Eco. Env. & Cons. 27 (1) : 2021; pp. (481-498)
Copyright@ EM International
ISSN 0971–765X

Convergence analysis of Terrestrial protected areas by 159 Countries

Yu Sang Chang, Moon Jung Kim and Sung Jun Jo*

Gachon University, Seongnam, Gyeonggi-do, South Korea

(Received 2 July, 2020; accepted 25 August, 2020)

ABSTRACT

Terrestrial biome protection is an important tool for biodiversity conservation.Differences in land use in protected areas are shown to have positive impact on biodiversity throughout the world. Aichi Target 11 states that by 2020, at least 17 percent of terrestrial areas globally should be conserved through effectively and equitably managed systems of protected areas. The major question of this research examines whether countries with low levels of terrestrial protection in the early years have been catching up faster to leading countries with higher terrestrial protection levels. Among four income subgroups as well as six regional subgroups out of a total of 159 countries, those subgroups with lower averaged protection levels in 1990 realized faster annual rate of increase for protection measure during the period of 1998 to 2015, displaying a process of catch-up. Furthermore, σ and γ convergence analysis of the income and the regional subgroups revealed the existence of the same type of relation between the 1990 protection level and annual rate of γ convergence as well as σ convergence. In sum, the initial level of protection measure was critical in generating the linkage between the rate of increasing averaged protection measure, the decreasing speed of γ convergence and the declining speed of σ convergence for respective income and regional subgroups of countries.Implication from these findings will be discussed.

Key words: *Terrestrial protection, PACOVW, PACOVD, σ convergence, Dispersion reduction, γ convergence, Catch-up process*

Introduction

According to United Nations there are 200,467 terrestrial and inland water protection areas as of 2016 covering 14.7% of the world's ecosystems (United Nations Environment Programmed World Conservation Monitoring Centre and International Union for Conservation of Nature, 2016a). Terrestrial biome protection areas are an important tool for biodiversity conservation (Rodrigues *et al.*, 2004). Differences in land use in protected terrestrial areas are shown to have a positive impact on biodiversity. Species richness and abundance, for example, are 10.6% and 14.5% higher than non-protected areas.

Terrestrial biomes on land are global scale biogeographic regions which are distinguished primarily by their predominant vegetation, and are mainly determined by temperature and rainfall. Environmental Performance Index measures for their terrestrial protected areas in 15 different biomes. For example, tropical forest biomes found in South America and boreal forests found in Canada may be representatives of forest biomes. Logging has depleted many old-growth temperate forests, while tropical forests have fallen victim to slash and burn farming and clear-felling for industrial use or cattle ranching. It has been estimated that over half of the world's original tropical forests, are already gone. It is important to preserve all types of biomes as each houses many unique forms of life. They also pro-

vide valuable ecosystem services such as erosion control and water retention that help sustain agriculture and human population (Hoekstra *et al.,* 2005). The value of these ecosystem services has been estimated at $33 trillion US per year (Costanza, *et al.,* 1997), and they total as much as 4.5 times the value of the Gross World Product (Bouman *et al.,* 2003).

The growth of terrestrial biome protection has been guided by the so-called the Aichi Biodiversity Targets (Convention on Biological Diversity, 2010). In 2010, Aichi Target 11 was adopted at the Convention on Biological Diversity (CBD) to be realized by 2020. Aichi Target 11 states that by 2020, at least 17 per cent of terrestrial and inland water area conserved through effectively and equitably managed ecologically representative and well-connected systems of protected areas.

Aichi Target 11 was further strengthened when the United Nations in 2015 adopted Sustainable Development Goals (United Nations, 2015). SDG 15 states to protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification and halt and reserve land degradation and halt biodiversity loss. More specifically, SDG target 15.1 states that by 2020, ensure the conservation, restoration, and sustainable use of terrestrial and inland freshwater, ecosystems and their services, in particular forests, wetlands, mountains and dry lands. Furthermore, SDG target 15.4 states that by 2020 ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development.

In order to meet these Aichi and SDG Targets, an additional 3.1 million square kilometers are needed to meet the 2020 target, and as of 2016, less than half of the world's terrestrial ecoregions outside of the Antarctic mainland satisfy the 17% target, according to a report issued by the United Nations Environment Programmer's World Conservation Monitoring Center and The International Union the Conservation of Nature (2016b) report.

To measure the terrestrial biome protection, the EPA calculates the proportions of important biomes that fall within protected areas of a country. The proportion of a biome type that is protected is, then, weighted in two ways. First, by the fraction each biome occupies within a country's total biome areas to develop the terrestrial biome protection-national weights indicator designated as code: PACOVD. Second, by the global extent of biomes to develop the terrestrial biome protection—global weights indicator designated as code: PACOVW. The protection indicators are measured in two ways because not all protection efforts are equal. For example, it would be much more important when a country protects a biome that is rare outside its border, because it matters much more than protecting a biome that is plentiful elsewhere. Unit of measurement for PACOVW and PACOVD are in percentage. Countries are not rewarded for protecting beyond the cap of 17% of any given biome so that higher levels of protection of some biomes cannot be used to offset lower levels of protection of other biomes.

Time series data on protected areas come from the World Databases on Protected Area (WDPA) produced by United Nations Environment Programmed World Conservation Monitoring Centre. Ecoregion boundaries are provided by the World Resources Institute "Terrestrial Ecoregions of the World" dataset. One of the most notable accomplishments in terrestrial protection area is the fact that as many as fifty countries have reached or exceeded the 17% cap determined in the Aichi Target 11. For example, Zambia, one of the world leaders, has 635 protected areas covering 37.9% of its total land area (United Nations Environment Programmed World Conservation Monitoring Centre, 2016b). Other global leaders include many European countries such as Germany, United Kingdom, Poland, Belgium, and Spain. On the other hand, there are many countries with only minimal levels of territorial protection even today. For example, this research will show later that there are 16 countries in the Middle East North Africa region whose average level of territorial protection in 1990 was only 1.22%. By 2015, however, the level of protection increased rapidly to reach 4.76%, which is still far below the Aichi's minimum 17% Target.

Therefore, the major question of this research examines whether countries with low level of terrestrial protection (TP) in the early years have been catching up faster to leading countries with higher TP levels. If so, how fast is the speed of catch-ups:For this analysis, a total of 159 countries were divided into four income subgroups as well as six regional subgroups. For our data, we use two TP measures of PACOVW and PACOVD available from Environmental Performance Index. The question of catch-up is examined first by comparing the increasing rate of mean TP measures among income

subgroups as well as among regional subgroups. Next, γ convergence method is used to determine annual speed of ranking changes or catch-up among individual countries within respective income and regional subgroup. And then, σ convergence method is used to estimate annual speed of decreasing relative dispersion or country differences of TP measures among individual countries within respective income and regional subgroups of countries.

Finally, outputs from the three phase analysis will be combined to see whether a linking relationship among these three outputs may exist. To our best knowledge, such a comprehensive convergence analysis on TP has not been published in the literature, making this research a possible new contribution.

Materials and Methods

Convergence Methodology

The convergence analysis attempts to examine two basis questions. First, do countries initially lagging in such performance measures as PACOVW and PACOVD index tend to improve faster so that they catch up to the performance of leading countries over time? Second, does dispersion of PACOVW and PACOVD index among countries get reduced over time?

Traditionally, γ convergence is used to examine the first question, while σ convergence is used to analyze the second question. γ convergence implies that the PACOVW index improve slowly in countries with high initial PACOVW measures and improve faster in countries with low initial PACOVW measures. The so-called Barro γ convergence method (Barro, 1991) regress the rate of improvement during a period on the initial value of the performance measure for respective countries. If the value of coefficient of slope is negative and statistically significant, then the catch-up process is demonstrated (Barro, 1991; Barro and Sala-i-Martin, 1992).

The use of "Barro regression" for both unconditional and conditional γ convergence was criticized to yield biased estimates (Friedman, 1992) due to Galton s Fallacy relating to the tendency of regression to mean. Instead, Friedman (1992) suggests that γ convergence can be more appropriately measured by tracking the inter-temporal change in the coefficient of variations of the distribution of performance measures for given countries. This method is known as γ convergence. If the trend is statistically significant and declining, γ convergence is confirmed. In addition, σ convergence method is simple to use.

Another criticism of γ convergence (Quah, 1996) is that the method does not provide us with the inter-temporal intra-distribution mobility of countries with respect to performance measures. Therefore, (Quah, 1993) suggests a method which is capable of capturing the full dynamics of evolving cross-country distribution using Markov Chain analysis. A simple approximation to Quah's methodology was proposed by Boyle and McCarthy (1997) where they use Kendall's index of rank concordance (Siegel, 1956) to measure changes in the ordinal ranking of countries over time. They label their method as ã convergence. By using γ convergence together with simple measure of γ convergence, they suggest that one can identify the nature of γ convergence and also a sense of the dynamics of the cross-country distribution of performance measures.

For our methodology, we use γ convergence (Boyle and McCarthy, 1997) and σ convergence (Friedman, 1992). Common measures of dispersion include standard deviation on coefficient of variation (Heckelman, 2015). For σ convergence, we have selected to use coefficient of variation (CV). CV is measured by dividing standard deviation by the sample average. Using CV which is dimensionless ratio enables us to compare the degree of dispersion for performance measures with different units. We then measure the inter-temporal changes by normalizing CV in subsequent years to CV at the initial year of 2003. Therefore, CV in 2003 is always 1.0. If CV in subsequent years is less than CV in the initial year, then, the normalized CV in subsequent years will be less than 1.0. If the values of normalized CVs in the subsequent years continue to decrease, and the differences between CVs are statistically significant, the result is viewed as evidence of σ convergence or reduction of dispersion. We use two sample t tests for CV (http://www.real-statistics.com/students-t-distribution/coefficient-of-variation-testing/). This test works best when the sample sizes are at least 10. Sime our sample sizes are much larger than 10, this test should work well.

For γ convergence model, Boyle and McCarthy (1997) suggested the use of Kendall s index of rank concordance which measures mobility of the indi-

vidual countries over time within the cross country distribution of a particular performance measure (Liddle, 2012; Chang *et al.,* 2019). In other words, γ convergence measures the degree of changing ranking order of countries between a given year and the initial year. The γ-convergence we use is Kendall s binary index version and is defined as follows:

$$\gamma_t = \left[\frac{var\ (AR\ (Y)_{it} + AR\ (Y)_{io})}{var\ (2 * AR\ (Y)_{io})}\right]$$

Where 545E (5L) = the actual rank of country i's performance measure in year t

545E (0) = the actual rank of country i's performance measure in year 0

Y_t = Binary Gamma Index in year t.

The γ index has the advantage of being of single number traced over time in two- dimension, analogous to the σ convergence index. The value of rank concordance ranges from zero to unity. If no change in rank order takes place, the rank concordance becomes unity. If a catch-up process is present, which result in change of rank order the index will be less than unity. The statistic is distributed as chi-square and we test the null hypothesis that γ convergence shows no difference between ranks of different years (Siegel, 1956).

According to Real Statistics Using Excel (http://www.real-statistics.com/reliability/kendalls-w/), the proper use of X^2 test to test statistical difference between Kendall's coefficients of concordance (W) on yearly γ indexes requires that the number of countries involved should be equal to 5 or more. Or the number of years being compared should be more than 15 years. In our case, the number of countries involved will be much larger than 5 countries. Therefore, we can use this X^2 test to validate the null hypothesis that W=0 or that there is no agreement between the years being compared.

How do we use σ and γ index together to evaluate reduction of dispersion as well as catch-up process? There are four different cases that can occur. The simplest case is when both σ and γ index are non-decreasing in values. Under the circumstance, neither reduction of dispersion nor catch-up may be taking place. The second case is that both ó and ã indexes are decreasing which indicates that both reduction of dispersion and catch-up process are taking place. The third case occurs where σ convergence measure is non-decreasing, while γ convergence value is in decline. Since γ convergence is a necessary but not sufficient condition for ó convergence, this indicates that catch-up process is taking place, while reduction of dispersion is not. The fourth case occurs where γ index is non-decreasing, while a substantial decline occurred in σ index. This indicates that country differences in performance measures remain so that no rank change among countries takes place. However, performance differences among countries have reduced considerably, which indicates conditional γ convergence. Put it another way, catch-up process may be taking place within respective subgroups of countries.

Data

For this research, there are two basic terrestrial biome protection measures of PACOVW and PACOVD which have been downloaded from Environmental Performance Index web site at http://epi2016.yale.edu/downloads. Yearly PACOVW and PACOVD measures during the period of 1990 to 2015 were available for 233 countries. Eliminating 24 countries with missing data leave 209 countries. There are 50 countries which have reached the cap of 17% Aichi Target during the period of 1990 to 2015. We have eliminated these 50 countries in order to concentrate convergence analysis on the remaining 159 countries that are in the active process of increasing their protection areas to reach the cap of 17%.

For categorizing four subgroups of countries by income level, World Bank's Gross National Income (GNI) per capita which converts the GNI of each country into US dollars using the World Bank Atlas method is used. According to the World Bank, four income groups are defined in 2015 as follows (https://blogs.worldbank.org/opendata/updated-income-classifications). The high income group contains those countries whose GNI per capita of $12,746 or more, followed by the upper middle-income group with GNI per capita between $4,126 and $12,745. The lower middle-income group contains those countries with GNI per capita between $1,045 and $4,125, while the lower income group contains those countries with $1,045 or less. GNI per capita using the Atlas method in current US dollars for countries in the world are available from the World Bank's web site at https://data.worldbank.org/indicator/ny.gnp.pcap.cd.

Out of a total of 159 countries, high income subgroup included 41 countries, followed by upper middle income subgroup of 49 countries, lower middle income subgroup of 42 countries and finally

low income subgroup of 27 countries.

The World Bank categorize 7 region of the world (https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups) from East Asia and Pacific (EAP), Europe and Central Asia (EAP), Latin America and Caribbean (LAC), Middle East and North Africa (MENA), North America (NA), South Asia (SA), and Sub Saharan Africa (SSA). Due to the fact that NA contains only 3 countries, NA is combined with ECA to form ECA&NA. Therefore, there are six regional subgroups in this study. The result of categorization is that EAP has 27 countries, followed by ECA and NA of 32 countries, LAC of 40 countries, MENA of 16 countries, SA of 7 countries and finally SSA of 37 countries, respectively.

Results

Historical averaged yearly PACOVW for the total group of 159 countries increased from 4.60% in 1990 to 9.57% by 2015 at the compounded annual growth rate (CAGR) of 2.97%, as shown in Table 1. Similarly, historical averaged yearly PACOVD also increased from 4.81% in 1990 to 9.30% by 2015 at the CAGR of 2.68%, as shown in Table 2.

When the average yearly PACOVW and PACOVD measures were analyzed by the four income subgroups, all four subgroups also displayed increasing trends supporting the increasing trends of both measures for the total group. However, the annual rate of increase varied substantially by the income subgroups. For PACOVW, lower middle income group displayed the most rapid rate of increase at 4.02%, followed by high income group at 3.2%, upper middle income group at 2.75%, and low income group at 1.98%. Replicating the same order, PACOVD measures also increased most rapidly at 3.76% by low middle, 3.18% by high, 2.31% by upper middle income, and 1.54% by low income subgroup.

It is important to note that the most rapidly increasing CAGRs of 4.02% and 3.76% were displayed by the low middle income group with the lowest average PACOVW level of 3.23% and PACOVD level of 3.37% in 1990. In contrast, the slowest in-

Table 1. Averaged PACOVW Measures for Total and Four Income Subgroups of 159 Countries (1990-2015)

Year	Total (159)	High (41)	Uppermiddle (49)	Lowermiddle (42)	Low (27)
1990	4.60	4.57	4.72	3.23	6.59
1991	4.82	4.93	4.97	3.37	6.63
1992	4.94	5.01	5.05	3.66	6.64
1993	5.32	5.70	5.11	4.20	6.85
1994	5.55	5.74	5.28	4.83	6.86
1995	5.66	5.83	5.39	5.04	6.86
1996	5.79	6.00	5.56	5.15	6.91
1997	5.98	6.16	5.72	5.33	7.21
1998	6.16	6.34	5.95	5.55	7.24
1999	6.32	6.60	6.18	5.61	7.27
2000	6.58	6.73	6.37	5.99	7.64
2001	6.81	6.84	6.68	6.23	7.90
2002	7.11	7.13	6.94	6.68	8.03
2003	7.35	7.36	7.22	6.79	8.44
2004	7.54	7.42	7.46	6.93	8.81
2005	7.68	7.54	7.52	7.03	9.18
2006	8.63	8.89	8.38	8.03	9.62
2007	8.84	9.01	8.64	8.06	10.15
2008	8.98	9.09	8.85	8.28	10.16
2009	9.15	9.31	8.91	8.48	10.42
2010	9.23	9.51	8.96	8.49	10.45
2011	9.27	9.56	8.99	8.52	10.50
2012	9.42	9.94	9.12	8.57	10.50
2013	9.51	10.01	9.19	8.64	10.67
2014	9.56	10.03	9.27	8.67	10.74
2015	9.57	10.03	9.29	8.67	10.74
CAGR	2.97%	3.20%	2.75%	4.02%	1.98%

creasing CAGRs of 1.98% and 1.54% were realized by the low income group with the highest average PACOVW level of 6.59% and PACOVD level of 6.99% in 1990. The second fastest increasing CAGRs of 3.2% and 3.18% belonged to the high income subgroup which began with the second highest PACOVW and PACOVD levels of 4.57% and 4.56% in 1990. Lastly, the third fastest increasing CAGRs of 2.75% and 2.31% were experienced by the upper middle income subgroup with theirthird highest lowest PACOVW and PACOVD levels of 4.72% and 5.04% in 1990.

These examples demonstrate that all three lagging subgroups of low middle, high and upper middle income groups with lower 1990 levels of PACOVW and PACOVD indexes trying to catch-up to the leading low income subgroup with faster increasing rates. As a result, the range of 2015 PACOVW measures became narrower at 2.07% (10.74%-8.67%) from 3.36% (6.59%-3.23%) in 1990. For PACOVD, the range became even more narrower at 1.75% (10.24%-8.49%) in 2015 from 3.22% (6.99%-3.37%) in 1990.

In other words, the level of terrestrial protection measures at the beginning appears to be the critical factor of determining annual rate of increase during the period under analysis. More specifically, the lower the 1990 level, the higher became the annual rate of increase following a process of catch-up. Put it another way, the effect of TPlevel at the beginning year appears to dominate the effect of income differences among these subgroups.

The next question was whether the similar effect from TP level at the beginning year would be discovered in regional analysis? When the average yearly PACOVW measures were analyzed by six regions, three regions of MENA, EAP, and ECANA displayed somewhat faster rate of increase than the total group's annual rate of increase at 2.97% with 5.58%, 4.45% and 3.23% respectively. In contrast, the remaining regions of LAC, SSA, and SA showed either the same or slower rates at 2.96%, 1.96%, and 1.85% respectively, as shown in Table 3.

The relationship between the 1990 level

Table 2. Averaged PACOVD Measures for Total and Four Income Subgroups of 159 Countries (1990-2015)

Year	Total (159)	High (41)	Upper middle (49)	Lower middle (42)	Low (27)
1990	4.81	4.56	5.04	3.37	6.99
1991	5.00	4.94	5.18	3.54	7.02
1992	5.12	5.03	5.24	3.84	7.04
1993	5.39	5.66	5.35	4.08	7.11
1994	5.64	5.69	5.52	4.76	7.12
1995	5.74	5.78	5.61	4.97	7.12
1996	5.89	5.96	5.73	5.14	7.22
1997	6.08	6.09	5.90	5.35	7.56
1998	6.21	6.26	6.06	5.46	7.59
1999	6.36	6.51	6.28	5.50	7.62
2000	6.54	6.66	6.39	5.83	7.75
2001	6.70	6.78	6.58	6.03	7.87
2002	6.95	7.01	6.78	6.45	7.95
2003	7.23	7.25	7.13	6.54	8.46
2004	7.35	7.32	7.27	6.68	8.57
2005	7.45	7.43	7.32	6.80	8.70
2006	8.42	8.89	8.15	7.77	9.21
2007	8.61	9.01	8.39	7.80	9.67
2008	8.77	9.10	8.55	8.11	9.68
2009	8.93	9.31	8.60	8.28	9.94
2010	9.00	9.51	8.64	8.31	9.97
2011	9.06	9.56	8.67	8.35	10.09
2012	9.19	9.86	8.81	8.41	10.09
2013	9.25	9.94	8.86	8.45	10.17
2014	9.29	9.96	8.89	8.48	10.24
2015	9.30	9.97	8.92	8.49	10.24
CAGR	2.68%	3.18%	2.31%	3.76%	1.54%

ofPACOVW to the CAGR during the 1990 to 2015 period by six regions appear to exist, supporting the earlier findings from the analysis by income groups. The most rapid CAGR of 5.58% realized by the MENA region which also displayed the lowest 1990 measure at 1.22%. The second and third most rapid CAGRs of 4.45% and 3.23% realized by EAP and ECA&NA region also displayed the second and third lowest 1990 measures of 2.95 and 4.4 respectively. In contrast, the highest and the second highest 1990 measures which belonged to SSA and LAC region realized the second slowest CAGR of 1.96% (SSA) and third slowest CAGR of 2.96% (LAC) respectively. SA represented a case of exception with a relatively high 1990 level of 4.86% yet realizing the slowest CAGR of 1.85%. In other words, with a minor variation, the general principle appears to be again that faster CAGRs were associated with those regionswith lower levels of PACOVW measures at the beginning year and *vice versa*.

For PACOVD, three regions with faster rate of increase than the total group were again in the order of MENA (4.43%), EAP (4.22%), and ECANA (3.48%). In contrast, the remaining three regions with slower rate of increase were led by LAC (2.54%), SSA (1.57%) and SA (1.14%), as shown in Table 4. The sequence of regional subgroups between the CAGR and 1990 PACOVD measure were identical to those displayed by PACOVW in Table 3. Thus, the same summary statement made far PACOVW is applicable for PACOVD as well.

Now that catch-up effects based on the averaged TP measures by the lagging income and regional subgroups have been established, next question was whether catch-up effects among individual countries within respective income and regional subgroups have taken place. Another relatedquestion was whether the degree of relative dispersion among individual countries within respective income and regional subgroups have also taken place. To answer these questions, we now turned to γ and σ convergence analysis.

First, Table 5 shows normalized σ and γ indexes of PACOVW for the total group of countries during

Table 3. Averaged PACOVW Measures for Six Regional Subgroups of 159 Countries (1990-2015)

Year	EAP(27)	ECA&NA(32)	LAC(40)	MENA(16)	SSA(37)	SA(7)
1990	2.95	4.40	5.50	1.22	6.44	4.86
1991	3.38	4.56	5.89	1.24	6.48	4.88
1992	3.42	4.71	6.17	1.25	6.53	4.91
1993	3.70	5.34	6.40	1.32	6.70	7.07
1994	4.34	5.72	6.55	1.39	6.71	7.08
1995	4.67	5.78	6.66	1.45	6.74	7.08
1996	4.72	6.13	6.83	1.48	6.78	7.09
1997	4.97	6.31	6.93	1.77	7.00	7.16
1998	5.12	6.48	7.33	1.95	7.02	7.17
1999	5.18	6.61	7.76	2.00	7.04	7.26
2000	5.43	6.96	8.07	2.04	7.31	7.27
2001	5.76	7.11	8.36	2.05	7.60	7.31
2002	6.05	7.62	8.59	2.62	7.72	7.33
2003	6.17	7.69	8.90	2.80	8.20	7.36
2004	6.31	7.93	8.98	2.91	8.58	7.36
2005	6.51	8.09	9.01	2.92	8.85	7.38
2006	7.90	8.46	10.53	3.79	9.56	7.45
2007	8.07	8.81	10.60	3.79	9.95	7.53
2008	8.15	8.91	10.77	4.38	9.99	7.53
2009	8.39	9.29	10.78	4.38	10.20	7.54
2010	8.61	9.40	10.81	4.40	10.23	7.60
2011	8.63	9.46	10.84	4.44	10.26	7.67
2012	8.70	9.57	11.29	4.47	10.27	7.69
2013	8.74	9.66	11.38	4.50	10.41	7.70
2014	8.75	9.71	11.39	4.76	10.46	7.70
2015	8.75	9.75	11.39	4.76	10.46	7.70
CAGR	4.45%	3.23%	2.96%	5.58%	1.96%	1.85%

1990 to 2015. Both indexes displayed declining trends indicating σ and γ convergence. The speed of ó convergence is about 3.45 times faster at the CAGR of -2.31% over the speed of γ convergence at -0.62%. Each yearly γ index met the statistical test of significance at less than 1% level. The test for yearly ó indexes were also valid from 2000 to 2015, as shown in Table 5.

Table 5 also shows the nearly identical distribution of yearly σ and γ indexes for PACOVD for the total group of countries during 1990 to 2015. Once again, both indexes decreased during the period indicating σ and γ convergence. Once again, the speed of σ convergence is about 3.5 times faster at the CAGR of -2.0% over the speed of γ convergence at -0.57%. Each yearly γ index met the statistical test of significance at less than 1% level. Yearly σ index from 2000 to 2014 also met the significance test, as shown in Table 6.

And then, σ and γ indexes of PACOVW were analyzed by four income subgroups in Table 4, all four income groups displayed downward trends supportingboth σ and γ convergence for the total group. The speed of σ convergence was the most rapid at -2.33% by the lower middle income group followed by -2.18% for the high income group, -1.95% for the upper middle group and finally -1.77% for the low income group, which replicated the same sequence displayed in the CAGR for the average PACOVW measures in Table 1. Yearly σ indexes from 2007 to 2015 met the statistical significance test for the high income group, as did the upper middle and the lower middle group for some selected years. However, none of the yearly ó index met the statistical significance test for the low income group.

The speeds of γ convergence again varied by income subgroups. The most rapid rate of reduction was essentially tied between -0.82% by the high income group, and -0.81% the lower middle group. The upper middle income group displayed -0.54% and the low income group displayedthe slowest annual speed at -0.49%. Once again, nearly the same sequence of income groups displayed in the CAGRs

Table 4. Averaged PACOVD Measures for Six Regional Subgroups of 159 Countries (1990-2015)

Year	EAP (27)	ECA&NA (32)	LAC (40)	MENA (16)	SSA (37)	SA (7)
1990	3.15	3.80	6.17	1.64	6.71	5.17
1991	3.54	3.90	6.56	1.66	6.74	5.19
1992	3.58	4.06	6.82	1.67	6.80	5.23
1993	3.81	4.66	7.12	1.73	6.82	5.73
1994	4.44	5.04	7.29	1.89	6.84	5.73
1995	4.79	5.11	7.38	1.95	6.87	5.73
1996	4.84	5.46	7.53	2.02	6.94	5.75
1997	5.11	5.64	7.62	2.34	7.17	5.89
1998	5.26	5.81	7.81	2.53	7.19	5.89
1999	5.31	5.94	8.20	2.55	7.21	6.03
2000	5.54	6.22	8.43	2.58	7.30	6.09
2001	5.78	6.38	8.60	2.59	7.47	6.18
2002	6.07	6.86	8.76	3.02	7.56	6.22
2003	6.20	6.93	9.12	3.12	8.16	6.27
2004	6.34	7.16	9.18	3.22	8.25	6.28
2005	6.56	7.32	9.20	3.22	8.34	6.34
2006	8.00	7.68	10.73	4.08	9.14	6.41
2007	8.18	8.00	10.78	4.08	9.49	6.46
2008	8.27	8.14	10.98	4.65	9.50	6.48
2009	8.51	8.45	11.01	4.65	9.71	6.50
2010	8.73	8.56	11.04	4.66	9.73	6.59
2011	8.74	8.61	11.09	4.69	9.79	6.80
2012	8.80	8.74	11.46	4.72	9.79	6.82
2013	8.84	8.84	11.51	4.74	9.86	6.87
2014	8.85	8.90	11.52	4.84	9.91	6.87
2015	8.85	8.93	11.53	4.85	9.91	6.87
CAGR	4.22%	3.48%	2.54%	4.43%	1.57%	1.14%

of PACOVW measure was repeated in the speeds of γ convergence as well. All γ indexes met the test of statistical significance at less than 1% level every year during the period.

The results from σ and γ indexes of PACOVD, as shown in Table 7were quite similar to the results for PACOVW. Both σ and γ convergence displayed by the respective income subgroups supported the total group of 159 countries. The speed of σ convergence were the fastest by the high income subgroup (-2.58%), followed by the lower middle subgroup (-2.26%), the upper middle subgroup (-1.67%) and the low income subgroup (-1.33%). The speed of γ convergence was also led by the high income subgroup (-0.94%), followed by the lower middle subgroup (-0.74%), the upper middle income subgroup (-0.44%) and the low income subgroup (-0.40%). Once again, nearly the same sequence of income groups displaying the CAGRs of PACOVD measure was repeated in both σ and γ convergence. One difference was that the high income group displayed the most rapid speeds instead of the low middle income group.

To explain, σ and γ convergence results from the income subgroups analysis appeared to be closely related to varying rates of increase on TP measures discovered earlier by in the income subgroups. The annual speed of γ convergence representing ranking changes among individual countries followed the sequence of ① high, ② low middle, ③ upper middle and ④ low income subgroups, closely matching the sequence of ① lower middle, ② high, ③ upper middle and ④ low middle subgroups for the rate of increase on PACOVW and PACOVD measures. The annual speed of σ convergence representing reduction of relative dispersion among individual countries for PACOVW follows the same sequence of ① low middle, ② high, ③ upper middle and ④ low income subgroup experienced for the rates of increase in both TP measures. Finally, the annual speed of ó

Table 5. Normalized Sigma and Gamma Indexes of PACOVW and PACOVDfor 159Countries (1990-2015)

	PACOVW (159)				PACOVD (159)			
Year	Sigma		Gamma		Sigma		Gamma	
1990	1.0000		1.0000		1.0000		1.0000	
1991	0.9741		0.9941	***	0.9757		0.9957	***
1992	0.9586		0.9887	***	0.9546		0.9886	***
1993	0.9331		0.9704	***	0.9375		0.9801	***
1994	0.9194		0.9552	***	0.9185		0.9650	***
1995	0.9052		0.9554	***	0.9027		0.9654	***
1996	0.8807		0.9604	***	0.8786		0.9700	***
1997	0.8615		0.9603	***	0.8539		0.9685	***
1998	0.8416		0.9575	***	0.8382		0.9663	***
1999	0.8207		0.9517	***	0.8192		0.9613	***
2000	0.7986	*	0.9410	***	0.8007	*	0.9571	***
2001	0.7864	*	0.9395	***	0.7863	*	0.9577	***
2002	0.7649	**	0.9310	***	0.7671	**	0.9490	***
2003	0.7582	**	0.9313	***	0.7640	**	0.9493	***
2004	0.7364	**	0.9262	***	0.7511	**	0.9467	***
2005	0.7263	**	0.9214	***	0.7431	**	0.9447	***
2006	0.6607	***	0.8922	***	0.6752	***	0.9080	***
2007	0.6487	***	0.8817	***	0.6608	***	0.8946	***
2008	0.6305	***	0.8751	***	0.6441	***	0.8844	***
2009	0.6167	***	0.8734	***	0.6324	***	0.8808	***
2010	0.6130	***	0.8720	***	0.6290	***	0.8782	***
2011	0.6110	***	0.8707	***	0.6261	***	0.8775	***
2012	0.5977	***	0.8595	***	0.6148	***	0.8677	***
2013	0.5920	***	0.8572	***	0.6099	***	0.8684	***
2014	0.5849	***	0.8563	***	0.6050	***	0.8680	***
2015	0.5840	***	0.8559	***	0.6041	***	0.8671	***
Annual %Change	-2.13%		-0.62%		-2.00%		-0.57%	

Table 6. Normalized Sigma and Gamma PACOVW Indexes of Four Income Subgroups for 159 Countries (1990-2015)

	High income (41)				Upper middle income (49)			
Year	Sigma		Gamma		Sigma		Gamma	
1990	1.0000		1.0000		1.0000		1.0000	
1991	0.9693		0.9885	***	0.9800		0.9933	***
1992	0.9506		0.9875	***	0.9729		0.9902	***
1993	0.9486		0.9598	***	0.9604		0.9887	***
1994	0.9431		0.9584	***	0.9537		0.9839	***
1995	0.9285		0.9678	***	0.9506		0.9949	***
1996	0.8900		0.9626	***	0.9270		1.0072	***
1997	0.8705		0.9555	***	0.8923		1.0118	***
1998	0.8375		0.9373	***	0.8634		1.0114	***
1999	0.7957		0.9384	***	0.8382		0.9949	***
2000	0.7849		0.9345	***	0.8405		0.9964	***
2001	0.7802		0.9291	***	0.8168		0.9760	***
2002	0.7419		0.9214	***	0.7854		0.9767	***
2003	0.7377		0.9201	***	0.7761		0.9729	***
2004	0.7358		0.9179	***	0.7610		0.9584	***
2005	0.7401		0.9081	***	0.7523		0.9583	***
2006	0.6841		0.8721	***	0.6996		0.9280	***
2007	0.6798	*	0.8630	***	0.6883	*	0.9004	***
2008	0.6700	*	0.8621	***	0.6621	*	0.8898	***
2009	0.6448	*	0.8607	***	0.6518	**	0.8872	***
2010	0.6355	**	0.8478	***	0.6479	**	0.8891	***
2011	0.6344	**	0.8417	***	0.6446	**	0.8890	***
2012	0.5911	**	0.8144	***	0.6360	**	0.8800	***
2013	0.5769	**	0.8124	***	0.6265	**	0.8800	***
2014	0.5763	**	0.8148	***	0.6144	**	0.8752	***
2015	0.5763	**	0.8148	***	0.6115	**	0.8737	***
Annual %Change	-2.18%		-0.82%		-1.95%		-0.54%	

convergence for PACOVD displayed exactly the same sequence as γ convergence.

Taking the 42 countries under the low income subgroups, it was suggested earlier that the lowest 1990 averaged PACOVW level at 3.23% became the driving force to generate the most rapid increase during 1990 to 2015 at the annual rate of increase at 4.02%. The result of this catch-up increased the averaged PACOVW level to 8.67% by 2015. The analysis of γ convergence indicates that the most rapid annual rate of increase was realized by the most active rate of ranking changes at -0.81% which took place among 42 countries in this subgroups. The most active ranking changes represent the most active rate of catch-up effect among these individual countries. The result of the most active catch-up effect among these countries, in turn, resulted in the most rapid reduction of dispersion at -2.33 measured in coefficient of variation representing a relative dispersion measure.

In short, the level of TP measure in the early year appear to exercise a decisive role of determining the annual rate of increasing TP measures during the period under analysis, which, in turn, influence the rate of catch-up (γ convergence) and eventually determine the rate of narrowing country differences (σ convergence) in their TP measures as well.

When normalized σ and γ indexes were analyzed by six regional subgroups, all σ and γ indexes showed declining trends, each region supporting σ and γ convergence displayed by the total groups of countries for both PACOVW and PACOVD.

Once again, the speed of σ convergence varied by regional subgroups. For σ indexes of PACOVW, three regions of EAP (-2.79%), ECANA (-2.23%) and LAC (-2.16%) displayed faster speed of σ convergence compared to the total group's speed at -2.13%. In contrast, three regions of MENA (-2.06%), SA (-1.71%) and SSA (-1.65%) displayed somewhat more slow speeds, as shown in Table 8.

As for σ convergence of PACOVD, three regions with faster speed were in the order of EAP(-2.92%),

Table 6. [Continued] Normalized Sigma and Gamma PACOVW Indexes of Four Income Subgroups for 159 Countries (1990-2015)

	Lower middle income (42)				Low income (27)		
Year	Sigma		Gamma		Sigma	Gamma	
1990	1.0000		1.0000		1.0000	1.0000	
1991	0.9641		0.9923	***	0.9951	0.9997	***
1992	0.9465		0.9820	***	0.9931	0.9997	***
1993	0.9147		0.9401	***	0.9569	0.9988	***
1994	0.8908		0.8862	***	0.9536	0.9988	***
1995	0.8581		0.8672	***	0.9536	0.9988	***
1996	0.8384		0.8657	***	0.9396	0.9954	***
1997	0.8167		0.8745	***	0.9384	0.9869	***
1998	0.8117		0.8832	***	0.9308	0.9860	***
1999	0.8048		0.8816	***	0.9267	0.9860	***
2000	0.7691		0.8744	***	0.8650	0.9496	***
2001	0.7443		0.8708	***	0.8776	0.9347	***
2002	0.7343		0.8554	***	0.8735	0.9377	***
2003	0.7211		0.8568	***	0.8742	0.9295	***
2004	0.7065		0.8551	***	0.7982	0.9191	***
2005	0.6998		0.8537	***	0.7557	0.9164	***
2006	0.6073	*	0.8399	***	0.7142	0.9154	***
2007	0.6074	*	0.8398	***	0.6604	0.8916	***
2008	0.5808	**	0.8383	***	0.6603	0.8916	***
2009	0.5625	**	0.8221	***	0.6596	0.8898	***
2010	0.5627	**	0.8221	***	0.6577	0.8907	***
2011	0.5621	**	0.8170	***	0.6532	0.8907	***
2012	0.5609	**	0.8157	***	0.6531	0.8907	***
2013	0.5617	**	0.8175	***	0.6509	0.8813	***
2014	0.5553	**	0.8162	***	0.6406	0.8834	***
2015	0.5552	**	0.8162	***	0.6406	0.8834	***
Annual %Change	-2.33%		-0.81%		-1.77%	-0.49%	

followed by LAC (-2.39%) and MENA (-2.31%). Three regions of ECANA (-1.74%), SSA (-1.37%) and SA (-0.64%) displayed slower speed than the total group's speed at -2.0%.

As for the speed of γ convergence for PACOVW, four regions of EAP (-1.33%), SA (-0.87%), ECANA (-0.80%) and LAC (-0.77%) displayed faster speed than the total group's speed at -0.62%. In contrast, MENA displayed the slowest speed at -0.42%, followed by SSA at -0.49%, as shown in Table 8.

In case of the speed of γ convergence for PACOVD, the faster speed over that of the total group at -0.57% was recorded by EAP at -1.23%, followed by LAC at -0.94% and ECANA at -0.93%. In contrast, the remaining three regions displayed slower speed at -0.39% by MENA, -0.37% by SSA, and -0.15% by SA. Every γ indexes met the statistical test of significance at 1% level. As for σ indexes, four regions of ECANA, LAC, EAP and SSA for PACOVW and three regions of ECANA, LAC and EAP for PACOVD successfully met the significance test typically in more recent years between 2006 to 2015.

In short, the ranking order on the annual speed of σ and γ convergence among the six regions did not display a close match between PACOVW and PACOVD, as was the case for the income subgroups. Neither was the clear-cut relationship shownin the income subgroups between the annual rate of increase to the annual speeds of σ and γ convergence occurred in the regional subgroups. One of the major reason was that the two regions, MENA and SA, displayed irregular patterns between increasing rates of TP measures to annual speeds of σ and γ convergence.When these two regions were removed from the analysis, the remaining four regions of EAP, ECANA, LAC and SSA in that order displayed matching speeds among the increasing rate of TP measure, speed of declining γ convergence and speed of σ convergence. the speed

Table 7. Normalized Sigma and Gamma PACOVD Indexes of Four Income Subgroups for 159 Countries (1990-2015)

	High income (41)				Upper middle income (49)			
Year	Sigma		Gamma		Sigma		Gamma	
1990	1.0000		1.0000		1.0000		1.0000	
1991	0.9613		0.9877	***	0.9813		0.9932	***
1992	0.9403		0.9864	***	0.9713		0.9912	***
1993	0.9329		0.9564	***	0.9579		0.9918	***
1994	0.9272		0.9568	***	0.9491		0.9878	***
1995	0.9107		0.9671	***	0.9407		1.0000	***
1996	0.8722		0.9608	***	0.9209		1.0139	***
1997	0.8597		0.9525	***	0.8840		1.0176	***
1998	0.8277		0.9345	***	0.8623		1.0163	***
1999	0.7864		0.9332	***	0.8369		0.9999	***
2000	0.7740		0.9336	***	0.8304		1.0037	***
2001	0.7694		0.9366	***	0.8089		0.9975	***
2002	0.7275		0.9269	***	0.7939		0.9986	***
2003	0.7229		0.9303	***	0.7912		0.9954	***
2004	0.7212		0.9307	***	0.7729		0.9926	***
2005	0.7266		0.9175	***	0.7659		0.9930	***
2006	0.6470	*	0.8497	***	0.7219		0.9528	***
2007	0.6434	*	0.8404	***	0.7053		0.9294	***
2008	0.6339	**	0.8321	***	0.6880	*	0.9224	***
2009	0.6093	**	0.8251	***	0.6818	*	0.9224	***
2010	0.5994	**	0.8026	***	0.6790	*	0.9229	***
2011	0.5983	**	0.8037	***	0.6764	*	0.9219	***
2012	0.5633	**	0.7942	***	0.6683	*	0.9029	***
2013	0.5491	***	0.7909	***	0.6629	*	0.9005	***
2014	0.5482	***	0.7901	***	0.6595	*	0.8979	***
2015	0.5482	***	0.7901	***	0.6565	*	0.8947	***
Annual %Change	-2.38%		-0.94%		-1.67%		-0.44%	

of σ and γ convergence in ECA, ECANA, LAC and SSE regions were influenced by the rate of increase on their TP measures, as was the case of income subgroups.

Discussion

Key findings from this research can be summarized as follows: First, historical averaged yearly PACOVW and PACOVD increased at the CAGR of 2.97% and 2.68% respectively from 1990 to 2015. Second, historical averaged yearly TP measures varied by four different income subgroups. The level of TP measures at the beginning year of 1990 appeared to be the critical factor of determining the CAGRs of TP measures for respective income subgroups. In other words, the lower was the 1990 TP level, the more rapid became the CAGR for respective income subgroups, following a catch-up process.

Third, the same relationship between the lower level of TP measures in 1990 to the higher CAGRs of six respective regional subgroups were also discovered, displaying a catch-up process. Fourth, statistically significant σ and γ convergence have been established for respective income subgroups with varying annual speed of reduction for both TP measures.

Fifth, the annual rate of declining ã convergence representing ranking change among individual countries within respective income subgroups for both TP measures followed nearly the same sequence of income subgroups displayed in determining the CAGRs of TP measures. Sixth, the annual speed of σ convergence representing reduction of relative dispersion among individual countries for both TP dispersion among individual countries for both TP measures also replicated nearly the same sequence of income subgroups displayed in determining the CARGs of TP measures.

Seventh, the levels TP measure in 1990 appeared

Table 7. [Continued] Normalized Sigma and Gamma PACOVD Indexes of Four Income Subgroups for 159 Countries (1990-2015)

	Lower middle income (42)				Low income (27)		
Year	Sigma		Gamma		Sigma	Gamma	
1990	1.0000		1.0000		1.0000	1.0000	
1991	0.9864		0.9954	***	0.9941	0.9997	***
1992	0.9442		0.9794	***	0.9920	0.9994	***
1993	0.9262		0.9666	***	0.9835	0.9994	***
1994	0.8877		0.9102	***	0.9793	0.9991	***
1995	0.8558		0.8941	***	0.9793	0.9991	***
1996	0.8402		0.8906	***	0.9536	0.9963	***
1997	0.8164		0.8922	***	0.9204	0.9872	***
1998	0.8168		0.9021	***	0.9128	0.9872	***
1999	0.8144		0.9040	***	0.9110	0.9872	***
2000	0.7808		0.8999	***	0.8875	0.9844	***
2001	0.7535		0.8984	***	0.8930	0.9719	***
2002	0.7397		0.8802	***	0.8866	0.9716	***
2003	0.7310		0.8795	***	0.8881	0.9560	***
2004	0.7180		0.8757	***	0.8687	0.9557	***
2005	0.7061		0.8764	***	0.8478	0.9563	***
2006	0.6206	*	0.8633	***	0.7989	0.9414	***
2007	0.6202	*	0.8633	***	0.7386	0.9170	***
2008	0.5905	**	0.8419	***	0.7382	0.9170	***
2009	0.5743	**	0.8305	***	0.7388	0.9048	***
2010	0.5741	**	0.8305	***	0.7386	0.9084	***
2011	0.5722	**	0.8323	***	0.7290	0.9051	***
2012	0.5712	**	0.8322	***	0.7289	0.9051	***
2013	0.5711	**	0.8348	***	0.7272	0.9029	***
2014	0.5645	**	0.8335	***	0.7157	0.9038	***
2015	0.5644	**	0.8307	***	0.7157	0.9038	***
Annual %Change	-2.26%		-0.74%		-1.33%	-0.40%	

to have played the critical role of determining CAGRs of TP measures which, in turn, influenced the rate of catch-up (γ convergence) and eventually determining the rate of reducing dispersion or country differences (σ convergence) as well for respective income subgroup.

Eighth, statistically significant σ and γ convergence have also been discovered for six regional subgroups with varying speeds of reduction for both TP measures. When two regions of MENA and SA were removed, the remaining four regions displayed nearly the same relationship between the CAGRs of TP measures and the annual speeds of ó and ãconvergence. In other words, the initial level of TP measure were critical in generating a linkage of the CAGRs, the speed of ã convergence and the speed of ó convergence for respective four regional subgroups of countries as well.

What are some policy implications for individual countries pursuing the expansion of TP measures? The most interesting finding from this research established the linkage between the initial level of TP measures - annual rate of increase of TP measure - annual speed of γ convergence - annual speed of ó convergence in that order. How can an individual country benefit from this finding? The answer may be deceptively simple. That is to use the difference of TP levels existing between two individual countries. For example, highlight the difference between the highest TP level from a leading country against the TP level of one's own country where both countries belong to either the same income or regional subgroup. And then, develop goals, policies and projects to close the gap for a catch-up during a selected period. It would also be useful to benchmark some other countries within the same subgroup who have achieved outstanding results in the implementation of TP activities.

How can different countries also use the outputs from this research in evaluating their past progress

Table 8. Normalized Sigma and Gamma PACOVW Indexes of Six Regional Subgroups for 159 Countries (1990-2015)

	East Asia & Pacific (27)				Europe, Central Asia& North America (32)			
Year	Sigma		Gamma		Sigma		Gamma	
1990	1.0000		1.0000		1.0000		1.0000	
1991	0.9257		0.9823	***	0.9534		0.9844	***
1992	0.9248		0.9823	***	0.9205		0.9772	***
1993	0.9020		0.9820	***	0.9236		0.9376	***
1994	0.8536		0.8991	***	0.9456		0.9401	***
1995	0.8114		0.8717	***	0.9359		0.9525	***
1996	0.8027		0.8749	***	0.8564		0.9434	***
1997	0.7813		0.8967	***	0.8305		0.9323	***
1998	0.7554		0.8844	***	0.8086		0.9165	***
1999	0.7549		0.8788	***	0.8023		0.9056	***
2000	0.7213		0.8935	***	0.7715		0.8818	***
2001	0.6970		0.8833	***	0.7614		0.8779	***
2002	0.7028		0.8647	**	0.7236		0.8788	***
2003	0.6939		0.8668	**	0.7211		0.8768	***
2004	0.6904		0.8686	**	0.6863		0.8700	***
2005	0.6710		0.8647	**	0.6888		0.8624	***
2006	0.5303	*	0.7913	**	0.6664		0.8474	***
2007	0.5356	*	0.7580	**	0.6485		0.8339	***
2008	0.5260	*	0.7555	**	0.6479		0.8318	***
2009	0.5028	**	0.7362	**	0.5960	**	0.8193	***
2010	0.4933	**	0.7204	**	0.5948	**	0.8222	***
2011	0.4933	**	0.7204	**	0.5937	**	0.8206	***
2012	0.4929	**	0.7158	**	0.5968	**	0.8185	***
2013	0.4936	**	0.7158	**	0.5768	**	0.8197	***
2014	0.4934	**	0.7158	**	0.5729	**	0.8189	***
2015	0.4934	**	0.7158	**	0.5690	**	0.8189	***
Annual %Change	-2.79%		-1.33%		-2.23%		-0.80%	

Table 8. [Continued] Normalized Sigma and Gamma PACOVW Indexes of Six Regional Subgroups for 159 Countries (1990-2015)

	Latin America & Caribbean (40)				Middle East & North Africa (16)			
Year	Sigma		Gamma		Sigma		Gamma	
1990	1.0000		1.0000		1.0000		1.0000	
1991	0.9941		0.9817	***	1.0042		1.0000	**
1992	0.9675		0.9548	***	0.9948		0.9979	**
1993	0.9688		0.9475	***	0.9463		0.9829	**
1994	0.9665		0.9436	***	0.8963		0.9872	**
1995	0.9647		0.9420	***	0.8535		1.0332	**
1996	0.9451		0.9374	***	0.8395		1.0289	**
1997	0.9249		0.9345	***	0.8225		1.1021	**
1998	0.9009		0.9259	***	0.7457		1.0743	**
1999	0.8259		0.8956	***	0.7273		1.1288	**
2000	0.8231		0.8899	***	0.7139		1.1374	**
2001	0.7974		0.8776	***	0.7163		1.1374	**
2002	0.7888		0.8722	***	0.6534		1.0582	**
2003	0.7857		0.8741	***	0.6300		1.0778	**
2004	0.7794		0.8724	***	0.6270		1.0735	**
2005	0.7771		0.8724	***	0.6291		1.0735	**
2006	0.6914	*	0.8530	***	0.7685		0.9965	**
2007	0.6877	*	0.8521	***	0.7685		0.9965	**
2008	0.6604	*	0.8497	***	0.6543		0.9195	**
2009	0.6596	*	0.8497	***	0.6544		0.9195	**
2010	0.6581	*	0.8515	***	0.6526		0.9195	**
2011	0.6553	*	0.8484	***	0.6495		0.9131	**
2012	0.5914	**	0.8189	***	0.6447		0.9131	**
2013	0.5805	**	0.8197	***	0.6410		0.9131	**
2014	0.5806	**	0.8234	***	0.5945		0.9003	**
2015	0.5800	**	0.8234	***	0.5944		0.9003	**
Annual %Change	-2.16%		-0.77%		-2.06%		-0.42%	

Table 8. [Continued] Normalized Sigma and Gamma PACOVW Indexes of Six Regional Subgroups for 159 Countries (1990-2015)

	Sub-Saharan Africa (37)					South Asia (7)		
	Sigma		Gamma			Sigma	Gamma	
1990	1.0000		1.0000			1.0000	1.0000	
1991	0.9963		0.9999	***		0.9970	1.0000	**
1992	0.9868		0.9987	***		0.9900	1.0000	**
1993	0.9747		0.9963	***		0.7205	0.8214	**
1994	0.9722		0.9967	***		0.7201	0.8214	**
1995	0.9643		0.9961	***		0.7201	0.8214	**
1996	0.9534		0.9990	***		0.7165	0.8214	**
1997	0.9573		0.9948	***		0.7081	0.8214	**
1998	0.9513		0.9947	***		0.7069	0.8214	**
1999	0.9467		0.9950	***		0.6953	0.8036	**
2000	0.9001		0.9697	***		0.6937	0.8036	**
2001	0.8967		0.9582	***		0.6930	0.8036	**
2002	0.8920		0.9609	***		0.6904	0.8036	**
2003	0.8756		0.9479	***		0.6876	0.8036	**
2004	0.8184		0.9295	***		0.6876	0.8036	**
2005	0.7888		0.9224	***		0.6856	0.8036	**
2006	0.7089		0.9151	***		0.6801	0.8036	**
2007	0.6696	*	0.9023	***		0.6685	0.8036	**
2008	0.6713	*	0.8997	***		0.6689	0.8036	**
2009	0.6718	*	0.8983	***		0.6689	0.8036	**
2010	0.6716	*	0.8983	***		0.6602	0.8036	**
2011	0.6696	*	0.8983	***		0.6540	0.8036	**
2012	0.6684	*	0.8979	***		0.6499	0.8036	**
2013	0.6674	*	0.8838	***		0.6500	0.8036	**
2014	0.6593	*	0.8847	***		0.6501	0.8036	**
2015	0.6590	*	0.8847	***		0.6501	0.8036	**
Annual %Change	-1.65%		-0.49%			-1.71%	-0.87%	

Table 9. Normalized Sigma and Gamma PACOVD Indexes of Six Regional Subgroups for 159 Countries (1990-2015)

	East Asia & Pacific (27)					Europe, Central Asia & North America (32)			
	Sigma		Gamma			Sigma		Gamma	
1990	1.0000	1.0000				1.0000		1.0000	
1991	0.9155	0.9837	***			0.9641		0.9947	***
1992	0.9135	0.9834	***			0.9244		0.9821	***
1993	0.9022	0.9862	***			0.9676		0.9448	***
1994	0.8409	0.9079	***			1.0204		0.9481	***
1995	0.7986	0.8795	***			1.0072		0.9636	***
1996	0.7911	0.8816	***			0.9157		0.9438	***
1997	0.7713	0.8932	***			0.8878		0.9278	***
1998	0.7456	0.8883	***			0.8655		0.9015	***
1999	0.7447	0.8911	***			0.8629		0.8984	***
2000	0.7110	0.9016	***			0.8351		0.8792	***
2001	0.6811	0.8924	***			0.8283		0.8804	***
2002	0.6904	0.8710	***			0.7883		0.8634	***
2003	0.6772	0.8717	***			0.7866		0.8649	***
2004	0.6745	0.8710	***			0.7513		0.8591	***
2005	0.6492	0.8759	***			0.7580		0.8519	***
2006	0.5110	**	0.8131	**		0.7357		0.8468	***
2007	0.5165	**	0.7629	**		0.7119		0.8283	***
2008	0.5070	**	0.7689	**		0.7119		0.8142	***
2009	0.4837	**	0.7362	**		0.6692		0.8006	***
2010	0.4749	**	0.7299	**		0.6688		0.8002	***
2011	0.4751	**	0.7299	**		0.6676		0.7990	***
2012	0.4759	**	0.7299	**		0.6747		0.8019	***
2013	0.4774	**	0.7327	**		0.6520	*	0.8007	***
2014	0.4772	**	0.7348	**		0.6481	*	0.7957	***
2015	0.4772	**	0.7348	**		0.6443	*	0.7920	***
Annual %Change	-2.92%		-1.23%			-1.74%	-0.93%		

Table 9. [Continued] Normalized Sigma and Gamma PACOVD Indexes of Six Regional Subgroups for 159 Countries (1990-2015)

	Latin America & Caribbean (40)			Middle East & North Africa (16)		
	Sigma	Gamma		Sigma	Gamma	
1990	1.0000		1.0000	1.0000	1.0000	
1991	0.9819		0.9787	*** 0.9953	0.9979	**
1992	0.9384		0.9517	*** 0.9887	0.9914	**
1993	0.9294		0.9416	*** 0.9957	0.9893	**
1994	0.9211		0.9354	*** 0.9099	0.9765	**
1995	0.9152		0.9341	*** 0.8762	1.0160	**
1996	0.9084		0.9322	*** 0.8519	1.0118	**
1997	0.8908		0.9314	*** 0.7821	1.0593	**
1998	0.8864		0.9309	*** 0.7169	1.0379	**
1999	0.8141		0.9010	*** 0.7125	1.0732	**
2000	0.8010		0.8990	*** 0.7039	1.0753	**
2001	0.7796		0.8950	*** 0.7035	1.0839	**
2002	0.7747		0.8934	*** 0.6207	1.0176	**
2003	0.7633		0.8889	*** 0.6085	1.0521	**
2004	0.7585		0.8859	*** 0.5956	1.0329	**
2005	0.7570		0.8870	*** 0.5955	1.0329	**
2006	0.6576	*	0.8297	*** 0.6344	0.9409	**
2007	0.6535	*	0.8258	*** 0.6343	0.9409	**
2008	0.6179	**	0.8246	*** 0.5885	0.9259	**
2009	0.6161	**	0.8246	*** 0.5887	0.9259	**
2010	0.6146	**	0.8206	*** 0.5872	0.9345	**
2011	0.6104	**	0.8136	*** 0.5849	0.9195	**
2012	0.5525	***	0.7901	*** 0.5821	0.9195	**
2013	0.5472	***	0.7921	*** 0.5786	0.9238	**
2014	0.5472	***	0.7909	*** 0.5575	0.9067	**
2015	0.5464	***	0.7907	*** 0.5569	0.9067	**
Annual%Change	-2.39%		-0.94%	-2.31%	-0.39%	

Table 9. [Continued] Normalized Sigma and Gamma PACOVD Indexes of Six Regional Subgroups for 159 Countries (1990-2015)

	Sub-Saharan Africa (37)			South Asia (7)		
	Sigma	Gamma		Sigma	Gamma	
1990	1.0000		1.0000	1.0000	1.0000	
1991	0.9953		1.0000	*** 0.9972	1.0000	**
1992	0.9833		0.9987	*** 0.9921	1.0000	**
1993	0.9814		0.9987	*** 0.8860	1.0000	**
1994	0.9783		0.9986	*** 0.8859	1.0000	**
1995	0.9707		0.9983	*** 0.8859	1.0000	**
1996	0.9513		1.0016	*** 0.8800	1.0000	**
1997	0.9297		0.9991	*** 0.8748	1.0000	**
1998	0.9238		0.9991	*** 0.8735	1.0000	**
1999	0.9192		0.9987	*** 0.8720	0.9821	**
2000	0.9016		0.9913	*** 0.8704	0.9821	**
2001	0.8894		0.9818	*** 0.8729	0.9821	**
2002	0.8819		0.9805	*** 0.8683	0.9821	**
2003	0.8806		0.9611	*** 0.8653	0.9821	**
2004	0.8669		0.9621	*** 0.8657	0.9821	**
2005	0.8529		0.9601	*** 0.8650	0.9821	**
2006	0.7687		0.9354	*** 0.8641	0.9821	**
2007	0.7238		0.9179	*** 0.8562	0.9643	**
2008	0.7238		0.9163	*** 0.8578	0.9643	**
2009	0.7260		0.9089	*** 0.8587	0.9643	**
2010	0.7266		0.9126	*** 0.8523	0.9643	**
2011	0.7201		0.9109	*** 0.8541	0.9643	**
2012	0.7190		0.9120	*** 0.8489	0.9643	**
2013	0.7181		0.9105	*** 0.8525	0.9643	**
2014	0.7094		0.9110	*** 0.8527	0.9643	**
2015	0.7091		0.9110	*** 0.8527	0.9643	**
Annual %Change	-1.37%		-0.37%	-0.64%	-0.15%	

and setting future targets? The most relevant outputs for individual countries are annual improvements rate and speed of γ convergence or catch-up process for PACOVD and PACOVW measures. However, these output measures vary so widely among different income and regional subgroups. Therefore, individual countries should be guided by output measures from the appropriate income and regional subgroup where they belong, rather than from the total group of 159 countries. For example, the annual improvement rate of PACOVW for the low middle income subgroup is about twice as fast compared to that of the low income subgroup. The annual improvement rate of PACOVW for MENA region is almost three times faster than that of SSA. Speed of catch-up of PACOVD for the high income subgroup is about 2.4 times faster compared with that of the low income subgroup. On the other hand, speed of catch-up of PACOVW for EAP region is about 3 times faster than that of MENA region.

Thus, in evaluating the past progress and setting the future target of PACOVW for a given country from the high income subgroup, the appropriate measure to use would be the annual improvement rate of 3.2% and the speed of catch-up at -0.52%. These values should represent the minimum values to be achieved by that country. For a country in SSA region, the appropriate annual improvement rate of PACOVD is 1.57%, and the speed of catch-up is at -0.37%. Again, these values should be the minimum values for that country to achieve.

There are several limitations to this research. The PACOVW and PACOVD data we have used represents purely quantitative percentage measures for protected areas, leaving many qualitative dimensions dealing with effectiveness and efficiency of protected areas (Chape *et al.,* 2005; Gelmann *et al.,* 2013; Kuempel *et al.,* 2016). Therefore, several new approaches of measuring the effectiveness of protection areas have been suggested (Barr *et al.,* 2011; Watson *et al.,* 2015). However, these important conceptual and practical measurement issues are beyond the scope of the present research. These will become future research topics which will extend the results from this research. Another interesting topic may be to use club convergence methodology to determine separate groupings of countries going beyond income and regional subgroups of countries analyzed in this research. Still, another possible topic can combine the convergence analysis of both terrestrial protection indicators together withsuch other measures as species protection indicators.

In spite of these limitations, this research has accomplished its modest objective of establishing statistically significant results of both ó and ã convergence for the ten income and regional subgroups of countries. In the process, an important linkage has been established between the initial TP level, rate of increase of TP measure, speed of ã convergence and speed of ó convergence within respective income and regional subgroups.

Reference

Barr, L.M., Pressey, R.L., Fuller, R.A., Segan, D.B., Mcdonald-Madden, E. and Possingham, H.P. 2011. A New way to measure the World's Protected Area Coverage. *PloS One*. 6(9) : e24707.

Barro, R.J. 1991. Economic growth in a cross section of countries. *The Quarterly Journal of Economics.* 106(2): 407-443.

Barro, R.J. and Sala-I-Martin, X. 1992. Convergence across states and regions, *Brookings Papers of Economic Activity.* 22(1) : 107-182.

Bouman, R., Costanza, R., Farley, J., Wilson, M.A., Portela, R., Rotmans, J., Villa, F. and Grasso, M. 2003. Modeling the dynamics of the integrated earth system and the value of global ecosystem services using the GUMBO model. *Ecological Economics*. 41(3) : 529-560.

Boyle, G.E. and McCarthy T.G. 1997. A simple Measure of γ-convergence. *Oxford Bulletin of Economics and Statics*. 59 : 257-264.

Chang, Y. S., Jeon, S., and Park, N. H. 2019. Do time phase and income influence the convergence in energy intensity? A cross-country analysis. *International Journal Energy Technology and Policy.* 15 (2-3) : 301-319.

Chape, S., Harrison, J., Spalding, M. and Lysenko, I. 2005. Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. *Philosophical Transactions of the Royal Society B: Biological Sciences*. 360(1454) : 443-455.

Costanza, R., d'Arge, R. and de Groot, R. 1997. The value of the world's ecosystem services and natural capital. *Nature*. 387(6630) : 253-260.

Convetion on Biological Diversity. 2010. Aichi biodiversity targets, https://www.cbd.int/sp/targets/ Access on April, 20, 2020.

Friedman, M. 1992. Do old fallacies ever die? *Journal of Economic Literature*. 30 (4) : 2129-2132.

Geldmann, J., Barnes, M., Coad, L., Craigie, I.D., Hockings, M. and Burgess, N.D. 2013. Effectiveness of terrestrial protected areas in reducing habitat loss and population declines. *Biological Conservation*. 161 : 230-238.

Heckelman, J. C. 2015. Economic freedom convergence

clubs. p.102-114In : R.J. Cebula, J. Hall, F. Mixon and J. Payne edited. *Economic Behavior, Economic Freedom, and Entrepreneurship*. Edward Elgar Publishing, Cheltenham.

Hoekstra, J.M., Boucher, T.M., Ricketts, T.H. and Roberts, C. 2005. Confronting a biome crisis: global disparities of habitat loss and protection. *Ecology Letters.* 8(1): 23-29.

Kuempel, C.D., Chauvenet, A.L.M. and Possingham, H.P. 2016. Equitable representation of ecoregions is slowly improving despite strategic planning shortfalls. *Conservation Letters*. 9(6) : 422-428.

Liddle, B. 2012. OECD energy intensity.*Energy Efficiency*. 5(4) : 583-597.

Quah, D. 1993. Galton's fallacy and tests of the convergence hypothesis. *Scandinavian Journal of Economics*. 95(4) : 427-43.

Quah, D. 1996. Empirics for economic growth and convergence. *European Economic Review*. 40(6) : 1353-1375.

Rodrigues, S.L., Andelman, S.J. and Bakarr, M.I. 2004. Effectiveness of the global protected area network in representing species diversity. *Nature*. 428(6983) : 640-643.

Siegel, S. 1956. *Nonparametric Statistics for the Behavioral Sciences*. McGraw-Hill, New York.

Watson, J.E.M., Darling, E.S., Venter, O., Maron, M., Walston, J., Possingham, H.P., Dudley, N., Hockings, M., Barnes, M. and Brooks, T.M. 2015. *Conservation Biology*. 30(2) : 243-248.

Data

Environmental Performance Index web site: http://epi2016.yale.edu/downloads/

United Nations Environment Programme World Conservation Monitoring Centre, & International Union for Conservation of Nature. 2016a. Protected planet report 2016. Cambridge UK and Gland, Switzerland: UNEP-WCMC; IUCN. https://portals.iucn.org/library/node/46261

United Nations Environment Programme World Conservation Monitoring Centre, & International Union for Conservation of Nature. 2016b. Update on global statistics December 2016.

http://wdpa.s3.amazonaws.com/Files_pp_net/PPR2016_update_Dec2016_Flyer-W...

United Nations. 1982. United Nations convention on the law of the sea. http://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf

United Nations. 2015. Sustainable development Goals, http://www.un.org/sustainabledevelopment.

Two sample t test for CV.http://www.real-statistics.com/students-t-distribution/coefficient-of-variation-testing/

Real statistics using Excel. http://www.real-statistics.com/reliability/kendalls-w/

World Bank (four income groups). https://blogs.worldbank.org/opendata/new-country-classifications-2016