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Dynamic Trends of Carbon Intensities among 127 Countries

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Abstract: Many countries in the world have been experiencing widely varying rates of change in their carbon intensity (CI) of economic output. The dynamic trend of CI in this research is measured by the progress ratio (PR) from an experience curve (EC) involving 127 countries during the period of 1980–2011. The overall average PR of 88.8% estimated for the total group of 127 indicates a decreasing trend of carbon intensity. This means that each doubling of the cumulative CO_2 emission by this group has reduced carbon intensity by 11.2%. While a majority of 83 countries experienced a decreasing trend with an average PR of 73.1%, the remaining 44 countries have experienced an increasing trend with an average PR of 114.5%. When two different types of EC, classical and kinked, were applied, 73 countries displayed a kinked slope with an average PR of 73.4%, and 54 countries displayed a classical slope with an average PR of 104.2%. Examination of the type of trend and slope of EC suggests the chance of a major improvement of the future CI in the following order: (1) the 35 countries with a classical slope and an increasing trend of CIs; (2) the nine countries with a kinked slope and an increasing trend of CIs; (3) the 19 countries with a classical slope and a decreasing trend of CIs; and (4) the 64 countries with a kinked slope and a decreasing trend of CIs. Further implications from these findings are discussed.

Keywords: carbon intensity of economic output; CO_2 emissions; progress ratio; classical experience curve; kinked experience curve

1. Introduction

An increase of carbon emission in the world has continued each year, from the 22.7 billion tons of CO_2 emitted in 1990 to the 36.3 billion tons in 2014. The first pause occurred in 2015 with an emission of 36.2 billion tons, a reduction of 0.1 billion tons [1]. However, the overall trend of global carbon emissions does not reveal the pervasive dynamic changes that individual countries experience in their carbon emission trends. For example, the four major countries—China, the United States, India, and Japan—have emitted a combined total of 19.7 billion tons of CO_2 in 2015, accounting for 54.42% of the global emissions. During the 25-year period from 1990 to 2015, China's emissions exceeded that of the United States for the first time in 2005, making China the largest producer of carbon emissions. Continuing a rapidly increasing trend, China's emission output grew to 10.7 billion tons, which was over twice the output of the United States (at 5.2 billion tons) by 2015. Similarly, India's emissions exceeded that of Japan in 2006. Additionally, by 2015, India's output of 2.5 billion tons was nearly twice that of Japan's output of 1.3 billion tons. These examples indicate that many countries in the world have changed their emission output rankings during the same period because of different rates of emission experienced by countries.

Among the large number of carbon emission influencing factors [2–5], the growth rate of a country may be the most important common influencing factor that affects emission outputs of every country. For that reason, the carbon intensity (CI) of economic output is widely used as the measure of comparing the carbon emission trends of multiple countries with different sized GDPs [3]. Despite a large number of studies adopting CIs as the measure of the carbon emission trends, a few issues still remain underexplored. First, most of the previous studies tend to focus on a specific country [6], a small number of countries [4], or multiple regions [5]. Zhu et al.'s article, examining the CI trend of 89 countries for three decades, is a rare exception. By analyzing the CI trend of 127 countries from 1980 to 2011, this study provides a comprehensive picture covering the countries that used to be either excluded or classified as RoW (Rest of World) [3]. Second, those studies focusing on the direction and speed of the CI change (examining the long-term CI trend) typically measure the CI change with a simple averaged annual rate [3]. While the average annual change is a useful way to demonstrate the long-term trend, it fails to capture the dynamic nature of change during the period. This research employs the experience curve (EC) methodology to address this issue. The progress ratio (PR) of the EC represents the rate of change for CI as a function of doubling cumulative carbon emission for individual countries. By using two types of EC, classical and kinked, we examine not only the rate of change for Cis, but also the multiple rates of CI change, if any.

Our analysis identifies better performing countries which have reduced CI from poorly performing countries which have increased CIs. The results not only show the list of countries that are likely to continue their decreasing trend of CI in the future, but also suggest which countries may be likely to reduce their future CI by breaking away from their past trends of increasing CI. To the best of our knowledge, using EC to estimate PRs of CIs for more than 100 countries has not been reported in the literature. Therefore, this research may present a new contribution in the carbon emission literature.

Following this introduction, this paper is organized into the following six sections. Section 2 presents a brief review of past studies on the trends of CIs for multiple countries. Section 3 presents a brief review of EC applications in the energy field. Section 4 explains the data and method used. Description of the results follows in Section 5. Finally, the conclusion and limitations of our findings are discussed in Section 6.

2. Background Information on Carbon Intensity of Economic Output (CI)

The use of CI instead of carbon emission will make for a more meaningful comparison among countries with different-sized GDPs. By factoring out the varying sizes of national economies, the use of CI enables the focus of the analysis to be on other factors such as different structures and productivities of the economy, different resource endowment, different past climate action, and other policies adopted by the respective countries. For example, the difference of carbon emissions in 2015 between China's 10.7 billion tons over Japan's 1.3 billion tons was about 823% higher. However, comparing the measures in CI, the difference is reduced to 184% higher with China's CI of 0.475 versus Japan's 0.257. Between the United States and Japan, the difference of emission in 2015 was 400% higher for the United States, whereas the difference in CI was only 12% higher. Here, the CI for the United States and Japan was 0.301 and 0.257, respectively. These CIs are measured in metric tons per 1000 Purchasing Power Parity (ppp) 2005 dollars.

The static concept of CI for a given year can be converted into a dynamic concept by expressing the rate of change from the previous year to a given year. The same process can also convert GDP and carbon emission into a dynamic concept. Table 1 shows how the annual % change in 2015 CI and 2015 real GDP in ppp dollars during 2014–2015 are combined to yield the % change of 2015 carbon emission for four major countries. For example, China had reduced their CI by 6.4% from 2014 to 2015. However, because the real GDP growth of 6.9% in 2015 was higher than the 6.4% reduction in CI, China ended up increasing their carbon emissions by 0.04%. On the other hand, Japan had reduced their carbon emissions by 2.3% in 2015 due to the combined effect of their low GDP growth rate of

0.5% and a high −3.0% reduction of CI. The second to the last column in Table 1 lists the 15-year trend of the annual average change of CI from 2000–2015. China and the United States are tied with a −2.4% reduction rate, followed by India's −1.5% and Japan's −0.9%.

Table 1. Rate of change for 2015 carbon intensity of economic output (CI) for four major countries.

	CI (2015) Metric ton per 1000 ppp 2005 Dollars	Real GDP Growth Rate 2014–2015	Change in 2015 CI from 2014	Change in 2015 Emission from 2014	Annual Average Change (2000–2015)	2015 Emission (in Billion tons)
China	0.475	6.90%	−6.40%	0.04%	−2.40%	10.70
US	0.301	2.30%	−4.30%	−2.40%	−2.40%	5.20
India	0.276	7.60%	−1.50%	5.40%	−1.50%	2.50
Japan	0.257	0.50%	−3.00%	−2.30%	−0.90%	1.30
World	0.295	3.10%	−1.30%	0.20%	−1.30%	36.20

Source: Olivier et al. [1].

How pervasive and consistent are the decreasing trends of CIs shown by these four countries when the analysis is expanded to include multiple countries? Using data available from a couple of yearly issues from the Low Carbon Economy Index [7,8], Table 2 presents the historical data of CIs for 19 major countries in the world for the years of 1990, 2000, 2008, and 2015. First, it can be observed that every country has displayed a decreasing trend of CI when the CIs are compared between 1990 and 2015. However, there is a wide variation in the reduction of CIs among the countries. For example, China recorded the highest reduction at 73%, whereas the reduction by Korea was the smallest at 7%, followed by Turkey's 22% reduction. Another important observation is that five out of the 19 countries have recorded an increasing trend between 1990 and 2000 and then begun a declining trend from 2000 to 2015. For example, Indonesia showed the largest fluctuating trends when its 1990s CI of 0.32 increased to 0.42 by 2000, followed by a decreasing trend that reached 0.39 in 2008 before finally decreasing to 0.208 by 2015. There are three other countries—Brazil, Korea, and Turkey—which also displayed fluctuating trends of CIs. Japan also recorded a moderate increase from 0.31 in 1990 to 0.32 in 2000, followed by a decline to 0.30 in 2008 and 0.257 by 2015. Saudi Arabia is the only country with an increasing trend from 0.63 in 1990 to 0.68 in 2000 and 0.77 by 2008, followed by a sharp declining trend that reached 0.411 by 2015.

Table 2. Historical CI for 19 major countries (1990, 2000, 2008, 2015) *.

	1990	2000	2008	2015
China	1.73	0.88	0.83	0.475
US	0.60	0.50	0.42	0.301
India	0.50	0.47	0.40	0.276
Japan	0.31	0.32	0.30	0.257
France	0.25	0.22	0.19	0.121
Italy	0.27	0.26	0.24	0.153
UK	0.41	0.31	0.25	0.157
Brazil	0.19	0.22	0.21	0.157
Argentina	0.31	0.30	0.27	0.190
Germany	0.45	0.32	0.28	0.195
Mexico	0.29	0.27	0.27	0.206
Turkey	0.27	0.30	0.27	0.211
Indonesia	0.32	0.42	0.39	0.208
Australia	0.61	0.54	0.47	0.347
Canada	0.59	0.55	0.50	0.351
Saudi Arabia	0.63	0.68	0.77	0.411
Russia	1.30	1.05	0.68	0.418
Korea	0.45	0.52	0.46	0.419
South Africa	1.07	1.05	0.94	0.583

* In metric ton per 1000 ppp 2005 dollars; Source: PwC [7,8].

Implications from these examples indicate that changing trends of CIs for multiple countries may display not only a greater degree of fluctuating trends, but may also include countries that follow increasing trends of CIs throughout the entire period. The literature analyzing CIs deals mainly with individual countries or sectors within a country [9–13]. An exception is the article by Zhu et al., which analyzed declining rates of CIs for 89 countries from 1980 to 2008 [3]. However, the declining rate is measured by a simple averaged annual rate during the period. In contrast, the rate of change of CIs in this research will be measured by PR from the experience curve methodology. In fact, this research will use two types of experience curves, the classical and kinked models. More specifically, this research will estimate and rank the historical rates of change for CI involving 127 countries during the period of 1980–2011. The resulting PR represents the rate of change for CI as a function of doubling cumulative carbon emission for individual countries. Varying rates of change for CI for multiple countries will require that the model to be used should be able to track both increasing and decreasing trends. Moreover, the model will also need to estimate multiple rates of change over a life-cycle. The experience curves to be used have these capabilities.

3. Experience Curve Applications in Energy

Even though the first industrial application of EC took place early in the 1930s [14], the active application of EC for carbon emissions and energy technologies did not begin until the 1990s. The first application of ECs to analyze CI of economic output was made in the late 1990s by Nakicenovic [15]. Using data available for the United States during the period of 1850–1900, the declining trend of CIs was analyzed as a function of cumulative CO_2 emissions by EC. The resulting negative experience slope was estimated and yielded a PR of 76%, indicating that each doubling of cumulative CO_2 emissions generated a 24% reduction in CI. This finding showed that a significant decarbonization of the U.S. economy has taken place during this period. A similar study was later repeated [16] showing that a PR of 79% was estimated for the economy of the whole world using EC. More recently, ECs have been applied to climate control, renewable energy, and other environmental issues. A review article by Weiss et al. [17] presented the PR for 75 energy-demand technologies with an average PR of 82%. Another group of 132 studies on energy supply technologies [18–20] yielded an average PR of 84%. Still another recent article [21] reviewed PRs for 11 power-generating technologies. Until now, however, no article analyzing CI for as many as 100 countries by the use of ECs has appeared in the literature, to our best knowledge.

Why do performance metrics such as CI typically follow a decreasing trend displaying an improvement pattern as a function of cumulative experience? According to recent learning and experience curve theories [20,22], the observed improvements are the cumulative results of a multitude of learning processes. In addition to learning by workers, from scaling and researching, learning by interactions and knowledge spill-over effects [23], learning by usage and consumption [24], and learning by learning [25] are also important learning processes. In short, the use of cumulative experience as an independent variable provides a rich conceptual explanation to the improvement outcomes of performance metrics, compared to the use of simple time as an independent variable in trend analysis. Furthermore, the rate of change in the performance outcomes in EC is related to the rate of change of cumulative experience. Since the rate of change of cumulative experience over a time period can vary for multiple reasons, the rate of change for performance outcome can also vary over a time period, thus providing a more flexible mechanism of estimating fluctuating PR.

When the trend of the performance metric is increasing rather than decreasing, ECs are capable of analyzing such cases as well. For example, Grubler [26] used ECs to estimate the positive experience slope for increasing reactor construction costs per KW for nuclear power as a function of cumulative installed capacity in both France and the United States. A positive experience slope translates into the value of a PR which exceeds 100%. Similarly, positive experience slopes have been reported for natural gas-fired power-plants [27] as well as on-shore wind power [28].

Learning rates are typically not the same throughout the life-cycle of a technology [29]. Sometimes, such changes in the slope are caused by technological breakthroughs [30]. In other cases, experience slopes became steeper in the later development stages of several renewable energy technologies [31]. Under these circumstances, traditional ECs can be modified to accommodate multiple experience slopes over a life-cycle. Such modified ECs, known as kinked ECs, with a kink (piecewise linear) in the slope, have been used in several studies [17,31–34]. Further explanation and application of the kinked model can be found in a review article by Chang and Lee [35].

In summary, ECs can deal with both increasing and decreasing trends of performance outcomes such as CI. ECs are also capable of estimating multiple rates of change over a life-cycle period. Compared to the use of time as independent variable, ECs are a more flexible alternative method of estimating the rate of change of performance outcomes.

4. Data and Method

Instead of using the traditional Kaya identity [36], we bypassed the process of estimating the carbon intensity of energy supply and energy intensity, and made a direct estimate of carbon intensity of economic output (CI). The CI measures used in this paper originate from the data series of the Energy Information Administration (EIA). CI is defined as the total carbon dioxide emission (TCO_2) divided by GDP. The unit for CI is in metric tons of carbon dioxide per 2005 Purchasing Power Parity (ppp) thousand U.S. dollars. The unit for total carbon dioxide emission is in millions of metric tons. CI is obtained from the EIA's International Energy Statistic website [37].

Our classical EC equation of carbon intensity is:

$$y(x_t) = ax_t^b, \tag{1}$$

where t = 1980, 1981, 1982, ..., 2011, $y(x_t)$ represents CI in year t, x_t represents the cumulative volume of carbon dioxide emission from year 1980 through year t, and a, b = parameters for Equation (1).

The kinked experience equations for the carbon intensity are defined if we have a break point at the year k like the following:

$$y(x_t) = ax_t^{b1}, \tag{2}$$

where a_1 and b_1 are parameters for Equation (2) (t = 1980, 1981, ..., $k - 1$), and

$$y(x_t) = ax_t^{b2} \tag{3}$$

where a_2 and b_2 are parameters for Equation (3) ($t = k, k + 1, \ldots, 2011$).

The PR for cumulative doubling of CO_2 emissions is derived through the equation PR = 2^b. The learning rate (LR) is defined as LR = 1 − PR. In logarithmic form, the classical experience equation is expressed as:

$$\ln y(x_t) = \ln a + b \ln x_t \tag{4}$$

The kinked experience equation for the first period can be expressed as:

$$\ln y(x_t) = \ln a_1 + b_1 \ln x_t \tag{5}$$

The kinked experience equation for the second period can be expressed as:

$$\ln y(x_t) = \ln a_2 + b_2 \ln x_t \tag{6}$$

We are able to combine the two kinked experience Equations, Equations (5) and (6), using a dummy variable which has a value of 1 if the year falls in the second period, and zero otherwise:

$$\ln y(x_t) = \ln a_1 + (\ln a_2 - \ln a_1) \times p + b_1 \log x_t + (b_2 b_1) \log x_t \times p \tag{7}$$

where $p = 0$ if $t = 1980, 1981, \ldots, k-1$, $p = 1$ if $t = k, k+1, \ldots, 2011$.

The breakpoint, k, is the year when a kink in the pattern of carbon intensity occurs. We assume all years are possibilities for the kinked year and compute the coefficient of determination R^2 of the kinked experience using Equation (7) for each candidate year. Then, we take the year with the largest R^2 as the kinked year. Thus, the kinked year is likely to vary by country.

Then, we test whether the difference between b_1 and b_2 is statistically significant. If the difference between b_1 and b_2 is not statistically significant, the classical EC should be used. If the difference between b_1 and b_2 is statistically significant, the kinked EC should be used.

The PR from the cumulative doubling of TCO_2 is derived from the equation, PR = 2^b. In other words, PR represents the rate of change of CI as a function of the doubled cumulative TCO_2. For example, if the PR is 80%, then, each doubling of cumulative TCO_2 will require 20% less CI. On the other hand, if the PR is 120%, then, each doubling of cumulative TCO_2 will require 20% more CI. Put in another way, if the historical trend of CI is decreasing, the PR will be less than 100%. Under this circumstance, doubling the cumulative TCO_2 will require a proportionately less CI, indicating higher decarbonization. Conversely, if the historical trend of CI is increasing, the PR will be greater than 100%, and doubling the cumulative TCO_2 will require a proportionately greater CI, indicating greater carbonization. Therefore, the PRs derived for different countries can indicate which countries have managed CO_2 emission better to generate a constant unit of GDP over time and which countries have not. Additionally, PRs can be used to project future CO_2 emission for respective countries as well.

We began with a total sample of 224 countries available from the EIA's website. However, some data was missing, so we eliminated 69 countries and ran an initial experience curve analysis on the remaining 155 countries. The results of our initial analysis showed 28 countries with PRs that were not statistically significant. Therefore, a final sample of 127 countries was used for analysis.

5. Results

The results of the PRs estimated from both the classical and the kinked experience curves are ranked from the lowest to the highest PR in Table A1. Zambia is ranked first with the lowest PR of 24.3%, while Lebanon is ranked 127th with the highest PR of 159.3%. Both PRs are derived from kinked experience curves and each PR is statistically significant, as shown in Table A1. In this ranking, China—which generated the largest amount of CO_2 emissions—is ranked 43rd with a PR of 76.2%, while the United States—which generated the second largest emissions—is ranked 36th with a PR of 72.7%.

During the period of 1980–2012, each doubling of cumulative CO_2 emissions has enabled China to generate 23.8% less CO_2 emissions in producing a constant unit dollar of China's GDP. For the United States, each doubling of cumulative CO_2 emissions has reduced CO_2 emissions by 27.3% per constant unit dollar of GDP produced in the United States. India, which generated the third largest emission, is ranked 64th with a PR of 90.3%.

The distribution of PRs for all 127 countries is displayed in a histogram in Figure 1. The average PR was 88.8%. There were approximately 85 countries representing 67% of the 127 countries within the range of one standard deviation, which suggests that the overall pattern appears to follow an approximately normal distribution.

Then, the total group of 127 countries was divided into two subgroups of increasing and decreasing experience slopes. The decreasing subgroup contained 83 countries ranging from the top-ranked Zambia with a PR of 24.3% to the 83rd ranked Japan with a PR of 97.7%. The average PR of the decreasing subgroup was 75.13%, as shown in Figure 2. The increasing subgroup contained 44 countries ranging from the 84th ranked Ecuador with a PR of 101.9% to the 127th ranked Lebanon with a PR of 159.3%. The average PR for this subgroup was 114.52%, as shown in Figure 3.

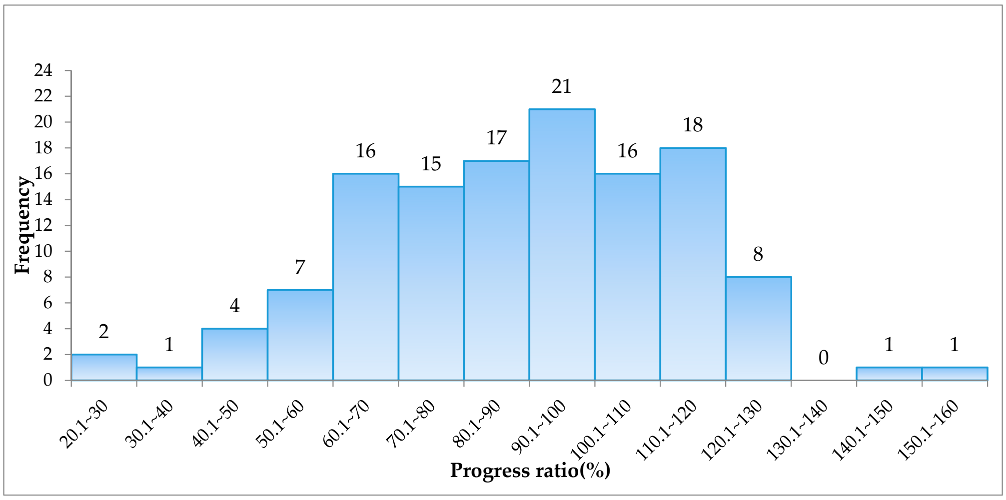

Figure 1. Histogram of progress ratios (PRs) from experience curve (EC) for CI of 127 countries.

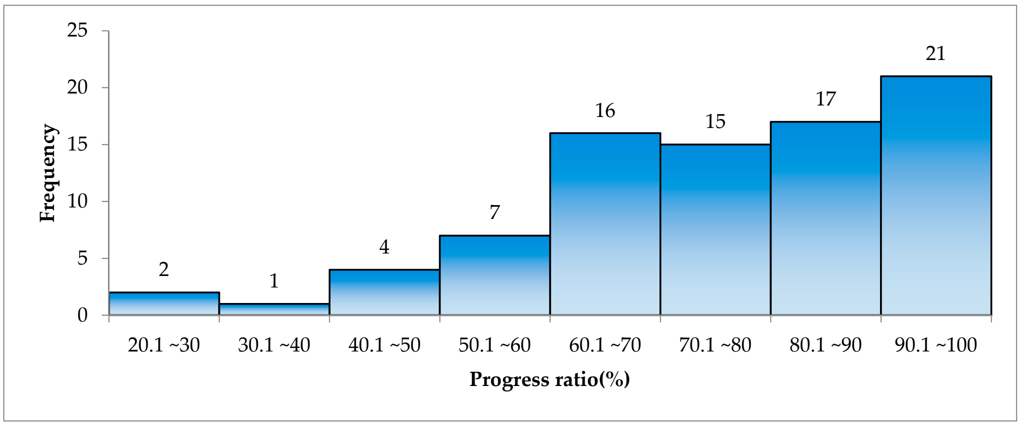

Figure 2. Histogram of PRs from EC for CI of 83 decreasing countries.

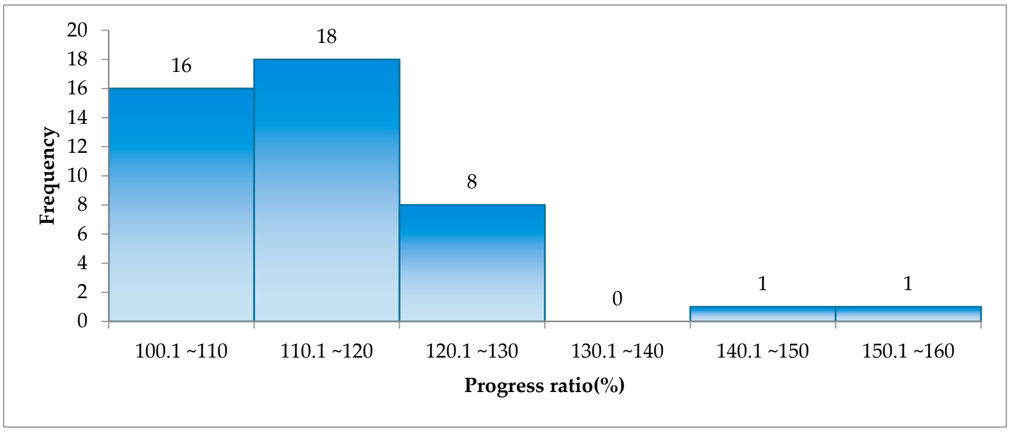

Figure 3. Histogram of PRs from EC for CI of 44 increasing countries.

Next, we divided the 127 countries into another two subgroups. The first subgroup contained 73 countries with experience curves represented by a kinked model. The average PR for the kinked subgroup was 73.38%, as shown in Figure 4. The range of this kinked subgroup was the same range as the total group. In contrast, the remaining 54 countries were grouped into the second subgroup with experience curves represented by a classical model.

The range of this subgroup was narrower, ranging from the 38th ranked Luxembourg with a PR of 73.2% to the 125th ranked Haiti with a PR of 127.7%. The average PR of this group was higher at 104.2%, as shown in Figure 5.

Pooling the results of the analysis from the two separate subgroups of trends and slopes, the question to be examined deals with which subgroups of countries are more likely to break away from the past trend for a major improvement of their CIs in the future. The subgroup of the 83 countries with decreasing trend are less likely to produce a major improvement in the future because they have already made excellent progress in the past, as indicated by their average PR of 75.13%. That leaves the subgroup of the 44 countries with an increasing trend. They have not kept abreast of the progress toward decarbonization as indicated by their average PR of 114.52%, which is significantly higher than the average PR of all 127 countries at 88.8%.

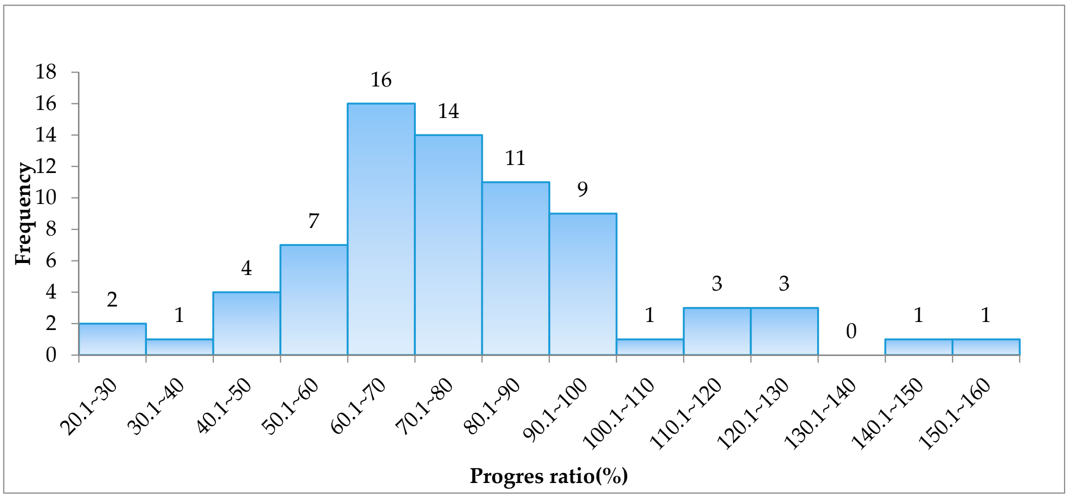

Figure 4. Histogram of PRs from EC for CI of 73 countries.

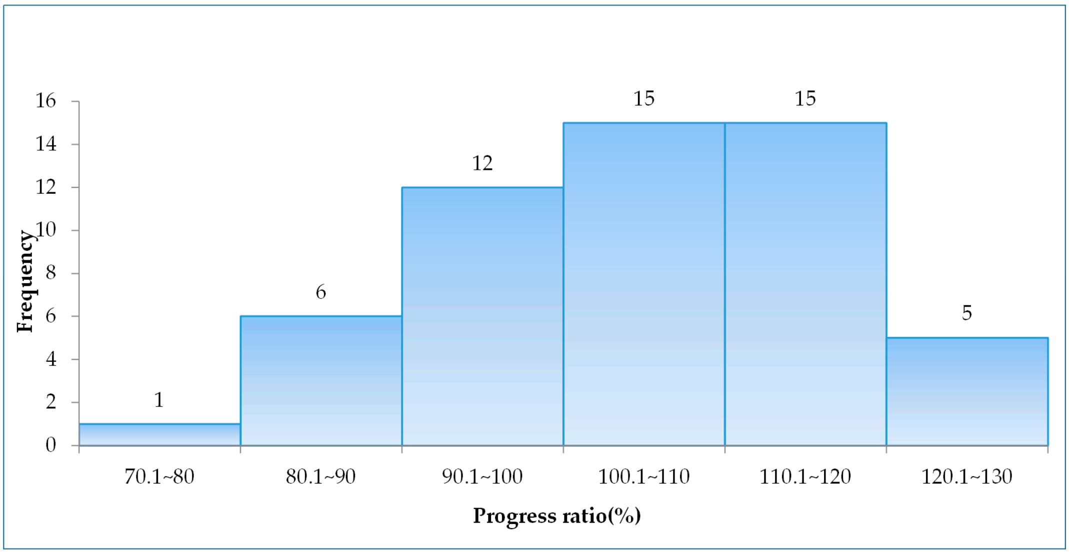

Figure 5. Histogram of PRs from EC for CI of 54 countries.

We further subdivided the subgroup of the 44 countries into two subgroups, one representing classical experience slopes and the other representing a kinked experience slopes. The average PR of the nine countries with a kinked slope was estimated at 125.68%, while an average PR of 111.65% was estimated for the 35 countries with a classical slope, as shown in Table 3. As for the subgroup of

83 countries with a decreasing trend, an average PR of 90.45% was estimated for the 19 countries with a classical slope, while the lowest average PR of 62.23% was estimated for the remaining 64 countries with a kinked slope, which are also shown in Table 3.

In order to highlight the differences existing among these four subgroups, experience curve diagrams for countries representing these four subgroups are displayed in Figures 6–9. Figure 6 shows the experience curve for Luxembourg, which represents a decreasing classical experience slope, while Figure 7 shows the experience curve for Togo, which represents an increasing classical experience slope. The value of the increasing classical slope for Togo is 0.284 while the value of the decreasing classical slope for Luxembourg is −0.45. The former has a PR of 121.8%, while the latter has a PR of 73.2%. Each country is displayed as a single classical experience curve.

Figure 8 shows the experience curve for Zambia, which represents a decreasing kinked slope, while Figure 9 shows the experience curve for Lebanon, which represents an increasing kinked slope. Zambia displays two kinked slopes made up of the first slope covering the period of 1980–2003 and the second slope covering the period of 2004–2011. The second kinked slope has a steeper value of −2.043 while the first kinked slope has a moderate value of −0.297. The PR from the second kinked slope for Zambia is 24.3%. For Lebanon, the first kinked slope covers the period of 1980–2000, and the second kinked slope covers the period of 2001–2011. Once again, the second kinked slope has a steeper value of 0.6717, while the first kinked slope has a moderate value of 0.1345. The PR from the second kinked slope for Lebanon is 159.3%.

In summary, a classical experience curve displays one slope for a given period, while a kinked experience curve displays two slopes during the given period. In general, the second kinked slope has a steeper value than the first slope. The kinked year, which begins a second kinked period, varies by country. Only the second kinked slope is used to estimate the PR for a given country.

Among these four subgroups, we selected the subgroup of the 35 countries with an increasing classical slope to have somewhat of a better chance at breaking away from their past trend for a major improvement in their CIs in the future. For example, they include countries like Congo (PR = 1.248), Togo (PR = 1.218), Guinea-Bissau (PR = 1.216), Tonga (PR = 1.209), Libya (PR = 1.182), and Comoros (PR = 1.178). The second-best chances may exist for the subgroup of the nine countries with an increasing kinked slope. Some of the candidate countries in this group include Benin (PR = 1.469), Maldives (PR = 1.272), Honduras (PR = 1.213), Tanzania (PR = 1.21), Cambodia (PR = 1.177), Cape Verde (PR = 1.152), and Thailand (PR = 1.131).

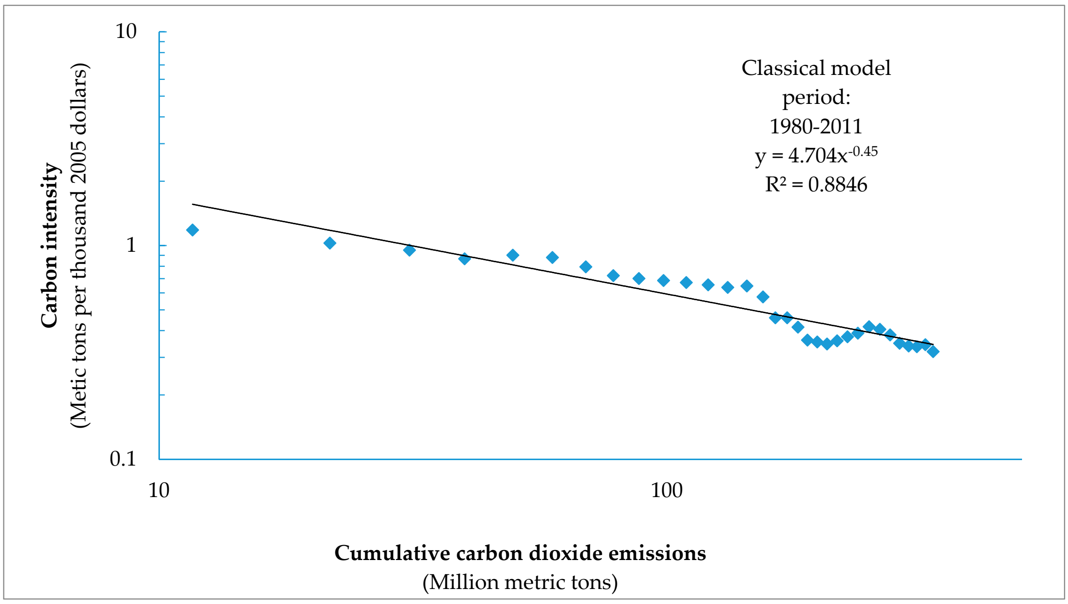

Figure 6. Decreasing classical EC (Luxembourg).

Table 3. Trend versus experience slope of 127 countries.

	Kinked Subgroup	Classical Subgroup	Total Group	
Decreasing	62.23% 64	90.45% 19	75.13% 83	Average PR Number of countries
Increasing	125.80% 9	111.65% 35	114.52% 44	Average PR Number of countries
Total	77.38% 73	104.20% 54	88.80% 127	Average PR Number of countries

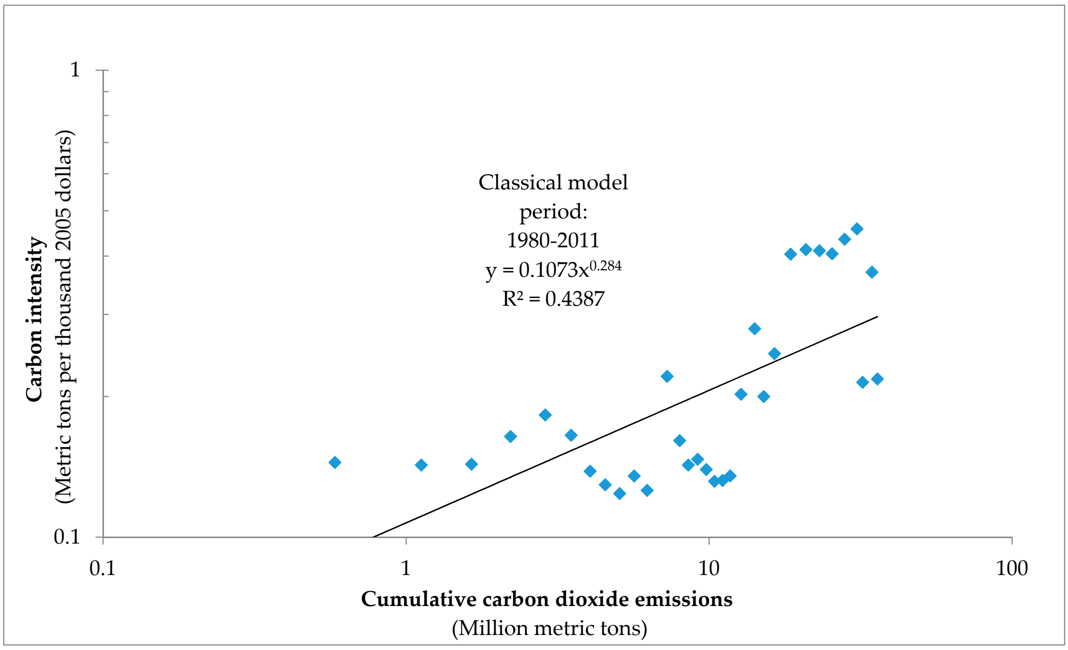

Figure 7. Increasing classical EC (Togo).

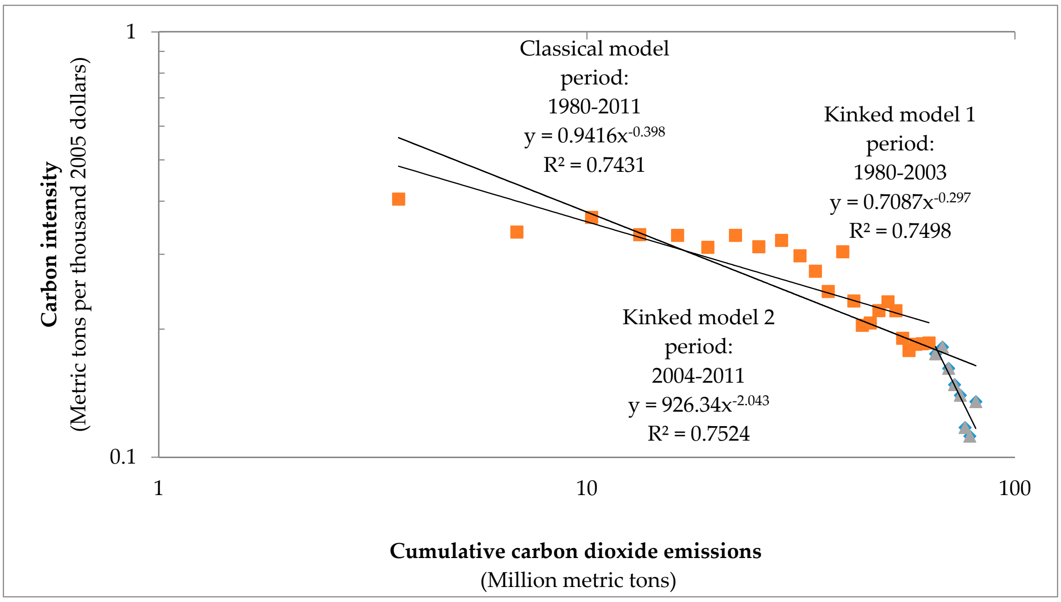

Figure 8. Decreasing kinked EC (Zambia).

This selection is made in spite of the fact that the average PR of the increasing kinked subgroup (125.68%) is higher than the average PR of the increasing classical subgroup (111.65%). We believe that the cumulative experience of better managing CO_2 emissions of a country will likely result in changing a currently increasing classical slope into a steep and decreasing kinked slope in the future.

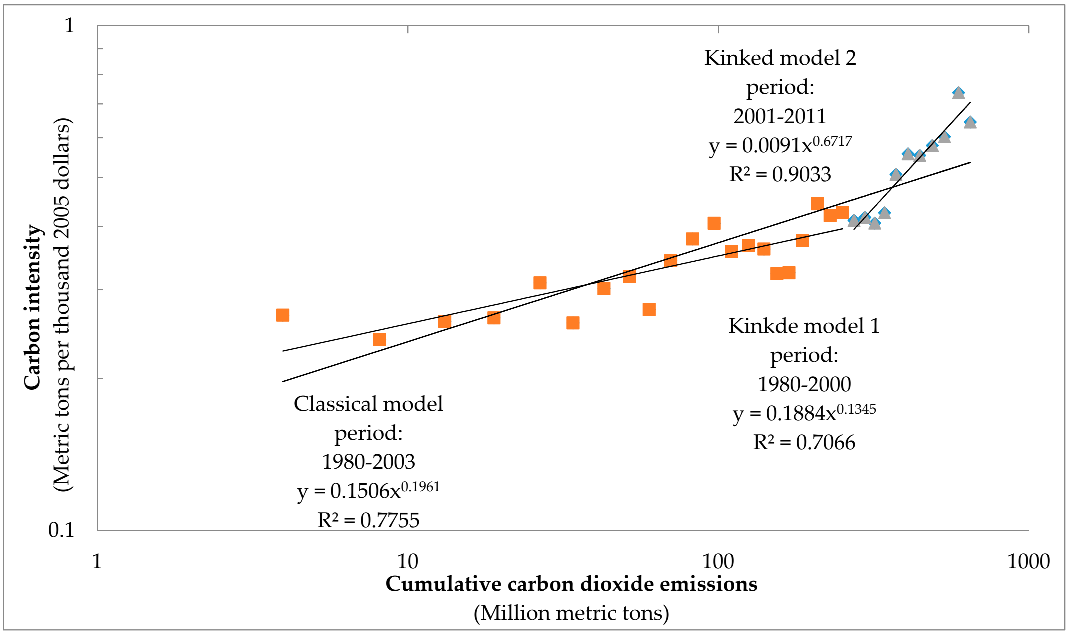

Figure 9. Increasing kinked EC (Lebanon).

On the other hand, the countries with an increasing kinked slope have already experienced one increasing kink in the past, so their current increasing kinked slope would need to be replaced by a decreasing second kinked slope. In this case, the chances of a second kink occurring may be somewhat less than the occurrence of a first kink, based on our experiences of working with many kinked slopes from other studies [38–41].

The subgroup of the 19 countries with a classical decreasing trend has an average PR of 90.45%. It is quite possible that some of these countries such as Uruguay (PR = 0.973), Kenya (PR = 0.962), Sri Lanka (PR = 0.959), and Algeria (PR = 0.951) may realize a steeper kinked decreasing slope resulting in a major improvement in their CIs as well.

We then examine the next question as to whether countries in any particular region or income level were more likely to break away from their past trends to make a major improvement in their CIs in the future. First, we proceed with dividing the 127 countries into subgroups of six regions: America, Africa, Asia, Europe, Middle East, and Oceania, following a definition established by the World Health Organization in Table 4. Only the regions of Asia and America displayed an average PR of 94.23% and 95.01%, which were somewhat higher than the total group's average of 88.78%. More relevant information to the question of improving future CI needs to come from the analysis of subgroups from increasing trends. There, we find five countries from the Middle East, such as Lebanon (PR = 1.593), Oman (PR = 1.146), and Iran (PR = 1.113), with an average PR of 120.64%, and Tonga from Oceania with a PR of 120.9%, which are higher than the average PR of 114.52% for the subgroup of the 44 countries with an increasing trend.

Table 4. PRs of regional subgroups for increasing vs. decreasing trend.

	Total Group (127)				Increasing Trend (44)				Decreasing Trend (83)			
Region	**#**	$\overline{X}$	**S.D.**	**CV**	**#**	$\overline{X}$	**S.D.**	**CV**	**#**	$\overline{X}$	**S.D.**	**CV**
Asia	22	94.23	18.09	0.19	9	110.09	8.26	0.08	13	83.25	14.43	0.17
Africa	41	87.69	27.64	0.32	14	116.36	11.45	0.10	27	72.83	20.93	0.29
Europe	17	71.34	11.84	0.17	0	0.00	0.00	0.00	17	71.34	11.84	0.17
Middle East	11	95.2	26.93	0.27	5	120.64	21.73	0.18	6	79.50	12.21	0.15
Oceania	5	73.7	29.8	0.41	1	120.90	0.00	0.00	4	61.90	16.22	0.26
America	31	95.01	19.77	0.21	15	113.01	6.34	0.06	16	78.14	15.53	0.20
Total	127	88.78	24.12	0.27	44	114.52	10.98	0.10	83	75.13	16.93	0.23

means “Number of countries”; $\overline{X}$ is “Average”; S.D. stands for “Standard deviation”; and CV is “Coefficient of variation”.

The same question was examined in Table 5 for the subgroups of countries defined by three income levels. Out of 127 countries, we were able to categorize 118 countries into the three income subgroups of high, middle, and low, following the categories defined by the World Bank. Among the 41 countries with increasing trends, only the low-income subgroup with nine countries such as Bangladesh (PR = 1.121), Tanzania (PR = 1.21), and Haiti (PR = 1.277) have a higher average PR of 121.03%, in comparison to 114.77%, which is the average PR of the 41 countries. Both the high-income subgroup with eight countries and the middle-income subgroup with 24 countries have average PRs that closely resemble the average PR for all 41 countries displaying increasing trends.

Table 5. PRs of income subgroups for increasing vs. decreasing trend.

	Total Group (118)				Increasing Trend (41)				Decreasing Trend (77)			
Income	**#**	$\overline{X}$	**S.D.**	**CV**	**#**	$\overline{X}$	**S.D.**	**CV**	**#**	$\overline{X}$	**S.D.**	**CV**
High	41	82.30	18.92	0.23	8	112.79	6.78	0.06	33	74.90	12.20	0.16
Middle	56	92.81	24.10	0.26	24	113.09	11.79	0.10	32	77.60	19.25	0.25
Low	21	87.48	33.70	0.39	9	121.03	12.00	0.10	12	62.32	18.66	0.30
Total	118	88.21	24.74	0.28	41	114.77	11.32	0.10	77	74.06	17.07	0.23

means “Number of countries”; $\overline{X}$ is “Average”; S.D. stands for “Standard deviation”; and CV is “Coefficient of variation”.

6. Conclusions

Key findings from this research are summarized as follows. First, the average PR for the total 127 countries is 88.8%, which explains a global trend of decreasing CIs. However, PRs for individual countries range widely from 24.3% to 159.3%, indicating a huge variation between countries.

Second, a majority of 83 countries experienced a decreasing trend of CIs with a PR of 73.1%, thus leading the world toward a rapid reduction of CI. The contribution by the United States, with a PR of 72.7%, and China, with a PR of 76.2%, are particularly noteworthy because these two countries represented about 43.9% of the global emissions in 2015.

Third, the most interesting finding from this research is that a large minority of 44 countries out of 127 countries, representing 34.5% of the total countries, experienced an increasing trend with an average PR of 114.5%. This unexpectedly large number of countries experiencing an increasing trend of CIs has not been reported earlier, possibly because the high emitting countries were more likely to be subjected to intensive studies in the past. Additionally, many of the high emitting countries typically displayed a decreasing trend of CIs. Fourth, among those 44 countries with an increasing trend, the three regions of America, Africa, and Asia contributed to a total of 38 countries, whereas none of the countries from the European region were included. As for countries categorized by income, a total of 33 middle- and low-income countries made up the 41 countries experiencing an increasing trend of CIs. Only eight out of 41 high income countries were included.

Fifth, on the basis of the types of experience curve, another large majority of 73 countries displayed a kinked slope with an average PR of 73.4%, whereas the remaining 54 countries displayed a classical slope with an average PR of 104.2%. This finding demonstrates the validity of using both kinked and classical experience curves. Sixth, among the 44 countries experiencing an increasing trend of CIs, the large majority of 35 countries displayed a classical slope, while only nine countries displayed a kinked slope.

Based on both the type of trend and slope, it is suggested that those 35 countries with a classical slope and an increasing trend of CIs have the best chances of a major improvement in their future CI trend. The remaining nine countries with an increasing trend and a kinked slope are likely to have the next best chances of a major improvement in their future trends. This will require a second kink in the future, which will generate a decreasing trend of CIs. Finally, there are 19 countries with a decreasing trend and with a classical slope. Some of these countries will also have good chances of realizing a kinked slope with a steeper decreasing trend in the future as they learn to manage their future CO_2 emissions more effectively.

The contribution of this study to the literature could be twofold. First, we examined all 127 countries whose historical records are available from 1980 to 2011. While the investigation of a relatively small number of major carbon emitting countries has produced fruitful insights, it is not clear whether we could apply the lessons to many other countries that have not been examined. Our results illustrate that there is a wide variation in terms of the CI trend among 127 countries and call for a more comprehensive approach. Second, by employing both classical and kinked EC, we clearly demonstrate that a majority of countries have displayed kinked PR with a variable rate of change during the period.

This research also bears some policy implications. First, the results allow individual countries to figure out how well they are doing in terms of CI compared to all 127 countries as well as the income and regional group peers. As this study analyzed the long-term trend of CIs of a large number of countries, some of which did not attract enough attention in the previous studies, policy makers can pinpoint their country's relative standing based on which they can develop policies for the future. Second, benchmarking the countries in the comparable group with a kinked slope would help policy makers identify the critical issues and change them to move their countries in the right direction.

There are several limitations to our study involving both conceptual and technical issues. Conceptually, the CI variable used in this study is a simplification of a complex relationship existing between carbon emissions and GDP. Many factors need to be evaluated to judge different CIs among countries, such as resource endowment, economic growth rate, energy consumption structure, international trade, and weather, to mention a few. However, in our analysis, different CIs among countries are evaluated only in terms of macro factors such as trend, slope, income, and region. In this sense, our selection should be viewed to represent the results of a first-round screening process. Technically, the model we used in this study is a simple aggregate experience curve which is driven by a single independent variable of cumulative CO_2 emissions and leaves room for further refinement. For example, CIs could also be significantly influenced by the development of low-carbon energy technologies that is affected by historical events, government policies, private sector initiatives, and search behavior [2,42,43]. Whether a significant change in those factors has resulted in the CI slope change for the countries exhibiting a kinked slope would be an interesting issue to investigate in the future.

To conclude, our research should be viewed as a modest beginning toward better understanding the wide variation of CIs between multiple countries. It is also important to note that future studies should include countries experiencing increasing trends of Cis, like the 44 countries we have identified in this study.

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Appendix A

Table A1. Classical and kinked EC analyses for 127 countries.

Country	Classical Experience Equation				Kinked	Kinked Experience Equation							Model
	log a	b	R^2	PR(=2^b)	year	log a_1	b_1	log a_2	b_2	$b_2 - b_1$	R^2	PR_2(=2^{b2})	Selection
1. Zambia	−0.06 (0.294)	−0.398 ** (0.078)	0.743	0.759	2004	−0.344 (0.204)	−0.297 ** (0.057)	6.831 (3.318)	−2.043 * (0.780)	−1.746 * (0.782)	0.886	0.243	Kinked
2. Liberia	−0.014 (0.079)	−0.064 (0.043)	0.01	0.957	2003	−0.096 (0.154)	−0.025 (0.093)	5.403* (5.403)	−1.807 ** (0.509)	−1.782 ** (0.518)	0.046	0.286	Kinked
3. Fiji	−0.948 ** (0.205)	0.049 (0.076)	0.032	1.035	2003	−0.709 ** (0.186)	−0.089 (0.077)	4.311 (2.067)	−1.375 * (0.577)	−1.286 * (0.582)	0.61	0.386	Kinked
4. Congo (Kinshasa)	−1.920 ** (0.091)	0.017 (0.030)	0.004	1.012	1993	−2.023 ** (0.137)	0.038 (0.052)	3.241 ** (0.597)	−1.159 ** (0.136)	−1.197 ** (0.146)	0.673	0.448	Kinked
5. Chad	−2.985 ** (0.133)	−0.592 ** (0.092)	0.717	0.663	1992	−2.999 ** (0.101)	−0.291 * (0.129)	−2.214 ** (0.396)	−1.106 ** (0.237)	−0.814 ** (0.270)	0.806	0.465	Kinked
6. Belize	−1.284 ** (0.053)	−0.014 (0.049)	0.03	0.99	2001	−1.282 ** (0.036)	−0.097 * (0.040)	1.327 (0.833)	−1.05 * (0.371)	−0.957 * (0.373)	0.413	0.483	Kinked
7. Madagascar	−2.369 ** (0.100)	0.104 ** (0.038)	0.205	1.075	2002	−2.240 ** (0.073)	0.026 (0.031)	1.959 * (0.834)	−1.044 ** (0.229)	−1.070 ** (0.231)	0.664	0.485	Kinked
8. Dominican Republic	−1.352 ** (0.102)	0.030 (0.023)	0.667	1.021	2003	−1.558 ** (0.073)	0.086 ** (0.016)	4.429 ** (0.946)	−0.998 ** (0.166)	−1.073 ** (0.166)	0.782	0.501	Kinked
9. Niger	−2.413 ** (0.122)	0.038 (0.047)	0.036	1.027	2005	−2.550 ** (0.063)	0.135 ** (0.027)	0.686 (0.502)	−0.945 ** (0.146)	−1.080 ** (0.149)	0.674	0.519	Kinked
10. Sweden	0.754 ** (0.190)	−0.314 ** (0.029)	0.808	0.804	1994	0.265 (0.132)	−0.233 ** (0.022)	5.364 ** (0.459)	−0.947 ** (0.062)	−0.715 ** (0.066)	0.972	0.519	Kinked
11. Mongolia	2.072 ** (0.410)	−0.361 ** (0.085)	0.544	0.779	1997	1.008 ** (0.139)	−0.055 (0.038)	4.758 ** (0.417)	−0.909 ** (0.080)	−0.854 ** (0.089)	0.961	0.533	Kinked
12. Spain	−0.567 ** (0.154)	−0.072 ** (0.019)	0.487	0.951	2004	−0.608 ** (0.176)	−0.066 ** (0.022)	6.273 ** (1.352)	−0.839 ** (0.151)	−0.077 ** (0.152)	0.681	0.559	Kinked
13. Austria	−0.559 ** (0.079)	−0.107 ** (0.013)	0.754	0.929	2003	−0.644 ** (0.056)	−0.092 ** (0.009)	4.376 ** (0.950)	−0.772 ** (0.128)	−0.680 ** (0.128)	0.895	0.586	Kinked
14. Burundi	−2.907 ** (0.049)	0.238 ** (0.050)	0.43	1.173	1994	−2.927 ** (0.050)	0.304 ** (0.098)	−1.124 * (0.438)	−0.741 * (0.258)	−1.045 ** (0.276)	0.736	0.598	Kinked
15. Korea, North	2.257 ** (0.531)	−0.243 ** (0.071)	0.636	0.845	1992	0.977 ** (0.194)	−0.033 (0.031)	5.771 ** (0.527)	−0.703 ** (0.068)	−0.670 ** (0.074)	0.944	0.614	Kinked
16. Mauritania	−1.633 ** (0.125)	0.246 ** (0.051)	0.348	1.186	1992	−1.699 ** (0.093)	0.153 * (0.058)	1.921 ** (0.527)	−0.700 ** (0.147)	−0.852 ** (0.158)	0.864	0.616	Kinked
17. Colombia	0.394 (0.410)	−0.168 ** (0.040)	0.679	0.89	1997	−0.224 (0.390)	−0.101 * (0.040)	5.982 ** (0.591)	−0.687 ** (0.055)	−0.586 ** (0.068)	0.9	0.621	Kinked
18. Denmark	0.709 ** (0.248)	−0.246 ** (0.037)	0.689	0.843	1998	−0.173 (0.145)	−0.904 ** (0.023)	3.850 ** (0.691)	−0.687 ** (0.094)	−0.596 ** (0.097)	0.953	0.621	Kinked
19. United Kingdom	1.644 ** (0.472)	−0.297 ** (0.052)	0.829	0.814	1992	0.317 (0.226)	−0.128 ** (0.027)	5.193 ** (0.243)	−0.674 ** (0.026)	−0.546 ** (0.037)	0.993	0.627	Kinked
20. Jordan	−0.434 ** (0.142)	0.049 (0.031)	0.119	1.035	2000	−0.814 ** (0.075)	0.152 ** (0.017)	3.502 ** (0.596)	−0.651 ** (0.104)	−0.803 ** (0.106)	0.898	0.637	Kinked

Table A1. *Cont.*

Country	Classical Experience Equation				Kinked	Kinked Experience Equation							Model
	log a	b	R^2	PR(=2^b)	year	log a_1	b_1	log a_2	b_2	$b_2 - b_1$	R^2	PR$_2$(=2^{b2})	Selection
21. Mozambique	0.317 (0.361)	−0.581 ** (0.106)	0.791	0.669	1986	−0.745 ** (0.237)	0.01 (0.110)	0.433 (0.331)	−0.623 ** (0.096)	−0.633 ** (0.146)	0.909	0.649	Kinked
22. New Zealand	−0.995 ** (0.107)	0.010 (0.019)	0.011	1.007	2006	−1.207 ** (0.080)	0.054 ** (0.014)	3.198 *** (0.539)	−0.624 ** (0.078)	−0.678 ** (0.079)	0.631	0.649	Kinked
23. Iraq	−2.649 ** (0.369)	0.296 ** (0.055)	0.341	1.228	1990	−3.462 ** (0.545)	0.418 ** (0.099)	3.896 ** (0.859)	−0.614 ** (0.117)	−1.032 ** (0.153)	0.804	0.653	Kinked
24. Venezuela	−0.511 ** (0.120)	−0.01 (0.017)	0.013	0.993	2001	−0.603 ** (0.110)	0.004 (0.016)	4.262* (1.512)	−0.601 * (0.188)	−0.605 ** (0.189)	0.47	0.659	Kinked
25. Portugal	−1.795 ** (0.121)	0.075 ** (0.020)	0.456	1.053	2006	−2.001 ** (0.103)	0.116 ** (0.017)	2.873 (1.110)	−0.589 * (0.154)	−0.704 ** (0.155)	0.859	0.665	Kinked
26. Switzerland	−0.847 ** (0.111)	−0.134 ** (0.018)	0.742	0.911	2000	−1.131 ** (0.152)	−0.813 ** (0.025)	2.136 ** (0.625)	−0.563 ** (0.089)	−0.481 ** (0.093)	0.929	0.677	Kinked
27. Cameroon	−2.433 ** (0.256)	0.108 (0.054)	0.15	1.078	1993	−2.537 ** (0.279)	0.13 (0.086)	0.847 (0.421)	−0.560 ** (0.087)	−0.690 ** (0.122)	0.407	0.678	Kinked
28. Finland	0.398 ** (0.122)	−0.191 ** (0.020)	0.692	0.876	1993	0.041 (0.196)	−0.129 ** (0.033)	2.961 ** (0.459)	−0.555 ** (0.065)	−0.426 ** (0.073)	0.86	0.681	Kinked
29. Vanuatu	−1.838 ** (0.050)	−0.337 ** (0.046)	0.525	0.792	1986	−1.677 ** (0.077)	−0.157 * (0.070)	−1.701 ** (0.117)	−0.554 ** (0.149)	−0.397 * (0.165)	0.582	0.681	Kinked
30. Greece	−1.266 ** (0.168)	0.048 (0.025)	0.133	1.034	1999	−1.853 ** (0.137)	0.150 ** (0.021)	3.249 ** (0.420)	−0.553 ** (0.055)	−0.703 ** (0.059)	0.94	0.682	Kinked
31. Argentina	−1.105 ** (0.185)	−0.022 (0.025)	0.069	0.984	1991	−1.815 ** (0.098)	0.098 ** (0.016)	−0.497 (0.247)	−0.102 ** (0.032)	−0.120 ** (0.036)	0.699	0.709	Kinked
32. Israel	−0.958 ** (0.063)	0.009 (0.012)	0.018	1.006	2001	−1.087 ** (0.042)	0.034 ** (0.008)	2.607 ** (0.316)	−0.496 ** (0.045)	−0.530 ** (0.046)	0.749	0.709	Kinked
33. Ireland	0.055 (0.182)	−0.188 ** (0.030)	0.716	0.878	1994	−0.631 ** (0.108)	−0.041 (0.021)	1.976 ** (0.136)	−0.488 ** (0.022)	−0.447 ** (0.030)	0.964	0.713	Kinked
34. Canada	0.737 ** (0.148)	−0.147 ** (0.017)	0.804	0.903	1997	0.295 ** (0.041)	−0.090 ** (0.005)	3.885 ** (0.236)	−0.483 ** (0.025)	−0.393 ** (0.026)	0.975	0.715	Kinked
35. Botswana	−0.705 ** (0.066)	−0.150 ** (0.019)	0.607	0.901	1992	−0.873 ** (0.114)	−0.076 (0.048)	0.572 ** (0.130)	−0.466 ** (0.034)	−0.391 ** (0.059)	0.869	0.724	Kinked
36. United States	1.560 ** (0.263)	−0.196 ** (0.024)	0.882	0.873	1996	0.852 ** (0.098)	−0.121 ** (0.009)	4.665 ** (0.185)	−0.459 ** (0.016)	−0.338 ** (0.018)	0.995	0.727	Kinked
37. Equatorial Guinea	−1.812 ** (0.120)	0.195 ** (0.041)	0.278	1.145	1997	−1.494 ** (0.146)	0.665 ** (0.114)	0.135 (0.160)	−0.455 ** (0.042)	−1.120 ** (0.150)	0.765	0.73	Kinked
38. Luxembourg	1.548 ** (0.244)	−0.450 ** (0.048)	0.885	0.732	1995	0.870 ** (0.089)	−0.268 ** (0.020)	0.753 (0.513)	−0.317 ** (0.092)	−0.049 (0.094)	0.975	0.803	Classical
39. Central African Republic	−2.701 ** (0.053)	0.05 (0.041)	0.106	1.035	1993	−2.704 ** (0.024)	0.158 ** (0.029)	−1.863 ** (0.062)	−0.437 ** (0.038)	−0.595 ** (0.048)	0.854	0.739	Kinked
40. Guinea	−2.552 ** (0.103)	−0.127 ** (0.035)	0.429	0.916	1994	−2.790 ** (0.054)	0.05 (0.033)	−1.673 ** (0.110)	−0.412 ** (0.034)	−0.462 ** (0.047)	0.858	0.752	Kinked
41. Belgium	0.495 ** (0.133)	−0.159 ** (0.018)	0.839	0.896	1994	0.345 (0.183)	−0.138 ** (0.026)	2.418 ** (0.305)	−0.399 ** (0.038)	−0.261 ** (0.047)	0.945	0.758	Kinked
42. Australia	−0.01 (0.128)	−0.058 ** (0.015)	0.647	0.961	2006	−0.12 (0.114)	−0.042 ** (0.014)	3.026 ** (0.608)	−0.396 ** (0.067)	−0.353 ** (0.069)	0.8	0.76	Kinked
43. China	4.085 ** (0.433)	−0.373 ** (0.041)	0.907	0.772	1993	2.527 ** (0.337)	−0.195 ** (0.036)	4.255 ** (0.583)	−0.392 ** (0.053)	−0.197 ** (0.064)	0.974	0.762	Kinked

Table A1. *Cont.*

Country	Classical Experience Equation				Kinked	Kinked Experience Equation							Model
	log a	b	R^2	PR(=2^b)	year	log a_1	b_1	log a_2	b_2	$b_2 - b_1$	R^2	PR_2(=2^{b2})	Selection
44. France	0.702 ** (0.095)	−0.243 ** (0.011)	0.962	0.845	1996	0.713 ** (0.172)	−0.245 ** (0.021)	2.055 ** (0.348)	−0.390 ** (0.038)	−0.145 ** (0.044)	0.974	0.763	Kinked
45. Pakistan	−1.379 ** (0.053)	0.011 (0.009)	0.041	1.008	2007	−1.460 ** (0.058)	0.025 * (0.010)	1.204 (0.451)	−0.327 * (0.058)	−0.352 ** (0.059)	0.306	0.797	Kinked
46. Nepal	−3.046 ** (0.091)	0.235 ** (0.031)	0.709	1.177	1998	−2.992 ** (0.107)	0.163 * (0.059)	−0.974 ** (0.260)	−0.320 ** (0.072)	−0.483 ** (0.093)	0.884	0.801	Kinked
47. Swaziland	−1.383 ** (0.043)	−0.275 ** (0.017)	0.82	0.826	1990	−1.390 ** (0.046)	−0.244 ** (0.033)	−1.677 ** (0.222)	−0.173 * (0.075)	0.071 (0.082)	0.841	0.887	Classical
48. Saudi Arabia	−0.448 * (0.194)	0.028 (0.032)	0.038	1.02	1993	−1.245 ** (0.290)	0.204 ** (0.058)	1.521 ** (0.224)	−0.274 ** (0.034)	−0.477 ** (0.068)	0.77	0.827	Kinked
49. French Guiana	−0.592 ** (0.048)	−0.072 ** (0.022)	0.242	0.845	1993	−0.608 ** (0.043)	−0.115 ** (0.035)	0.262 (0.189)	−0.377 ** (0.069)	−0.262 ** (0.078)	0.622	0.834	Kinked
50. Syria	−0.448 * (0.194)	0.028 (0.032)	0.038	1.02	1989	−1.134 ** (0.371)	0.174 * (0.079)	1.387 ** (0.206)	−0.254 ** (0.032)	−0.428 ** (0.085)	0.816	0.839	Kinked
51. Mali	−2.722 ** (0.103)	−0.243 ** (0.046)	0.645	0.845	1989	−2.754 ** (0.267)	−0.297 (0.317)	−2.288 ** (0.071)	−0.425 ** (0.031)	−0.128 (0.319)	0.731	0.745	Classical
52. Puerto Rico	0.484 ** (0.156)	−0.237 ** (0.027)	0.763	0.849	2001	0.926 ** (0.305)	−0.327 ** (0.054)	1.977 (1.305)	−0.452* (0.198)	−0.124 (0.205)	0.898	0.731	Classical
53. Bermuda	−1.130 ** (0.095)	−0.134 ** (0.039)	0.319	0.911	1992	−1.303 ** (0.124)	0.145 (0.108)	−0.928 ** (0.192)	−0.235 ** (0.078)	−0.379 ** (0.133)	0.768	0.85	Kinked
54. Morocco	−1.492 ** (0.050)	−0.015 (0.010)	0.042	0.99	1993	−1.457 ** (0.041)	−0.028 ** (0.009)	−0.203 (0.214)	−0.217 ** (0.035)	−0.189 ** (0.036)	0.703	0.86	Kinked
55. Norway	−0.690 ** (0.100)	−0.133 ** (0.016)	0.775	0.912	1985	−0.807 ** (0.098)	−0.120 ** (0.023)	−0.166 (0.122)	−0.213 ** (0.020)	−0.093 ** (0.030)	0.896	0.863	Kinked
56. Angola	−2.531 ** (0.146)	0.272 ** (0.035)	0.611	1.207	1993	−2.358 ** (0.203)	0.181 * (0.069)	0.061 (0.492)	−0.209 * (0.092)	−0.390 ** (0.115)	0.881	0.865	Kinked
57. Bahrain	0.853 ** (0.166)	−0.071 * (0.030)	0.359	0.952	1985	0.453 (0.311)	0.027 (0.099)	1.481 ** (0.126)	−0.183 ** (0.021)	−0.210 * (0.102)	0.783	0.881	Kinked
58. Netherlands Antilles	2.085 ** (0.088)	−0.180 ** (0.017)	0.702	0.883	1995	2.563 ** (0.318)	−0.298 ** (0.069)	1.884 ** (0.383)	−0.138 (0.069)	0.16 (0.097)	0.865	0.909	Classical
59. Gabon	−0.019 (0.184)	−0.172 ** (0.042)	0.572	0.888	2006	−0.194 (0.138)	−0.118 ** (0.033)	−1.469 (2.771)	0.086 (0.555)	0.204 (0.556)	0.771	1.061	Classical
60. Somalia	−1.047 ** (0.173)	−0.166 * (0.061)	0.39	0.891	1991	−1.197 ** (0.161)	−0.032 (0.082)	−2.371 ** (0.420)	0.261 (0.139)	0.293 (0.161)	0.733	1.198	Classical
61. Cyprus	−0.771 ** (0.065)	0.007 (0.015)	0.012	1.005	1992	−0.857 ** (0.189)	0.032 (0.061)	0.025 (0.114)	−0.160 ** (0.024)	−0.192 ** (0.065)	0.601	0.895	Kinked
62. Reunion	−1.592 ** (0.048)	0.207 ** (0.019)	0.738	1.154	1993	−1.676 ** (0.086)	0.240 ** (0.052)	−0.302 * (0.108)	−0.158 ** (0.029)	−0.397 ** (0.060)	0.933	0.896	Kinked
63. Netherlands	0.453* (0.179)	−0.147 ** (0.023)	747	0.903	2005	0.127 (0.079)	−0.100 ** (0.010)	4.565 (3.420)	−0.628 (0.390)	−0.527 (0.390)	0.941	0.647	Classical
64. India	−0.406 (0.209)	−0.026 (0.023)	0.095	0.982	2003	−0.855 ** (0.126)	0.032 * (0.015)	0.706 (0.535)	−0.148* (0.054)	−0.180 ** (0.056)	0.779	0.903	Kinked
65. Costa Rica	−2.088 ** (0.054)	0.022 (0.014)	0.059	1.015	1992	−2.022 ** (0.044)	−0.022 (0.019)	−1.352 ** (0.141)	−0.144 ** (0.033)	−0.122 ** (0.038)	0.602	0.905	Kinked

Table A1. *Cont.*

Country	Classical Experience Equation				Kinked	Kinked Experience Equation							Model
	log a	b	R^2	PR(=2^b)	year	log a_1	b_1	log a_2	b_2	$b_2 - b_1$	R^2	PR$_2$(=2^{b2})	Selection
66. Peru	−1.141 ** (0.186)	−0.088 ** (0.031)	0.564	0.941	1982	−1.535 ** (0.158)	−0.015 (0.049)	−0.810 ** (0.076)	−0.143 ** (0.013)	−0.128 * (0.051)	0.816	0.906	Kinked
67. Antigua and Barbuda	−0.620 ** (0.083)	−0.138 ** (0.041)	0.468	0.909	1983	−0.313 (0.259)	0.102 (0.601)	−0.847 ** (0.051)	−0.029 (0.029)	−0.131 (0.602)	0.8137	1.073	Classical
68. Lesotho	−2.629 ** (0.030)	−0.128 ** (0.044)	0.267	0.915	2010	−2.632 ** (0.036)	−0.18 ** (0.029)	3.565	−3.203	−3.016 (87.590)	0.801	0.109	Classical
69. Mexico	−0.716 ** (0.158)	−0.049 * (0.019)	0.542	0.967	1989	−1.202 ** (0.110)	0.021 (0.015)	−0.079 (0.072)	−0.122 ** (0.009)	−0.143 ** (0.107)	0.898	0.919	Kinked
70. Burma (Myanmar)	−1.978 ** (0.195)	−0.100 * (0.048)	0.233	0.933	2009	−2.211 ** (0.106)	−0.032 (0.027)	0.652 (3.327)	−0.657 (0.602)	−0.625 (0.602)	0.793	0.634	Classical
71. Yemen	−0.443 * (0.175)	−0.100 ** (0.033)	0.344	0.933	1993	−1.062 ** (0.132)	0.087 ** (0.031)	−0.876 * (0.348)	−0.032 (0.064)	−0.119 (0.071)	0.871	0.978	Classical
72. United Arab Emirates	−1.294 ** (0.308)	0.165 ** (0.043)	0.477	1.121	1986	−2.268 ** (0.650)	0.338 * (0.134)	0.612* (0.245)	−0.095 * (0.035)	−0.433 ** (0.138)	0.892	0.936	Kinked
73. Egypt	−0.726 ** (0.205)	−0.008 (0.028)	0.012	0.994	1988	−1.476 ** (0.060)	0.136 ** (0.011)	−0.088 (0.082)	−0.094 ** (0.012)	−0.230 ** (0.016)	0.844	0.937	Kinked
74. Tunisia	−0.680 ** (0.174)	−0.086 * (0.035)	0.277	0.942	2007	−0.950 ** (0.082)	−0.02 (0.017)	−0.843 (4.754)	−0.103 (0.774)	−0.082 (0.775)	0.86	0.931	Classical
75. Guyana	−0.608 ** (0.087)	−0.084 ** (0.028)	0.145	0.943	1989	−0.668 ** (0.133)	0.003 (0.075)	−1.441 ** (0.232)	0.166 * (0.073)	0.163 (0.105)	0.5	1.122	Classical
76. Indonesia	−1.267 ** (0.125)	0.056 ** (0.016)	0.521	1.04	1999	−1.072 ** (0.142)	0.024 (0.020)	−0.126 (0.240)	−0.075 * (0.028)	−0.099 ** (0.034)	0.728	0.949	Kinked
77. Korea, South	0.123 * (0.054)	−0.076 ** (0.007)	0.689	0.949	1991	0.258 (0.134)	−0.100 ** (0.020)	0.814 * (0.305)	−0.154 ** (0.035)	−0.054 (0.040)	0.818	0.899	Classical
78. Algeria	−0.271 (0.158)	−0.073 ** (0.023)	0.291	0.951	2001	−0.672 ** (0.201)	−0.003 (0.030)	−2.970 * (1.133)	0.268 (0.146)	0.271 (0.149)	0.744	1.204	Classical
79. Sao Tome and Principe	−1.090 ** (0.038)	0.279 ** (0.026)	0.712	1.213	1990	−1.577 ** (0.031)	0.100 ** (0.013)	−0.974 ** (0.014)	−0.069 * (0.027)	−0.169 ** (0.032)	0.98	0.953	Kinked
80. Sri Lanka	−1.963 ** (0.071)	−0.060 ** (0.017)	0.237	0.959	2008	−2.049 ** (0.085)	−0.036 (0.022)	−0.475 (1.763)	−0.35 (0.322)	−0.314 (0.322)	0.391	0.785	Classical
81. Kenya	−1.626 ** (0.086)	−0.056 ** (0.019)	0.354	0.962	1983	−1.459 ** (0.159)	−0.09 (0.062)	−1.851 ** (0.095)	−0.009 (0.019)	0.081 (0.065)	0.582	0.994	Classical
82. Uruguay	−1.480 ** (0.154)	−0.040 (0.036)	0.078	0.973	1998	−1.089 ** (0.064)	−0.162 ** (0.016)	−1.705 * (0.654)	0.019 (0.134)	0.181 (0.135)	0.566	1.013	Classical
83. Japan	−0.095 (0.110)	−0.106 ** (0.011)	0.817	0.929	1987	0.3 (0.378)	−0.152 ** (0.046)	−0.803 ** (0.113)	−0.034 ** (0.012)	0.118 * (0.048)	0.922	0.977	Kinked
84. Equador	−1.327 ** (0.069)	0.027 * (0.013)	0.186	1.019	2010	−1.281 ** (0.053)	0.016 (0.010)	3.932	−0.775	−0.791 (0.452)	0.455	0.584	Classical
85. Burkina Faso	−2.790 ** (0.030)	0.038 * (0.014)	0.169	1.027	1997	−2.766 ** (0.021)	−0.007 (0.014)	−2.221 ** (0.206)	−0.151 (0.075)	−0.144 (0.076)	0.508	0.901	Classical
86. Hong Kong	−1.445 ** (0.067)	0.039 ** (0.011)	0.236	1.027	1994	−1.548 ** (0.088)	0.064 ** (0.017)	−2.322 ** (0.351)	0.164 ** (0.051)	0.100 (0.054)	0.463	1.12	Classical
87. Ghana	−2.005 ** (0.054)	0.043 ** (0.013)	0.25	1.03	1990	−2.098 ** (0.167)	0.09 (0.070)	−2.028 ** (0.109)	0.047 (0.026)	−0.042 (0.074)	0.302	1.033	Classical

Table A1. *Cont.*

Country	Classical Experience Equation				Kinked	Kinked Experience Equation							Model
	log a	b	R^2	PR(=2^b)	year	log a_1	b_1	log a_2	b_2	$b_2 - b_1$	R^2	PR_2(=2^{b2})	Selection
88. Malaysia	−1.060 ** (0.101)	0.048 ** (0.014)	0.416	1.034	1983	−0.883 ** (0.065)	−0.026 (0.016)	−0.789 ** (0.107)	0.01 (0.015)	0.036 (0.022)	0.719	1.007	Classical
89. Turkey	−1.569 ** (0.086)	0.058 ** (0.011)	0.677	1.041	1982	−0.416 (1.739)	−0.2 (0.381)	−1.543 ** (0.070)	0.055 ** (0.009)	0.255 (0.381)	0.756	1.039	Classical
90. Sudan and South Sudan	−2.156 ** (0.087)	0.066 * (0.025)	0.128	1.047	2009	−2.048 ** (0.065)	0.033 (0.022)	−1.318 (13.636)	−0.051 (2.558)	−0.083 (2.558)	0.286	0.965	Classical
91. Brazil	−2.030 ** (0.107)	0.071 ** (0.013)	0.667	1.05	1990	−1629 ** (0.119)	0.007 (0.017)	−1.626 ** (0.163)	0.024 (0.019)	0.018 (0.025)	0.844	1.017	Classical
92. Philippines	−1.751 ** (0.165)	0.073 * (0.028)	0.21	1.052	1987	−1.104 ** (0.181)	−0.083 * (0.038)	−1.140 ** (0.374)	−0.015 (0.056)	−0.068 (0.068)	0.438	0.99	Classical
93. Vietnam	−1.367 ** (0.106)	0.075 ** (0.018)	0.359	1.053	2010	−1.277 ** (0.085)	0.056 ** (0.015)	5.576	−0.853	−0.909 (4.359)	0.508	0.554	Classical
94. American Samoa	−0.316 ** (0.081)	0.108 ** (0.034)	0.405	1.078	1989	−0.290 (0.145)	0.031 (0.126)	−0.296 * (0.126)	0.104 (0.057)	0.074 (0.138)	0.452	1.075	Classical
95. Saint Lucia	−1.723 ** (0.052)	0.117 * (0.046)	0.323	1.084	2000	−1.813 ** (0.017)	−0.056 (0.031)	−1.252 ** (0.157)	−0.072 (0.089)	−0.017 (0.094)	0.933	0.951	Classical
96. Qatar	−1.328 ** (0.118)	0.123 ** (0.015)	0.755	1.089	1989	−1.611 ** (0.546)	0.171 * (0.079)	−1.945 ** (0.294)	0.195 ** (0.035)	0.024 (0.086)	0.84	1.145	Classical
97. Kuwait	−1.305 ** (0.112)	0.125 ** (0.017)	0.269	1.091	1992	−1.925 * (0.760)	0.261 (0.160)	−1.862 * (0.805)	0.203 (0.116)	−0.057 (0.197)	0.375	1.151	Classical
98. Mauritius	−2.194 ** (0.084)	0.127 ** (0.025)	0.688	1.092	2000	−2.177 ** (0.112)	0.114 * (0.042)	−1.367 ** (0.338)	−0.072 (0.083)	−0.186 (0.093)	0.727	0.951	Classical
99. Seychelles	−1.181 ** (0.055)	0.167 ** (0.028)	0.591	1.123	1983	−1.740 ** (0.000)	−0.249 ** (0.000)	−1.101 ** (0.049)	0.129 ** (0.028)	0.378 ** (0.028)	0.666	1.094	Kinked
100. Cayman Island	−1.324 ** (0.049)	0.145 ** (0.145)	0.802	1.106	1988	−1.719 ** (0.081)	−0.145 (0.111)	−1.090 ** (0.060)	0.01 (0.049)	0.155 (0.122)	0.802	1.007	Classical
101. Bolivia	−1.915 ** (0.117)	0.151 ** (0.026)	0.691	1.11	2001	−1.545 ** (0.065)	0.018 (0.022)	−1.542 (1.134)	0.083 (0.213)	0.09 (0.044)	0.832	1.059	Classical
102. Iran	−1.751 ** (0.093)	0.155 ** (0.011)	0.892	1.113	1986	−1.709 ** (0.284)	0.140 ** (0.045)	−1.302 ** (0.158)	0.101 ** (0.019)	−0.039 (0.048)	0.938	1.073	Classical
103. Guatemala	−2.486 ** (0.178)	0.159 ** (0.040)	0.567	1.117	1994	−1.905 ** (0.121)	−0.051 (0.039)	−2.205 ** (0.325)	0.111 (0.067)	0.162 * (0.077)	0.861	1.08	Classical
104. Bangladesh	−3.119 ** (0.094)	0.165 ** (0.017)	0.918	1.121	1992	−2.949 ** (0.160)	0.116 ** (0.038)	−3.107 ** (0.152)	0.164 ** (0.026)	0.048 (0.046)	0.936	1.12	Classical
105. Saint Vincent Grenadines	−1.921 ** (0.031)	0.172 ** (0.038)	0.58	1.127	1994	−2.259 ** (0.088)	−0.008 (0.056)	−1.704 ** (0.035)	−0.035 (0.039)	−0.027 (0.068)	0.851	0.976	Classical
106. Thailand	−1.963 ** (0.156)	0.161 ** (0.161)	0.887	1.118	1990	−1.358 ** (0.263)	0.038 (0.048)	−2.072 ** (0.107)	0.177 ** (0.014)	0.139 ** (0.050)	0.951	1.131	Kinked
107. Grenada	−1.659 ** (0.033)	0.185 ** (0.022)	0.616	1.137	1999	−1.631 ** (0.039)	0,198 ** (0.037)	−2.259 ** (0.449)	0.648 (0.316)	0.449 (0.319)	0.701	1.567	Classical
108. Nicaragua	−1.684 ** (0.113)	0.195 ** (0.031)	0.78	1.145	1992	−1.559 ** (0.184)	0.12 (0.071)	−1.09 ** (0.169)	0.054 (0.043)	−0.066 (0.083)	0.879	1.038	Classical
109. Dominica	−1.908 ** (0.022)	0.196 ** (0.030)	0.781	1.146	2001	−2.016 ** (0.027)	0.133 ** (0.025)	−1.689 ** (0.105)	−0.030 (0.141)	−0.163 (0.143)	0.133	0.979	Classical

Table A1. *Cont.*

Country	Classical Experience Equation				Kinked	Kinked Experience Equation							Model
	log a	b	R^2	PR(=2^b)	year	log a_1	b_1	log a_2	b_2	$b_2 - b_1$	R^2	$PR_2(=2^{b2})$	Selection
110. Trinidad and Tobago	−0.872 ** (0.224)	0.196 ** (0.039)	0.626	1.146	1998	−1.478 ** (0.282)	0.342 ** (0.055)	−0.038 (0.531)	0.049 (0.083)	−0.293 ** (0.100)	0.874	1.035	Classical
111. Oman	−1.893 ** (0.154)	0.196 ** (0.031)	0.776	1.146	2005	−1.680 ** (0.111)	0.138 ** (0.023)	−3.805* (1.202)	0.530* (0.198)	0.392 (0.200)	0.915	1.444	Classical
112. Martinique	−2.006 ** (0.103)	0.200 ** (0.032)	0.69	1.149	1989	−1.914 ** (0.104)	0.001 (0.092)	−1.438 ** (0.150)	0.037 (0.042)	0.035 (0.101)	0.884	1.026	Classical
113. Cape Verde	−1.968 ** (0.166)	−0.454 * (0.171)	0.381	0.73	1986	−1.683 ** (0.115)	−0.817 ** (0.271)	−2.684 ** (0.078)	0.204 ** (0.067)	1.021 ** (0.279)	0.853	1.152	Kinked
114. El Salvador	−4.325 ** (0.423)	0.231 ** (0.041)	0.799	1.174	1995	−3.650 ** (0.582)	0.154 * (0.060)	−0.747 (0.798)	−0.098 (0.074)	−0.253* (0.095)	0.927	0.934	Classical
115. Cambodia	−3.556 ** (0.149)	0.389 ** (0.054)	0.79	1.309	1983	−5.105 ** (0.003)	0.003 * (0.001)	−3.161 ** (0.120)	0.235 ** (0.038)	0.232 ** (0.039)	0.894	1.177	Kinked
116. Comoros	−2.537 ** (0.020)	0.236 ** (0.052)	0.745	1.178	2007	−2.570 ** (0.021)	0.211 ** (0.057)	−2.250 * (0.701)	0.012 (0.786)	−0.199 (0.788)	0.773	1.008	Classical
117. Libya	−2.008 ** (0.142)	0.241 ** (0.023)	0.79	1.182	1986	−1.473 ** (0.221)	0.103 * (0.047)	−1.360 ** (0.287)	0.144 ** (0.045)	0.041 (0.065)	0.868	1.105	Classical
118. Tonga	−1.577 ** (0.028)	0.274 ** (0.022)	0.831	1.209	2006	−1.602 ** (0.036)	0.255 ** (0.026)	−1.119 * (0.272)	−0.073 (0.234)	−0.329 (0.236)	0.844	0.951	Classical
119. Tanzania	−1.509 ** (0.098)	−0.084 ** (0.027)	0.319	0.943	1996	−1.552 ** (0.159)	−0.055 (0.055)	−3.045 ** (0.219)	0.275 ** (0.053)	0.330 ** (0.077)	0.683	1.21	Kinked
120. Honduras	−2.430 ** (0.142)	0.228 ** (0.037)	0.808	1.171	1989	−1.980 ** (0.109)	−0.024 (0.050)	−2.617 ** (0.135)	0.279 ** (0.035)	0.303 ** (0.061)	0.92	1.213	Kinked
121. Guinea−Bissau	−1.482 ** (0.049)	0.282 ** (0.034)	0.856	1.216	1987	−1.887 ** (0.144)	0.035 (0.132)	−1.326 ** (0.034)	0.188 ** (0.024)	0.153 (0.134)	0.941	1.139	Classical
122. Togo	−2.232 ** (0.160)	0.284 ** (0.071)	0.439	1.218	1999	−1.891 ** (0.048)	−0.021 (0.029)	−2.142 * (0.942)	0.315 (0.313)	0.336 (0.315)	0.754	1.244	Classical
123. Congo (Brazzaville)	−2.173 ** (0.170)	0.320 ** (0.047)	0.698	1.248	1991	−1.794 ** (0.095)	−0.077 (0.067)	−1.295 ** (0.176)	0.104 (0.050)	0.181 * (0.084)	0.899	1.075	Classical
124. Maldives	−1.496 ** (0.051)	0.400 ** (0.029)	0.891	1.32	1984	−3.506 ** (0.056)	−0.120 ** (0.018)	−1.432 ** (0.054)	0.347 ** (0.031)	0.467 ** (0.036)	0.922	1.272	Kinked
125. Haiti	−3.897 ** (0.179)	0.353 ** (0.062)	0.665	1.277	1982	−3.568 ** (0.411)	−0.740 (1.522)	−4.097 ** (0.156)	0.423 ** (0.048)	1.162 (1.523)	0.726	1.341	Classical
126. Benin	−2.715 ** (0.171)	0.356 ** (0.067)	0.794	1.28	1987	−2.465 ** (0.131)	−0.03 (0.166)	−3.269 ** (0.060)	0.555 ** (0.024)	0.585 ** (0.168)	0.951	1.469	Kinked
127. Lebanon	−1.893 ** (0.154)	0.196 ** (0.031)	0.776	1.146	2001	−1.669 ** (0.129)	0.134 ** (0.029)	−4.698 ** (0.624)	0.672 ** (0.105)	0.537 ** (0.109)	0.907	1.593	Kinked

* $p < 0.05$; ** $p < 0.01$, *** $p < 0.001$; Numbers in parentheses are standard errors of coefficient.

References

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