y, determine the level of CO_2 a nation finds acceptable. The coefficient μ_j, for significant variables y_j, $j = 1,2,\ldots,l$, gives the expected change in CO_2 emissions for any country i from marginal changes in y_j.

B. *Regression Results*

This sub-section explains the regressions results in terms of the variables that were found to have the greatest power in explaining the pressure to 1) continue carbon dioxide emissions and 2) reduce emissions of CO_2. The variables that were included in the analysis and failed to be

16. *Id.*

17. For the data used for the construction of the following variables, see: COTWO, GDP, COAL, TRAFFIC, OIL, WOODED, PROTECTED, CROP CONCERN, and DEFOREST, ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT, ENVIRONMENTAL INDICATORS, (1991); SEA, CENTRAL INTELLIGENCE AGENCY, WORLD FACTBOOK 1990 (1990); LABOR, ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT, LABOUR FORCE STATISTICS 1968-88, (1990); GAS, ENERGY INFORMATION ADMINISTRATION, 1989 INTERNATIONAL ENERGY ANNUAL, (1989); WINTER and SUMMER, STATESMAN'S YEARBOOK, (Brian Hunter, ed. 1991); INDUSTRY, ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT, INDUSTRIAL POLICIES, DEVELOPMENTS AND OUTLOOK IN OECD COUNTRIES, (1986); and SOTWO, WORLD HEALTH ORGANIZATION, AIR QUALITY IN SELECTED URBAN AREAS 1979-1980 (1983).

significant in the regressions are also discussed. Both categories of variables yield insight into the dynamics of international pollution control.

1. The Supply Equation

The first regression equation was designed to isolate the supply variables that determine the production of CO_2 emissions. Since 80 percent of emissions result from burning fossil fuels, variables related to energy usage provide the best fit. The highest significance was achieved by defining CO_2 (COTWO) as a function of a constant (CONSTANT), per capita gross domestic product (GDP), percentage of energy from solid fuels (COAL) and percentage of GDP from energy intensive industry (INDUSTRY):

$$(3)\ \text{COTWO} = -5.84 + .34\ \text{GDP} + .064\ \text{COAL} + .059\ \text{INDUSTRY}$$

GDP, annual per capita income in thousands of U.S. dollars, is the most significant variable. This variable carries a coefficient of .342 and a highly significant *t*-statistic of 7.27. Given the thirteen degrees of freedom in the regression, the *t*-statistic must exceed 2.16 to satisfy a 95 percent confidence level. A loose interpretation of the coefficient indicates that increasing an OECD country's per capita GDP by $342, with other variables constant, would raise per capita CO_2 emissions by one ton.

COAL, the variable for percentage of energy from solid fuels, reflects a country's dependance on highly polluting fuels. Solid fuels include coal, wood and combustible biomass, with coal being predominant. A coefficient of .064 and a *t*-statistic of 4.64, are also highly significant. With other variables constant, the regression indicates that shifting six percent more energy production onto solid fuels would increase CO_2 emissions by one ton per capita.

The COAL variable partially reflects a country's energy policy. In the context of the model, perhaps countries that choose high polluting fuels for energy do so because the economic benefits from these fuels result in support for supply of pollution that outweighs the loss in support for abatement. The benefits may reflect price and availability of the fuel as well as technology and other factors.

INDUSTRY gives the percentage of GDP from energy intensive industry. With a coefficient of .072, INDUSTRY has a significant *t*-statistic of 2.24. The coefficient implies that obtaining seven percent more of GDP from energy intensive industry, other variables constant, would cause CO_2 production to increase by one ton per capita. INDUSTRY partially captures the industrial structure in OECD countries. Because investment in energy intensive industry accounts for part of the variation in CO_2 emissions, it is a significant supply factor.

Together, the supply variables yield an adjusted R-squared of .80. This means that a country's per capita GDP, the structure of its energy supply and the structure of its industry (the independent variables) can combine to explain eighty percent of the variation in CO_2 emissions.

Additional supply variables received consideration before settling on the most significant equation. One of the more significant and interesting was TRAFFIC, a measurement of road traffic annually in thousands of miles per capita. Since gasoline accounts for a large proportion of fossil fuel consumption, TRAFFIC, in isolation, was strongly significant in many regressions. However, gasoline consumption is also highly correlated with many of the other variables, including GDP and INDUSTRY. TRAFFIC tends to interfere with these and other variables when added to regressions, raising their standard errors and driving down t-statistics, even though singly it may be most significant. TRAFFIC is not significant in combination with GDP and INDUSTRY, indicating that much of its information is accounted for in the other variables.

Other variables, reflecting additional information about energy supply and regional differences, fell short of significance. Variables for the percentage of energy from oil (OIL) and the percentage of energy from natural gas were unimportant compared to COAL. It is likely that the significant information in energy differences is contained in the COAL variable, and the additional variables result in overspecification. Regional variables representing average high summer temperature (SUMMER) and average low winter temperature (WINTER) were added to capture differences in fossil fuel use resulting from climate. Neither was significant.

Since land use changes can contribute significant quantities of CO_2, DEFOREST, a variable for net percent change in cropland and forest, was included. With the resulting t-statistic of $-.51$, the coefficient was not significantly different than zero. Variables reflecting quantities of oil, coal or natural gas reserves are also potential supply factors, but proved to be insignificant in explanatory power. The insignificance of energy reserves may reflect the difficulty in accurately estimating the availability of untapped fossil fuels, or may suggest that various nations value reserves differently.

2. The Abatement Equation

Finding significant abatement variables proved less straight forward than finding supply variables. The abatement factors are more difficult to surmise, less universal, and less easily quantified. Using ordinary least squares, specifying CO_2 (COTWO) as a function of a constant (CONSTANT), per capita gross domestic product (GDP), sulfur dioxide levels (SOTWO), percentage of wooded land area (WOODED), and percentage of land area protected from development (PROTECTED) achieved the highest significance and were found to explain eighty one percent of the variation in carbon dioxide emissions:

$$(4)\ \text{COTWO} = -.22 + .34\ \text{GDP} + -.004\ \text{SOTWO} + -.020\ \text{WOODED} + -.098\ \text{PROTECTED}$$

GDP is the most significant variable. However, the sign is not the negative that was expected in the abatement equation. The coefficient of .34 is the same as the supply regression, and the *t*-statistic is a highly significant 7.84. With twelve degrees of freedom, a *t*-statistic of greater than 2.18 satisfies a 95 percent confidence interval.

The next significant abatement variable, SOTWO, reflects average atmospheric sulfur dioxide (SO_2) levels measured in urban areas. From data published by the World Health Organization, the 90th percentile readings were used to calculate the average of all readings for all monitored cities in each country in 1980.[18] This produces a coefficient of −.004 and a *t*-statistic of 3.08. The negative sign on SOTWO indicates that while people have tolerated higher emissions of CO_2, they demand lower SO_2 emissions.

WOODED gives the percentage of land area in forest and permanent vegetation. The regression gives a coefficient of −.20 and a significant *t*-statistic of 2.94. The coefficient suggests that decreasing wooded land by .20 percent, all else constant, would increase per capita CO_2 emissions by one ton. Intuitively, this may be interpreted to imply that the higher the percentage of wooded land in a country, the more vulnerable people feel to the effects of pollution from fossil fuels.

The next variable, PROTECTED, gives the percentage of land protected from development. PROTECTED just misses the significance level cutoff with a *t*-statistic of 2.14, but is close enough to include on the significant list. The coefficient of −.10 infers that per capita CO_2 emissions increase by one ton when protected land decreases by .10 percent of

18. WORLD HEALTH ORGANIZATION, AIR QUALITY IN SELECTED URBAN AREAS 1979-1980, (1983).

total land. Protecting land from development is a common response when pollution and other concerns threaten environmental public goods. Thus, PROTECTED likely reflects the polution's expected level of threat to the environment, as well as human effectiveness in responding to the threat.

Variables reflecting the direct effects of global warming are absent in the equation. The variables missing from the list of significant factors are as striking as the variables included. The key economic concerns associated with global warming are agricultural impacts and rising sea levels. To capture these concerns, CROP, a variable for the percentage of all land suitable for crops or pasture, and SEA, a dummy variable indicating susceptibility to rising sea levels were analyzed. CROP should have a negative sign since countries with higher agricultural resources should place a higher cost on global warming and therefore lower their CO_2 emissions. When CROP is added to the regression, the sign is negative but the standard error is so large that the result is highly insignificant.

The insignificance of CROP may reflect the uncertainty in the effects and timing of global warming. This uncertainty might mean that the threat to agricultural land is not weighted equally in all countries, and thus CROP does not emerge as a common abatement factor. To fully examine the role of potential agricultural losses in determining emissions, other measures of dependance on agriculture could be tested. Contribution of agriculture to GDP is one possible example.

Predicting possible sea level rise is difficult and quantifying the susceptibility to this rise adds another level of difficulty. In lieu of precise measurement, a simple zero-one dummy was constructed that takes on the value one if a country has shoreline that would suffer significant damage from expanding oceans. Using Data from the *World Factbook 1990*, the variable was set equal to one for all countries with a border of more than 60 percent coastline.[19] These values were adjusted for particularly vulnerable countries.[20] Ireland and Norway were changed to zero due to their less susceptible and less developed rocky coasts. The Netherlands became one due to its coastal lowlands. Clearly this variable lacks precision, which partially explains why the *t*-statistic is insignificant and the variable has the wrong sign.

CONCERN, a variable measuring percentage of population concerned about global warming, may be an important but even less precise determinant of CO_2 emissions. The percent concerned, taken from an

19. U.S. Central Intelligence Agency, HANDBOOK OF THE NATIONS, (1990).
20. *See supra* note 7.

OECD survey, showed no significance in accounting for carbon emission levels. While the reliability of the results of such a survey may be questioned, the insignificance of this variable suggests that people's awareness of the global warming problem has not yet become important in determining political support for abatement of CO_2.

Two additional variables failed to appear with significance. GAS, a variable for consumer gasoline prices in U.S. dollars, (which may capture people's response to energy pricing) fell marginally short of the significance level. The variable LABOR measures the percentage of the labor force in industry. It is reasoned that the more the income of the population is tied to the carbon producing industry, the higher the tolerance people would have for CO_2 pollution due to the potential for income loss. This variable was not important for the data examined.

IV. Interpretations: Reservations and Implications

This section interprets the results of the empirical study, in the context of the general conceptual model and econometric principles. Ideally, the regression equations indicate the key economic variables effecting carbon dioxide emissions, society's perception of these factors and the ability of groups to translate economic interests into political pressure. In addition, the regression results provide some indication about the similarity or diversity among the countries included in the analysis. Of course, the information gathered is limited by estimation technique itself. The following paragraphs summarize the results and speculate about their implications.

Using OLS, the supply and abatement factors significant in explaining CO_2 emissions for OECD countries were isolated. The significant supply factors are GDP, per capita gross domestic product; COAL, percentage of energy from solid fuels; and INDUSTRY, percentage of GDP from energy intensive industry. The specific results for the support for supply equation are not surprising. Three factors explain over eighty percent of the variation in carbon dioxide emissions. GDP, COAL and INDUSTRY variables conform to the expectation that supply factors relate to energy requirements and use in production.

The significant abatement factors include GDP again; SOTWO, SO_2 pollution concentration; WOODED, percentage of land in forest and permanent vegetation; and PROTECTED, percentage of land protected from development. These factors explain eighty-one percent of the variation in carbon dioxide emissions. WOODED and PROTECTED are easily interpreted. They capture some of the population's concerns associated with pollution and the strength of the response to those concerns. The presence of SOTWO is more mysterious.

The regional characteristics of SO_2 pollution may account for its appearance in the CO_2 abatement vector. Sulfur dioxide pollution is linked to CO_2 pollution through fossil fuels. Burning fossil fuels is responsible for about 50 percent of all SO_2 produced.[21] All other sources are natural. SO_2 pollution, most common in acid rain, results in direct impacts on human health, acidification of the environment and deforestation. Whereas CO_2 remains in the biosphere for 500 years, SO_2 has an atmospheric lifetime of up to five days. Thus, while some SO_2 can travel significant distances, most emissions lead to local pollution. The consequences of CO_2 are obscure, delayed, and diluted, while the consequences of SO_2 are direct, immediate, and concentrated.

The relationship between CO_2 and SO_2 may be illustrative of a global pollutant not being responsive to environmental concerns while a local pollutant with similar sources is responsive. The implication is that, in the foreseeable future, global CO_2 emissions will only drop to the extent that individual nations find it economical to reduce related local pollutants.

The results for the support for abatement equation are surprising in terms of the variables that are not significant. Three variables directly connected to global warming, ARABLE, SEA and CONCERN, do not appear with significance in the abatement regression. Their insignificance does not necessarily indicate that countries do not expect CO_2 emissions to have considerable environmental impacts. The results may indicate that not all OECD countries are recognizing and responding to the same abatement factors.

The conceptual model implies that any significant reduction in CO_2 emissions requires a multilateral agreement, and the more homogenous the countries, the more likely such an agreement. None of the significant abatement variables reflect the expected direct global costs that would accrue if CO_2 emissions result in global warming. The insignificance of key variables in the empirical study may simply indicate wide differences between countries, both in determining the effects of CO_2 emissions, and the importance of those effects, suggesting that a multilateral agreement is unlikely.

21. DONALD J. WUEBBLES & JAE EDMONDS, U.S. DEP'T OF ENERGY, A PRIMER ON GREENHOUSE GASES (1988).

Concerning differences among nations, another caveat about the empirical study is in order. Estimation of the regression equations was based on a sample consisting of only 17 countries and that these countries were chosen partly for their similarities in development. The isolated factors may not hold for other nations. In addition, when interpreting the coefficients, one must bear in mind that they may be relevant only within a narrow range of emissions, or they may be somewhat biased by the imposition of linearity.

Taken together, the regression equations reflect the dominance of supply factors, GDP in particular, in driving overall emissions levels. Recall that in both equations, GDP carries a positive sign, indicating that as production and incomes rise, so does pollution of this type. Because the production side increases emissions, whereas increasing incomes should tend to result in pressure to decrease emissions, it appears that the production side associated with increases in carbon dioxide emissions dominates the increasing demand for environmental quality.

The dominance of the supply effect reveals that policymakers are responding to the concerns of domestic industry, and that the response to support for abatement is insignificant in comparison. This conforms to the observation that no nations have initiated significant reductions in CO_2 emissions.[22] Perhaps the empirical results may reflect optimism on the part of industrialized nations about the ability for human societies to adapt to change through technological advance and/or resource mobility, producing less pressure for immediate emission abatement. Alternatively, maybe nations are simply unwilling to make sacrifices in economic growth, regardless of the environmental threat. In any case context of the model, apparently policymakers view the marginal support for abatement to be less than the marginal support for continued CO_2 emissions.

Information problems may also account for the dominance of support for supply over support for abatement. Certainly, imperfect information about global warming complicates achieving support for abatement. In the face of uncertainty, latitude exists for a range of perceptions about the implications of any global warming. Many questions remain, concerning how much, if any, warming will occur, how soon warming will occur and the magnitude and distribution of the effects. Current perceptions are based on the present understanding of CO_2 and

22. Hilary F. French, *After the Earth Summit: The Future of Environmental Governance*, WORLD WATCH PAPER 107, (March 1992).

climate change, which may be flawed.[23] If evidence mounts that excessive CO_2 forebodes a catastrophe, political support for abatement may mount.

It is debatable whether better knowledge about the links between CO_2, global warming, environmental change and economic impacts would result in more homogenous support functions. Quantifying the impacts of CO_2 on the world's economies may only provide better evidence that support for abatement functions should be skewed. That may only galvanize the resistance to international consensus. The disparities in support for abatement functions promise to be a persistent problem, suggesting that a meaningful reduction in CO_2 emissions will involve at least some compensation between nations.

Finally, political factors may be responsible for the overall result. The difficulties in estimating environmental costs combined with the sheer number of people affected by pollution may prevent a unified political response. In contrast, the economic advantages of cheap fossil fuels are easily determined, allowing producers of CO_2 to speak quite loudly and with a single voice in support of continued emissions.

V. Conclusion

In conclusion, international pollution is determined by both economic and political variables. In the case of carbon dioxide emissions, economic concerns associated with production and economic growth are certainly the driving force behind continued emissions. Based on the evidence, any pressure to abate carbon dioxide emissions, and therefore, the prospect of global warming, appear to be associated with the perceived vulnerability of forest resources to warming, manifested concern with growth per se and the local effects of related pollutants.

The factors found to be insignificant in explaining emissions indicate that either individual nations judge climate change to be unlikely, or do not perceive their resources to be vulnerable to expected changes. This result also indicates that potential consumers of global warming have yet to muster the political strength to challenge vested interests. The small number of significant variables suggests substantial differences between nations, even among OECD countries.

International pollution promises to be the subject of growing social

23. Thomas C. Schelling, *Some Economics of Global Warming*, 82(1) The American Economic Review 1 (1992).

concern. Effective solutions to these problems necessarily require international agreements. Finding common ground among nations involved is central to identifying the potential for multilaterial action. Defining sources of divergence is also key to enhancing the possibility for efficiency or equity based compensation. Additional research is warranted to examine the degree to which economic and political incentives can be aligned in dealing with nationally based pollutants having global consequences.