VALIDITY OF DYNAMICS IN TESTING THE ENVIRONMENTAL KUZNETS CURVE HYPOTHESIS: OECD EVIDENCE

YI-CHIA WANG*

ABSTRACT. The hypothesis called the Environmental Kuznets Curve (EKC) suggests that environmental deterioration in an economy, in some aspects, can be curbed after a certain threshold of income per capita is achieved. Most existing empirical studies, regardless of whether they support or disagree with this hypothesis, are based on inappropriate regressions that use variables with different integration orders. This paper corrects this dynamic deficiency in the conventional EKC test by running a balanced regression that uses variables integrated with the same order. The results indicate that the revised EKC regression developed in this paper improves the cointegration test amongst pollution and the polynomial of income per capita. However, the modified regression shows no evidence for long-run EKC phenomena for sulfur dioxide emissions, as well as carbon dioxide emissions in the selected high-income OECD countries, during the period 1870–2001.

KEYWORDS: Environmental Kuznets Curve; EKC; SO_2, CO_2, panel estimation; OECD

J.E.L. CODE: Q50; Q53

1. INTRODUCTION

THIS PAPER STUDIES a new specification of regression for testing the environmental Kuznets curve (EKC) hypothesis using a panel database. In contrast to the conventional panel estimation, this paper avoids working with unbalanced regressions that include time-series variables with different orders of integration. In this paper, it is shown that a higher power of an I(1) variable (e.g. the second or third power of income per capita) will be asymptotically accompanied by more complex and higher orders of integration. Therefore, when the variables involved in a regression have dynamic properties, their stationarity should be carefully examined before conducting any statistical estimation and inference.

The arrangement of this paper begins with a review of some selected pollution-income studies. Following the literature review, section 3 mathematically demonstrates how the conventional EKC regression is asymptotically inappropriate when it includes a squared or cubic polynomial of integrated variables. An empirical support to this mathematical demonstration is then provided in section 4 using a panel data set for selected OECD

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[*] **Corresponding author**: YI-CHIA WANG, *Box 882, Department of Economics, Tunghai University, Taichung, Taiwan.* Email: `ycwang@thu.edu.tw`. Tel: +886 4 2359-0121 ext. 36127; Fax: +886 4 2359-0702.

countries. Section 5 performs a conventional EKC regression so that one can judge the improvement of an alternative EKC regression proposed in section 6. This paper concludes in section 7.

2. EKC REVIEW AND ASSESSMENT

The observation of the environment–income relationship can be traced back to the late 1960s. At that time the Club of Rome found that the depletion of raw materials, energy and (non-renewable) natural resources had shared a similar upward trend with economic development over several decades (Meadows, Meadows, and Behrens (1972)). This started serious concern with regard to environmental protection. After people gained satisfaction from better material life, their willingness to pay for a cleaner environment and eagerness to reduce the intensity of energy use rose accordingly. Especially in developed economies, pollution control, energy renewal and afforestation had become their major targets in both public and private sectors in recent decades. Wildavsky (1988) remarked on this growing consciousness and attempts to protect the environment by concluding that 'richer is safer and cleaner'. However, convincing empirical evidence to support the causality and the relationship between the evolution of pollution and growing income was scant at the time when the above authors proposed their observational arguments.

Empirical works on the relationship between environmental degradation and a country's wealth were not commenced until the beginning of the 1990s. A pioneering working paper proposed by Grossman and Krueger (1991) (later published in 1995) investigated the relationship between GDP per capita and the three air pollutants — ambient concentrations of sulfur dioxides (SO_2), smoke/dark matters, and suspended particulate matters — for 42 low- and high-income countries with a sample period 1977–1984. The random effect estimation in their paper revealed that both ambient SO_2 concentrations and smoke/dark matters followed an N-shaped trajectory against GDP per capita. That is, the concentration levels of these two pollutants accumulated before GDP per capita reaches the vicinity of 5,000 US$ and then declined as the economy keeps developing until the second turning point was surpassed.[1] These two pollutants eventually grow unboundedly with ever-escalading income per capita.

Instead of using the measure of ambient concentrations of air pollutants, Panayotou (1993) chose airborne SO_2 emissions per capita on a national basis. His research partly echoed the results from Grossman and Krueger (1991). He concluded that the relationship between per capita SO_2 emissions and income per capita follows a bell-shaped pattern, which was similar

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[1] These second turning points were around 15,000 US$ for SO_2 and 12,000 US$ for smoke/dark matters, respectively

to the relationship between income inequality and income per capita proposed in the mid-1950s by Kuznets (1955). Therefore, Panayotou (1993) labeled this bell-shaped pollution–income relationship as the ‘environmental Kuznets curve’ (EKC), which had become a commonly-cited term in the environmental literature.

Most EKC studies employ a panel of countries with a variety of income levels over a number of periods. They are in favor of estimating the following reduced-form regression:

$$EP_{i,t} = \beta_0 + \beta_1 Y_{i,t} + \beta_2 Y_{i,t}^2 + \beta_3 Y_{i,t}^3 + \boldsymbol{\beta} Z_{i,t} + \eta_i + \gamma_t + \epsilon_{i,t}, \qquad (1)$$

where $EP_{i,t}$ and $Y_{i,t}$ respectively represent a certain index of environmental pressure (air pollution, for example) and the level of income per capita in country i at time t.[2] $\boldsymbol{\beta}$ denotes a row vector of coefficients of other non-income explanatory variables, $Z_{i,t}$,[3] and the regression leftover includes country-specific effects (η_i), time-specific factors (γ_t) and a pure white noise ($\epsilon_{i,t}$). Different combinations of the estimated β_1, β_2 and β_3 can lead to distinct shapes of environmental pressure–income relationship. Detailed discussion of these shapes can be referred to de Bruyn and Heintz (1999).

When estimating the reduced-form regression (1), pooled cross-section OLS and panel estimation were the most preferred econometric techniques in previous studies. Panayotou (1993), for example, applied pooled cross-section OLS estimation with three types of air pollutant as dependent variables: per capita emissions of sulfur dioxide, suspended particles and nitrogen oxides (NO_X). His finding revealed that the above pollutants support the EKC hypothesis with the thresholds of income per capita equaling 3,000, 4,500 and 5,500 US$ (market exchange rate adjusted), respectively. However, because he failed to test and correct for the country-specific and time-specific components embedded in equation (1), the estimated coefficients were suspected to have the problems of omitted-variable bias, heteroscedasticity and serial-correlated residuals.

Due to its deficiency, pooled OLS estimation was nearly abandoned after the late 1990s and gradually replaced by panel estimation technique to avoid the above-mentioned econometric problems. Stern and Common (2001), for example, used the data of sulfur emissions from A.S.L and Associates’ yearly report for 73 countries and concluded that the fixed effect estimation for the EKC regression was preferred to random effect with the support of Hausman test. With the elimination of country-specific factors by applying fixed effect estimation, their results seemed to support the existence of an EKC pattern between (logarithm) per capita sulfur emissions and (logarithm) income per capita in his full sample and the two

[2] Logarithm transformation of variables is also commonly used.

[3] To be precise, these are the variables excluding ‘contemporaneous’ income per capita.

subsamples (OECD and non-OECD countries). However, based on the significant coefficients estimated, this concave curve had a turning point equaling 908,178 in real 1990 US$ per capita (purchasing power parity adjusted) for his non-OECD subsample, which was far beyond their sample range of per capita income levels. In effect, these non-OECD countries still have to suffer from monotonically increasing sulfur emissions (with decreasing speed) for many decades after arriving at this high income level. By contrast, their result in the OECD group suggested that these developed countries will be on the declining path after achieving 9,239 US$ per capita income level.

Given the acceptance of the EKC relationship between degrading environment and upgrading wealth, growth optimists tend to believe that economic development is the most useful and surest way to green our nature (Beckerman (1972), Simon (1981) and Wildavsky (1988)). As long as an economy achieves a certain living standard, environmental quality will become a luxury good with income elasticity greater than unity, which in turn increases the value of environmental amenities (Pezzey (1989), Selden and Song (1994), Baldwin (1995), and Day and Grafton (2003)). These arguments seemingly suggest that the environmental degradation is only a short-term phenomenon at the beginning of economic development and will be mitigated in the long run after income per capita surpasses the level where the turning point of the EKC occurs.

EKC studies have been investigated for nearly two decades and continuously broadened in many aspects. and most of the regressions are performed based on historical data series. From a time-series point of view, next section shows how a non-linearly transformed variable, such as income per capita, will distort its original order of integration so that a majority of existing EKC studies need to be reexamined.

3. ASYMPTOTICAL INVALIDITY OF EKC REGRESSIONS

The number of stochastic trends embedded in a variable is the order of integration. That is, if a variable contains M stochastic trends, it is integrated with order M and for simplicity, it is often written as an I(M) variable in the econometric literature. An I(M) variable will be stationary after M^{th} difference. For example, a simple I(2) variable x_t can be expressed as:

$$x_t = A_t + \varepsilon_t; \tag{2}$$

$$A_{t+1} = A_t + B_t + \eta_t; \tag{3}$$

$$B_{t+1} = B_t + \nu_t, \tag{4}$$

where ε_t, η_t and ν_t are level-stationary white noises, and A_t and B_t represent two distinct stochastic trends (random walk processes). The first difference of x_t (Δx_t) will be an I(1) variable when the first stochastic trend A_t is eliminated. The second difference of x_t will eliminate the second stochastic trend so that $\Delta^2 x_t$ is a stationary process.

Let w_t and z_t be two I(1) variables sharing a stochastic trend B_t but having different and uncorrelated white noises, ϵ_t and ξ_t, as follows:

$$w_t = B_t + \epsilon_t \tag{5}$$

$$z_t = \theta B_t + \xi_t \qquad \theta \in (\text{constant}). \tag{6}$$

The definition of cointegration means that a linear combination of variables with 'the same order' of integration can eliminate the same stochastic trend and become a level-stationary process. In this case, a linear combination $z_t - \theta w_t = \xi_t - \theta \epsilon_t$ is a stationary process. That is, when running an OLS regression with one variable on another, one can have a stationary combination of residual series. Therefore, the regression coefficient, $\hat{\theta}$, is meaningful and super-consistent, although its standard error calculated using the usual formulae may be incorrect.

The above dynamic concept is also valid in panel estimation, especially when it uses consecutive time points. In most of the EKC studies, it is the reduced-form regression (1) that generates the curvature and plausible turning points. However, this regression is appropriate only when the incorporated variables (environmental pressure, income per capita and its second and third order of polynomial) share the same stochastic trend and produce a well-behaved residual series. Income per capita, indeed, is found to be a typical I(1) variable in many countries. The empirical findings from Perman and Stern (2003) and later in this paper both show that the development-related pollutants, such as SO_2 and CO_2 emissions per capita are also I(1) variables.

Assuming that income per capita y_t is a random walk series with a drift $b > 0$, it can be written as:

$$y_t = b + y_{t-1} + v_t \tag{7}$$

or equivalently

$$y_t = y_0 + bt + \sum_{i=1}^{t} v_i; \qquad v_i \sim i.i.d.N(0, \sigma_v^2). \tag{8}$$

Equation (8) shows that in addition to the drift term, the shock v_t is accumulating. Thus, it is difficult to have statistical inferences about y_t unless the persistent shocks are eliminated.

The orders of integration for y_t^2 and y_t^3 are especially of interest if the reduced-form EKC regression is to be meaningful. Derived from equation (8), the first difference of y_t^2 can be expressed as:

$$\begin{aligned}\Delta y_{t+1}^2 = y_{t+1}^2 - y_t^2 = b(2y_0 + b) + 2b(b + v_{t+1})t \\ + \left(2v_{t+1}\sum_{i=1}^{t} v_i + v_{t+1}^2 + 2b\sum_{i=1}^{t} v_i + 2bv_{t+1} + 2y_0 v_{t+1}\right).\end{aligned} \tag{9}$$

As can be seen, the first difference of y_t^2 contains accumulated shocks $\sum_{i=1}^{t} v_i$ in equation (9), so that at least y_t^2 is an I(1) variable. However, equation (9) contains additional terms of shocks, suggesting that the trending behavior in y_t^2 is stronger and more complicated than an I(1) stochastic trend. In addition, when implementing the second difference of y_t^2, it comes to:

$$\begin{aligned}\Delta^2 y_{t+1}^2 = \Delta y_{t+1}^2 - \Delta y_t^2 = 2b^2 + 2b(v_{t+1} - v_t)t \\ + \left\{v_{t+1}^2 + v_t^2 + 2\left[(v_{t+1} - v_t)\sum_{i=1}^{t} v_i + b(v_{t+1} + v_t) + y_0(v_{t+1} - v_t)\right]\right\}.\end{aligned} \tag{10}$$

Equation (10) shows rare possibility that Δy_t^2 is a level-stationary variable. It can be inferred that the cube of y_t will not be a simple I(1) process either. Therefore, involving y_t, y_t^2 and y_t^3 in a regression is 'unbalanced' and none of their linear combinations can completely eliminate stochastic trends asymptotically. This concept has brought to us some worries for a majority of EKC studies using a reduced-form regression (1). The estimated coefficients in regression (1) and corresponding EKC turning points are neither meaningful nor appropriate, given the fact that income per capita contains a unit root.

Recent EKC researchers have noticed this problem. Perman and Stern (2003) concluded that the logarithm of sulfur emissions, income per capita and its square are all non-stationary in levels for 74 countries spanning 31 years, using two different panel unit root tests developed by Levin and Lin (1993) and Im, Pesaran, and Shin (2003), respectively. Though Perman and Stern (2003) remarked that the reduced-form regression was meaningful only when the OLS residuals were stationary, they did not conduct further tests of higher order of integration for their non-linearly transformed variables. With a non-stationary regression residual series, they rejected the EKC cointegration relationship and concluded that the EKC pattern does not exist in sulfur emissions.

To sum up, the prerequisite of the standard cointegration relationship between a certain index of pollution and the polynomial of income per capita is that they must have the same order of integration. With the same order of integration, they should also be able to share the same stochastic trend and generate an I(0) residual series in a regression otherwise we may reach a spurious conclusion.

4. EMPIRICAL INVALIDITY OF EKC REGRESSIONS

To provide an empirical support to the argument in the previous section in an asymptotical sense, it is necessary to have a time span as long as possible in a panel of observations. Therefore, data selection for GDP, population and emissions of certain pollutants are based on the availability of their long time span. In this paper, GDP and population data are directly available from Maddison (2003). Two major air pollutants are selected as their data have been recorded for more than one century in many advance economies. For SO_2 emissions this paper selects 19 OECD countries and 17 out of them are for CO_2 emissions.[4]

4.1 Data Description

The historical data of an individual country's population and GDP levels were constructed by Maddison (2003) from the late 19th century to the early 21st century, covering almost all countries in the world. Population levels were estimated in the mid-year and GDP levels were recorded by million 1990 International Geary-Khamis dollars (US$). Detailed data construction methods were outlined in Maddison (2003).

A.S.L. and Associates' yearly reports recorded SO_2 emissions for a majority of countries from 1850 to 1990. Stern (2005) extended this data set beyond 1990 using published data for around 70 countries and, where such published data did not exist, by extrapolation of growth rates or by using econometric estimation based on either the emission frontier method or an EKC method. Consistently based on the estimation criteria from A.S.L. and associates' yearly data, Stern's work included anthropogenic SO_2 emissions from mining and smelting activities, burning hard coal, brown coal, and petroleum. Therefore, the series of sulfur emissions will not be affected by different calculation methods.

CO_2 emissions are those stemming from the burning of fossil fuels (including solid fuel, liquid fuel and gas) and the manufacture of cement production. According to this criterion, the Oak Ridge National Laboratory (ORNL) organized by the Carbon Dioxide Information Analysis Center (CDIAC), records more than 100 years of CO_2 emissions based on fuel consumption for the majority of advanced countries (for the United Kingdom, ORNL even traces emissions back to 1750), and at least 50 years for many developing economies.

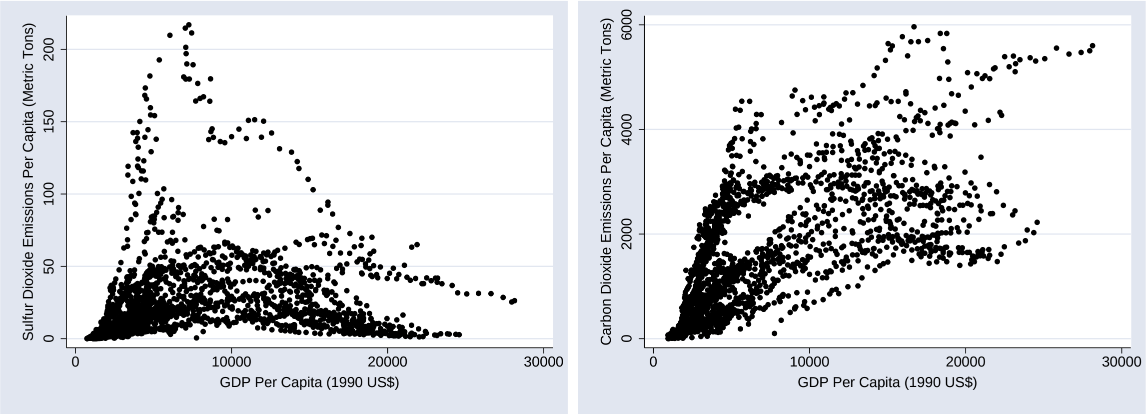
[4] These 19 OECD countries are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Span, Sweden, Switzerland, United Kingdom and the United States. For CO_2 emissions, Japan and Portugal are excluded due to the lack of data.

The empirical studies of this paper extract the above data sets by an 132-year period from 1870 to 2001. Next I will use variables measured in per-capita form (i.e. sulfur and carbon emissions per capita and GDP per capita) to avoid the mis-measurement driven by population size. A broad look at these per-capita variables is left in Figures A1 to A3 in Appendix A.1.

4.2 *Visual Observation of Emission–Income Relationship*

Visual observation of Figure 1 reveals two different patterns of the pollution–income relationship in selected OECD countries. As far as SO_2 emissions are concerned, per capita emissions of this air pollutant seem to follow an inverted U-shaped tendency as per capita GDP grows. In contrast, CO_2 emissions per capita demonstrates a concave trajectory against individual income levels. This development-dependent greenhouse gas emission may be curbed when countries are wealthy enough to innovate suitable alternatives of power generating technology (e.g. solar energy) as well as enforce a stricter international treaty of carbon regulations. Therefore, it is not surprising that a decreasing speed of CO_2 emissions is observed when higher levels of income per capita are achieved.

FIGURE 1: Scatter Diagrams for SO_2 Emissions Per Capita and CO_2 Emissions Per Capita, against GDP Per Capita in Selected OECD Countries.



Note: The above graphs are plotted for SO_2 emissions in 19 high-income OECD countries, and 17 high-income OECD countries for CO_2 emissions, during the period 1870–2001.

Although the non-linear relationship between the two pollutants and income per capita can be observed in Figure 1, appropriate and meaningful regressions are still required for statistical inferences. Next, some panel unit root tests are performed for per-capita variables to be involved in EKC regressions.

4.3 Panel Unit Root Test

The panel unit root test for a single variable $z_{i,t}$ is to estimate the following equation using a panel of observations:

$$\Delta z_{i,t} = \alpha_i + \gamma_{i,t} + \rho_i z_{i,t-1} + \sum_{j=1}^{q_i} \delta_j \Delta z_{i,t-j} + \epsilon_{i,t}; \qquad i = 1, \ldots, N, \;\; t = 1, \ldots, T, \tag{11}$$

where α_i and $\gamma_{i,t}$ denote country-specific and time-specific effects, respectively. The inclusion of the augmented terms of $\Delta z_{i,t-j}$ is for the correction of q_i order of serial correlation for each country i. If the variable $z_{i,t}$ has an obvious time trend, it should be included in the regression (11) and the alternative hypothesis will be that $z_{i,t}$ is trend stationary. ρ_i is the main coefficient of interest in testing the existence of a unit root.

To test the stationarity of $z_{i,t}$ series, Im, Pesaran, and Shin (2003) proposed a group mean statistic by individually testing the null hypothesis of $\rho_i = 0$ versus an alternative that ρ_i is negative. This allows heterogeneous coefficients $\hat{\rho}_i$ for each country.

Table 1 implements these two versions of panel unit root test for SO_2 emissions per capita ($S_{i,t}$), CO_2 emissions per capita ($C_{i,t}$) and different non-linear transformations of GDP per capita ($Y_{i,t}$).

TABLE 1: Panel Unit Root Tests for Selected OECD Countries.

	Selected variables in levels[†]					
	$Y_{i,t}$	$Y^2_{i,t}$	$Y^3_{i,t}$	$Y^{\frac{1}{2}}_{i,t}$	$S_{i,t}$	$C_{i,t}$
Sample coverage ($N \times T$)	$19 \times 132 = 2508$	$19 \times 132 = 2508$	$19 \times 132 = 2508$	$19 \times 132 = 2508$	$19 \times 132 = 2508$	$17 \times 132 = 2244$
Im, Pesaran, and Shin (2003) test statistics	14.0049	26.5531	28.7923	7.0169	5.4809	1.9175
Critical values	-2.51	-2.51	-2.51	-2.51	-2.51	-2.51
Conclusion	non-stationary	non-stationary	non-stationary	non-stationary	non-stationary	non-stationary
	Selected variables in first difference					
	$\Delta Y_{i,t}{}^{\ddagger}$	$\Delta Y^{2}_{i,t}{}^{\ddagger}$	$\Delta Y^{3}_{i,t}{}^{\dagger}$	$\Delta Y^{\frac{1}{2}}_{i,t}{}^{\ddagger}$	$\Delta S_{i,t}{}^{\ddagger}$	$\Delta C_{i,t}{}^{\ddagger}$
Sample coverage ($N \times T$)	$19 \times 131 = 2489$	$19 \times 131 = 2489$	$19 \times 131 = 2489$	$19 \times 131 = 2489$	$19 \times 131 = 2489$	$17 \times 131 = 2227$
Im, Pesaran, and Shin (2003) test statistics	-22.4345	-1.4300	8.9716	-31.7544	-35.5765	-40.6118
Critical values	-1.89	-1.89	-2.51	-1.89	-1.89	-1.89
Conclusion	stationary	non-stationary	non-stationary	stationary	stationary	stationary
	Selected variables in second difference[‡]					
	$\Delta^2 Y_{i,t}$	$\Delta^2 Y^2_{i,t}$	$\Delta^2 Y^3_{i,t}$	$\Delta^2 Y^{\frac{1}{2}}_{i,t}$	$\Delta^2 S_{i,t}$	$\Delta^2 C_{i,t}$
Sample coverage ($N \times T$)	$19 \times 130 = 2470$	$19 \times 130 = 2470$	$19 \times 130 = 2470$	$19 \times 130 = 2470$	$19 \times 130 = 2470$	$17 \times 130 = 2210$
Im, Pesaran, and Shin (2003) test statistics	-33.5977	-26.8590	-16.0793	-33.3067	-34.7438	-31.8859
Critical values	-1.89	-1.89	-1.89	-1.89	-1.89	-1.89
Conclusion	stationary	stationary	stationary	stationary	stationary	stationary

[†] Test specification includes individual intercepts and a linear trend.

[‡] Test specification includes individual intercepts and no trends.

[*] The above test specifications are chosen based on the average pattern of the series in Figures A4 to A6.

[*] Lag length is optimally selected by Hannan-Quinn lag length selection criteria (maximum=12) for each variable.

[*] 5% left-sided critical values for Im, Pesaran, and Shin (2003) test statistics are from Im, Pesaran, and Shin (2003) (Table 2) with $N = 15$ and $T = 100$.

In Table 1, it is firstly concluded that the null hypothesis of containing a unit root cannot be rejected for all per-capita variables in levels, while a first difference of $Y_{i,t}$, $S_{i,t}$ and $C_{i,t}$ makes them stationary. In contrast, the second and third powers of $Y_{i,t}$ are not stationary after taking first differences so that their integration orders are suspected to be greater than one. Secondly, in the lower part of Table 1, a second difference of $Y_{i,t}^2$ and $Y_{i,t}^3$ reduces their integration order to zero.

The summary of the panel unit root test from Im, Pesaran, and Shin (2003) is that, in the selected OECD countries, income per capita and development-dependent SO_2 and CO_2 emissions per capita are empirically I(1), while the non-linear transformations of income per capita are integrated with order two, except for the case of $Y_{i,t}^{\frac{1}{2}}$.[5] Therefore, an EKC regression (1) cannot be a cointegration equation as it includes the explanatory variables, $Y_{i,t}$, $Y_{i,t}^2$, and $Y_{i,t}^3$, with different order of integration. This concern is shown in the next section.

5. CONVENTIONAL EKC REGRESSIONS

The following conventional EKC regression that has been widely adopted in existing studies helps this section illustrate the argument proposed in the previous section:

$$EP_{i,t} = \alpha_0 + \alpha_1 Y_{i,t} + \alpha_2 Y_{i,t}^2 + \epsilon_{i,t}. \tag{12}$$

It is noticed that equation (12) excludes the cubic term of income per capita, $Y_{i,t}^3$. This assumption comes from the facts that Figure 1 shows no clear multiple turning points in both per capita SO_2 and CO_2 EKC regressions. Table 2 records the estimation results of these two regressions using pooled OLS, fixed effect and random effect techniques, respectively.

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[5] In fact, one might find a different power $\in (0,1)$ or $\in (1,2)$ other than $\frac{1}{2}$ for income per capita and reach the same I(1) conclusion.

TABLE 2: The Estimation Results of Conventional EKC Regression.

	Regression results from SO_2 emissions per capita			Regression results from CO_2 emissions per capita		
Estimated coefficients	Fixed Effect	Random Effect	Pooled OLS	Fixed Effect	Random Effect	Pooled OLS
α_0	-0.5489 (0.7771)	-0.5612 (4.9911)	-3.5441 (1.2768)	126.8288 (26.7832)	125.8106 (169.5758)	-121.5248 (46.2639)
α_1	0.0072 (0.0002)	0.0072 (0.0002)	0.0077 (0.0003)	0.2864 (0.0072)	0.2866 (0.0072)	0.3457 (0.0124)
α_2	-3.22×10^{-7} $(9.87{\times}10^{-9})$	-3.22×10^{-7} $(9.87{\times}10^{-9})$	-3.33×10^{-7} $(1.63{\times}10^{-8})$	-7.37×10^{-6} $(3.33{\times}10^{-7})$	-7.36×10^{-6} $(3.33{\times}10^{-7})$	-9.41×10^{-6} $(5.80{\times}10^{-7})$
Hausman test		$\chi^2(2) = 2.39$			$\chi^2(2) = 5.12$	
Adjusted R^2	0.7301	0.3177	0.1737	0.8565	0.7190	0.5294
Sample Coverage ($N \times T$)	$19 \times 132 = 2508$	$19 \times 132 = 2508$	$19 \times 132 = 2508$	$17 \times 132 = 2244$	$17 \times 132 = 2244$	$17 \times 132 = 2244$
Residual Im, Pesaran, and Shin (2003) test statistics	1.1770	1.7779	1.3812	1.2390	1.2430	1.9612
EKC turning point, $(-\frac{\alpha_1}{2\alpha_2})$ (1990 US$, PPP adjusted)	$\$11,127$ (87)	$\$11,132$ (87)	$\$11,596$ (152)	$\$19,427$ (425)	$\$19,418$ (427)	$\$18,368$ (526)

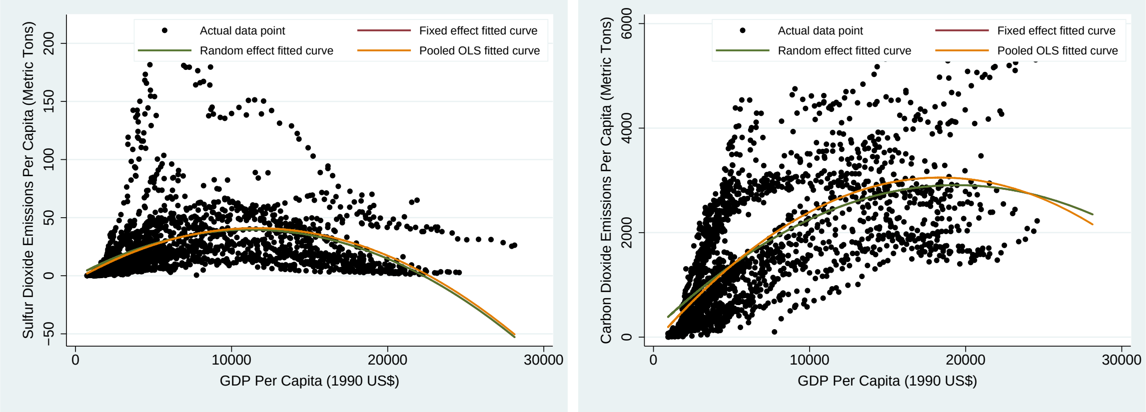
[*] Standard errors are in parentheses.

[*] Hausman test finds no evidence of fixed effects for both air pollutants.

[*] The residual test is based on the Im, Pesaran, and Shin (2003) panel unit root test with individual intercepts. Their left-sided critical value at 5% level of significance is -1.89 for $N = 15$ and $T = 100$.

Some sensible and significant turning points are estimated in Table 2. The conventional EKC regression for CO_2 emissions per capita generates turning points within the sample range. This suggests that these high-income countries are moving towards a declining path of CO_2 emissions with their current income level. On the other hand, the turning points of the typical local pollutant, SO_2 emissions per capita, are 50% lower than global CO_2 emissions. However, these turning points for both air pollutants shown in Figure 2 are estimated based on a theoretically unbalanced regression so that the regression residual are not stationary according to the residual Im, Pesaran, and Shin (2003) test statistics in Table 2. This empirical evidence re-affirms the central argument in this paper.

FIGURE 2: Fitted Curves for SO_2 Emissions Per Capita and CO_2 Emissions Per Capita, against GDP Per Capita in Selected OECD Countries (Based on Equation (12)).



Note: The above graphs are plotted for SO_2 emissions in 19 high-income OECD countries, and 17 high-income OECD countries for CO_2 emissions, during the period 1870–2001.

Some turning points were estimated by existing EKC studies using the same quadratic functional form for a panel of observations. For instance, Selden and Song (1994) and Perman and Stern (2003) had estimated the turning points for SO_2 emissions equaling $10,292 (1985 US$) and $10,975 (1990 US$), respectively. Similarly, Agras and Chapman (1999) estimated the turning point of CO_2 emissions equaling $13,630 (1985 US$) from the same quadratic function, though, most of the CO_2 EKC studies, such as Cole and Elliott (2003) and Galeotti and Lanza (2005), tended to believe that the emissions of this pollutant are monotonically increasing without a turning point in the long run. However, the absence of testing the stationarity of regression residuals in these studies leaves the long-run cointegration relationship between the two air pollutants and income per capita in doubt.

6. AN ALTERNATIVE REGRESSION FOR EKC TEST

A possible solution to avoid running an unbalanced EKC regression could be a regression that uses $Y_{i,t}$ and $Y_{i,t}^{\frac{1}{2}}$ as explanatory variables in testing the EKC cointegration relationship between both air pollutants and income per capita. This alternative approach maintains the merit of capturing the non-linear emission–income pattern without encountering any problems caused by unbalanced regressions. Using the same OECD sample used in the previous section, the following regression is estimated in Table 3.

$$EP_{i,t} = \beta_0 + \beta_1 Y_{i,t} + \beta_2 Y_{i,t}^{\frac{1}{2}} + \epsilon_{i,t}. \tag{13}$$

TABLE 3: The Estimation Results of the Revised EKC Regression (13).

	Regression results from SO_2 emissions per capita			Regression results from CO_2 emissions per capita		
Estimated coefficients	Fixed Effect	Random Effect	Pooled OLS	Fixed Effect	Random Effect	Pooled OLS
$\hat{\beta}_0$	-59.3924 (2.4165)	-59.4220 (5.4886)	-65.4314 (3.6827)	-1163.7010 (85.5160)	-1168.4780 (185.7651)	-2166.0980 (136.3716)
$\hat{\beta}_1$	-0.0105 (0.0003)	-0.0105 (0.0003)	-0.0109 (0.0005)	-0.1095 (0.0117)	-0.1100 (0.0117)	-0.2204 0.0192
$\hat{\beta}_2$	2.0260 (0.0608)	2.0266 (0.0608)	2.1379 (0.0936)	44.7252 (2.1340)	44.8351 (2.1332)	67.7330 (3.4363)
Hausman test		$\chi^2(2) = 1.54$			$\chi^2(2) = 4.53$	
Adjusted R^2	0.7311	0.3253	0.2015	0.8527	0.7136	0.5012
Sample Coverage ($N \times T$)	$19 \times 132 = 2508$	$19 \times 132 = 2508$	$19 \times 132 = 2508$	$17 \times 132 = 2244$	$17 \times 132 = 2244$	$17 \times 132 = 2244$
Residual Im, Pesaran, and Shin (2003) test statistics	-0.5952	-0.5949	-0.4675	1.1484	1.1488	1.4491
EKC turning point, $(\frac{-\hat{\beta}_2}{2\hat{\beta}_1})^2$ (1990 US\$, PPP adjusted)	\$9,226 (97)	\$9,228 (97)	\$9,588 (172)	\$41,730 (5056)	\$41,531 (4998)	\$23,602 (1783)

[*] Standard errors are in parentheses.

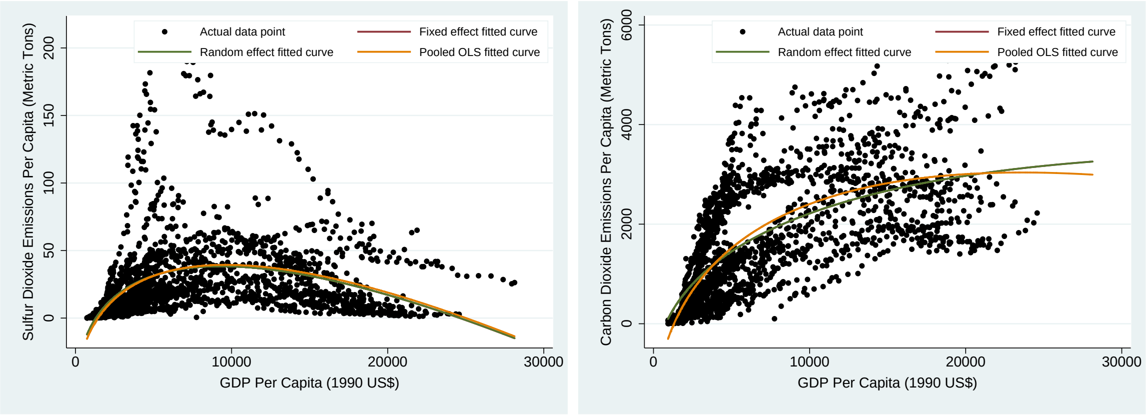
[*] Hausman test finds no evidence of fixed effects for both air pollutants.

[*] The residual test is based on the Im, Pesaran, and Shin (2003) panel unit root test with individual intercepts. Their left-sided critical value at 5% level of significance is -1.89 for $N = 15$ and $T = 100$.

Due to possible existence of country-specific effect, the estimated coefficients produced by the pooled OLS technique may suffer from unfavorable bias. In terms of random and fixed effect estimation techniques, as can be seen, the Hausman test statistics for the two techiniques are not greater than the required critical value (5.99 for 5% level of significance) so that the random effect estimation is preferred.

With the estimated coefficients of $\hat{\beta}_1 < 0$ and $\hat{\beta}_2 > 0$, both CO_2 and SO_2 emissions per capita are predicted to follow an inverted-U EKC pattern regardless of different estimation techniques. Again, the estimated turning point of SO_2 emissions is far lower than that of CO_2 emissions. This result is consistent with previous findings (e.g. Selden and Song (1994)). However, even if there is a turning point, holding other things constant, the selected 17 OECD countries still have to suffer from increasing CO_2 emissions per capita until individual income levels reach the threshold of around 41,600 US$, which lies outside the sample range. The fitted curves for the two air pollutants are drawn in Figure 3.

FIGURE 3: Fitted Curves for SO_2 Emissions Per Capita and CO_2 Emissions Per Capita, against GDP Per Capita in Selected OECD Countries.



Note: The above graphs are plotted for SO_2 emissions in 19 high-income OECD countries, and 17 high-income OECD countries for CO_2 emissions, during the period 1870–2001.

Compared to Table 2, the estimated turning points of SO_2 emissions per capita in Table 3 are slightly lower in the quadratic-form specification than those generated by regression (13). In contrast, the estimated EKC turning points of CO_2 emissions per capita increase dramatically from 19,000 US$ in Table 2 to 41,000 US$ in Table 3, using fixed effect and random effect estimation techniques.

From Tables 2 to 3, the residual test statistics from Im, Pesaran, and Shin (2003) have shown a tendency to reject the null hypothesis that the regression is spurious. This suggests that the use of $Y_{i,t}^{\frac{1}{2}}$ instead of $Y_{i,t}^{2}$ improves the EKC regression in Engle–Granger cointegration sense. Although the stationarity of regression residual is improved, it still contains a unit root so the a long-run non-linear cointegration relationships between the two air pollutants and income per capita does not exist.

7. CONCLUDING REMARKS

This paper revisits the validity of conventional method of testing the EKC hypothesis from the long time-series perspective. Before performing estimations, it is emphasized that in a cointegrating regression, both the dependent variable and selected regressors should be integrated with the same order. Through implementing the formal panel unit root test from Im, Pesaran, and Shin (2003), this paper demonstrates that the second and third powers of income per capita are integrated with orders higher than one in selected high-income OECD countries during the period 1870–2001. As a result, income per capita and its second and third degree of polynomial cannot share the same stochastic trend with the two I(1) dependent variables, per capita SO_2 and CO_2 emissions.

To avoid the problem of running an unbalanced regression, this paper includes only income per capita and its square root transformation in the set of explanatory variables. To the best of my knowledge, this is the first attempt to correct the dynamic invalidity of testing the EKC hypothesis in literature using a balanced regression. Indeed, based on the selected OECD sample, the balanced EKC regression suggested in this paper produces a more stationary residual series than the conventional unbalanced equation.

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APPENDICES

A.1. INDIVIDUAL TIME-SERIES GRAPHS

FIGURE A1: GDP Per Capita for 19 High-income OECD Countries for 1870–2001.

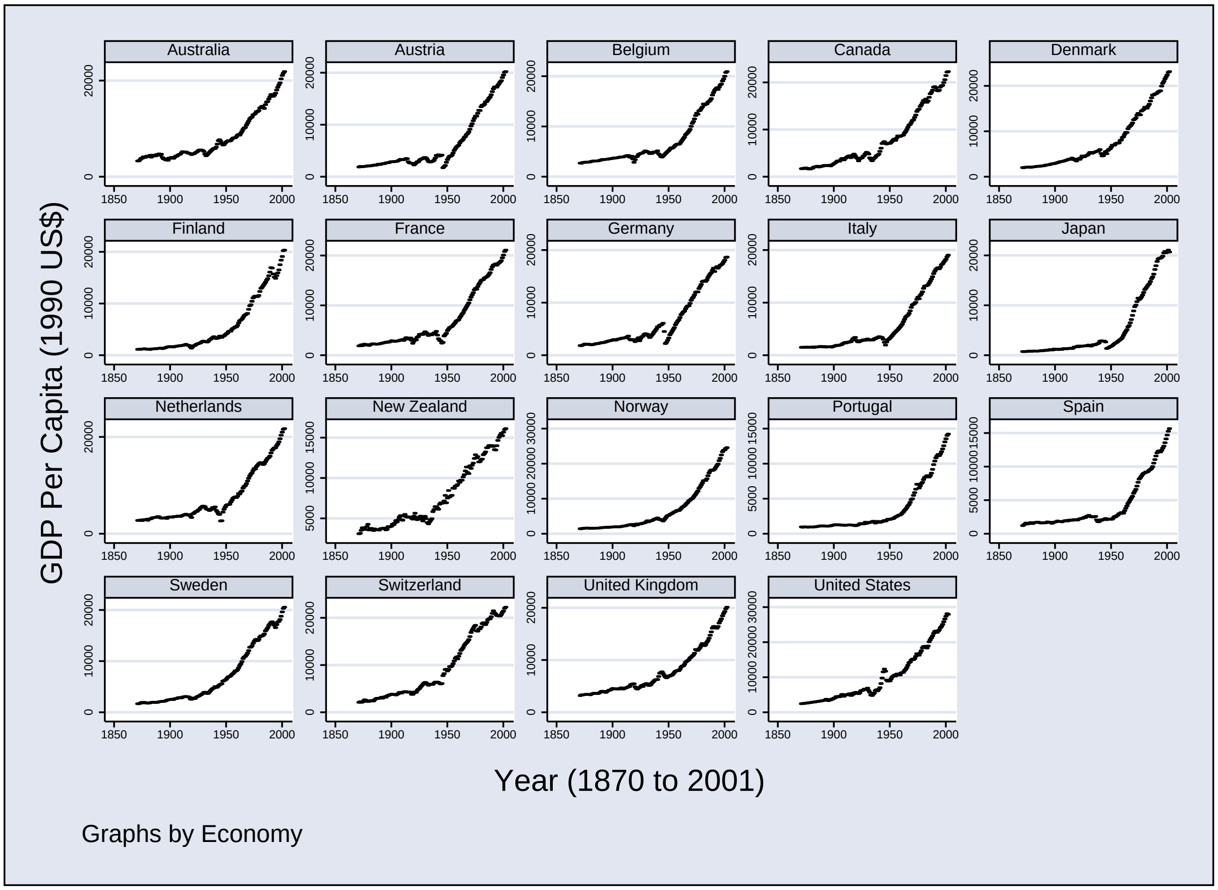

FIGURE A2: SO_2 Emissions Per Capita for 19 High-income OECD Countries for 1870–2001.

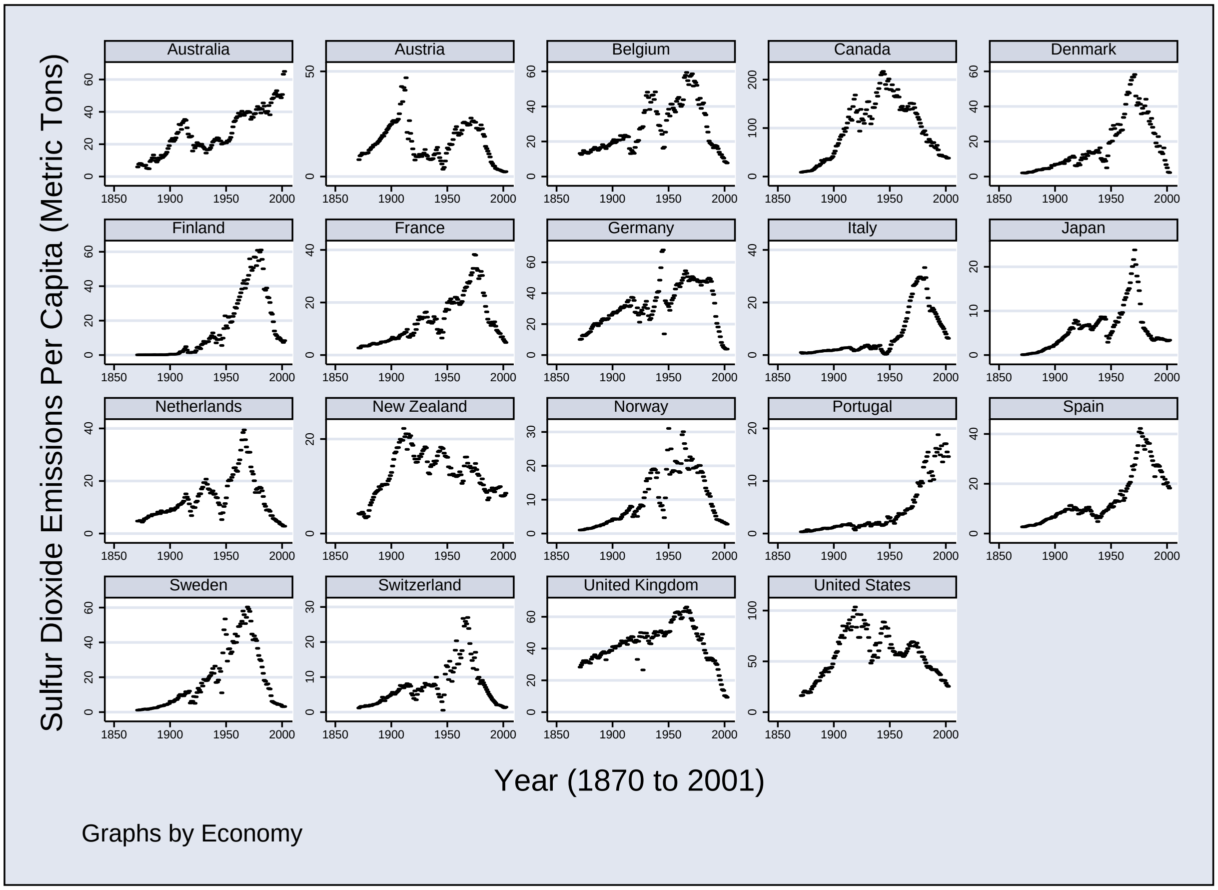

FIGURE A3: CO$_2$ Emissions Per Capita for 17 High-income OECD Countries for Period 1870–2001.

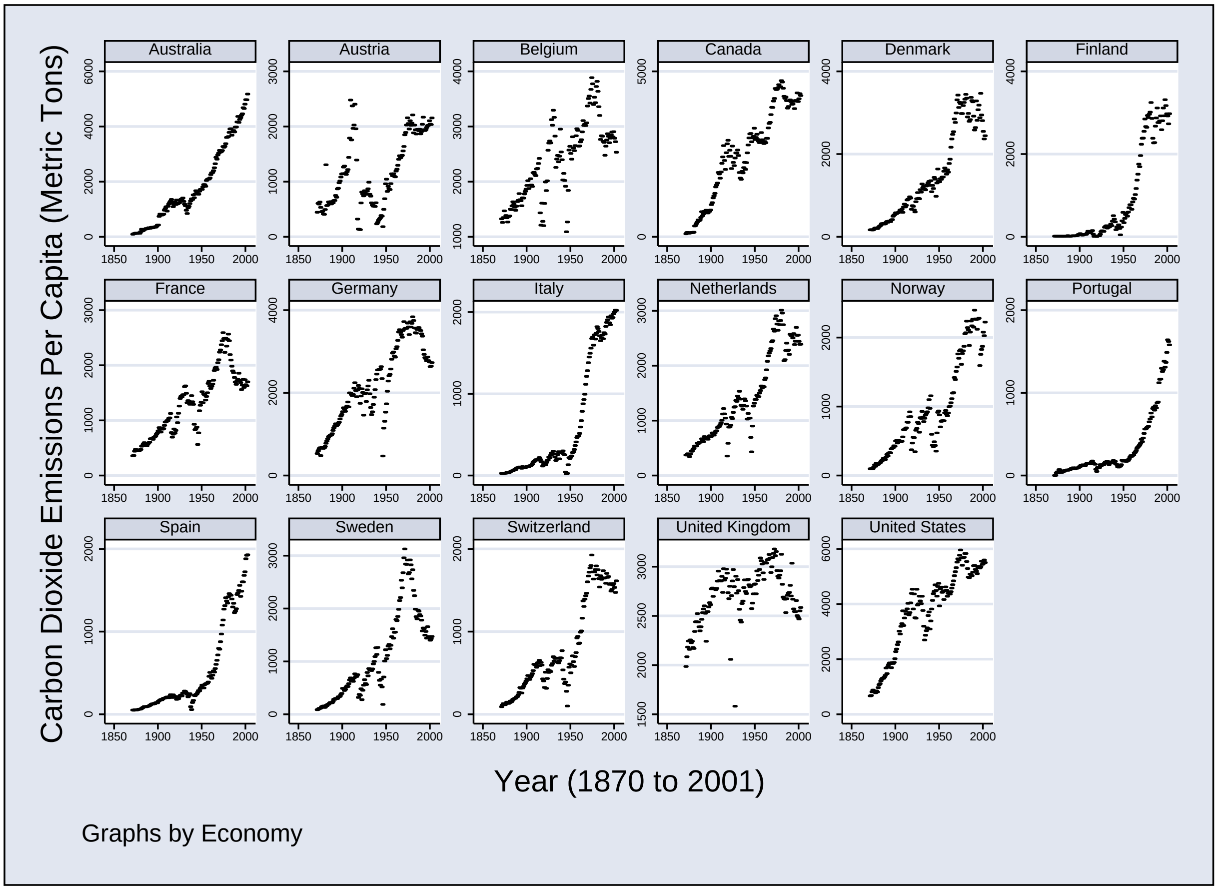

FIGURE A4: Non-linear Transformations of Income Per Capita.

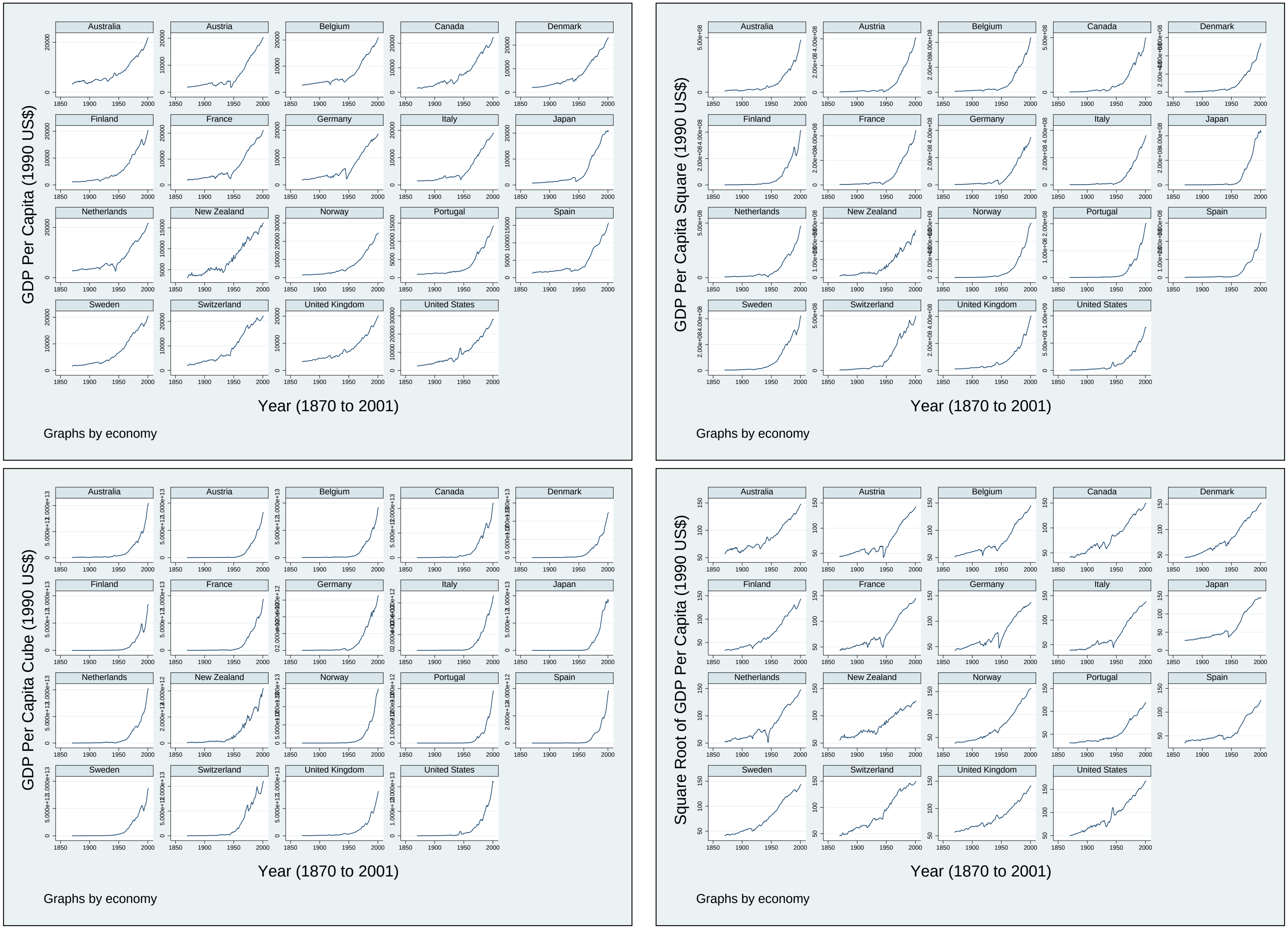

FIGURE A5: First Differences of Non-linear Transformations of Income Per Capita.

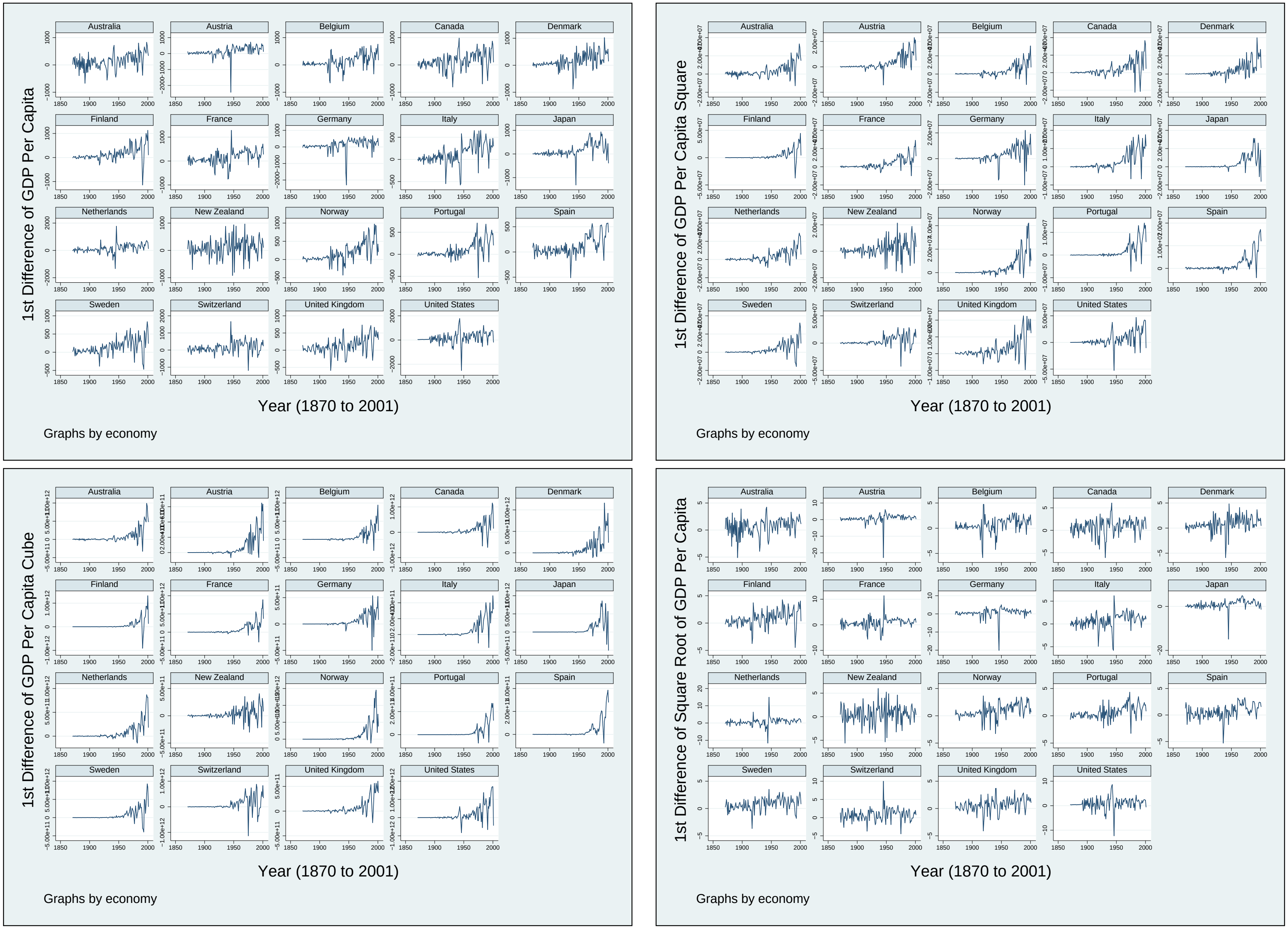

FIGURE A6: Second Differences of Non-linear Transformations of Income Per Capita.