The Implications of Global Ecological Elasticities for Carbon Control: A STIRPAT Formulation

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In this paper, we analyze the impact of real energy price on CO_2 emissions for OECD countries using an ordinary least squares regression estimation of a STIRPAT model formulation for environmental impact. We model country-level CO_2 emissions over the 1978-2007 period as a function of an index of real energy price, population, and gross domestic product per capita. We find that, although rising real energy prices generally have a negative impact on CO_2 emissions, the ecological impact elasticity is inelastic for all countries, suggesting that a cap-and-trade system may be preferred to a carbon tax system for global carbon control.

INTRODUCTION

Through their consumption and production decisions, people emit greenhouse gasses (GHGs). Carbon dioxide (CO_2) accounts for most of the human-generated GHGs. These flows of CO_2 accumulate into atmospheric stocks. The atmospheric stock traps heat and results in global warming which then results in climate change. The global mean temperature is at its warmest level in 12,000 years leading to climate change which affects people, animals, and plants through storms, floods, droughts, and sea level changes. As a result, climate change and global warming are at the forefront of international policy discussions (Stern, N., 2008).

From an economic perspective, CO_2 emissions are a negative externality, meaning that the full cost of the emissions is not borne by the emitter. Even in the realm of negative externalities, CO_2 emissions are a different type of negative externality because they are global in both their origins and impacts making international cooperation a necessity. The effects are very long term and involve a flow-stock process, there is lots of uncertainty in the scientific process, and the effects are very large and potentially irreversible (Stern, N., 2008). The quantity of CO_2 that must be reduced and the timing of these reductions are still under debate. In theory, the optimal amount of reductions sets marginal control costs equal to marginal benefit, where marginal benefit is the reduction in damages caused by climate change with the discount rate determining if we should reduce CO_2 emissions more slowly or more quickly.

Essentially there are three ways to potentially reduce CO_2 emissions: command-and-control, carbon taxes, and cap-and-trade. Command-and-control regulations and standards impose constraints on actions or technologies which result in extra costs and emission reductions. Carbon taxes are taxes placed on items that lead to carbon emissions, such as fossil fuels. Under a cap-and-trade system, a specific quantity of allowable emissions is set as the cap. Credits are allocated or auctioned to emitters who then trade the credits or “rights to emit” in an open market.

Much of the existing policy debate in the environmental literature has focused on cap-and-trade versus carbon taxes. According to basic economic theory, both a carbon tax approach which sets the price and the cap-and-trade approach which sets the quantity would lead to the exact same outcome in terms of the quantity of carbon emitted and the price of carbon. This result, however, no longer holds true if there are uncertainties regarding the cost and benefit functions. In the case of climate change, there are very large uncertainties with respect to the benefits since they will accrue in the future, while the costs of controlling carbon are currently known. In this case, it has been shown that the price (tax) approach is superior to the quantity (cap-and-trade) approach (Weitzman, 1974).

The theoretical debates regarding carbon taxes versus cap-and-trade rage on in the literature with little empirical evidence with regard to what will actually work in terms of implementation. Some favor a harmonized carbon tax such as William Nordhaus (2006, 2007, 2009), while others favor cap-and-trade systems such as Robert Stavins (Jaffe et al., 2010). Often much of the reasoning for favoring one or the other comes down to political and institutional concerns rather than economic ones. Issues like administrative costs, revenues, tax distortions, enforceability, corruption, monitoring, fines, political negotiations, and lobbying define the current debates.

In this paper, we analyze the impact of energy prices on CO_2 emissions for OECD countries. We find that although rising real energy prices generally have a negative impact on CO_2 emissions, the ecological impact elasticity is inelastic for all countries, implying that a cap-and-trade system may be preferred to a carbon tax system.

DATA AND METHODOLOGY

The data set consists of CO_2 emissions, an index of real energy price, population, and GDP data for the 29 Organization of Economic Cooperation and Development (OECD) countries from 1978-2007. The data come from the OECD and International Energy Agency (IEA) and are described in table 1.

TABLE 1
VARIABLES AND DEFINITIONS

Variable	Source	Measurement
Real Energy Price	Energy Prices and Taxes: Indices of real energy prices for households and industry (total energy)	For each country year 2005 = 100
CO_2 emissions	CO_2 Emissions from Fuel Combustion: CO_2 emissions sectoral approach	Measured as millions of tonnes of CO_2 emissions
GDP	CO_2 Emissions from Fuel Combustion: GDP using purchasing power parities	Measured as billions of 2000 US dollars
Population	CO_2 Emissions from Fuel Combustion: Population	Measured in millions

In table 2, we show the correlations between CO_2 emissions and the real energy price index, population, GDP, and GDP per capita for each country. The first thing to note is how many countries show a positive relationship between real energy prices and CO_2 emissions. This would provide initial evidence that many countries really do not respond to price changes; or, if they are responding, that response is outweighed by other factors. In 18 of the 29 countries we see the expected negative correlation between the price of CO_2 in the form of energy prices and the quantity of CO_2 emissions. We also see that in 21 countries the correlation between population and CO_2 emissions is positive as we expect. Lastly, a positive relationship between the GDP variables and CO_2 emissions occurs in 19 countries.

TABLE 2
CORRELATIONS WITH CO_2 EMISSIONS FOR OECD COUNTRIES

Country	Real Energy Price	Population	GDP	GDP per Capita
Australia	0.50	0.99	1.00	0.99
Austria	-0.28	0.90	0.90	0.89
Belgium	-0.37	0.10	0.06	0.06
Canada	0.56	0.94	0.96	0.96
Czech Republic	-0.44	0.53	-0.54	-0.55
Denmark	-0.52	-0.35	-0.34	-0.33
Finland	0.29	0.74	0.71	0.70
France	0.24	-0.38	-0.32	-0.33
Germany	0.09	-0.95	-0.96	-0.96
Greece	-0.72	0.98	0.90	0.86
Hungary	-0.81	0.94	-0.45	-0.51
Ireland	-0.38	0.91	0.97	0.98
Italy	0.60	0.77	0.97	0.96
Japan	-0.84	0.91	0.96	0.96
Korea	0.07	0.98	0.98	0.99
Luxembourg	-0.14	-0.22	-0.19	-0.22
Mexico	0.76	0.98	0.98	0.81
Netherlands	0.26	0.91	0.91	0.91
New Zealand	-0.28	0.98	0.98	0.96
Norway	0.69	0.88	0.89	0.90
Poland	-0.87	-0.63	-0.71	-0.68
Portugal	-0.75	0.75	0.98	0.99
Slovak Republic	-0.21	-0.77	-0.61	-0.54
Spain	-0.33	0.95	0.98	0.97
Sweden	-0.75	-0.65	-0.71	-0.72
Switzerland	-0.55	0.77	0.78	0.78
Turkey	0.80	0.98	0.99	0.98
UK	-0.03	-0.55	-0.56	-0.56
US	-0.39	0.94	0.95	0.95

Note: Highlighted correlations have expected sign.

In order to further the analysis we chose to use a traditional Ordinary Least Squares (OLS) model. According to the IPAT model:

$$I=P*A*T$$

environmental impact (I) is a function of population (P), affluence (A), and technology (T) (Commoner, 1972; Ehrlich and Holdren, 1971). In order to make the model useful for hypothesis testing it was redesigned into the STIRPAT formulation where:

$$I_i = aP^b_i A^c_i T^d_i e_i$$

by Dietz and Rosa (1994). This multiplicative model can then be transformed into a linear estimation such that:

$$log\ I=a+b(log\ P)+c(log\ A)+e$$

where the error term accommodates variations in technology. In the environmental economics literature the more common estimating equation is:

$$log\ I=a+b(log\ P)+c(log\ A)+d(log\ A)^2+e$$

in accordance with the environmental Kuznets curve (EKC) hypothesis (York et al, 2003).

The EKC hypothesis states that for many air pollutants, growing levels of GDP per capita initially lead to high levels of pollution which then fall as development increases implying $c > 0$ and $d < 0$. In their seminal work Grossman and Krueger (1995) found that "while increases in GDP may be associated with worsening environmental conditions in very poor countries, air and water quality appear to benefit from economic growth once some critical level of income has been reached" (Grossman and Krueger, 1995, p. 370). The EKC literature, however, has shown mixed results in terms of empirical evidence (Stern, D., 2004). In addition to affluence, CO_2 emissions are also positively related to the size of the population (Dietz and Rosa, 1997; Shi, 2003) implying $b > 0$.

In our model, we partially disaggregate technology (T) by adding real energy prices into the equation. The estimated model is:

$$ln(I_j)= \beta_0 + \beta_1\, ln(Real\ Energy\ Price\ Index_j) + \beta_2 ln(P_j) + \beta_3 ln(A_j) + \beta_4 ln(A_j)^2 + \varepsilon_j$$

where I = CO_2 emissions, P = Population, A= GDP per capita, and j = 1978-2007.

We expect $\beta_1 < 0$ implying that as the real energy price index rises, people should use less energy, lowering the amount of CO_2 emissions. β_1 can be interpreted as the elasticity of CO_2 emissions with respect to real energy price. We expect $\beta_2 > 0$ since more people would use more energy implying an increase in CO_2 emissions. Lastly, we expect GDP per capita to follow a quadratic function where, at lower levels of GDP capita, we expect increased GDP per capita to have a positive effect on CO_2 emissions, but we expect that at higher levels of GDP per capita, emissions will begin to drop in accordance with the inverted U-shape of the EKC hypothesis implying $\beta_3 > 0$ and $\beta_{4.} < 0$.

RESULTS AND DISCUSSION

Table 3 shows the OLS results for the model. In the table, we first see that the adjusted R-squared ranges from 0.2289 to 0.9918. This clearly implies that the model has predictive power for some countries, but is less effective in explaining emissions in a small number of countries.

First, we find that 20 of the 29 countries show the expected positive effect of population on CO_2 emissions. Of these 20, 12 are statistically different from zero at the 95% level of confidence. Of the 9 countries which show a negative effect for population on CO_2 emissions, 4 are statistically significantly different from zero at the 95% level of confidence. Thus, for 41% of the countries included in our sample, population has a statistically significant positive effect on CO_2 emissions as we would expect. However, for 14% of the countries in our sample, population has a statistically significant negative effect on CO_2 emissions, opposite our expectations.

Next, when we examine GDP per capita, we see that 6 of the 29 countries have the expected positive effect of GDP on CO_2 emissions along with the expected negative effect of GDP^2 creating the inverted-U in accordance with the EKC hypothesis. Of these 6 countries only one, the Slovak Republic, has results which are statistically significant at the 95% level of confidence for both GDP and GDP^2. There are 21 countries which show a U-shaped relationship between GDP per capita and CO_2 emissions, implying that emissions fall as GDP increases and then begin to rise. Of these 21, 12 are statistically significant at the 95% level meaning that in 41% countries we find a U-shaped relationship between GDP and CO_2 emissions, opposite of the EKC hypothesis. These results provide little support for the EKC hypothesis which is not terribly surprising since the EKC hypothesis is development focused and most of the countries in the OECD sample would generally be considered developed nations. In addition, when looking at scatter plots of the relationship between GDP per capita and CO_2 emissions none show a clear U-shaped relationship of any type. However, if we omit the GDP^2 term we find a pattern in the residuals, leading us to believe that the inclusion of the squared term is necessary for our estimation.

TABLE 3
OLS ESTIMATION RESULTS

		Constant		Real Energy Price		Population		GDP per Capita		(GDP per Capita)^2	
Country	**R^2 Adj.**	β_0	**p-value**	β_1	**p-value**	β_2	**p-value**	β_3	**p-value**	β_4	**p-value**
Australia	0.9915	5.9151	0.0082	-0.1485	0.0140	1.3410	0.0000	-2.6858	0.0744	0.5005	0.0259
Austria	0.8577	14.6350	0.0223	-0.0617	0.5460	1.3082	0.2726	-8.5281	0.0056	1.3957	0.0053
Belgium	0.2690	9.0066	0.5621	-0.3615	0.0017	3.4788	0.3364	-6.3383	0.2714	0.9314	0.3389
Canada	0.9673	20.6627	<0.00001	-0.3649	<0.00001	0.6146	0.0021	-9.9467	<0.00001	1.6411	<0.00001
Czech Republic	0.4229	-11.9375	0.5027	-0.4645	0.1154	13.3478	0.0270	-8.6423	0.2224	1.5264	0.2364
Denmark	0.2289	-23.0886	0.3393	-0.3082	0.0361	5.9110	0.2587	12.6680	0.2398	-2.1274	0.2356
Finland	0.6022	13.9117	0.0120	-0.3509	0.0449	3.9803	0.0056	-9.5136	0.0080	1.5243	0.0078
France	0.8062	72.8701	<0.00001	-0.3445	0.0025	-4.7723	0.0025	-31.0255	<0.00001	5.2215	<0.00001
Germany	0.9503	20.6656	0.0001	-0.1070	0.0339	-2.0744	0.0007	-2.5025	0.1571	0.3620	0.2148
Greece	0.9753	-1.0982	0.8407	-0.4046	0.0005	4.7720	<0.00001	-2.8761	0.4295	0.5126	0.4088
Hungary	0.9479	-26.5695	<0.00001	0.1363	0.1045	12.5746	<0.00001	0.1925	0.9055	0.0491	0.8799
Ireland	0.9768	1.3169	0.1159	-0.1644	0.0579	0.7695	0.1312	0.9623	0.0167	-0.1028	0.1412
Italy	0.9547	7.1949	0.0415	-0.1362	0.0134	1.1315	0.0437	-3.9960	0.0046	0.7483	0.0017
Japan	0.9695	19.1972	<0.00001	-0.2845	<0.00001	-0.2070	0.8037	-7.1112	0.0000	1.2571	<0.00001
Korea	0.9832	-10.4356	0.1091	-0.4566	0.0409	5.3988	0.0328	-2.3196	0.1377	0.5334	0.0430
Luxembourg	0.5933	28.7230	<0.00001	-0.5301	0.0099	-5.3166	0.0020	-17.5032	<0.00001	2.5996	<0.00001
Mexico	0.9756	-1.8714	0.6999	0.0792	0.2055	1.1887	<0.00001	1.4146	0.7432	-0.2424	0.8021
Netherlands	0.8665	7.0019	0.0498	-0.2115	0.0217	0.8999	0.4603	-2.4007	0.4382	0.4153	0.3568
New Zealand	0.9719	3.3108	0.6422	-0.2008	0.0713	1.8317	0.0000	-1.7754	0.6963	0.4244	0.5866
Norway	0.8369	14.1485	0.0243	-0.3264	0.0325	-2.7140	0.2056	-4.4171	0.0796	0.8405	0.0485
Poland	0.8769	11.8907	<0.00001	-0.8094	<0.00001	0.4237	0.4073	-4.0250	0.0033	0.9586	0.0026
Portugal	0.9803	-4.8454	0.3354	-0.0743	0.7243	0.5187	0.7362	4.5208	0.0496	-0.5952	0.2090
Slovak Republic	0.7524	0.8770	0.7706	0.5307	0.0006	-4.0266	<0.00001	6.4570	0.0085	-1.4195	0.0055
Spain	0.9771	15.4853	0.0001	0.1557	0.0702	-0.5925	0.2780	-7.2453	0.0000	1.4775	<0.00001
Sweden	0.7842	20.5336	0.0001	-0.5697	0.0002	2.7076	0.0074	-11.9793	0.0003	1.7953	0.0005
Switzerland	0.5987	14.9405	0.2045	-0.1362	0.0714	0.1460	0.7529	-6.7602	0.3142	1.0464	0.2982
Turkey	0.9918	-3.9197	0.0001	0.0126	0.5870	1.3085	<0.00001	2.5216	0.0115	-0.3986	0.0652
UK	0.5013	21.8501	0.0249	-0.3035	0.0039	-1.1683	0.5409	-6.1489	0.0027	0.9975	0.0045
US	0.9447	26.9024	<0.00001	-0.2055	0.0000	-0.4448	0.1917	-9.6090	<0.00001	1.5284	<0.00001

Notes: CO_2 emissions is the dependent variable in all estimations. For Turkey N=28 for years 1980-2007. For all other countries N=30 for years 1978-2007. Coefficients with corresponding p-values less than 0.05 are highlighted. All variables are measured in natural logs.

Lastly, we examine the effect of real energy price on CO_2 emissions. Here we find that 24 countries show the expected negative impact for energy price. Of these 24, 18 are statistically significant at the 95% level of confidence, implying that in about 62% of the countries we see that an increase in real energy price would cause a decrease in CO_2 emissions. Of the 5 countries where a rise in real energy price causes a rise in CO_2 emissions, only the results for the Slovak Republic are statistically significant at the 95% level of confidence. A summary of our results is provided in table 4.

TABLE 4
SUMMARY OF OLS RESULTS

Finding	Number Of Countries	Number of Statistically Significant Countries	Percentage of Countries Statistically Supporting Finding at 95% Level of Confidence	Countries
$\beta_1 > 0$	5	1	3%	Slovak Republic
$\beta_2 > 0$	20	12	41%	Australia, Canada, Czech Republic, Finland, Greece, Hungary, Italy, Korea, Mexico, New Zealand, Sweden, Turkey
$\beta_2 < 0$	9	4	14%	France, Germany, Luxembourg, Slovak Republic
$\beta_3 > 0$ and $\beta_4 < 0$ *(EKC, Inverted U-Shape)*	6	1	3%	Slovak Republic
$\beta_3 < 0$ and $\beta_4 > 0$ *(U-Shape)*	22	12	41%	Austria, Canada, Finland, France, Italy, Japan, Luxembourg, Poland, Spain, Sweden, UK, US
$\beta_3 > 0$ and $\beta_4 > 0$ *(Increasing)*	1	0	0%	N/A
$\beta_3 < 0$ and $\beta_4 < 0$ (Decreasing)	0	0	0%	N/A

In our table 4 summary, we see that the Slovak Republic is the only country which provides clear support for the EKC theory and it is the only country that shows a significant positive effect for real energy price on CO_2 emissions. Given that from 1978-1989 the Slovak Republic was part of Czechoslovakia which was still under communist rule, we thought the data might be suspect. In order to correct for this possibility, we re-estimated the model using only data from 1990-2007 for all the former communist countries. These results are reported in table 5.

TABLE 5
OLS RE-ESTIMATION RESULTS FOR FORMER COMMUNIST COUNTRIES

		Constant		Real Energy Price		Population		GDP per Capita		(GDP per Capita)^2	
Country	**R^2 Adj.**	β_0	**p-value**	β_1	**p-value**	β_2	**p-value**	β_3	**p-value**	β_4	**p-value**
Czech Republic	0.5736	-31.1321	0.0334	0.6670	0.0016	8.1045	0.0336	10.3804	0.0493	-1.9135	0.0453
Hungary	0.6617	-18.3713	0.0230	0.1195	0.3666	10.1448	0.0115	-1.6782	0.3502	0.3980	0.2999
Poland	0.7909	-28.9920	0.2349	-0.4405	0.0040	11.7408	0.1073	-5.5385	0.0037	1.2419	0.0042
Slovak Republic	0.8410	38.9882	0.0001	-0.2538	0.1220	-22.5923	0.0001	2.8330	0.0730	-0.5183	0.1101

Notes: For former communist countries we performed a second estimation with data from the 1990-2007 period (N=18) in an effort to ensure data accuracy. CO_2 emissions is the dependent variable in all estimations. Coefficients with corresponding p-values less than 0.05 are highlighted. All variables are measured in natural logs.

In their 2003 work York et al. point out that the coefficients in the STIRPAT model can be interpreted as ecological elasticities or the "proportional change in environmental impacts due to any driving force." Table 6 displays the ecological elasticities for real energy price.

The most important thing to note from this ecological elasticity table is that although there is some variation, all countries are inelastic (or even positive), meaning that a 1% rise in energy price will lead to a less than 1% reduction in CO_2 emissions. Since emissions are very unresponsive to changes in energy price, it appears as though the only way to truly achieve a significant reduction in global CO_2 emissions is to implement a cap-and-trade program which strictly limits the quantity of emissions. Although it is clearly possible to implement a carbon tax so large that it would force significant reductions in CO_2 emissions, what we are seeing is that over the 30 years from 1978-2007 the 29 OECD nations have generally been very unresponsive to increases in energy prices. It seems that a carbon tax which allows for more carbon emissions provided that households and industry are willing to pay the tax is an unlikely method of solving the global climate change problem given that in many cases it appears as though people would be willing to simply pay the tax rather than change their behaviors. Therefore, limiting the quantity of allowable emissions seems a more straightforward policy toward resolving climate change.

TABLE 6
REAL ENERGY PRICE ECOLOGICAL ELASTICITIES

Country	EE	Country	EE
Poland (1978-2007)	-0.8	US	-0.2
Poland (1990-2007)	-0.4	New Zealand	-0.2
Sweden	-0.6	Ireland	-0.2
Luxembourg	-0.5	Australia	-0.2
Czech Republic (1978-2007)	-0.5	Italy	-0.1
Czech Republic (1990-2007)	0.67	Switzerland	-0.1
Korea	-0.5	Germany	-0.1
Greece	-0.4	Portugal	-0.1
Canada	-0.4	Austria	-0.1
Belgium	-0.4	Turkey (1980-2007)	0.01
Finland	-0.4	Mexico	0.08
France	-0.3	Hungary (1978-2007)	0.14
Norway	-0.3	Hungary (1990-2007)	0.12
Denmark	-0.3	Spain	0.16
UK	-0.3	Slovak Republic (1978-2007)	0.53
Japan	-0.3	Slovak Republic (1990-2007)	-0.3
Netherlands	-0.2		

Note: Highlighted elasticities are significant at the 95% level of confidence.

CONCLUSIONS AND FUTURE RESEARCH

In the debate regarding carbon taxes versus cap-and-trade there has been little empirical research into how households and industry around the world would actually respond to various policies. This study attempts to fill this gap by examining real energy prices in OECD countries for the years 1978-2007 and using OLS to estimate CO_2 emissions using a real energy price index, population, and GDP per capita.

Every year, global demand to emit CO_2 increases as population grows and GDP rises. As discussed previously, under a carbon tax system the quantity of emissions can increase as demand increases; however, there will be a price to pay in the form of the tax. It appears as though in some of the lower income OECD countries in 2007 (Turkey, Mexico, Hungary, and the Slovak Republic), households and industries are more willing to pay the price to emit. In these cases, energy prices do not really impact CO_2 emissions. In all countries, we find that the ecological elasticity for the real price index is inelastic meaning that a 1% rise in real energy prices will lead to a less than 1% reduction in CO_2 emissions.

Clearly, the demand for CO_2 emissions is not perfectly inelastic for any country. Eventually, as the price increases, people will to begin to respond by innovating and determining new ways to reduce CO_2 emissions that may not be viable at low carbon prices. In this sense, a cap-and-trade market which sets the quantity of emissions would be valuable because it would continue to drive the price upward as the demand for the right to pollute increases over time rather than allowing countries to pay to emit. It is very important, however, that, in future institutional arrangements, all countries must be subject to the same worldwide cap to avoid the free-rider problem. Also, countries should not be able to pay their way out of not meeting their obligations by paying fines. Similarly, no "safety valve" mechanism which sets a price ceiling on the price of permits under a cap-and-trade program should be implemented. It is only by allowing the price of carbon to continue to increase that we can fulfill the goal of reducing global CO_2 emissions by stimulating the necessary innovation.

In future research we would hope to add some of the non-OECD countries to the data set so that we can make a more robust comparison between developed and developing nations. In addition, we hope to examine these effects on a fuel by fuel basis by country so that we can see how the price of coal impacts CO_2 emissions from coal, how the price of oil impacts CO_2 emissions from oil, and how the price of natural gas effect CO_2 emissions from natural gas. By performing this type of analysis we would remove any potential impacts from non-CO_2 emitting types of energy. In the current analysis the results for a country like France which is heavily nuclear dependent could be questionable given that the price of nuclear power has been included in the real energy price index. Lastly, we hope to analyze the results on the household versus industry level.

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