NORTHERN ARIZONA UNIVERSITY
The W. A. Franke College of Business

The Cost of CO_2 Emission Cuts

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Xiaobing Zhao

Northern Arizona University
The W. A. Franke College of Business
20 W. McConnell Drive, Room 311
PO Box 15066
Flagstaff, AZ 86011-5066
Xiaobing.Zhao@nau.edu
(928) 523-7279
Fax: (928) 523-7331

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1. Introduction

Pioneered by Grossman and Krueger's (1991, 1995) and Shafik and Bandyopadyay (1992), there is a voluminous literature on the "environmental Kuznets curve" (EKC) hypothesis.[1] This hypothesis postulates an inverted U-shaped relationship between (logarithm of) levels of pollution or emissions of wastes per capita and (logarithm of) income per capita. That is, at low income levels, emissions are hypothesized to increase with income but at a slower pace; beyond a critical income level (i.e., the turning point) emissions are conjectured to decrease as income further increases. If this hypothesis were true, it would suggest that countries might not need to make significant carbon dioxide (CO_2) emission cuts envisaged by the Kyoto Protocol since economic growth will eventually lead to environmental improvement.

An overview article by Dasgupta et al. (2002) presents three different views about the shape of the EKC—conventional (the standard inverted U shape), pessimistic (the EKC will flatten or increase beyond the turning point), and optimistic (the turning point occurs at lower levels of income and pollution is lower at each level of economic development). This article indicates that the optimistic view is the most likely due to increasing effectiveness of environmental regulation, greater public awareness of pollution, etc.

Unfortunately, empirical evidence in support of the EKC hypothesis and the optimistic view is very weak as soon as econometrics problems in early studies are taken into account. Econometric criticisms of the EKC are generally divided into four groups— heteroskedasticity, simultaneity, omitted variables bias, and cointegration issues. [2] Now the central question is not whether we should make emission cuts or not, but how much we should cut. The importance of this question is manifested in the disagreements at the 2009 United Nations Climate Change Conference in Copenhagen (Müller 2010) and the 2010 State of the Union Address by United States President Barack Obama (State of the Union Address Library 2010). To answer this question, we need to study a reverse EKC. That is, we need to investigate how emissions and emission cuts affect income (not how income affects emissions as in the EKC studies). If the adverse impact of emission cuts on income is small, it may be sensible to make significant cuts, vice verse.[3]

We focus on the reverse EKC relationship for CO_2 emissions due to its particular importance. CO_2 emissions are believed to be the major driving force of global warming (IPCC 2007). The importance of CO_2 emission reduction is emphasized in a Wall Street Journal article, in which Robert Stavins from Harvard University and Steven Hayward from the American Enterprise Institute for Public

[1] See for instance Holtz-Eakin and Selden (1995), Galeotti and Lanza (1999), Dijkgraaf and Vollebergh (2001), Martinez-Zarzoso and Bengochea-Morancho (2004), and Galeotti, Lanza, and Pauli (2006) among others.
[2] See Stern and Common (2001), Perman and Stern (2003), and Stern (2004).
[3] There is a voluminous literature on the relationship between energy consumption and economic growth. See Ozturk (2010) for a comprehensive review. We in this paper instead focus on the relationship between emission cuts and income.

Policy Research debate whether carbon emission cuts can hurt economic growth (Wall Street Journal 21 September 2009).

We start by deriving an income-CO_2 relationship based on a structural production function, which captures the idea that income/output depends on energy consumption and therefore CO_2 emissions. Our structural model enables us to identify and include all relevant economic variables in our empirical regression model. We then use a similar methodology that Tucker (1995) employs. That is, we estimate the reverse EKC relationship year by year. Such an approach not only circumvents the non-stationarity issue but also allows us to project the future relationship between income and CO_2 emissions.

The remainder of the paper is organized as follows: Section 2 presents the data and our methodology. Section 3 reports the empirical results. Section 4 concludes the paper with a brief summary.

2. Data and Methodology

Methodology

Income or output depends on energy consumption, which is directly related to CO_2 emissions. [4] Therefore, a natural way to model the impact of CO_2 emissions on income is to use a production function. Specifically, we consider a Cobb-Douglas type production function:[5]

$$Y_i = e^{\varepsilon_i} A L_i^{\alpha} K_i^{\beta} E_i^{\gamma} \qquad (1)$$

where Y_i is the total income measured by real Gross Domestic Product (GDP), A represents productivity (we assume that the countries in our sample are homogenous in terms of technology level), K_i represents capital, L_i stands for labor, E_i is energy, ε_i captures the effects of all other variables, and $\alpha,\ \beta, \gamma < 1$. This model augments the standard Cobb-Douglas production function by taking into account a fact that energy is an input required to produce output. Given the technology level at a point in time, there is a direct linear relationship between energy consumption and CO_2 emissions.[6] That is, $E_i = bCO_{2i}$, where CO_{2i} represents corresponding CO_2 emissions. Then we have,

$$Y_i = b^{\gamma} e^{\varepsilon_i} A L_i^{\alpha} K_i^{\beta} CO_{2i}^{\gamma} \qquad (2)$$

To get income per capita, we divide both sides by L_i. We further assume that the production function exhibits constant returns to scale (i.e., $\alpha + \beta + \gamma = 1$). Then we get

[4] Coondoo and Dinda (2002) find that for developed countries the causality between income and emission runs from emission to income.
[5] See Choinière and Horowitz (2006) for another application: they investigate the relationship between income and temperature using a Cobb-Douglas production function with temperature added as an input along with physical and human capital. Temperature lowers the marginal product of physical and human capital in their model.
[6] See Pereira and Pereira (2010).

$$\frac{Y_i}{L_i} = b^{\gamma} e^{\varepsilon_i} A \left(\frac{K_i}{L_i} \right)^{\beta} \left(\frac{CO_{2i}}{L_i} \right)^{\gamma} \tag{3}$$

Taking log on both sides, we have

$$\log(\left(\frac{Y_i}{L_i} \right) = \log(b^{\gamma} A) + \beta \log\left(\frac{K_i}{L_i} \right) + \gamma \log\left(\frac{CO_{2i}}{L_i} \right) + \varepsilon_i \tag{4}$$

Let $a = \log(b^{\gamma} A)$, we finally have

$$\log(\left(\frac{Y_i}{L_i} \right) = a + \beta \log\left(\frac{K_i}{L_i} \right) + \gamma \log\left(\frac{CO_{2i}}{L_i} \right) + \varepsilon_i \tag{5}$$

We focus on Equation (5) to estimate the reverse EKC relationship between income and CO_2 emissions. Since our model applies to countries that are homogenous in terms of technology and productivity, we focus on 23 OECD countries and exclude Mexico, South Korea, Turkey and Eastern European countries which have substantial lower income in the empirical tests.

Furthermore, we estimate this model year by year similar to Tucker (1995). This approach has three advantages compared to the panel regression approach typically used in the EKC studies. First, this cross-sectional approach allows us to focus on the long-run equilibrium relationship between CO_2 emissions and income (not the short-run transitory relationship), which is more informative. Second, it also circumvents the non-stationarity problem that Perman and Stern (2003) identify. Since the regression is performed in a cross-sectional rather than a time-series fashion, non-stationarity becomes irrelevant. Third, this approach also allows time-variation in the income-CO_2 relationship, which not only is empirically appealing but also enables us to project the reverse EKC relationship for future years.

Data

We obtain macroeconomic data of the 23 OECD countries from the Penn World Tables. The Penn World Tables provide national income accounts-type of variables converted to international prices. The homogenization of national accounts to a common numeraire allows valid comparisons of income across countries.[7] Since the Penn World Tables do not provide data for capital per capita, we use investment share of GDP as a proxy. Intuitively, a country that invests more in capital should have a higher capital per capita. We also use population as a proxy for labor since we want to focus on the commonly studied income measure—real GDP per capita not real GDP per worker.

[7] Data comes from Alan Heston, Robert Summers and Bettina Aten, Penn World Table Version 6.1, Center for International Comparisons at the University of Pennsylvania, October 2002.

Table 1 Summary Statistics

Country	Real GDP per capita		Per Capita CO_2 Emissions (Metric Tons)		Investment Share of GDP	
	Mean	Variance	Mean	Variance	Mean	Variance
Australia	21968	11590773	16.23	4.43	24.30	5.76
Austria	22691	11352814	7.65	0.52	23.48	1.33
Belgium	20925	8950416	13.30	1.02	21.49	5.35
Canada	22521	9723764	17.53	0.64	23.59	3.63
Denmark	23473	10329842	11.72	1.33	20.82	6.62
Finland	19295	6843468	10.34	0.81	25.66	15.83
France	21466	7659316	6.73	0.42	22.43	1.82
Germany	21573	8310459	10.76	0.12	22.95	2.28
Greece	12617	2195956	7.77	2.39	21.24	7.03
Iceland	22135	6953045	9.14	2.35	22.47	8.19
Ireland	16566	40905805	8.09	3.72	20.87	6.68
Italy	19563	6127625	7.17	0.35	21.70	1.28
Japan	20943	10100368	8.55	0.65	30.58	3.92
Luxembourg	34153	107253949	25.22	12.20	24.10	4.23
Netherlands	21712	10503012	14.50	1.62	21.50	1.28
New Zealand	18375	4099589	8.26	1.30	20.93	5.96
Norway	26678	26894709	8.58	0.82	24.52	12.70
Portugal	13737	7961366	4.41	1.78	21.11	11.29
Spain	15817	9003585	6.63	1.36	22.77	8.90
Sweden	21679	7178270	7.28	0.56	20.15	2.78
Switzerland	26561	3118714	6.28	0.09	27.66	2.43
United Kingdom	20423	12724419	10.09	0.23	17.43	3.30
United States	28267	21036980	20.04	0.30	20.10	4.86

The CO_2 emissions per capita data for the 23 OECD countries are from the US Energy Information Administration (http://www.eia.doe.gov/environment.html). Since the emissions data start in 1980 and the macroeconomic data from the Penn World Tables end in 2004, our data sample covers the period from 1980 to 2004.

Table 1 contains summary statistics of the variables used in this paper. Among 23 countries, real GDP per capita ranges from $12,617 in Greece to $34,153 in Luxembourg. Portugal has the lowest rate of CO_2 emission per capita which is 4.41 metric tons while Luxembourg has the highest rate of 25.22 metric tons per capita. In terms of investment share of GDP, it ranges from 17.43% in the United Kingdom to 30.58% in Japan.

3. Empirical Results

We estimate Equation (5) year by year from 1980 to 2004. The coefficient estimates and the adjusted R^2 are reported in Table 2. To save space, we do not report the White (1980) heteroscedasticity-consistent t-ratios. The significant coefficient estimates at the 5% level for two-sided tests are in bold. As we can see, the impact of CO_2 emissions on income is statistically significant in each year. In fact, the coefficient estimate increases from 0.28 in 1980 to 0.35 in 2004, with an average of 0.31. That is, holding constant other relevant variables, a one percent cut in CO_2 emissions will on average reduce income per capita by 0.31%.

Table 2 Impact of CO_2 Emissions on Income

Year	a	β	γ	Adj-R^2
1980	**8.32**	0.24	**0.28**	0.45
1981	**8.43**	0.23	**0.27**	0.38
1982	**8.35**	0.25	**0.28**	0.30
1983	**8.14**	0.31	**0.30**	0.37
1984	**7.49**	**0.54**	**0.29**	0.53
1985	**7.38**	**0.57**	**0.30**	0.56
1986	**7.49**	**0.53**	**0.32**	0.51
1987	**6.97**	**0.71**	**0.30**	0.56
1988	**7.33**	**0.60**	**0.30**	0.49
1989	**7.41**	**0.57**	**0.30**	0.44
1990	**7.61**	**0.51**	**0.31**	0.37
1991	**7.83**	**0.45**	**0.31**	0.37
1992	**7.46**	**0.56**	**0.33**	0.40
1993	**7.56**	**0.57**	**0.29**	0.41
1994	**7.35**	**0.63**	**0.30**	0.40
1995	**7.23**	**0.64**	**0.34**	0.38
1996	**7.58**	0.53	**0.34**	0.35
1997	**7.84**	0.48	**0.30**	0.29
1998	**7.25**	0.65	**0.32**	0.30
1999	**8.31**	0.32	**0.33**	0.23
2000	**8.85**	0.17	**0.31**	0.18
2001	**9.61**	-0.06	**0.30**	0.18
2002	**10.73**	-0.42	**0.31**	0.24
2003	**10.79**	-0.46	**0.34**	0.29
2004	**10.98**	-0.51	**0.35**	0.35

There are several popular proposals regarding CO_2 emission cuts. However, a deep linear cut of 50% below 1990 emissions by 2050 may be more relevant to policy discussions.[8] This proposal means at least a 1% cut in CO_2 emissions per year. If a 1% cut in CO_2 emissions will on average reduce income per capita by 0.31% as we show in Table 2, the cost of emission cuts is not only statistically but also economically significant. Since the average economic growth rate for the 23 OECD countries from 1980 to 2004 is only about 2% per year based on our data, a 0.31% reduction in GDP per capita per year represents a 15% slowdown in economic growth.[9] This is the central finding of our paper.[10]

The above analysis is informative but may not be accurate in the sense that it does not take into account the time variation in the impact of CO_2 emissions on income and the time value of money. Intuitively, if the impact of CO_2 emissions increases over time fast enough to offset the effects of the time value of money, the cost of emission cuts will increase and the average cost estimate we use in the above analysis may underestimate the true cost; vice verse. Next we examine the time variation in the impact of CO_2 emissions on income and the effects of the time value of money.

Table 2 indicates that the impact of CO_2 emissions on income seems to be increasing over time. To estimate the trend, we consider the following time-trend model.

$$\gamma_t = c + dTrend_t + e_t \qquad (6)$$

where γ_t is the impact estimate in a year estimated from previous regressions. The results are reported in Table 3. The t-ratios are based on Newey and West (1987) HAC standard errors with the lag parameter set equal to 1. The time trend is statistically significant at the one percent level. The adjusted R^2 is 47%, indicating a reasonable fit of the model. Since the coefficient of the time trend is 0.002, it suggests that the impact of CO_2 emissions on income increases by 0.2% per year over our sample period of 1980 to 2004.

Table 3 Time Trend in the Reverse EKC Relationship

	Coefficient	T-Stat	Adj-R^2
Constant	**-3.676**	**-4.32**	0.47
Time trend	**0.002**	**4.68**	

If we assume the trend will continue, the impact of CO_2 emissions on income will continue to increase in the future. However, the present value of the impact still partly depends on the time preference of society or the discount rate. To see the impact of the discount rate, we conduct a simple analysis. First,

[8] See Paltsev, Reillya, Jacobya and Morris (2009).

[9] 0.31 is 15% of 2.

[10] How much emission cuts we should make will also depend on the marginal benefit of emission cuts which is beyond the scope of this paper.

we project the impact of emissions on income in future years based on our time trend model of Equation (6). We consider four particular years for simplicity, 2020, 2030, 2040 and 2050. Then, we discount the impact back to the present assuming a number of discount rates as in Heal and Kriström (2002). The results are reported in Table 4. As we can see, the present values of the future impacts are often less than the average impact we use previously which is 0.31 (12 out of 20 or about 60%). This finding suggests that even if we take into account the time value of money and the time variation in the impact of emissions, the average impact analysis we have had in the previous discussion may still be relevant. That is, to reduce emissions by 50% by 2050, the annual economic cost is about 0.3% reduction in income for the 23 OECD countries.

Table 4 Present Values of Future Impacts

Discount rate	$\gamma_{2020} = 0.36$	$\gamma_{2030} = 0.38$	$\gamma_{2040} = 0.40$	$\gamma_{2050} = 0.42$
1%	**0.33**	**0.35**	**0.37**	**0.38**
2%	0.30	**0.32**	**0.33**	**0.35**
3%	0.27	0.29	0.30	**0.32**
4%	0.25	0.26	0.27	0.29
5%	0.22	0.24	0.25	0.26

4. Conclusion

We study how CO_2 emission cuts affect income in this paper. First we derive an income-CO_2 relationship based on a structural production function, which is a natural way to model the relationship between income and CO_2 emissions. We then use a similar methodology as Tucker (1995) to estimate the income-CO_2 relationship. Such an approach not only allows us to focus on the long-run relationship but also enables us to project the relationship between income and CO_2 emissions for future years.

Our main findings are as follows. Over the 1980-2004 period, for 23 OECD countries, the reverse EKC relationship between CO_2 emissions and income is statistically and economically significant. To reduce emissions 50% below 1990 levels by 2050, the economic cost per year for developed countries is about 0.3% reduction in GDP per capita which represents a 15% slowdown in economic growth.

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