Climate Change: How Feasible are Market Based Solutions?

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Using data from the International Energy Agency, this paper uses a STIRPAT model to examine the effect of fuel price changes on CO_2 emissions from oil, natural gas, and coal. Estimations are run for 16 OECD countries using data from 1980-2012. Overall, the results show that the emissions from fossil fuels are highly inelastic to price changes. Given that historic data show little or no responsiveness to price changes, and that significant cuts in emissions will be required in order to stem the continuing problem of climate change, relatively large price increases will be needed in most developed countries.

INTRODUCTION

Economists have long favored market based solutions to the climate change problem by proposing carbon taxes or cap-and-trade markets as feasible solutions. This paper argues that given the price increases required to deter climate change, it is unlikely that our elected officials will do much to resolve the climate change debate.

This paper uses a modified STIRPAT model to examine the ecological impact elasticities of various fossil fuels in numerous OECD countries including the US. The STIRPAT model, or stochastic impacts by regression on population, affluence, and technology, has been used to analyze the effects of the driving forces (population, affluence, and technology) on a variety of environmental impacts (York, 2003b). In this particular paper, the environmental impact is measured as the CO_2 emissions from coal, oil, and natural gas. In its modified form, other factors can also be added to the STIRPAT model such as the price of the specified fossil fuels. After controlling for population and affluence, the STRPAT allows us to examine the impact of changes in fossil fuel prices on the emissions from those specific fossil fuels.

Using data from the International Energy Agency, this paper uses the STIRPAT model to examine the effect of fuel price changes on CO_2 emissions from oil, natural gas, and coal. Estimations are run for 16 OECD countries using data from 1980-2012. Overall, the results show that the emissions from fossil fuels are highly inelastic to price changes. In several cases, as fossil fuel prices increase, fossil fuel emissions increase as well. Given that historic data show little or no responsiveness to price changes, and that significant cuts in emissions will be required in order to stem the continuing problem of climate change, relatively large price increases will be needed in most developed countries. Given, that many of the developed nations are democracies, it seems that many politicians may have a difficult choice to make between the longevity of human survival on the planet versus the longevity of their own political careers.

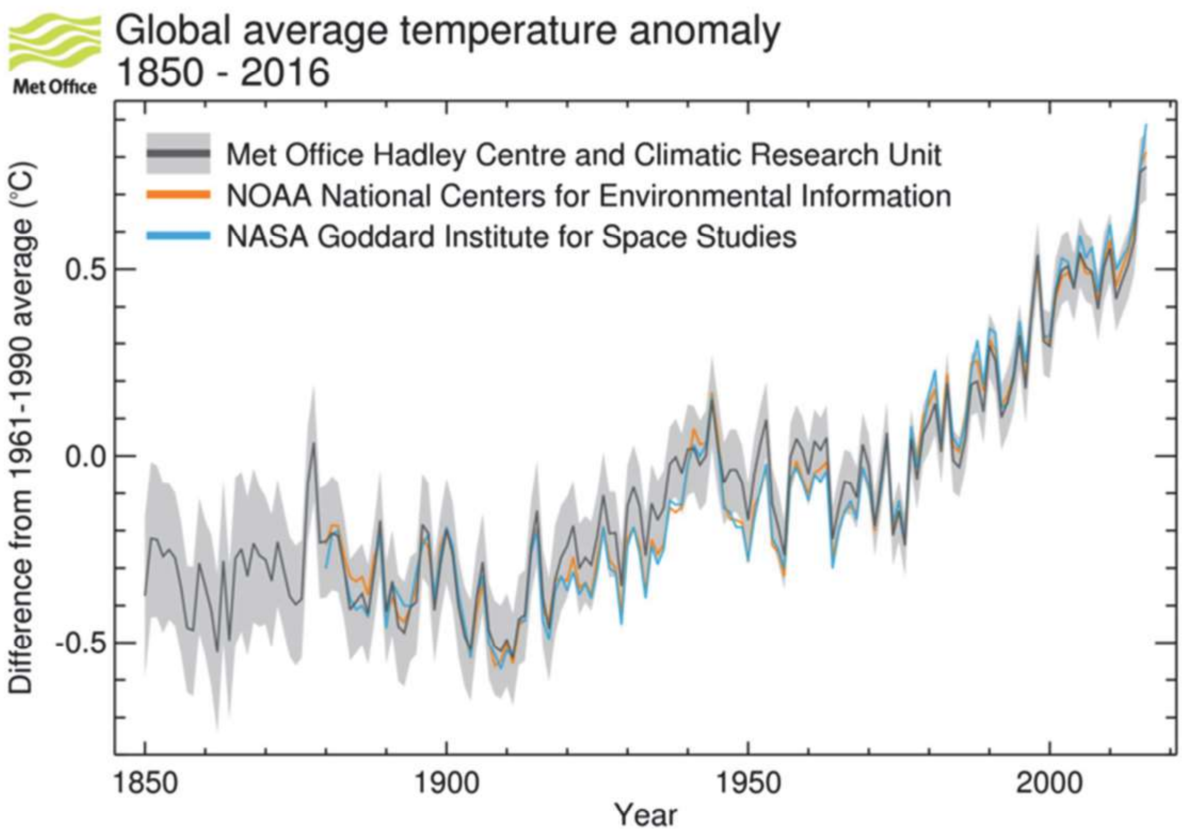
BACKGROUND

Figure 1, below, from the Met Office Hadley Center shows the global average temperature anomaly for combined land-surface air temperature and sea-surface temperature from 1850 to 2016. We can see that global temperature anomalies have been positive and on a continual rise since 1990.

Many believe that in large part this continued increase in surface temperatures is related to increasing use of fossil fuels around the globe (Hansen, 2008). In order to reduce emissions from fossil fuels many economists have argued in favor of market based solutions such as:

1. *Carbon Taxes:* Taxes can be placed on items that lead to carbon emissions such as fossil fuels, coal, and petroleum products.
2. *Cap-and-Trade:* A specific quantity of allowable emissions is set as the cap. Credits may be allocated or auctioned. Emitters then trade the credits or "right to emit" in an open market.

FIGURE 1
GLOBAL AVERAGE TEMPERATURE SERIES: COMBINED LAND-SURFACE AIR TEMPERATURE AND SEA-SURFACE TEMPERATURE



The favoring of market based solutions stems from the work of Montgomery (1972) which argued that a given reduction in pollution can be achieved more cheaply under market based solutions (cap-and-trade) than under command-and-control regulation. Basic economic theory would indicate that carbon tax and cap-and-trade approaches are equivalent – although Weitzman (1974) argues the superiority of a price approach such as a carbon tax under conditions of uncertainty. Due mostly to political and institutional concerns, some economists favor a harmonized carbon tax such as William Nordhaus (2006, 2007, 2009), while others favor a cap-and-trade system such as Robert Stavins (Jaffe, 2010). Rather than focus on the specifics of which approach might be more effective, this paper attempts to estimate the actual price changes that might be required in order to achieve a targeted rate of reduction in CO_2 emissions.

Hansen writes that "If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO_2 will need to be reduced from its current 385 ppm to at most 350 ppm, but likely less than that" (Hansen, et.al., 2008, p. 217). Estimates by the International Panel on Climate Change (IPCC) show that to achieve a target of 350 ppm will require a minimum of a 50% reduction in CO_2 emissions (IPCC, 2007, p. 39, Table TS.2).

The goal of this paper is to estimate ecological impact elasticities using a STIRPAT model, from which we can then calculate the price increases in varying fossil fuels that will be required in order to achieve a 50% reduction in CO_2 emissions from those fuels.

MODEL

According to the IPAT model environmental impact (I) is a function of population (P), affluence (A), and technology (T) (Ehrlich, 1971; Commoner, 1972).

$$I = P*A*T \qquad (1)$$

To make the model useful for hypothesis testing it was redesigned into the STIRPAT formulation by Dietz (1994).

$$I_i = aP^b{}_i A^c{}_i T^d{}_i e_i \qquad (2)$$

This multiplicative model can then be transformed into a linear model where the error term accommodates variations in technology.

$$log\ I = a + b\ (log\ P) + c\ (log\ A) + e \qquad (3)$$

In environmental economics the more common equation which allows for the estimation of an environmental Kuznets curve is:

$$log\ I = a + b\ (log\ P) + c\ (log\ A) + d\ (log\ A)^2 + e \qquad (4)$$

The coefficients in this equation can be interpreted as ecological impact elasticities.

In order to further disaggregate the model we can reformulate the model for T, the technology variable, since it is not a single factor but comprises many separate factors that influence environmental impacts. T can include all factors whose effects are not captured by population and affluence (Dietz, 1997). T can be directly disaggregated by including additional factors in the STIRPAT model that are theorized to influence impact (emissions) per unit of production (GDP). Additional factors can be added to the basic STIRPAT model so long as they are conceptually appropriate for the multiplicative specification of the model (York, 2003b). Examples of additional variables that have been included in the STIRPAT estimation in an effort to disaggregate T include an education index, land area, a life expectancy index, percent of GDP not in the service sector, percent of GDP from industry, percent of population over age 15, percent of urban population, and dummy variables for capitalist nations, civil liberties, latitude, political rights, state environmentalism, and world system position (York, 2003a).

In this vein, this paper attempts to disaggregate T by estimating the impact of prices of fossil fuels as well as the "taste" for fossil fuels as measured by the percentage of electricity generation coming from non-fossil fuels. Therefore, the final estimating equation is:

$log\ (I_j) = \beta_0 + \beta_1\ log\ (Real\ Coal\ Price\ Index_j) + \beta_2\ log\ (Real\ Natural\ Gas\ Price\ Index_j) + \beta_3\ log\ (Real\ Oil\ Price\ Index_j) + \beta_4\ log\ (Population_j) + \beta_5\ log\ (GDP\ PPP\ per\ capita_j) + \beta_6\ log\ (GDP\ PPP\ per\ capita_j) + \beta_7\ log\ (Percentage\ of\ Electricity\ Generation\ from\ Non\text{-}Fossil_j) + e_j$ (5)

where I = CO_2 Emissions from Coal, from Oil, and from Natural Gas, j = 1980-2012 and logs are base 10 logs in accordance with Dietz (2007).

HYPOTHESES

Using I as the CO_2 emissions from coal, oil, and natural gas leads to three different sets of hypotheses. In all cases we expect β_4 to be positive as increased population would lead to an increased amount of emissions (Shi, 2003). We expect β_5 to be positive and β_6 to be negative in accordance with the environmental Kuznets curve (EKC) hypothesis (Grossman, 1995). We expect β_7 to be negative since a large percentage of electricity generation coming from non-fossil sources should imply a reduction in emissions from the various fossil fuels.

The impact of the prices of coal, oil, and natural gas will have differing impacts on the emissions in each specification. When CO_2 emissions from coal is the dependent variable, we would anticipate that an increased price of coal, should lead to decreased demand for coal, and therefore less emissions from coal implying that β_3 should be negative. On the other hand, if the price of natural gas or oil rises, we would expect consumers to substitute away from those forms of energy towards coal which should lead to increased emissions from coal implying that β_1 and β_2 should be positive. Similar logic applies to the equations estimated for natural gas and coal. Table 1 displays the expected signs for the coefficients in the three estimating equations.

TABLE 1
HYPOTHESES TO BE TESTED

I = CO_2 Emissions from Coal	I = CO_2 Emissions from Natural Gas	I = CO_2 Emissions from Oil
$\beta_1 < 0$ (Own Price)	$\beta_1 > 0$ (Price of Substitute)	$\beta_1 > 0$ (Price of Substitute)
$\beta_2 > 0$ (Price of Substitute)	$\beta_2 < 0$ (Own Price)	$\beta_2 > 0$ (Price of Substitute)
$\beta_3 > 0$ (Price of Substitute)	$\beta_3 > 0$ (Price of Substitute)	$\beta_3 < 0$ (Own Price)
$\beta_4 > 0$ (Population)	$\beta_4 > 0$ (Population)	$\beta_4 > 0$ (Population)
$\beta_5 > 0$ & $\beta_6 < 0$ (EKC)	$\beta_5 > 0$ & $\beta_6 < 0$ (EKC)	$\beta_5 > 0$ & $\beta_6 < 0$ (EKC)
$\beta_7 < 0$ (Preference for Non-Fossil)	$\beta_7 < 0$ (Preference for Non-Fossil)	$\beta_7 < 0$ (Preference for Non-Fossil)

DATA

As can be seen in Table 2, the primary source of data used in the estimations is the International Energy Agency (IEA). Indexed fuel price data comes from *Energy Prices and Taxes* while data on emissions, population, and GDP come from *CO_2 Emissions from Fuel Combustion*. Information on electricity generation comes from the US Energy Information Administration website. Time series data from the IEA spans 1978-2012 while the US Energy Administration time series begins in 1980. Hence, 1980-2012 (32 years) is the sample used.

It is important to note that the price data is measured as an index and cannot be used to compare relative prices between fuels or between countries. In can only be used to compare how the price of one fuel within one country is changing over time. The base year for each price index is 2010 so in 2010 the price index is equal to 100 for all three fuels (coal, oil, and natural gas) in all sixteen countries.

The IEA data covers 33 of the 35 current OECD countries. No data were available for Iceland or Latvia. Australia, Canada, Chile, Estonia, Germany, Greece, Ireland, Israel, Mexico, Netherlands, New Zealand, Norway, Slovenia, Spain, and Sweden did not have any information on coal prices and therefore were excluded from the estimations. Missing data on electricity generation led to the exclusion of

Luxembourg and the Slovak Republic. For 16 of the current 35 OECD countries data on the full set of variables was available. For those 16 countries, data was missing for certain years which lead to a reduction in the sample size for five of the 16 countries. Table 3 lists the 16 countries included in the data set along with the years used in the estimations.

TABLE 2
VARIABLE SOURCES AND MEASUREMENT

Variable	*Source*	*Measurement*
Real Coal Price Index	*OECD/IEA Energy Prices and Taxes* : End Use Prices: Indices of Energy End Use Prices: Real Index for Industry and Households: Coal	Index derived from nominal end-use price including taxes. For each country year 2010=100
Real Oil Price Index	*OECD/IEA Energy Prices and Taxes* : End Use Prices: Indices of Energy End Use Prices: Real Index for Industry and Households: Oil Products	Index derived from nominal end-use price including taxes. For each country year 2010=100
Real Natural Gas Price Index	*OECD/IEAEnergy Prices and Taxes* : End Use Prices: Indices of Energy End Use Prices: Real Index for Industry and Households: Natural Gas	Index derived from nominal end-use price including taxes. For each country year 2010=100
CO_2 emissions from Coal	*OECD/IEA CO_2 Emissions from Fuel Combustion* : CO2 Emissions from Fuel Combustion: Sectoral Approach: Coal/peat	Measured as millions of tonnes of CO_2 emissions
CO_2 emissions from Oil	*OECD/IEA CO_2 Emissions from Fuel Combustion:* CO_2 Emissions from Fuel Combustion: Sectoral Approach: Oil	Measured as millions of tonnes of CO_2 emissions
CO_2 emissions from Natural Gas	*OECD/IEA CO_2 Emissions from Fuel Combustion* : CO_2 Emissions from Fuel Combustion: Sectoral Approach: Gas	Measured as millions of tonnes of CO_2 emissions
GDP PPP	*OECD/IEA CO_2 Emissions from Fuel Combustion:* Indicators: GDP PPP	Compiled for individual countries at market prices in local currency and annual rates then scaled to 2005 price levels and converted to US dollars using the yearly average 2005 purchasing power parities (PPPs).
Population	*OECD/IEA CO_2 Emissions from Fuel Combustion:* Indicators: Population	Measured in millions
% of Electricity Generation from Non-Fossil	US Energy Information Administration: https://www.eia.gov/beta/international/data/browser/ accessed 1/7/2016	Calculated as the percentage of electricity generation coming from Nuclear and Renewables

TABLE 3
COUNTRIES AND YEARS USED IN ESTIMATIONS

Country	Years used in Estimation	Sample Size (N)
Austria	1980-2012	32
Belgium	1980-2012	32
Czech Republic	1993-2012	19
Denmark	1986-2012	26
Finland	1980-2012	32
France	1980-2012	32
Hungary	1980-2012	32
Italy	1980-2012	32
Japan	1980-2012	32
Korea	1987-2012	25
Poland	1980-2012	32
Portugal	1997-2012	15
Switzerland	1980-2012	32
Turkey	1982-2012	30
United Kingdom	1980-2012	32
United States	1980-2012	32

For these 16 countries, there are large fuel price swings that occur over the 1980-2012 period. Instances where the ratio of the maximum price over the minimum price exceeded three are listed in Table 4. In each case, the minimum and maximum real price index along with the year in which it occurred is listed. It is interesting to note that in most cases the low fuel prices did not occur at the earliest point in the period nor did the highest price occur at the end of the period. For a fuller understanding of fuel price swings, please see Appendix A which includes time series plots of all three fuel price indices for each country.

TABLE 4
LARGE FUEL PRICE CHANGES

Country	Coal Price Minimum	Coal Price Maximum	Nat. Gas Price Minimum	Nat. Gas Price Maximum	Oil Price Minimum	Oil Price Maximum
Belgium	32.57 (1994)	101.77 (2008)				
Finland	36.99 (1988)	150.25 (2011)	36.85 (1989)	143.50 (2012)		
Hungary			16.68 (1980)	119.50 (2009)		
Japan	30.19 (2000)	130.21 (2008)				
Korea					29.43 (1990)	111.51 (2012)
Poland	27.37 (1986)	112.53 (2011)	16.52 (1980)	107.75 (2012)		
Switzerland	41.96 (1994)	142.04 (2008)				
Turkey	33.90 (1982)	108.26 (2009)			25.10 (1982)	109.56 (2012)

RESULTS

The full results for all of the models estimated using the Cochrane-Orcutt method are displayed in Appendix B (Tables 10, 11, and 12). Tables 5, 6, and 7 included here display a summary of the full results. For each table the various possible results are listed in the first column. In the middle column the first number is the number of countries displaying a statistically significant result ($\alpha = 0.10$) and the second number in parentheses displays the overall number of countries whose sign support that result. The third column lists the countries which display statistically significant results.

Coal Estimations

In Table 5 we see the results for the estimations which use CO_2 emissions from coal as the dependent variable. First and foremost, we see that the estimated impact elasticity for the coal price index is often either positive, or negative and highly inelastic. Of the 16 countries, six show a positive relationship between the price of coal and CO_2 emissions from coal, but for only one of these, Turkey, is the relationship statistically significant. Nine countries exhibit a negative inelastic relationship. Of these, five are statistically significant. Finally, only one country, the UK, shows a negative elastic relationship which is statistically significant. Overall, these results imply that CO_2 emissions from coal are not very sensitive to changes in the price of coal. Relatively large increases in the price of coal will be required in order to effectively reduce CO_2 emissions from coal.

For the oil price index and the natural gas price index we generally find that oil and natural gas are substitutes for coal. As the price of natural gas rises, emissions from coal rise in 10 of the 16 countries and this result is statistically significant in four of them. We do find a negative or complementary relationship between coal and natural gas in six countries, but this result is statistically significant only for Belgium. For the price of oil the results are similar, a positive substitute relationship is again estimated for 10 countries, but is statistically significant for only four of them. A negative complementary relationship is again estimated for six countries, but this time the negative result is statistically significant for Denmark, Hungary, and the UK.

Population generally has the expected positive impact on CO_2 emissions from coal. This positive relationship occurs in 11 countries, but it is statistically significant for only three of them. Conversely, a negative relationship is estimated for only five countries, but it is statistically significant in four of the five.

The income estimates display limited support for the environmental Kuznets curve (EKC) hypothesis. In seven countries, we see the expected positive relationship with GDP per capita and a negative relationship with GDP per capita squared. Of these seven, two are statistically significant. The signs in the estimates for the other nine countries do not support the EKC hypothesis, but none of these estimates are statistically significant.

Finally, the percentage of electricity generated from non-fossil fuels supports our expected hypothesis that as the taste for non-fossils rises, the amount of emissions from a fossil fuel such as coal should fall. This negative relationship exists for 13 countries and is statistically significant in six of them, while there are no statistically significant results for a positive relationship.

In sum, the results for the coal equation show that most signs and relationships support our expected hypotheses. The fact that most of the estimates support our expectations provides further support that the equations are properly identified and that the relationship between the price of coal and the CO_2 emissions from coal is not confounded by the effect of other variables missing from the equation. CO_2 emissions from coal are highly inelastic to the price of coal, implying that large price increases will be required in order to effectively reduce CO_2 emissions from coal.

TABLE 5
RESULTS FOR COAL EMISSIONS

Results for Price of Coal	**Number of Countries**	**Countries with Statistically Significant Results**
Positive	1 (6)	Turkey
Negative Inelastic	5 (9)	Czech Republic, Demark, Finland, Japan, US
Negative Elastic	1 (1)	UK
Results for Price of Natural Gas	**Number of Countries**	**Countries with Statistically Significant Results**
Positive	4 (10)	Korea, Switzerland, UK, US
Negative	1 (6)	Belgium
Results for Price of Oil	**Number of Countries**	**Countries with Statistically Significant Results**
Positive	4 (10)	Austria, Belgium, Czech Republic, Japan
Negative	3 (6)	Denmark, Hungary, UK
Results for Population	**Number of Countries**	**Countries with Statistically Significant Results**
Positive	3 (11)	Finland, Japan, Poland
Negative	4 (5)	Austria, Belgium, France, Switzerland
Results for EKC	**Number of Countries**	**Countries with Statistically Significant Results**
Positive GDPPC, Negative GDPPC SQD	2 (7)	Belgium, US
Negative GDPPC, Positive GDPPC SQD	0 (8)	
Positive GDPPC, Positive GDPPC SQD	0 (1)	
Results for Non-Fossil Preferences	**Number of Countries**	**Countries with Statistically Significant Results**
Positive	0 (3)	
Negative	6 (13)	Austria, Denmark, Finland, France, Poland, UK

Natural Gas Estimations

Table 6 displays the results for the estimations which use CO_2 emissions from natural gas as the dependent variable.

Here we find that the relationship between the price of natural gas and CO_2 emissions from natural gas tends to be negative but inelastic, again implying that relatively large price increases will be required in order to effectively reduce CO_2 emissions from natural gas.

Here, coal appears to have more of a complementary relationship with natural gas. As the price of coal rises, CO_2 emissions from natural gas falls in 10 of the 16 countries and this result is statistically significant in France and the US. Only Hungary shows a statistically significant substitute relationship. By comparison, oil appears to be more of a substitute for natural gas. As the price of oil rises, CO_2 emissions from natural gas rise in 9 of the 16 countries and this result is statistically significant in Korea, the UK, and the US. Only Turkey displays a statistically significant complementary relationship.

As population increases, CO_2 emissions from natural gas increases as expected in 13 of the 16 countries and this result is statistically significant in 9 of them. Only Denmark and the UK display a negative statistically significant result for the relationship between population and CO_2 emissions from natural gas.

Again, the EKC hypothesis is generally supported in 10 of the 16 countries and the result is statistically significant in four of them. Hungary is the only country which displays a statistically significant result that does not support the EKC hypothesis.

Finally, the preference for non-fossils as measured by the percentage of electricity generated by non-fossils generally has the expected negative relationship with CO_2 emissions from natural gas. This negative relationship is estimated for 13 of the 16 countries and is statistically significant in nine of them.

The results for CO_2 emissions from natural gas, again tend to support our hypotheses which lends further support to the claim that the relationship between the price of natural gas and CO_2 emissions from natural gas is inelastic, implying that relatively large price increases will be required in order to effectively reduce CO_2 emissions from natural gas.

TABLE 6
RESULTS FROM NATURAL GAS ESTIMATIONS

Results for Price of Coal	Number of Countries	Countries with Statistically Significant Results
Positive	1 (6)	Hungary
Negative	2 (10)	France, US
Results for Price of Natural Gas	**Number of Countries**	**Countries with Statistically Significant Results**
Positive	1 (5)	Japan
Negative Inelastic	5 (10)	Finland, Poland, Switzerland, UK, US
Negative Elastic	1 (1)	Turkey
Results for Price of Oil	**Number of Countries**	**Countries with Statistically Significant Results**
Positive	3 (9)	Korea, UK, US
Negative	1 (7)	Turkey
Results for Population	**Number of Countries**	**Countries with Statistically Significant Results**
Positive	9 (13)	Austria, Finland, France, Hungary, Italy, Japan, Switzerland, Turkey, US
Negative	2 (3)	Denmark, UK
Results for EKC	**Number of Countries**	**Countries with Statistically Significant Results**
Positive GDPPC, Negative GDPPC SQD	4 (10)	Austria, Czech Republic, Denmark, Portugal
Negative GDPPC, Positive GDPPC SQD	1 (4)	Hungary
Positive GDPPC, Positive GDPPC SQD	0 (2)	
Results for Non-Fossil Preferences	**Number of Countries**	**Countries with Statistically Significant Results**
Positive	0 (3)	
Negative	9 (13)	Austria, Belgium, Czech Republic, Finland, Japan, Korea, Turkey, UK, US

Oil Estimations

Finally, Table 7 displays the results for the estimations in which CO_2 emissions from oil is the dependent variable. Here we find that oil price has a negative inelastic relationship with CO_2 emissions from oil in all 16 countries and that the result is statistically significant in six of them.

These estimations show that natural gas seems to be more of a substitute for oil. A positive relationship between natural gas price and CO_2 emissions from oil occurs in 9 of the 16 countries and the relationship is statistically significant in the UK and the US. There are no statistically significant results supporting a complementary relationship between natural gas prices and CO_2 emissions from oil. For coal, the results are more divided, nine countries display a substitute relationship between coal price and CO_2 emissions from oil and seven display a complementary relationship. Each result is supported by one country which displays a statistically significant result.

Oddly, for population we see a primarily negative relationship between population and CO_2 emissions from oil. As population increases, CO_2 emissions from oil decreases in 12 countries and this result is statistically significant in 8 of them. Only Hungary is statistically significant for the expected positive relationship between population and CO_2 emissions from oil.

Here, the results for the EKC hypothesis are also much more mixed. The estimations for 8 countries (5 statistically significant) support the EKC hypothesis while the estimates for 8 countries (4 statistically significant) do not.

Finally, as expected, more electricity generation from non-fossils leads to lower CO_2 emissions from oil. This result occurs in 13 of the 16 countries and is statistically significant in 8 of them.

The results for CO_2 emissions from oil do not provide as much support for our expected hypotheses. The results for population are generally opposite of our expectations and the EKC hypothesis finds very limited support. However, the result that CO_2 emissions from oil are highly inelastic with respect to the price of oil is supported in all 16 countries. Again, this implies that relatively large increases in the price of oil would be required in order to reduce CO_2 emissions from oil.

TABLE 7
RESULTS FROM OIL ESTIMATIONS

Results for Price of Coal	**Number of Countries**	**Countries with Statistically Significant Results**
Positive	1 (9)	Poland
Negative	1 (7)	Japan
Results for Price of Natural Gas	**Number of Countries**	**Countries with Statistically Significant Results**
Positive	2 (9)	UK, US
Negative	0 (7)	
Results for Price of Oil	**Number of Countries**	**Countries with Statistically Significant Results**
Positive	0 (0)	
Negative Inelastic	6 (16)	Finland, Italy, Korea, Poland, Turkey, US
Negative Elastic	0 (0)	
Results for Population	**Number of Countries**	**Countries with Statistically Significant Results**
Positive	1 (4)	Hungary
Negative	8 (12)	Belgium, Denmark, Finland, Italy, Japan, Poland, UK, US
Results for EKC	**Number of Countries**	**Countries with Statistically Significant Results**
Positive GDPPC, Negative GDPPC SQD	5 (8)	Denmark, Korea, Poland, Switzerland, Turkey
Negative GDPPC, Positive GDPPC SQD	4 (8)	Finland, Japan, Portugal, US
Results for Non-Fossil Preferences	**Number of Countries**	**Countries with Statistically Significant Results**
Positive	0 (3)	
Negative	8 (13)	Austria, Belgium, Denmark, France, Italy, Korea, Portugal, US

Summary

In summary, the ecological impact elasticities for the prices of the varying fossil fuels on the CO_2 emissions resulting from those fuels are highly inelastic as can be seen in Table 8. The highlighted p-values are significant at the $\alpha = 0.10$ level.

For coal and natural gas we actually see a total of 11 cases where as the price of the fossil fuel increases, emissions from that fuel increase as well, implying that further price increases in these fuels would have little to no effectiveness in reducing CO_2 emissions.

For another 35 instances, we see that the price of the fossil fuel has a negative but inelastic relationship with the CO_2 emissions from that fuel. In these cases, increases in fuel price should reduce CO_2 emissions from that fuel, but the price increases required must be proportionally larger than the expected impact they will have on CO_2 emissions.

Finally, in the remaining 2 cases, fuel price has a negative but elastic relationship with CO_2 emissions from that fuel implying that relatively small increases in the fuel price would lead to relatively large declines in emissions from that fuel.

To summarize, in 46 of the 48 cases, fuel price increases seem to be a relatively ineffective way to reduce CO_2 emissions from fossil fuels. People will either not react to the price increase or it will reduce their emissions by a relatively small amount.

TABLE 8
ECOLOGICAL IMPACT ELASTICITIES (OWN PRICE)

Country		Coal Price	Natural Gas Price	Oil Price
Austria	*Coefficient*	0.1354	-0.0338	-0.1403
	p-value	0.2151	0.6874	0.1996
Belgium	*Coefficient*	-0.0724	-0.1041	-0.1357
	p-value	0.4862	0.4526	0.2698
Czech Republic	*Coefficient*	-0.6395	-0.2492	-0.2029
	p-value	0.0607	0.3242	0.1211
Denmark	*Coefficient*	-0.5946	0.1600	-0.0780
	p-value	0.0563	0.5998	0.5418
Finland	*Coefficient*	-0.3260	-0.8945	-0.1614
	p-value	0.0180	0.0000	0.0513
France	*Coefficient*	-0.1322	0.0455	-0.1358
	p-value	0.5735	0.7999	0.1171
Hungary	*Coefficient*	0.1108	-0.0455	-0.0400
	p-value	0.1796	0.4138	0.6672
Italy	*Coefficient*	0.1462	0.0186	-0.1446
	p-value	0.3567	0.8226	0.0947
Japan	*Coefficient*	-0.0881	0.4955	-0.1912
	p-value	0.0821	0.0931	0.1496
Korea	*Coefficient*	0.1149	-0.2080	-0.3194
	p-value	0.1874	0.4234	0.0118
Poland	*Coefficient*	-0.0334	-0.1122	-0.1527
	p-value	0.5408	0.0295	0.0219
Portugal	*Coefficient*	-0.8170	0.5615	-0.3515
	p-value	0.4838	0.5509	0.2226
Switzerland	*Coefficient*	0.1498	-0.4082	-0.0162
	p-value	0.6148	0.0261	0.8628
Turkey	*Coefficient*	0.3167	-1.2247	-0.1540
	p-value	0.0022	0.0003	0.0645
United Kingdom	*Coefficient*	-1.3043	-0.3145	-0.0754
	p-value	0.0393	0.0579	0.5155
United States	*Coefficient*	-0.2820	-0.2170	-0.1100
	p-value	0.0000	<0.00001	0.0010

Note: Highlighted p-values are significant at the 90% level.

Policy Impact

In order to further the analysis, it is necessary to examine the reduction in emissions which actually need to occur.

As stated previously, Hansen writes that "If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO_2 will need to be reduced from its current 385 ppm to at most 350 ppm, but likely less than that" (Hansen, et.al., 2008, p. 217). Estimates by the International Panel on Climate

Change (IPCC) show that to achieve a target of 350 ppm will require a minimum of a 50% reduction in CO_2 emissions (IPCC, 2007, p. 39, Table TS.2).

Using the calculated ecological impact elasticities from Table 8 we can now calculate the varying price increases in fossil fuels that would be required in order to achieve a 50% reduction in CO_2 emissions.

Table 9 displays the required price increase in each country that would result in a 50% reduction in emissions from that fuel. Results from ecological impact elasticities that were statistically significant (α = .10) in Table 8 are highlighted in Table 9. In cases where positive ecological impact elasticities occur an NA+ is shown in Table 9 since price increases would not lead to decreases in CO_2 emissions.

For the statistically significant estimates, we see price increases ranging from:

- 78% - 567% for Coal (38% for UK which is elastic)
- 55% - 445% for Natural Gas (40% for Turkey which is elastic)
- 156% - 454% for Oil.

If we look at the US in particular we see that all of the results are statistically significant and that coal prices would need to increase 177%, natural gas prices 230%, and oil prices 454%. It seems very unlikely that we can expect our elected officials to vote for such large price increases. Instead it seems far more likely that officials will do very little to effectively reduce CO_2 emissions through fossil fuel price increases.

TABLE 9
REQUIRED PRICE CHANGES TO ACHIEVE 50% REDUCTION IN EMISSIONS

Country	Coal	Natural Gas	Oil
Austria	NA+	1480.55%	356.30%
Belgium	690.93%	480.26%	368.51%
Czech Republic	78.19%	200.62%	246.48%
Denmark	84.09%	NA+	640.76%
Finland	153.38%	55.89%	309.78%
France	378.09%	NA+	368.28%
Hungary	NA+	1098.86%	1249.94%
Italy	NA+	NA+	345.73%
Japan	567.76%	NA+	261.44%
Korea	NA+	240.39%	156.55%
Poland	1495.91%	445.62%	327.47%
Portugal	61.20%	NA+	142.27%
Switzerland	NA+	122.49%	3082.03%
Turkey	NA+	40.83%	324.71%
United Kingdom	38.34%	158.98%	663.10%
United States	177.32%	230.40%	454.52%

Note: Highlighted values are based on statistically significant estimates (α = 0.10).

CONCLUSION

Using data from the International Energy Agency, this paper uses a STIRPAT model to examine the effect of fuel price changes on CO_2 emissions from oil, natural gas, and coal. Estimations are run for 16 OECD countries using data from 1980-2012. Overall, the results show that the emissions from fossil fuels are highly inelastic to price changes. In the US the necessary price increases to achieve a 50% reduction in CO_2 emissions would be 177% for coal, 230% for natural gas, and 454% for oil. Estimates for some countries for some fuels are even higher. Given these large price increases, it seems unlikely that politicians will make the necessary efforts to reduce CO_2 emissions to the extent required.

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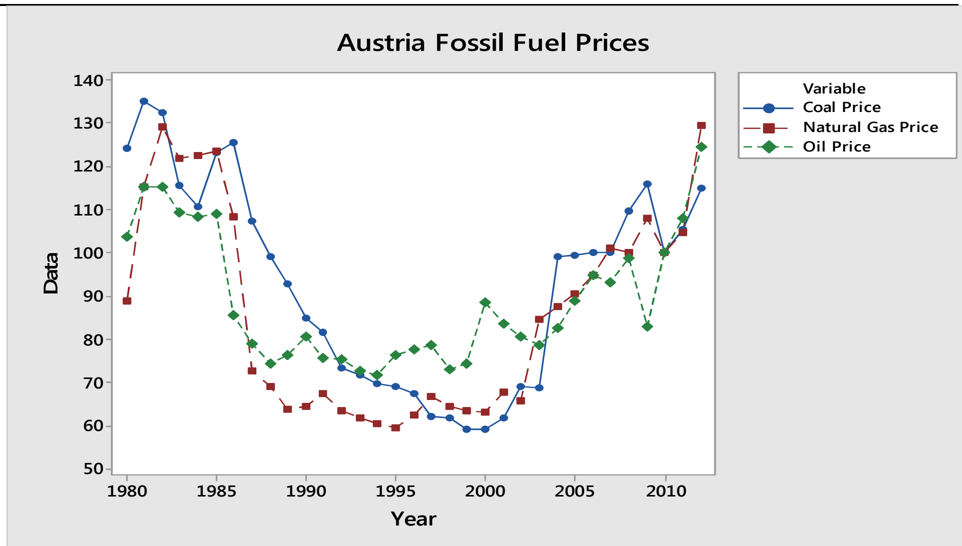
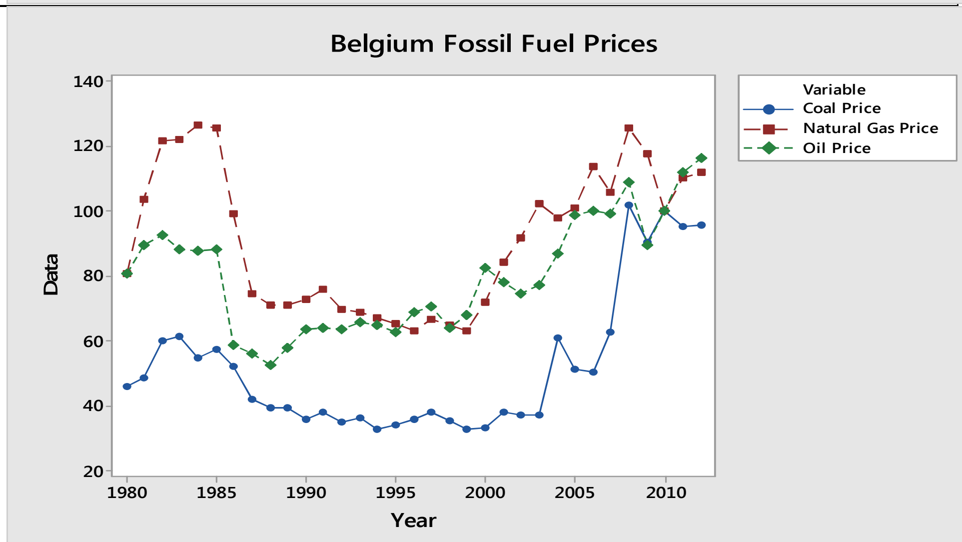
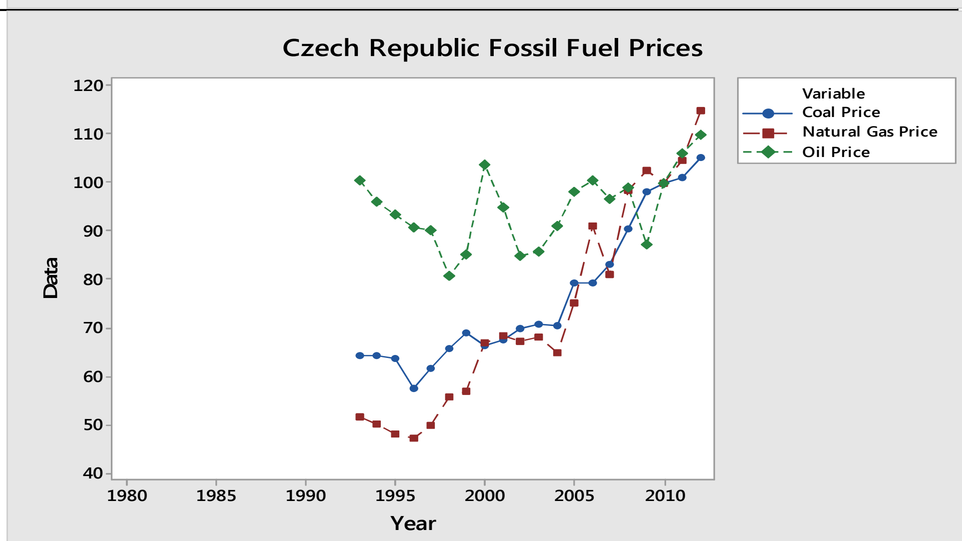
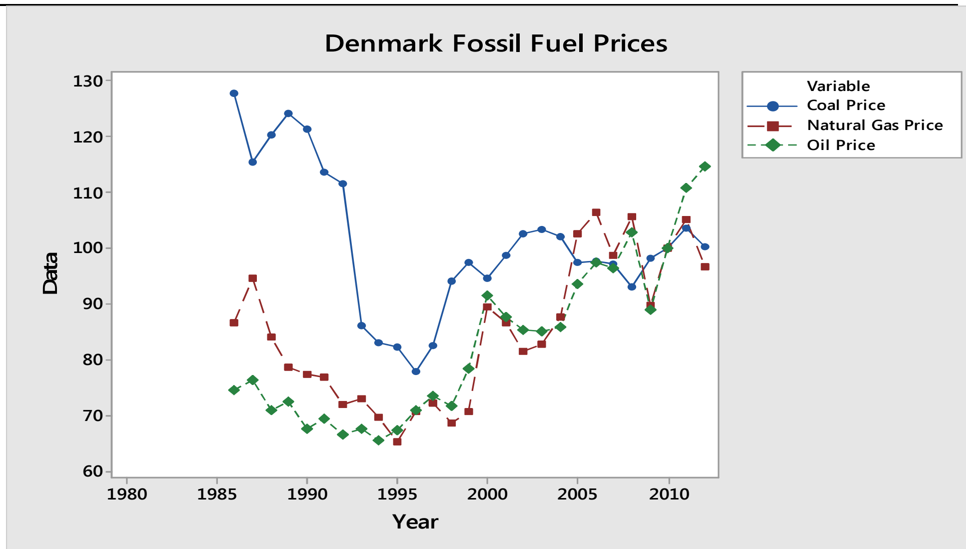
APPENDIX A: TIME SERIES PLOTS OF FUEL PRICES





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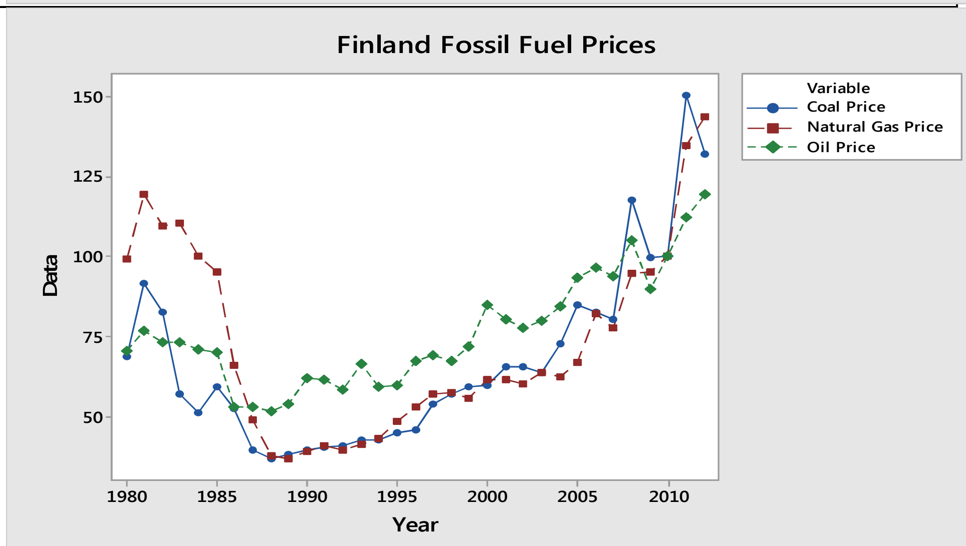
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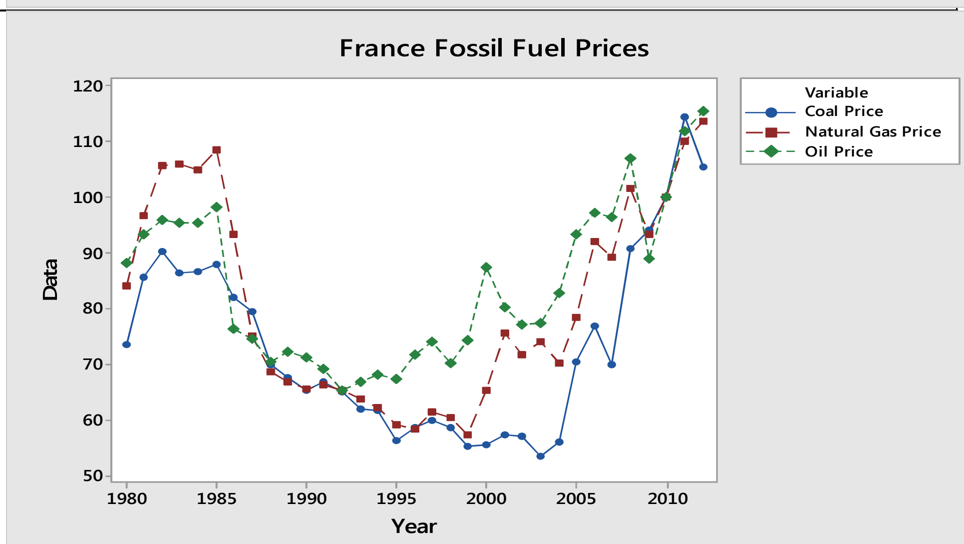
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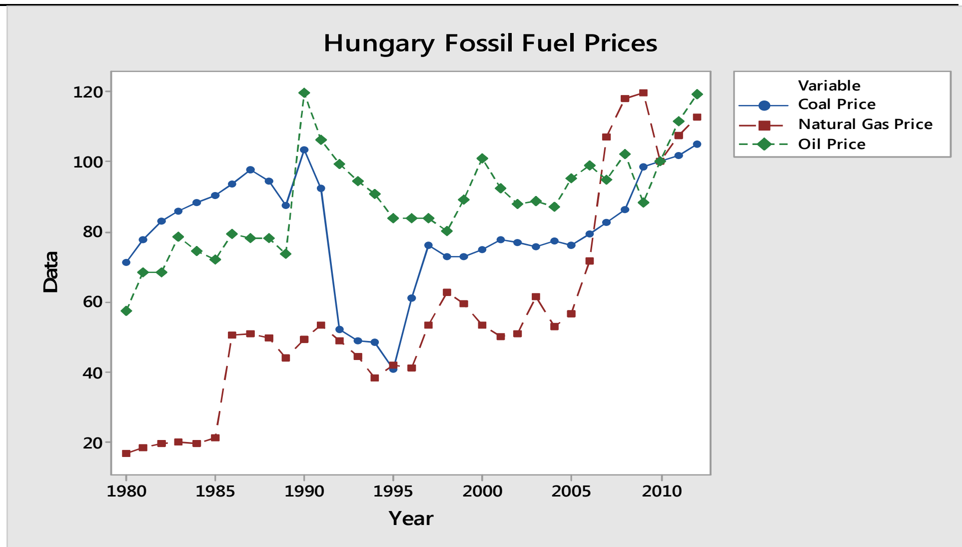
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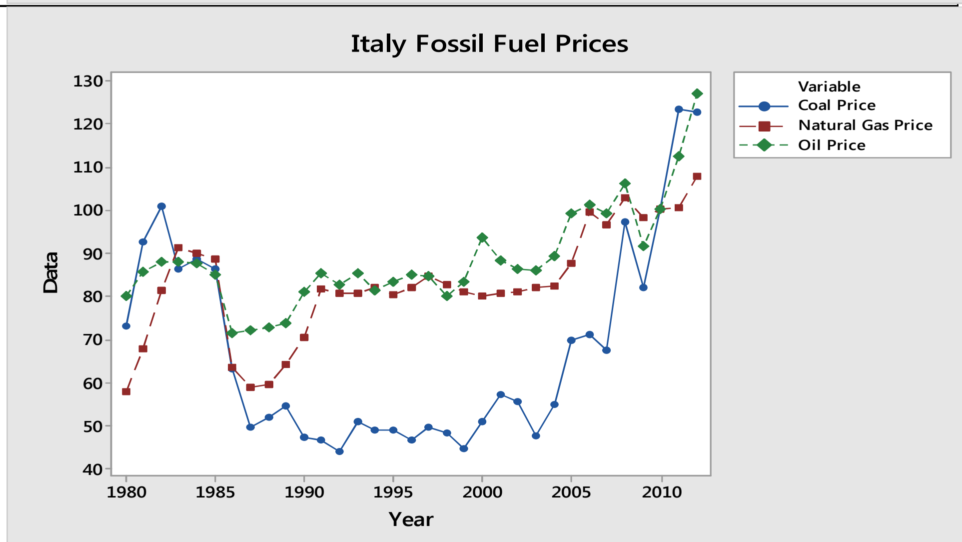
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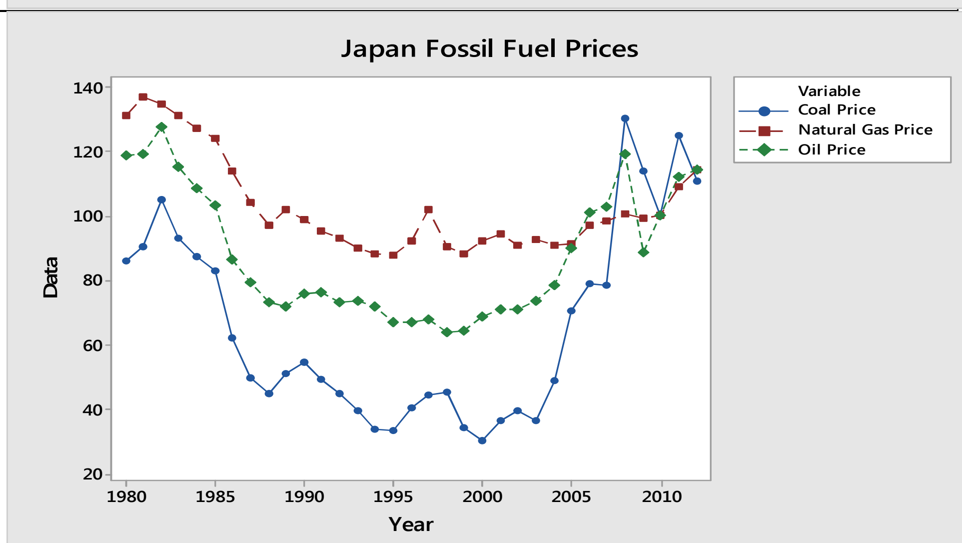
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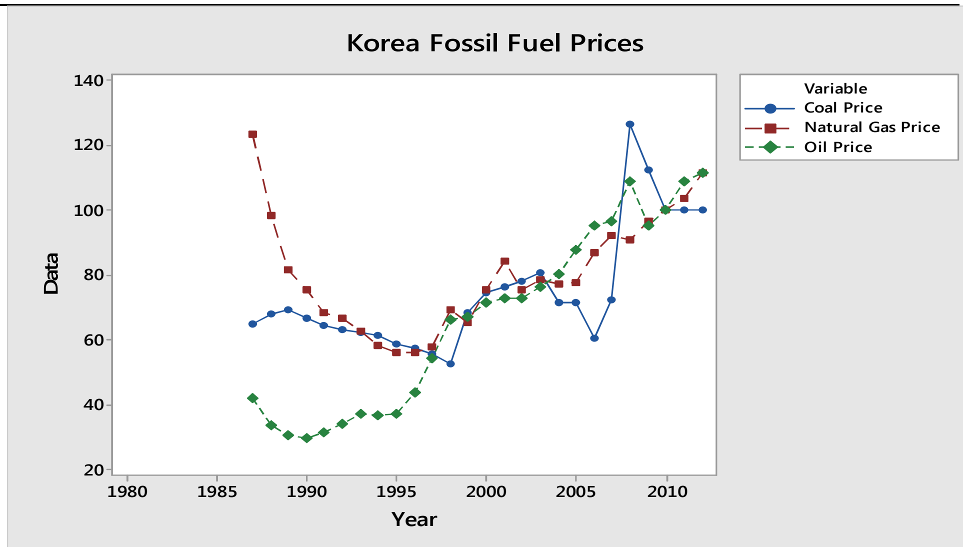
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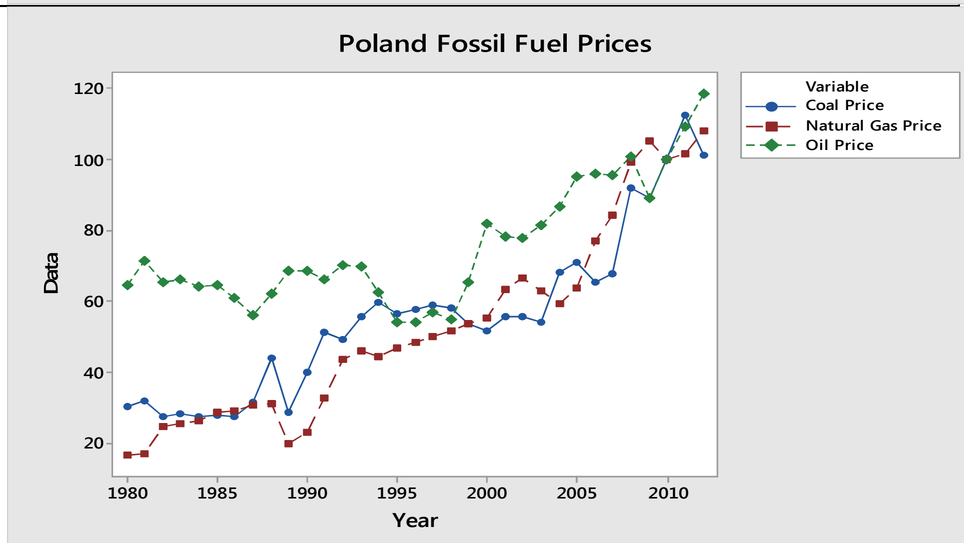
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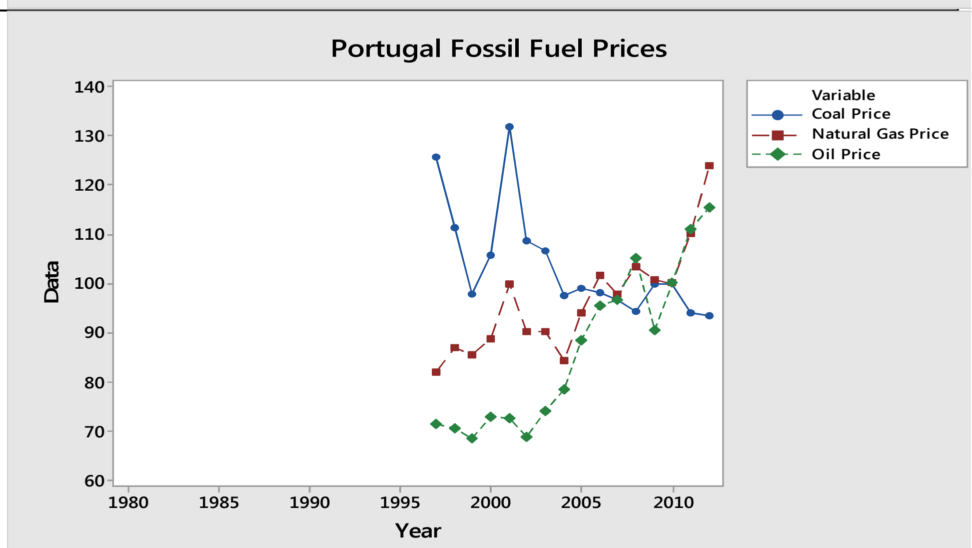
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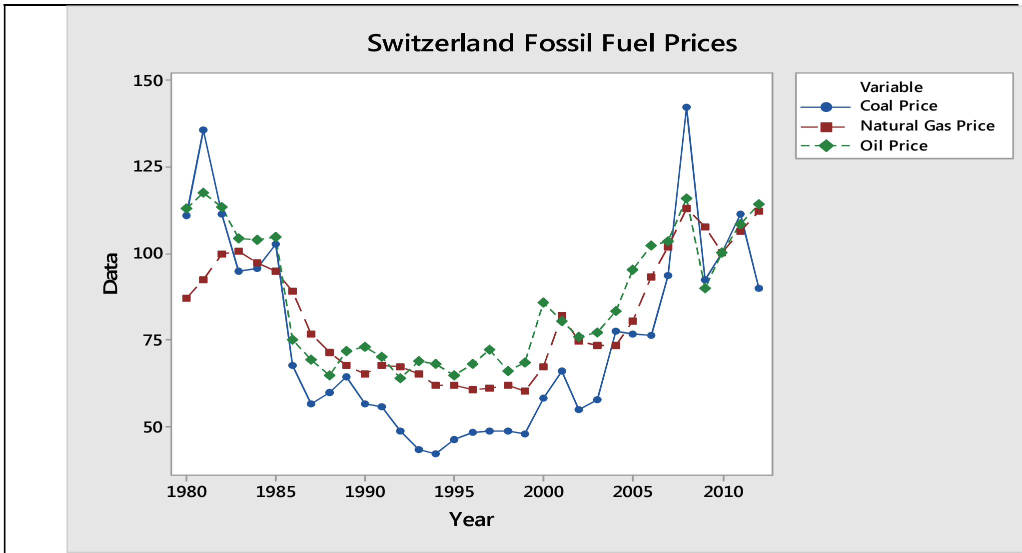
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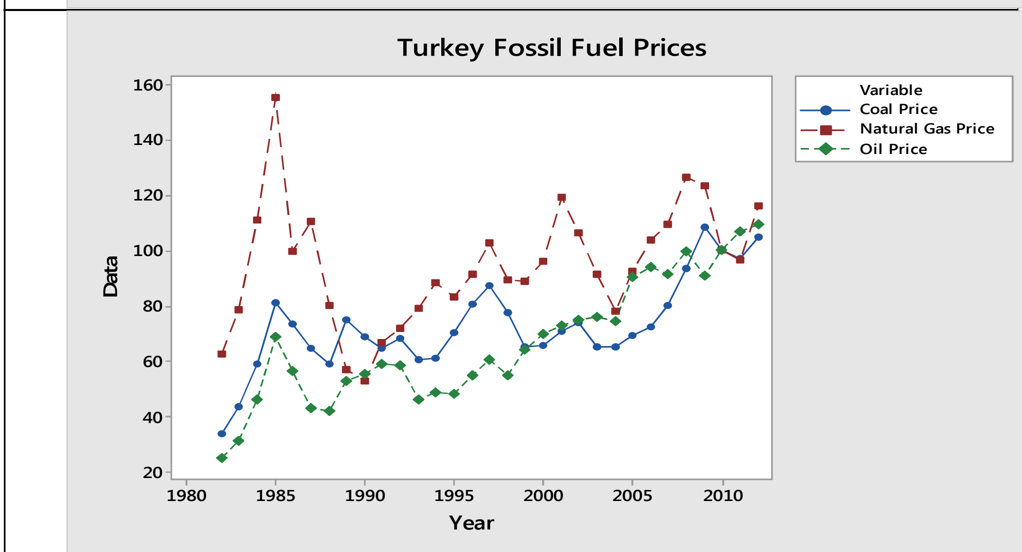
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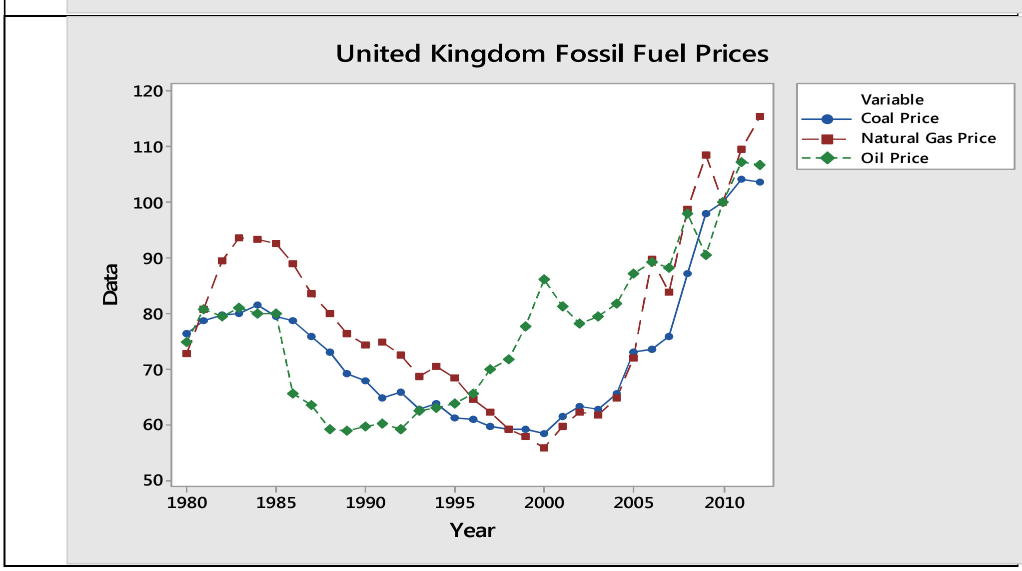
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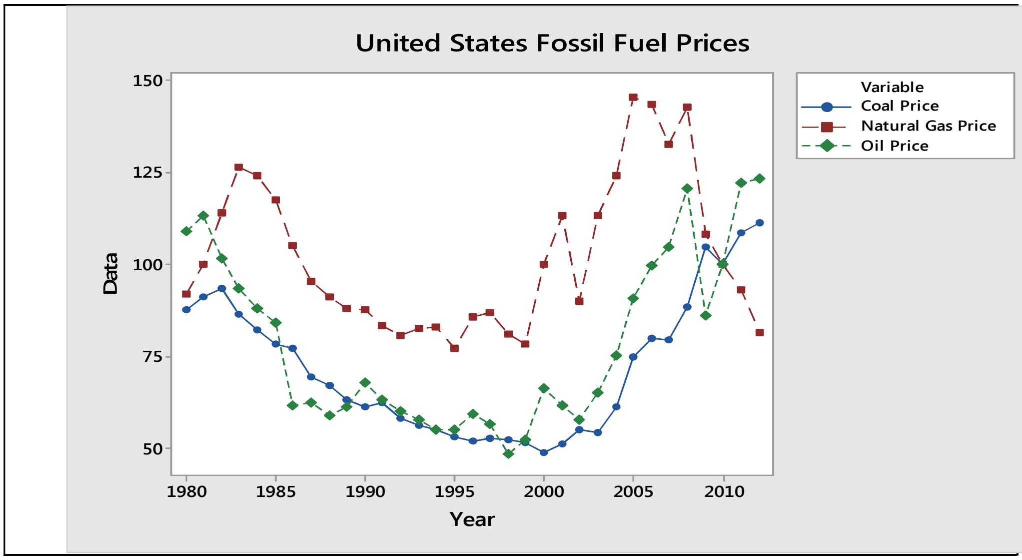
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APPENDIX B: FULL MODEL RESULTS

TABLE 10
DEPENDENT VARIABLE: CO_2 EMISSIONS FROM COAL

Country		Constant	Coal Price	Natural Gas Price	Oil Price	Population	GDP per capita	GDP per capita squared	% of electricity generation from non-fossil fuels	F	Adjusted R-sqd	Cochrane-Orcutt Rho	DW	N
Austria	*Coefficient*	-1.8536	0.1354	-0.0987	0.6587	-6.7641	9.1407	-2.6963	-1.1993	10.7586	0.7304	0.1917	1.98	32
	p-value	0.7977	0.2151	0.4352	0.0008	0.0004	0.3431	0.4148	<0.00001	0.0000				
Belgium	*Coefficient*	-5.5453	-0.0724	-0.2301	0.6007	-11.6063	25.6333	-9.0416	-0.0252	289.9003	0.9723	-0.3918	2.29	32
	p-value	0.4574	0.4862	0.0862	0.0003	<0.00001	0.0203	0.0191	0.7726	0.0000				
Czech Repubic	*Coefficient*	3.9456	-0.6395	-0.0545	0.2975	0.9735	-3.7375	1.5229	0.0782	9.2224	0.7918	0.0873	2.05	19
	p-value	0.4008	0.0607	0.7400	0.0561	0.6631	0.4383	0.4148	0.5268	0.0008				
Denmark	*Coefficient*	27.3652	-0.5946	0.5429	-2.2012	4.1341	-34.7235	12.1004	-0.1640	24.3311	0.8404	-0.1315	2.10	26
	p-value	0.3510	0.0563	0.3993	0.0057	0.3400	0.3836	0.3733	0.0509	0.0000				
Finland	*Coefficient*	2.0347	-0.3260	0.0962	-0.0703	4.2435	-5.2186	1.9519	-1.5718	50.8984	0.9164	-0.0187	2.18	32
	p-value	0.5396	0.0180	0.3399	0.7333	0.0020	0.3022	0.2819	<0.00001	0.0000				
France	*Coefficient*	17.7326	-0.1322	-0.0640	0.2713	-5.8225	-8.8107	3.3068	-1.9647	13.2025	0.9431	0.5892	2.19	32
	p-value	0.3358	0.5735	0.8151	0.3051	0.0392	0.7311	0.7163	0.0010	0.0000				
Hungary	*Coefficient*	-0.6757	0.1108	0.0297	-0.2141	2.3045	-2.7196	1.5226	0.0184	1.8434	0.9842	0.9786	1.94	32
	p-value	0.9094	0.1796	0.5875	0.0359	0.6702	0.6265	0.5360	0.4471	0.1248				
Italy	*Coefficient*	14.7909	0.1462	-0.3647	0.4137	1.7203	-23.8353	8.5540	-0.1588	1.9364	0.6825	0.6678	1.70	32
	p-value	0.2300	0.3567	0.1615	0.2508	0.4949	0.2003	0.2019	0.3145	0.1076				
Japan	*Coefficient*	-11.2632	-0.0881	0.1577	0.2286	9.0619	-8.5995	3.1547	0.0044	95.8982	0.9790	0.3071	1.98	32
	p-value	0.0779	0.0821	0.4248	0.0954	0.0000	0.1247	0.1181	0.9286	0.0000				
Korea	*Coefficient*	-3.6510	0.1149	0.5732	0.1545	1.7210	1.6813	-0.4930	-0.1636	123.9270	0.9875	0.3327	1.49	25
	p-value	0.4339	0.1874	0.0145	0.3797	0.6275	0.5088	0.5956	0.2439	0.0000				
Poland	*Coefficient*	-17.7427	-0.0334	0.0884	-0.1070	12.2295	0.2780	0.1315	-0.1168	4.7252	0.9721	0.9315	2.38	32
	p-value	0.0006	0.5408	0.1502	0.2502	0.0002	0.8556	0.8660	0.0438	0.0019				
Portugal	*Coefficient*	-217.1520	-0.8170	1.4135	-1.2993	-1.0478	332.9240	-125.6560	-0.2645	2.0213	0.4776	0.2347	1.80	15
	p-value	0.5103	0.4838	0.3552	0.3712	0.8954	0.5070	0.5066	0.2295	0.1868				
Switzerland	*Coefficient*	-45.6124	0.1498	0.9463	0.2553	-10.1580	65.9241	-21.0198	-0.0050	6.1324	0.9242	0.6821	1.65	32
	p-value	0.4038	0.6148	0.0545	0.5540	0.0010	0.3498	0.3623	0.9984	0.0003				
Turkey	*Coefficient*	-1.2119	0.3167	-0.0528	0.0592	0.1500	3.3379	-1.1180	-0.0836	151.4983	0.9787	0.1078	1.86	30
	p-value	0.0593	0.0022	0.3655	0.5687	0.7887	0.0514	0.1458	0.2564	0.0000				
United Kingdom	*Coefficient*	-1.4009	-1.3043	0.7269	-0.7327	6.1277	-6.0159	1.7045	-0.5143	14.9019	0.8852	0.3413	2.01	32
	p-value	0.8850	0.0393	0.0797	0.0395	0.1372	0.5617	0.6448	0.0830	0.0000				
United States	*Coefficient*	-6.0997	-0.2820	0.1815	0.0570	0.6082	9.9218	-3.1417	-0.2282	41.6138	0.9528	0.3211	1.47	32
	p-value	0.1327	0.0000	0.0012	0.2963	0.2819	0.0239	0.0313	0.1927	0.0000				

TABLE 11
DEPENDENT VARIABLE: CO_2 EMISSIONS FROM NATURAL GAS

Country		Constant	Coal Price	Natural Gas Price	Oil Price	Population	GDP per capita	GDP per capita squared	% of electricity generation from non-fossil fuels	F	Adjusted R-sqd	Cochrane-Orcutt Rho	DW	N
Austria	*Coefficient*	-17.42140	0.03892	-0.03377	0.13119	4.32411	19.32400	-6.50513	-0.64073	92.4184	0.9813	0.3688	1.8189	32
	p-value	0.00218	0.61373	0.68743	0.25411	0.00229	0.00844	0.00964	0.00009	0.0000				
Belgium	*Coefficient*	-1.29401	-0.05774	-0.10411	0.15576	0.79832	0.82493	0.31575	-0.21236	56.9626	0.9628	0.3027	1.9061	32
	p-value	0.88711	0.56881	0.45260	0.30767	0.64811	0.94808	0.94323	0.08239	0.0000				
Czech Republic	*Coefficient*	-15.76450	0.31484	-0.24923	-0.13238	0.56728	24.91120	-9.43990	-0.32380	14.5486	0.7332	-0.2966	2.0100	19
	p-value	0.00515	0.51623	0.32420	0.43870	0.82788	0.00022	0.00026	0.04898	0.0001				
Denmark	*Coefficient*	-78.48470	0.08576	0.16001	-0.47588	-4.28584	109.18700	-35.85100	0.05517	225.3689	0.9769	-0.1915	2.5795	26
	p-value	0.00002	0.53854	0.59981	0.16891	0.04406	0.00001	0.00002	0.14465	0.0000				
Finland	*Coefficient*	-14.80060	0.28291	-0.89455	0.44578	12.13370	9.95067	-3.47886	-0.58713	29.5352	0.9811	0.6236	2.2492	32
	p-value	0.03010	0.10413	0.00002	0.11523	0.00015	0.30153	0.30849	0.00685	0.0000				
France	*Coefficient*	4.74389	-0.34070	0.04550	0.04013	3.35862	-12.29370	4.48751	0.11271	70.0374	0.9556	0.1407	1.8632	32
	p-value	0.65931	0.02864	0.79992	0.82787	0.05963	0.40881	0.39630	0.63978	0.0000				
Hungary	*Coefficient*	-3.87350	0.19528	-0.04550	-0.11543	11.18030	-11.33490	5.23707	-0.03031	2.4057	0.8024	0.8965	2.4934	32
	p-value	0.40646	0.02512	0.41376	0.24739	0.01018	0.05679	0.04575	0.27266	0.0513				
Italy	*Coefficient*	-7.66169	-0.09317	0.01857	-0.01306	4.06509	1.42641	0.36805	0.04080	565.6762	0.9919	-0.0221	1.9878	32
	p-value	0.00379	0.27464	0.82255	0.92895	0.00010	0.73610	0.80867	0.54360	0.0000				
Japan	*Coefficient*	-42.5025	0.0005	0.4955	0.1336	15.7516	14.0894	-4.8303	-0.2177	147.6776	0.9871	0.3315	1.8980	32
	p-value	0.0001	0.9947	0.0931	0.4972	<0.00001	0.0961	0.1122	0.0057	0.0000				
Korea	*Coefficient*	-10.41970	-0.15887	-0.20800	0.69796	5.54244	2.16427	-0.49561	-0.47131	596.5782	0.9963	0.1847	1.7175	25
	p-value	0.06367	0.12872	0.42337	0.00196	0.18949	0.45911	0.64041	0.00836	0.0000				
Poland	*Coefficient*	3.10183	0.05313	-0.11220	-0.02197	-1.35085	-0.06930	0.44039	-0.05175	37.0122	0.9720	0.5487	1.7731	32
	p-value	0.14968	0.33390	0.02950	0.78540	0.34413	0.95314	0.46418	0.31895	0.0000				
Portugal	*Coefficient*	-618.46900	-1.15135	0.56155	-0.09440	11.15690	913.41900	-342.30500	-0.02182	77.2095	0.9627	-0.1022	2.6579	15
	p-value	0.00135	0.14905	0.55087	0.91571	0.04178	0.00165	0.00176	0.86949	0.0000				
Switzerland	*Coefficient*	-20.68570	0.00181	-0.40821	0.09828	5.01962	22.85700	-7.39084	-0.39038	40.3427	0.9774	0.5026	2.4677	32
	p-value	0.31423	0.98761	0.02611	0.55566	0.00001	0.38657	0.39348	0.70356	0.0000				
Turkey	*Coefficient*	-5.54951	0.18996	-1.22466	-1.23997	8.14339	-8.53062	4.69847	-0.98255	8.9653	0.9858	0.8222	1.9156	30
	p-value	0.58141	0.70758	0.00025	0.02300	0.01847	0.57727	0.54047	0.00331	0.0000				
United Kingdom	*Coefficient*	6.10962	0.03427	-0.31450	0.27320	-3.82620	4.66529	-1.75037	-0.30664	3.6804	0.9748	0.9592	1.9278	32
	p-value	0.37078	0.89497	0.05785	0.09416	0.11411	0.45292	0.42244	0.01692	0.0077				
United States	*Coefficient*	-2.48097	-0.24134	-0.21702	0.19408	2.25353	0.96803	-0.49377	-0.49168	77.0474	0.9674	0.2609	2.0102	32
	p-value	0.44035	<0.00001	<0.00001	0.00017	0.00003	0.77252	0.65933	0.00151	0.0000				

TABLE 12
DEPENDENT VARIABLE: CO_2 EMISSIONS FROM OIL

Country		Constant	Coal Price	Natural Gas Price	Oil Price	Population	GDP per capita	GDP per capita squared	% of electricity generation from non-fossil fuels	F	Adjusted R-sqd	Cochrane-Orcutt Rho	DW	N
Austria	*Coefficient*	-3.5675	0.0571	0.0001	-0.1403	0.6399	5.8522	-1.8509	-0.3368	4.2567	0.8711	0.7232	2.1397	32
	p-value	0.5451	0.5093	0.9995	0.1996	0.7007	0.4562	0.4906	0.0142	0.0035				
Belgium	*Coefficient*	-2.6770	0.0793	-0.0148	-0.1357	-2.8003	9.3507	-2.9536	-0.2931	5.0504	0.6435	0.2676	1.9971	32
	p-value	0.7122	0.3352	0.8935	0.2698	0.0540	0.3579	0.4059	0.0038	0.0013				
Czech Republic	*Coefficient*	0.9467	-0.0216	-0.0782	-0.2029	-1.9068	3.6010	-1.0662	-0.0845	2.7012	0.8514	0.6793	1.8100	19
	p-value	0.8366	0.9143	0.4508	0.1211	0.3927	0.5100	0.6084	0.4766	0.0684				
Denmark	*Coefficient*	-18.7008	0.0021	0.0168	-0.0780	-2.5632	28.2209	-9.0649	-0.1556	101.4606	0.9542	-0.1762	2.1057	26
	p-value	0.0017	0.9682	0.8837	0.5418	0.0031	0.0007	0.0012	<0.00001	0.0000				
Finland	*Coefficient*	6.7970	0.0260	-0.0591	-0.1614	-1.4879	-5.8442	2.1494	-0.0268	7.1516	0.8555	0.5050	2.1754	32
	p-value	0.0005	0.6004	0.2018	0.0513	0.0382	0.0291	0.0244	0.6634	0.0001				
France	*Coefficient*	11.0810	-0.1109	-0.0368	-0.1358	-1.2160	-9.3592	3.5857	-0.5375	24.1099	0.8460	0.0213	1.9521	32
	p-value	0.0295	0.1019	0.6496	0.1171	0.1207	0.1677	0.1381	0.0000	0.0000				
Hungary	*Coefficient*	-6.5569	-0.0132	0.0042	-0.0400	8.5550	-1.3690	0.6518	0.0000	4.1714	0.9401	0.7269	1.7103	32
	p-value	0.0624	0.8580	0.9331	0.6672	0.0007	0.7922	0.7741	0.9998	0.0039				
Italy	*Coefficient*	11.3254	0.0092	0.0666	-0.1446	-4.3587	-2.0519	0.8289	-0.1567	42.0002	0.9731	0.5959	1.8251	32
	p-value	0.0001	0.8091	0.2666	0.0947	<0.00001	0.5921	0.5489	0.0003	0.0000				
Japan	*Coefficient*	26.7248	-0.1004	-0.2394	-0.1912	-7.8714	-10.2595	4.0240	-0.0289	14.4073	0.8817	0.3585	1.9241	32
	p-value	0.0003	0.0430	0.2097	0.1496	0.0002	0.0757	0.0545	0.5444	0.0000				
Korea	*Coefficient*	-1.6973	-0.0402	-0.0848	-0.3194	-0.9581	9.4285	-3.4814	-0.2329	114.7549	0.9720	0.0174	1.6905	25
	p-value	0.6071	0.5305	0.6099	0.0118	0.7077	0.0001	0.0000	0.0282	0.0000				
Poland	*Coefficient*	4.9680	0.0890	0.0286	-0.1527	-3.1824	2.5432	-0.8013	-0.0340	206.8837	0.9841	0.1385	1.8943	32
	p-value	0.0002	0.0519	0.4395	0.0219	0.0001	0.0089	0.0957	0.4609	0.0000				
Portugal	*Coefficient*	61.9894	0.3603	-0.5273	-0.3515	0.2209	-92.2068	35.5364	-0.2410	87.3564	0.9562	-0.5545	2.8815	15
	p-value	0.0829	0.1406	0.1023	0.2226	0.8670	0.0897	0.0858	0.0004	0.0000				
Switzerland	*Coefficient*	-30.5777	0.0179	0.1444	-0.0162	-0.2596	41.9879	-13.7424	0.2533	6.9220	0.5113	-0.1406	2.0492	32
	p-value	0.0048	0.8104	0.1089	0.8628	0.4951	0.0029	0.0031	0.7590	0.0001				
Turkey	*Coefficient*	-1.1737	0.0538	0.0040	-0.1540	0.1119	5.5659	-2.5644	-0.0623	3.9116	0.9535	0.8056	1.7008	30
	p-value	0.4244	0.4974	0.9280	0.0645	0.8142	0.0242	0.0365	0.1947	0.0065				
United Kingdom	*Coefficient*	9.8276	-0.2701	0.2537	-0.0754	-2.9402	-3.1845	1.1909	0.1149	24.2365	0.7661	-0.2848	2.2708	32
	p-value	0.0142	0.2870	0.0971	0.5155	0.0314	0.3747	0.3587	0.3181	0.0000				
United States	*Coefficient*	9.6785	-0.0456	0.0715	-0.1100	-1.0396	-5.8292	2.1834	-0.1743	29.6733	0.9513	0.4910	1.6866	32
	p-value	0.0002	0.1801	0.0219	0.0010	0.0048	0.0227	0.0113	0.0840	0.0000				