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DEPENDENCE OF ECONOMIC GROWTH ON CO_2 EMISSIONS

CHIROK HAN[a] AND HYELIM LEE[b*]

[a,b]*Korea University, Korea*

This paper examines the effects of CO_2 emissions on GDP by using a dynamic model for panel data from 19 OECD countries. The results indicate a significant decline in the dependence of economic growth on pollution, suggesting technological progress toward economic growth with less pollution, and providing indirect empirical support for the environmental Kuznets curve hypothesis.

Keywords: Growth, Pollution, CO_2, Dynamic Panel Data, OECD
JEL classification: C23, Q43

1. INTRODUCTION

Previous studies of the relationship between economic growth and pollution have focused mainly on the effects of economic growth on pollution. One of the most widely debated observations in this regard is Grossman and Krueger's (1991) environmental Kuznets curve (EKC), which states that at low levels of income, environmental degradation increases as the economy grows and environmental pollution decreases when the economy develops further enough to exceed a critical threshold. Important studies of the EKC include Shafik (1994), Holtz-Eakin and Selden (1995), Moomaw and Unruh (1997), Schmalensee *et al*. (1998), Grossman and Krueger (1995), Selden and Song (1994), Shafik and Bandyopadhyay (1992), and Panayotou (1993, 1997), among others. Stern (2004) provides a chronological and critical review of previous research on the EKC hypothesis. Dasgupta *et al.* (2002), Lieb (2003), Dinda (2004), He (2007), Aslanidis (2009), Kijima *et al.* (2010) and Bo (2011) also review the literature on empirical and theoretical discussions on the EKC. Wagner (2008) discusses that the seemingly strong evidence for an inverted U-shaped relationship vanishes when the issues of nonlinear transformation of integrated regressors and cross-sectional dependence in the panel data are taken into account.

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Previous studies have also examined the directional relationship between energy consumption and growth, including the causality from energy consumption to economic growth. Kraft and Kraft (1978) find causality from GNP to energy consumption in the U.S. by using data for the 1947-1974 period. Coondoo and Dinda (2002) conduct Granger causality tests and report that the causal relationship between CO_2 emissions and income varies according to region. Dinda and Coondoo (2006) investigate the causality issue in the income-emission relationship using a cross-country panel data set by employing panel unit root tests. Halicioglu (2009) finds that in Turkey, CO_2 emissions are determined by energy consumption, income, and foreign trade, and that income is also determined by CO_2 emissions, energy consumptions and foreign trade. Lee (2006) conducts a thorough exploration of the directional relationship by considering the G-11 countries and finds different directional evidences for different countries. A good summary of the evidences in empirical studies up to 2004 is also available in Lee (2006). Lee and Chang (2008) analyze panel data from 16 Asian countries for the 1971-2002 period, and find long-run unidirectional causality from energy consumption to economic growth.

In the present paper, we focus on the directional causality from pollution to economic growth. While the extant works (e.g., Lee, 2006; Lee and Chang, 2008) assess the existence of the directional causality and measure the overall magnitude over the whole sample period, we investigate how this directional causality has evolved over time, that is, how the dependence of economic growth on the emission of pollutants has changed over time. The results of this study can be interpreted as the technological development with regard to how much pollution is required for economic growth. A decrease in this causality over time would suggest ‘environment-friendly’ technological progress, which is one of the classical arguments for the EKC hypothesis (Panayotou, 1993).

To estimate the directional causal relationship from pollution to economic growth, we use panel data from 19 OECD countries that have signed and ratified the Kyoto Protocol.[1] Specifically, we regress economic growth on the growth of air pollution (measured by CO_2 emissions) while controlling for important variables such as capital, openness, human capital accumulation and other economic conditions. We take into account unobservable country-specific characteristics and global business cycles by including country fixed effects and common time effects. We account for simultaneity

[1] As an anonymous referee correctly pointed out, the EKC hypothesis can be better evaluated empirically by examining more countries (including developing countries) than considered in the present paper. This is especially relevant if cross-country variation is the main source of information. However, the primary interest of the present paper is in the temporal evolution of the directional causality from pollution to growth. In this context, countries in different development phases are likely to exhibit different behavior in terms of this causality, and thus it may not be desirable to pool many heterogenous countries. We consider those 19 countries to avoid this issue and maximize homogeneity.

and endogeneity in the panel dynamic specification. The results indicate that the dependence of economic growth on CO_2 emissions has significantly weakened over time, providing partial support for Panayotou's (1993) arguments for the EKC hypothesis.

The rest of this paper is organized as follows. Section 2 explains the models. Section 3 presents the data and estimation results, and Section 4 concludes.

2. ECONOMETRIC MODELS

Our econometric model is based on the Cobb-Douglas production function $Y = AK^{\gamma}L^{1-\gamma}$ with constant returns to scale, where *Y* is GDP, *K* is the capital stock, and *L* is the amount of labor. The *A* coefficient measures total factor productivity and includes factors other than *K* and *L*. Dividing by *L* and taking the natural logarithm, we have $\ln y = \ln A + \gamma \ln k$, where $y = Y / L$ and $k = K / L$. The logarithm of total factor productivity is to be explained by CO_2 emissions, country specific effects (levels and trends), common time effects, and other factors such as human capital and openness. Thus, the preliminary model is

$$\ln y_{it} = \alpha_{0i} + \alpha_i t + \delta \ln c_{it} + X_{it}\beta + u_{it}, \tag{1}$$

where *i* and *t* denote country and year, respectively, α_{0i} is the individual-specific level of the log of per capita GDP, and α_i is the coefficient on the individual-specific trend. The control variables in X_{it} contain the capital stock per worker (in the log form), human capital, openness, common time effects, and others. The key variable is c_{it}, which is the level of CO_2 emissions per employee in period *t* for country *i*. We include incidental linear trends ($\alpha_i t$) in the model to account for a diverse range of observed trends in total factor productivity (Coe and Helpman, 1995). The δ parameter measures the CO_2 elasticity of production. Note that $\ln c_{it}$ may be endogenous because given technology, production and CO_2 emissions may be determined simultaneously by economic agents.

The effects of past GDP can persist over multiple periods, and the idiosyncratic error term u_{it}, which includes the effects of all time-varying unobservable factors except for idiosyncratic linear trends and common time effects, may be strongly correlated over time. This persistence implies serial dependence in u_{it}, and to account for this autocorrelation, we include lagged dependent variables on the right-hand side of the equation, thus leading to

$$\ln y_{it} = \alpha_{0i} + \alpha_i t + \delta \ln c_{it} + X_{it}\beta + \sum_{j=1}^{p} \varphi_j \ln y_{it-j} + u_{it}. \tag{2}$$

We handle the country specific trends by differencing the equation. In this case, the transformed idiosyncratic error term is Δu_{it}, which should be less persistent but may still retain temporal dependence. We then adjust the lag order p to make this disturbance serially uncorrelated, and after this adjustment, we have the following dynamic panel data model:

$$\Delta \ln y_{it} = \alpha_i + \delta \Delta \ln c_{it} + \Delta X_{it} \beta + \sum_{j=1}^{p} \varphi_j \Delta \ln y_{it-j} + \varepsilon_{it}, \tag{3}$$

where the lag order p is selected such that the remaining idiosyncratic error ($\varepsilon_{it} = \Delta u_{it}$) is serially uncorrelated. Thus, the dynamic equation in levels (2) and that in differences (3) may be different in terms of their lag orders, even though they are both denoted by p.

The control variables X_{it} contain the capital stock (in the log form), trade openness, measured human capital, other economic conditions, and common time effects. We specify openness to influence the growth rate, not the level, of productivity as in Harrison (1996). We include human capital in the equation in the simplest Mincerian form (see, e.g., Mincer, 1974; Heckman and Klenow, 1997; Bils and Klenow, 2000; Krueger and Lindahl, 2001; Na *et al.*, 2011) following Barro and Lee (2010) and Cohen and Soto (2007). We use Barro and Lee's (2010) data for the population aged 25 and over. The data are available every five years, and we linearly interpolate for interim years so that the changes are the same for corresponding five-year periods. The variables for human capital are $\Delta S_{1,it-5}$ and $\Delta S_{2,it-5}$, where $S_{1,it}$ is the change in the average years of primary education and $S_{2,it}$ is the sum of the average years of secondary and tertiary education. Here we lag the schooling variables five years and only five years to ensure their weak exogeneity without losing too many degrees of freedom. In addition, we include the level of log GDP per worker to account for the dependence of the growth rate on the income level. When p lags of the income growth rate appear on the right hand side, the inclusion of any of $\ln y_{it-1}$, …, $\ln y_{it-p-1}$ gives the same estimates for the rest of the explanatory variables. Here we simply choose $\ln y_{it-1}$. We include common time effects in ΔX_{it} to account for global business cycles. In sum, ΔX_{it} contains $\Delta \ln k_{it}$, $OPEN_{it}$, $\Delta S_{1,it-5}$, $\Delta S_{2,it-5}$, $\ln y_{it-1}$ and the vector of time dummies τ_t.

Here the objective is to detect a weakening relationship between pollution and economic growth. For this, we choose a simple strategy of interacting CO_2 emissions with a linear time trend. In this way, we parameterize the declining trend in the dependence of economic growth on CO_2 emissions and statistically test its significance. Thus, the final model is

$$\Delta \ln y_{it} = \alpha_i + \delta_0 \Delta \ln c_{it} + \delta_1 t \Delta \ln c_{it} + \Delta X_{it} \beta + \sum_{j=1}^{p} \varphi_j \Delta \ln y_{it-j} + \varepsilon_{it} \,, \tag{4}$$

where $\Delta X_{it} = (\Delta \ln k_{it}\,,\ \Delta S_{1,it-5}\,,\ \Delta S_{2,it-5}\,,\ OPEN_{it}\,,\ \ln y_{it-1}\,,\ \tau_t)$, with τ_t denoting the vector of period dummies.

Unobserved country-specific effects α_t are likely to be correlated with explanatory variables and are thus regarded as fixed effects. The control variables $\Delta \ln k_{it}$, $\Delta S_{1,it-5}$, $\Delta S_{2,it-5}$ and $\ln y_{it-1}$ are predetermined at time *t*, and $\Delta \ln c_{it}$ and $OPEN_{it}$ are specified as endogenous because they are determined simultaneously with GDP.

In the following section, we estimate Model (4) and related models by using the first-difference one-step GMM estimation method (Arellano and Bond, 1991) rather than the two-step efficient estimation because the one-step estimator has good asymptotic properties when the time dimension is moderate (Alvarez and Arellano, 2003). We do not consider system GMM (Arellano and Bover, 1995; Blundell and Bond, 1998) because the persistence of the dependent variable is not a concern and the first-difference GMM is more robust in the presence of non-stationary initial conditions (Hahn, 1999).

3. DATA AND EMPIRICAL RESULTS

We use data collected based on their availability for the 1981-2009 period for 19 OECD countries that have signed and ratified the Kyoto Protocol.[2] We limit the scope of the countries in order to maximize their homogeneity. The CO_2 data (publicly available from the Oak Ridge National Laboratory) provide national CO_2 emissions (in metric tons) from using fossil-fuels, manufacturing cement, and flaring gas. For national accounts, Penn World Table 7.1 provides PPP-converted real GDP per capita (RGDPCH, *Y/N*), PPP-converted real GDP per worker (RGDPWOK, *Y/L*), and the population (POP, *N*). We measure employment by the number of workers, $L = N\left(\frac{Y}{N}\right)\Big/\left(\frac{Y}{L}\right)$. Alternatively, Source-OECD provides employment data, but because data on some countries are incomplete, we lose considerable degrees of freedom, and thus we use the Penn World Table. The data on the capital stock (*K*) are from Source-OECD's Economic Outlook, and the data on trade openness data are from Penn World Table 7.1 (OPENK, openness at constant 2005 prices). For human capital, we use Barro and Lee's

[2] The 19 countries include Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, New Zealand, Portugal, Spain, Sweden, Switzerland, the Netherlands, and the U.K. We exclude the U.S. because it has not ratified the Kyoto Protocol.

(2010) data on average years of schooling for the population aged 25 and over. These data are available every five years, and we linearly interpolate observations for interim years. As noted in Na *et al.* (2011), this may result in inaccurate estimates, but this issue is not a serious concern in the present study because we use data on the education level only to control for human capital. Because we take the log of all variables except for S (measured in years) and $OPEN$ (measured as a ratio) and include country fixed effects in the equations, we are not concerned about the unit of measurement for these variables.

We first estimate (3) with $p=1$ by using Arellano and Bond's (1991) first-difference one-step GMM for the first 10-year period (1981-1990) and for the last 10-year period (2000-2009). Table 1 shows the results. In the early years, every 10% increase in CO_2 emissions increases GDP by 0.657%, whereas in the recent years, in increases GDP by only 0.325%.[3]

Table 1. Dynamic Panel GMM Estimation of (3) for Two Subperiods

Variable	1981-1990		2000-2009	
$\Delta \ln y_{it-1}$	0.1583**	(0.0725)	0.3211***	(0.0926)
$\Delta \ln k_{it}$	0.6939***	(0.1493)	0.4393***	(0.1557)
$\ln y_{it-1}$	-0.0935**	(0.0470)	-0.2139***	(0.0237)
$\Delta \ln c_{it}$	0.0882***	(0.0286)	0.0188	(0.0184)
$\Delta S_{1,it-5}$	-0.2157	(0.2261)	0.1279**	(0.0653)
$\Delta S_{2,it-5}$	0.1084*	(0.0615)	-0.0098	(0.0171)
$OPEN_{it}$	0.0010	(0.0006)	0.0001	(0.0002)
Arellano-Bond specification test				
Order 1	-2.846 (p-value = 0.004)		-2.858 (p-value = 0.004)	
Order 2	0.643 (p-value = 0.520)		1.594 (p-value = 0.111)	

Notes: 1) The dependent variable is $\Delta \ln y_{it}$. 2) Estimates and panel- robust standard errors (in parentheses) are presented. 3) *, ** and *** denote significance at the 10%, 5% and 1% levels respectively. 4) Year dummies are included.

We can visualize the decline in the dependence of economic growth on CO_2 emissions by running a dynamic panel regression of (3) for each overlapping 10-year

[3] An anonymous referee suggested that a test be conducted for the parameter stability in the two sub-periods. For this, we ran the regression over the whole sample period with two dummy variables (called '*period2*' and '*period3*') for the period 1991-1999 and 2000-2009 and the interaction of the dummies and $\Delta \ln c_{it}$ included. The coefficient of $period3 \times \Delta \ln c_{it}$ is -0.073 and is statistically significant (p-value= 0.008). This implies that the CO_2 dependence of growth is significantly smaller in more recent periods.

period (e.g., for 1981-1990, 1982-1991, 1983-1992, etc.) For each sub-period, we take the annual time effects into account. Figure 1 shows the estimated coefficients (together with the approximate 95% confidence intervals) of $\Delta \ln c_{it}$ based on Arellano and Bond's (1991) method. The results indicate a declining trend.[4]

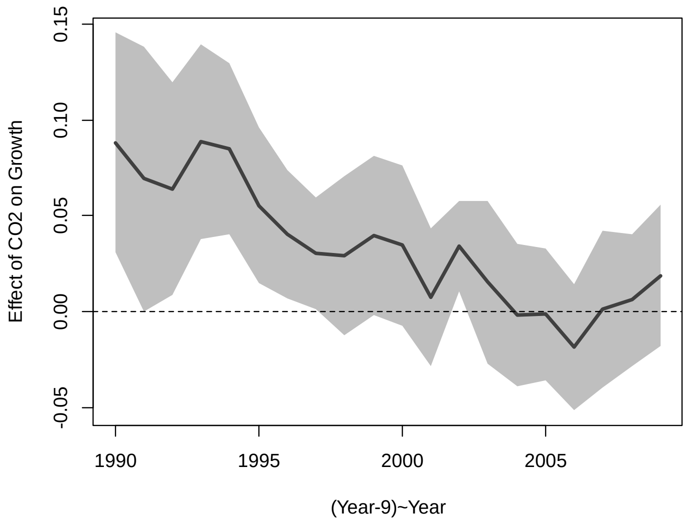

Figure 1. Effects of CO_2 Emissions (overlapping 10-year periods)

For the whole panel, we regress (4) using Arellano and Bond's (1991) one-step GMM method with $p = 1$. Because we have only 19 cross-sectional units (and 29 years from 1981 to 2009), the use of full lags of the dependent variable and predetermined and endogenous explanatory variables as instruments may result in undesirable results. (For example, the 'xtabond' procedure in Stata 11 gives estimates identical to the LSDV estimates.) We overcome this issue by using lags of the variables up to order 10 for the predetermined and endogenous variables. (This can be done by specifying the 'maxldep (10)' and 'maxlag (10)' options in Stata; see Stata Corp., 2007.) Table 2 shows the results.

[4] An upturn is observed for most recent years, but data gives no information about whether this recent upward trend will be only temporary or more persistent.

Table 2. GMM Estimation Results for the Whole Sample (1981-2009)

$\Delta \ln y_{it-1}$	$\Delta \ln k_{it}$	$\Delta \ln c_{it}$	$(t-1980)\Delta \ln c_{it}$
0.2184*** (0.0536)	0.5972*** (0.0765)	0.1027*** (0.0279)	-0.0031** (0.0012)
$\ln y_{it-1}$	$\Delta S_{1,it-5}$	$\Delta S_{2,it-5}$	$OPEN_{it}$
-0.0827*** (0.0176)	-0.0100 (0.0345)	0.0153 (0.0117)	0.0001 (0.0001)

Notes: 1) The dependent variable is $\Delta \ln y_{it}$. 2) The first-difference GMM estimates and panel-robust standard error are reported. 3) *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively. 4) The model includes year dummies. 5) The Arellano-Bond specification test statistics are -3.5764 (p-value =0.0003) for the first order and 0.1805 (p-value=0.8567) for the second order.

The elasticity of the output growth with respect to the growth of CO_2 emissions is estimated to be 0.1027 in year 1980, and then declines by 0.0031 every year. This decline is statistically significant at the 5% level.[5]

4. CONCLUSION

This paper investigates the causal relationship between CO_2 emissions and economic growth by estimating dynamic panel data models with country-level panel data from 19 OECD countries that are parties to the Kyoto Protocol for the 1981-2009 period. The results indicate that, on average, the effects of CO_2 emissions on economic growth have declined significantly, suggesting technological progress toward economic growth with less pollution, and providing indirect empirical support for the environmental Kuznets curve hypothesis.

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[5] Note that this linear falling trend only describes the properties of the data and should not be extrapolated to the period out of sample.

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Mailing Address: Chirok Han, Department of Economics, Korea University, Anam-dong Seongbuk-gu, Seoul, Korea. Tel: 82 2 3290 2205. E-mail: chirokhan@korea.ac.kr.

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