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Modelling the nonlinear relationship between CO2 emissions from oil and economic growth

Kuan-Min Wang *

Department of Finance, Overseas Chinese University, 100 Chiao Kwang Road, Taichung, 40721, Taiwan

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ABSTRACT

The purpose of this paper is to examine the relationship between carbon dioxide (CO2) emissions from oil and GDP, using panel data from 1971 to 2007 of 98 countries. Previous studies have discussed the environmental Kuznets curve (EKC) hypothesis, but little attention has been paid to the existence of a nonlinear relationship between these two variables. We argue that there exists a threshold effect between the two variables: different levels of economic growth bear different impacts on oil CO2 emissions. Our empirical results do not support the EKC hypothesis. Additionally, the results of short-term analyses of static and dynamic panel threshold estimations suggest the efficacy of a double-threshold (three-regime) model. In the low economic growth regime, economic growth negatively affects oil CO2 emissions growth; in the medium economic growth regime, however, economic growth positively impacts oil CO2 emissions growth; and in the high economic growth regime, the impact of economic growth is insignificant.

1. Introduction

As Azomahou et al. (2006) point out, there are two reasons to study carbon dioxide (CO2) emissions. First, the greenhouse gas effect is considered a huge threat to the health of the environment; of the many greenhouse gases, CO2 is the most problematic and the most difficult to manage. In addition, CO2 has a very long lifespan (i.e. 50–200 years).[1] Second, CO2 emissions mostly derive from energy consumption — a crucial factor relating to modern production and consumption in the world economy. CO2 is produced mostly as a result of fossil-fuel consumption — including that of coal, petroleum, and natural gas — and cement production.[2] For these two reasons, the relationship between CO2 emissions and economic growth is of concern to most economists and environmentalists.

Regarding studies of the relationship between CO2 emissions and GDP, most of the literature focuses on discussions of the environmental Kuznets curve (EKC). These studies argue that the relationship between the two variables takes the shape of an inverted-U curve. This means that at a relatively low income level, and as income increases, energy consumption will increase as well — which in turn will raise CO2 emission levels and environmental pollution. Therefore, at a relatively low income level, CO2 emissions and income correlate positively. As income increases to a certain higher level, awareness of environmental protection is enhanced, and both people and the government become more willing to spend more resources on enforcing regulations and creating environmental policies, thus leading to decreases in environmental pollution and CO2 emissions. The above discussion highlights why the EKC is an inverted-U curve: as income increases, the relationship between income and CO2 emissions switches from a positive number to 0, and then to a negative number. Thus, the income elasticity related to CO2 emissions also changes from a positive number to 0, and then to a negative number, as income increases. When applied to econometric analysis, this phenomenon implies that the estimated relationship between CO2 emissions and GDP could be positive, 0, or negative, depending on the unique economic and environmental status of the country under examination.

The income elasticity related to CO2 emissions is a good indicator in studying the relationship between CO2 emissions and GDP. If the income elasticity is greater than 1, it means that the growth rate of CO2 emissions is higher than the GDP growth rate. In such a case, it is said that CO2 emissions and GDP are cross-coupling with each

* Tel.: +886 4 27016855x2383; fax: +886 4 24521646.
E-mail address: wkminn@ocu.edu.tw.

[1] Scientists estimate that CO2 remains stable in the atmosphere for anywhere from 50 to 200 years (see: http://greennature.com/article281.html).

[2] As per the CO2 Emissions from Fuel Combustion Highlights (2010 Edition), total fuel CO2 emissions across the globe in 1971 were 14096.3 million tons, which increased to 29381.4 million tons in 2008, representing a growth rate of 108.4%. The oil CO2 emissions in 1971 were 6837.8 million tons, which increased to 10821.0 million tons in 2008, representing a growth rate of 58.25%. In 2008, 43% of the CO2 emissions from fuel combustion were produced from coal, 37% from oil, and 20% from gas. The growth rates for these fuels in 2008 were quite different, reflecting varying trends that are expected to continue in the future.

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other. If the income elasticity is positive but less than 1, however, the growth rate of CO2 emissions is smaller than that of GDP, and it is said that the two variables are relative-decoupling with each other. On the other hand, if the income elasticity is 0 or a negative number, then the CO2 growth rate is not affected by the economic growth rate — or, the CO2 growth rate is decreasing with the economic growth rate. In this case, the two variables are said to be absolute-decoupling with each other.

In the literature in this field, most studies use a single country or region as the sample under examination. For instance, Grossman and Krueger (1991), Gallagher (2004), and Stern (2007) focus on Mexico; Carson et al. (1997) and Aldy (2005) study the United States; List and Gallet (1999) look at both OECD and non-OECD countries in their sample; Vincent (1997) focuses on Malaysia; and Auffhammer and Carson (2008) utilise Chinese data. Recent studies (e.g. Azomahou et al., 2006; Diao et al., 2009; Romero-Ávila, 2008) analyse the problem with new econometric models or tests, such as the nonparametric panel data model, state-of-the-art panel stationarity test, linear model, quadratic function model, or cubic function model. However, most studies employ a linear rather than nonlinear model and utilise the levels, rather than the growth rates, of the variables.

The research methodologies adopted by many of these previous studies bear several shortcomings. First, most studies utilise the ordinary least squares (OLS) model, whose estimation result is an averaged outcome that is very sensitive to outliers. In addition, if the data are characterised by heteroscedasticity, the estimation result may be biased. Second, as discussed above, the inverted-U curve EKC contains a time factor: the time trend of CO2 emissions as income increases. In comparison, most studies analyse the EKC by using methods involving cross-sectional data (e.g. Grossman and Krueger, 1991; Panayotou, 1993; Robers and Grimes, 1997; Shafik, 1994). Cross-sectional analytical methods cannot reveal the impact of time; therefore, the estimation result may not be able to offer a 'big picture' perspective. Third, the aforementioned articles do not include in the regressions the lagged CO2 emission.[3] This lagged variable is crucial to the study of the phenomenon, because the lagged variable could impact the current variable over time.

In addition to the aforementioned methodology problems, there is one more issue we wish to address. Previous studies on this topic usually assume that at a certain time, each country is found at a unique and different point on the same EKC (Dinda, 2004). Some studies employ time-series data to conduct single-country case studies; examples include those of Jalil and Mahmud (2009) and Zhang and Cheng (2009). These studies can analyse the time trend inherent in the relationship between CO2 emissions and GDP; however, since they are single-country case studies, the results are not generalisable, and it is impossible to use the results to compare countries.

To overcome the limitations inherent in the use of cross-sectional and time-series data, some studies have started to utilise panel data to conduct empirical studies (e.g. Apergis and Payne, 2009; Aslanidis and Iranzo, 2009; Lantz and Feng, 2006; Seldon and Song, 1994; Wagner, 2008). Panel data could be considered a combination of cross-sectional and time-series data; therefore, panel data could reveal the impact of individual differences or time transitions, which in turn have greater explanatory power. In addition, since panel data have both individual and time dimensions, there are more observations in a panel data sample; this increases the degrees of freedom, enhances the estimation efficiency, and reduces the possibility of multicollinearity. Especially when conducting multi-country analysis, if one uses time-series data from a single country, it is possible that the analysis would ignore the impact of economic integration, and the estimation result could suffer from an inefficient-testing power problem. On the other hand, cross-sectional data ignore the impact of time (e.g. the impact of the business cycle). For this reason, recent studies in the field of international economic integration often utilise panel data. Carson (2010) surveys previous theoretical and empirical studies and concludes that several factors could affect the estimation results of EKC models; these include econometrics models, sample countries, pollution indices, explanatory variables, data attributes, and income and pollution functions. However, there is no mention of the possible nonlinear relationship between CO2 emissions and GDP.

The purpose of the current study is to investigate whether there is a nonlinear relationship between oil-based CO2 emissions and GDP. Our sample includes 98 countries, and the time span is from 1971 to 2007. In the discussion of the relationship between oil CO2 emissions and GDP, previous studies have focused on the inverted-U curve-shaped relationship between the two variables — that is, most previous studies have focused on the establishment of the EKC. Unlike these studies, the current study examines the existence of a threshold effect in the relationship between the two variables. In other words, we would like to see if different levels of economic growth yield different effects vis-à-vis this relationship. This study focuses on the following three points. First, we investigate whether the long-term relationship between oil CO2 emissions and GDP is stable. Concurrently, we examine the nature of that relationship: cross-coupling, relative-decoupling, or absolute-decoupling. The answer can be used to test the EKC hypothesis. Second, we utilise the economic growth rate as the threshold variable, to construct static and dynamic panel threshold models (PTMs). The estimation result of the PTMs could be used to examine the existence of a nonlinear relationship between oil CO2 emissions and GDP. Third, we investigate the impact of population growth on the growth rate of oil CO2 emissions and on the convergence velocity from the short-term disequilibrium to the long-term equilibrium.[4]

The empirical findings can be summarised as follows. First, the cointegration test result indicates that in the long term, the relationship between oil CO2 emissions and GDP is steady. The long-term income elasticity shows that the two variables relative-decouple with each other. Second, the estimation results of the panel static and dynamic models show that in the short term, the three-regime model is appropriate for describing the relationship between the two variables. In the low economic growth regime, GDP negatively affects the growth rate of oil CO2 emissions; however, in the medium economic growth regime, GDP has a significantly positive impact on the growth rate of oil CO2 emissions, and in the high economic growth regime, the

[3] The dynamic model includes as one of the explanatory variables the lagged dependent variable. If the explanatory variables of a regression model include only exogenous variables, the model is called a 'static model'. The advantage of a dynamic model is that it considers the impact of time; its disadvantage is that there would be an endogenous heteroscedasticity problem with the residual. Since this problem has remained unresolved, most previous studies have employed static models. In this study, we use both static and dynamic models and compare the estimation results thereof.

[4] Previous EKC studies include some important macroeconomic variables in their linear models. The effects of these macroeconomic variables on the environment are mixed. Cropper and Griffiths (1994), Bruvoll and Medin (2003), Shi (2003), and Lantz and Feng (2006) each include the population variable in the regression and obtain a significantly monotonic relationship between the population and various forms of environmental variables. This finding suggests that a larger population would increase the demand for goods and services, which in turn would consume more natural resources. On the other hand, Seldon and Song (1994), Kahn and McDonald (1994), Tiffen et al. (1994), and Patel et al. (1995) each find population to relate negatively to environmental variables. One possible explanation for this finding is that as the population increases, more people become aware of the importance of environmental protection, and so the government raises environmental protection standards (Seldon and Song, 1994). In the current study, unlike in previous studies, we include the population growth in the short-term PTM model, to investigate the impact of population growth on the growth rate of oil CO2 emissions and on the short-term convergence adjustment of the model. The current study therefore is the first such attempt within the field, on this research topic.