Fact or Fiction: The Relationship between Carbon Linkage and Carbon Dioxide Environmental Kuznets Curve

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Abstract

This study tested for cross-sectional dependencies between carbon dioxide (CO2) emissions and per capita gross domestic product (GDP) among countries in four regions: Africa, America, Asia, and Europe. When cross-sectional correlations are identified in a group of countries, panel data regression with common factors proposed by Pesaran (2006) is used to determine whether the environmental Kuznets curve (EKC) hypothesis is supported for CO2 emissions in the respective regions. The empirical results show that a cross-sectional dependency is only absent among African countries and that cross-sectional dependencies are significant among the countries in Europe, Asia, and America. The primary factors responsible for such cross-sectional correlations are regional carbon leakage and GDP growth.

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Once cross-sectional dependencies are removed from CO2 emissions, the relationship between CO2 emissions and GDP in Asia, Europe, and America follows an inverted U-shaped curve. After eliminating cross-sectional correlations from both CO2 emissions and per capita GDP, the relationship between CO2 emissions and GDP in Asia, Europe, and America follows a U-shaped curve. These results show that with their use of current technology, countries in Asia, Europe, and America have deviated from their long-term equilibrium output levels, resulting in severe pollution. The results of this study can provide governments with a valuable input in the formulation of their policies in respect of the reduction in carbon emissions.

1 Introduction

The global climate has undergone significant changes over the last few decades, particularly with regard to rising temperatures. Most environmental indicators show that the primary cause of this phenomenon is greenhouse gas emissions generated by human activity. According to a report by the Intergovernmental Panel on Climate Change (IPCC), if appropriate measures are not taken to reduce the emission of greenhouse gases, the average global temperature will increase by between 2 and 4.5 degrees Celsius by the end of the twenty-first century. Thus, countries from around the world signed the Kyoto Protocol in 1997 to commit themselves to reducing greenhouse gas emissions by an average of 5.2 % by 2012, compared to the level in 1990[1]. The emissions from carbon dioxide, released from the use of fossil fuels such as coal, oil, and natural gas, account for over 60% of the greenhouse gas emissions.

The experience of many countries at various levels of economic development indicates a correlation between the levels of greenhouse gas emissions and income. Using regression for reduced form equations, Grossman and Krueger (1991, 1995) analyzed cross-sectional data from various countries and discovered relationships in the form of an inverted U-shaped curve between income and two types of greenhouse gases: smoke and sulfur dioxide. In other words, they found that the environment deteriorates as national income levels rise but then improves with a further increase in development. Since Grossman and Krueger (1991, 1995) proposed the environmental Kuznets curve (EKC) hypothesis, researchers have applied many econometric methods to verify the existence of the EKC relationship in different countries and for different greenhouse gases. Recently, a number of empirical studies have investigated whether an EKC relationship exists between CO2 and GDP, and whether CO2 emissions exhibit convergence (Aldy (2006), Barassi, Cole and Elliot (2008), Nourry (2009), Romero-Avila (2008), Strazicich and List (2003), and Westerlund and Basher (2007)). However, there are three major issues in most of the studies done using panel data to analyze the EKC models of CO2. First, it is difficult to find the appropriate esti-

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[1] A supplement to the United Nations Framework Convention on Climate Change (UN-FCCC) was issued after three meetings by the UN-FCCC in Kyoto, Japan in December 1997. The purpose of this supplement was to stabilize greenhouse gas emissions in the atmosphere to appropriate levels in order to prevent further harm to human life due to severe climate change.

mation method that has been selected. In the process of choosing suitable econometric models for the CO2 EKC curve, panel data cointegration must be taken into consideration in the selection of estimation methods when unit roots exist within the CO2 emissions and per capita GDP. Second, cross-sectional correlations may exist in CO2 emissions depending on the amount of fossil fuels used or imported. Third, according to research on economic growth (such as Quah, 1994), per capita GDP, the independent variable used in the analysis of EKC models of CO2 emissions, differs depending on the region in which the country is situated and converges at the same level as that of other countries in the same region. This regional convergence demonstrates that a cross-sectional correlation exists in the per capita GDP within a region. Disregarding the possibility of cross-sectional correlations increases the inaccuracy in estimating the relationship between per capita GDP and CO2 emissions. For the first and second issues, Wagner (2006) conducted cross-sectional panel unit root (CIPS) tests and found that with the existence of a cross-sectional correlation, unit roots also existed within the series of CO2 emissions and per capita GDP. Furthermore, he employed the PANIC method proposed by Bai and Ng (2004) to estimate the parameters of CO2 EKC curves. Although he resolved the first two empirical issues of EKC models for CO2, he did not account for the fact that the per capita GDP of countries in different regions may converge at different income levels. Moreover, he did not provide clear explanations for the existence of a cross-sectional correlation in the series.

Recent studies on CO2 reduction policies have identified carbon leakage as a major concern. Babiker (2005) and Kuik and Gerlagh (2003) discovered that while countries pursue trade liberalization, industries that produce high CO2 emissions in countries with strict environmental protection regulations tend to relocate to developing countries, which usually have no such strict regulations. As a result, the overall CO2 emissions in any given area are unlikely to drop. Such carbon leakage may be cited as an explanation for the fluctuations in CO2 emissions among countries within a given region. However, most studies on carbon leakage still use numerical simulations. In addition, no previous study has incorporated the concept of carbon leakage to explain the EKC of CO2 in a given region.

When a cross-sectional correlation exists in a region of the EKC curve, conventional panel data methods reveal inconsistent estimates of EKC parameters. We therefore adopt the common correlated effects (CCE) method proposed by Pesaran (2006) to analyze the relationship between carbon emissions and per capita GDP, once the cross-sectional dependency among the variables has been removed. In addition to adopting a different approach, we refer to earlier studies dealing with carbon leakage and regional convergence to explain the reasons for a cross-sectional dependency between carbon emissions and per capita GDP series, which is not dealt with by Wagner (2006).

The study makes three major contributions that distinguish it from other existing studies on the estimation and explanation of regional CO2 EKC curve. First, the authors divide the data into four groups depending on the region and perform CIPS tests proposed by Pesaran (2007). Where there is a cross-sectional correlation in the series, the authors use CCE method (Pesaran, 2006) to eliminate the cross-sectional dependency in CO2 emissions caused by carbon leakage and estimate the EKC for CO2 emissions and income. Second, after removing the cross-sectional correlation from CO2 emissions and per capita GDP, the authors eliminate the inherent tendencies in regional carbon emissions and per capita GDP caused by trade liberalization and technology spillovers. We refer to the resulting EKC following the elimination of the cross-sectional correlation as the EKC with deviation from the regional growth equilibrium, which can be used to explain the influence on carbon emissions when all industries in all the countries of a region increase their production output. Third, to identify the cause of cross-sectional correlation in CO2 emissions, we apply the concept of carbon leakage to explain the cross-sectional correlation in CO2 EKC curves and provide suggestions to policymakers for reducing carbon emission.

This study is organized as follows. Section 2 describes the data sources and econometric methods used in the study. Section 3 outlines the analyses and presents the empirical results. Section 4 then outlines the implications of these results for economic policy and draws a number of conclusions.

2 Econometric methods

The data on CO2 emissions was obtained from the Carbon Dioxide Information Analysis Center (CDIAC) [2]. The data related to fossil fuel emissions represented the total accumulated CO2 emissions. The data on GDP and population was obtained from the Penn World Table Version 6.2. In examining the relationship between CO2 emissions and income, The authors

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[2] An affiliate of the U.S. Department of Energy, providing information on the greenhouse effect and global climate change.

used CO2 emissions and per capita GDP, as suggested by Friedl and Getzner (2003), to negate the influence of population. This study collected data related to GDP and CO2 emissions of each country from the period 1972 to 2003. The 94 countries included in this study are located in Africa, America, Asia, and Europe [3]. Before estimating the EKC models, all data on per capita CO2 emissions and per capita GDP was converted using a natural logarithm.

The basic regional EKC model is listed as below:

$$\mathrm{lne}_{it} = \alpha_i + \theta_i t + \beta_1 \, \mathrm{lny}_{it} + \beta_2 \, (\mathrm{lny}_{it})^2 + u_{it}, \tag{1}$$

where lne_{it} and lny_{it} denote the logarithm of the CO2 per capita and per capita GDP, respectively. In selecting an econometric method to calculate (1), the authors encountered two major issues. The first was whether a cross-sectional correlation existed among the countries in (1). The other issue was that the panel involved a large n and T. The existence of unit roots among the variables must be considered in our selection of the appropriate econometric procedures.

To test whether a cross-sectional correlation exists within the CO2 emissions and GDP series and determine the most appropriate method for parameter estimation, this study uses the adjusted Lagrange multiplier (LM_{adj}) test proposed by Pesaran, Ullah, and Yamagata (2008). When the results of the LM_{adj} test show that a cross-sectional correlation does not exist in the series, we select the panel unit root test (Im, Pesaran, and Shin (IPS), 2003) to check for panel unit roots in the CO2 emissions and GDP series. When the results of the LM_{adj} test show evidence of a cross-sectional correlation in the data, the CIPS test proposed by Pesaran (2007) is used to check for unit roots.

$$\Delta x_{it} = a_i + b_i x_{it-1} + c_i \bar{x}_{t-1} + \sum_{j=1}^{p_i} d_{ij} \Delta x_{it-j} + \sum_{j=1}^{\bar{p}} \alpha_{ij} \Delta \bar{x}_{t-j} + \varepsilon_{ij}, \tag{2}$$

where x_{it} is the series of CO2 emissions and GDP per capita, respectively, $i = 1, 2, \ldots, N$, $t = 1, 2, \ldots, T$, $\bar{p} = \max_i \{p_i\}$ [4], $\Delta x_{it-j} = x_{it-j} - x_{it-j-1}$,

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[3] Our analysis is based on the balanced panel data for the 94 countries listed in Table 6.

[4] In empirical literatures, $p = 4$ is chosen to prevent the excessive loss of initial value data.

$\bar{x}_{t-1} = 1/N \sum_{i=1}^{N} x_{it}$ and $\Delta\bar{x}_{t-j} = 1/N \sum_{i=1}^{N}(\bar{x}_{t-j} - \bar{x}_{t-j-1})$. (2) is used to calculate the t_i statistic for $\hat{b}_i$ in each country and then average all of the test statistics, as follows:

$$CIPS(N,T) = N^{-1} \sum_{i=1}^{N} t_i(N,T) \tag{3}$$

The CIPS test enabled us to determine whether unit roots exist in the CO2 and GDP series when cross-sectional correlations exist.

When cross-sectional correlations do not exist and unit roots are identified in $\ln e_{it}$ in the EKC model, the authors use the error correction least square dummy variable (error correction LSDV) method proposed by Kao and Chiang (1997) to estimate the parameters of (1). The authors then use the DF_ρ, DF_t, and ADF cointegration tests developed by Kao (1999) to determine the existence of the CO2 EKC relationship. Where a cross-sectional correlation exists in $\ln e_{it}$, the authors use the CCE method proposed by Pesaran (2006) and incorporate the artificial independent variables of the cross-sectional average into (1) to eliminate the cross-sectional correlation in the CO2 emissions in $\ln e_{it}$ [5].

$$\text{lne}_{it} = \alpha_i + \theta_i t + \beta_1 \text{ lny}_{it} + \beta_2 \text{ } (\text{lny}_{it})^2 + \beta_3 \text{ } \overline{\text{lne}_t} + \beta_4 \text{ } \overline{\text{lny}_t} + \beta_5 \text{ } \overline{(\text{lny}_t)^2} + e_{it}. \tag{4}$$

Equation (4) was used to estimate the EKC curve for CO2 emissions and derive the relationship between CO2 emissions and income after removing cross-sectional correlation from the residuals.

If a cross-sectional correlation exists in both CO2 and GDP series, then common trends exist in the emissions and per capita GDP series simultaneously. The primary reasons for the common trends generated are carbon leakage and technology spillover caused by trade liberalization. If these common trends are overlooked during the EKC estimation, biases will occur in the estimation of the parameters. To understand the influence of the common trends on the EKC estimation, the authors use a two-stage method to derive consistent estimators for the EKC model. First, we use the augmented regression approach proposed by Pesaran (2007) to remove, respectively, the

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[5] This study does not adopt the estimation method of Bai and Ng (2004), as used by Wagner (2006), primarily because of the issue of lower power in the test statistic. For the details, please refer to Caner (2012).

cross-sectional correlation from $\ln e_{it}$ and $\ln y_{it}$.

$$\begin{aligned}\mathrm{lne}_{it} &= \kappa_{1i} + \tau_{1i}t + \tau_{11}\overline{\mathrm{lne}_t} + \tau_{12}\Delta\overline{\mathrm{lne}_t} + \eta_{1it}, \\ \mathrm{lny}_{it} &= \kappa_{2i} + \tau_{2i}t + \tau_{21}\overline{\mathrm{lny}_t} + \tau_{22}\Delta\overline{\mathrm{lny}_t} + \eta_{2it}.\end{aligned}$$

We then extract the residuals $\hat{\eta}_{1it}$ and $\hat{\eta}_{2it}$ and use the two variables for estimation in the EKC model.

$$\hat{\eta}_{1it} = \alpha_i + \beta_1\hat{\eta}_{2it} + \beta_2\hat{\eta}_{2it}^2 + e_{it} \tag{5}$$

The de-factor EKC curve is obtained from the two-stage system method from Equation (5).

3 Empirical results

3.1 Results of panel data unit root tests and cointegration tests

Before selecting suitable econometric methods for the regional CO2 EKC curve, this study uses the LM_{adj} test proposed by Pesaran, Ullah, and Yamagata (2008) to identify cross-sectional correlations in CO2 emissions and per capita GDP. As shown in Table 1, at a 5% level of significance, a cross-sectional correlation is found in Asia, Europe, and America, but a cross-sectional dependency does not exist in the $\ln e_{it}$ and $\ln y_{it}$ in the African region. The apparent absence of a cross-sectional dependency among African countries is primarily because the countries in this region are underdeveloped, and thus the CO2 emissions and income of these countries do not have strong cross-sectional correlations. According to the IPS unit root test results for Africa that are shown in Table 2, unit roots exist both in the $\ln e_{it}$ and $\ln y_{it}$ simultaneously. Consequently, we adopt the error correction LSDV method to estimate the parameters of the African EKC curve as (1).

A cross-sectional dependency is found to exist in the $\ln e_{it}$ and $\ln y_{it}$ for European, Asian, and American countries, for which we use the CIPS unit root test proposed by Pesaran (2007). When the CIPS statistic is performed, cross-sectional units in the same region are permitted to have different lag numbers, but with an upper limit of 4 [6]. These results are shown in Table 3.

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[6] From the AIC values, we can determine the optimal lag number for the cross-sectional units in the same region.

The outcome of the CIPS test shows that by permitting different lags, unit roots are absent in the $\ln e_{it}$ and $\ln y_{it}$ series for Asia, Europe, and America [7]. Based on the results in Table 3, Equation (4) is adopted in estimating the EKC curve in these three regions.

3.2 Results of regional EKC estimation

The results of the EKC estimations for each region are shown in Table 4. With regard to the EKC curve for Africa, both series contain unit roots but do not have a cross-sectional correlation. Thus, we use the error correction LSDV method to estimate (1). These results indicate that the relationship between CO2 emissions and income does not appear to be an inverted U-shaped curve. This outcome is similar to the findings of Orubu, Omotor, and Awopegba (2009). The reason for the absence of an inverted U-shaped EKC curve may be that the majority of the countries on the African continent are underdeveloped, with many African governments pursuing policies to promote GDP growth rather than environmental issues.

As for countries in Asia, Europe, and America, a significant cross-sectional dependencies can be observed with regard to CO2 emissions. The cause of the cross-sectional correlation is an international division of labor among the countries in the region resulting from trade liberalization in accordance with the environmental protection laws in each country. High polluting industries tend to become more concentrated in countries where the environmental protection laws are less strict, leading to carbon leakage in the region. According to Babiker (2005) and Kuik and Gerlagh (2003), the pollution transfer caused by the international division of labor creates cross-sectional dependencies in CO2 emissions. When we estimate the parameters of the EKC curve, the cross-sectional correlations must be removed in the panel data regression.

From Table 4, after removing cross-sectional correlations using the method proposed by Pesaran (2006), the estimated EKC curves for Asia, Europe,

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[7] Similar to IPS, the alternative hypothesis of the CIPS unit root test is that unit roots do not exist in the series of some countries. To enhance the robustness of the test, we first remove the cross-sectional correlation before performing CIPS unit root tests. It is worth noting that no critical values corresponding to CIPS tests have previously been reported in the existing literature. However, the critical values are calculated by the bootstrapping method. The critical values for $\ln e_{it}$ and $\ln y_{it}$ for Europe are -7.0862 and -11.3837, respectively, whereas those for America are -2.3085 and -13.4339, respectively. The results are considerably below the critical values, indicating that unit roots do not exist in the $\ln e_{it}$ and $\ln y_{it}$ of America and Europe.

and America show an obvious inverted U-shape. This demonstrates that the relationship between CO2 emissions and per capita GDP in these regions supports the EKC hypothesis. As shown in the differences in the estimated parameters, we can see that governments in Europe began to assign greater importance to environmental protection in the early 1970s. Compared with Asian and American countries, where environmental issues began to be noticed in the 1990s, the curvatures of the EKC curves for European countries are greater. These results also indicate that the earlier the countries within a region implement carbon reduction policies, the higher the possibility that CO2 emissions in the region can be reduced.

3.3 Relationship between CO2 and GDP with deviation from long-term trends

The outcomes presented in Table 1 reveal that cross-sectional correlations exist in the per capita GDP in American, Asian, and European countries. These empirical results conform to the results obtained by Wagner (2006) using world GDP data. After removing the cross-sectional dependency from $\ln e_{it}$ and $\ln y_{it}$ (including intercepts and common trends, respectively), Equation (5) is computed using a panel pooled regression. Table 5 contains the estimated parameters of regional de-factor EKC curves for Asia, Europe, and America after removing common trends from CO2 emissions and per capita GDP. The results show that the parameters for the three regions are all positive, which indicate that the EKC curves are U-shaped. This consequence demonstrates after controlling for cross-sectional correlations in CO2 emissions caused by Carbon leakage, and in GDP per capita caused by the international division of labor. These outcomes display that under the premise that greenhouse gasses are inferior goods, pursuing growth in per capita GDP, thereby increasing production in all industries in a country, will be accompanied by an increase in CO2 emissions.

4 Conclusion

Certain conclusions can be drawn from the empirical results of this study. First, unit roots exist in the series of CO2 emissions and per capita GDP of Africa, whereas the CO2 emissions and income in Asian, European, and American countries form stationary series. Second, using the LM_{adj} test, the authors discover cross-sectional dependencies among countries in Asia, Europe, and America. Third, when the authors control for the cross-sectional dependency of EKC curves in the four regions, the relationship between CO2 and income still maintains an inverted U-shaped curve in the American, Asian, and European regions, but not in Africa. This outcome explains why the public in regions with a higher average income show greater concern for issues related to CO2 reduction. Fourth, the authors estimate EKC curves with a deviation from equilibrium trends (de-factor EKC curves) and find that pollution in Asia, Europe, and America increases with income and tends not to decline. This result shows that the countries in these regions have deviated from the optimal production level and cost they can bear; in other words, they are producing more CO2 emissions. This indicates that when a cross-sectional dependency exists in CO2 emissions, the efforts of a single country to reduce CO2 will not be particularly effective. These empirical results should provide policymakers with a valuable input in their decisions in respect of the reduction of carbon emissions.

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Table 1: LM_{adj} statistic

	Asia	Africa	Europe	America
$\ln e_{it}$	5.9633*	0.1848	11.976*	4.2011*
$\ln y_{it}$	6.2531*	-0.2171	26.003*	7.0116*

[a] $*$ implies rejection of the null hypothesis at 5%.

[b] The critical value is ±1.96.

Table 2: IPS and Kao statistics for EKC curve of African countries

IPS statistic	Statistics	p-value
$\ln e_{it}$	-1.4244	0.0772
$\ln y_{it}$	-0.1824	0.4276
Kao panel cointegration statistics	Statistics	p-value
DF_ρ	-30.8275	0.0000^*
DF_t	-19.9752	0.0000^*
ADF	-7.5987	0.0000^*

[a] IPS regression includes intercept and deterministic trend.

[b] $*$ implies rejection of the null hypothesis at 5%.

Table 3: CIPS unit root statistics for different regions

	$\ln e_{it}$		$\ln y_{it}$	
	Statistics	p-value	Statistics	p-value
Asia	-3.0711	0.0011^*	-5.7512	0.0000^*
Africa	-3.5475	0.0002^*	-6.3964	0.0000^*
Europe	-7.3312	0.0000^*	-2.0659	0.0194^*
America	-16.614	0.0000^*	-11.5145	0.0000^*

[a] Equation includes intercept and deterministic trend.

[b] $*$ implies rejection of the null hypothesis at 5%.

Table 4: EKC estimation results

	Africa	Asia	Europe	America
t	-0.0044	-0.0007	-0.0001	0.0004
t-statistics	-0.9204	-0.0256	-0.0193	0.0807
$p(N)$-value	0.1787	0.4898	0.4923	0.4678
$\ln y_{it}$	-4.2323	2.5968	18.3459	9.7162
t-statistics	-3.4633	8.2460	20.2908	14.1225
$p(N)$-value	0.0003*	0.0000*	0.0000*	0.0000*
$(\ln y_{it})^2$	0.3327	-0.1138	-0.9075	-0.5275
t-statistics	4.0125	-6.0906	-19.9403	-13.3523
$p(N)$-value	0.0000*	0.0000*	0.0000*	0.0000*
$\overline{\ln y_{it}}$		1.0795	0.9491	1.0616
t-statistics		2.4418	5.6184	7.6228
$p(N)$-value		0.0073*	0.0000*	0.0000*
$\overline{\ln y_{it}}$		-2.7251	-17.9068	-7.1034
t-statistics		-0.5468	-4.6415	-0.5345
$p(N)$-value		0.2923	0.0000*	0.2965
$\overline{(\ln y_{it})^2}$		0.1176	0.8859	0.3805
t-statistics		0.3247	4.6940	0.4971
$p(N)$-value		0.3727	0.0000*	0.3096
R^2	0.1301	0.5378	0.4680	0.3878
Adj R^2	0.1200	0.5339	0.4622	0.3843

[a] Kao (1998) panel cointegration regression without cross-sectional dependence is used for African countries.

[b] EKC equation includes fixed effects.

[c] $*$ implies rejection of the null hypothesis at 5%.

Table 5: Estimation results with de-factored observations

	Asia	Europe	America	
$\ln y_{it}$	0.4710	0.3792	0.1248	
t-statistics	3.2219	4.2687	2.2029	
$p(N)$-value	0.0006*		0.0000*	0.0138*
$(\ln y_{it})^2$	4.0910	3.5555	0.8487	
t-statistics	2.8952	1.7245	1.0995	
$p(N)$-value	0.0019*	0.0423*	0.1358	
R^2	0.0312	0.0405	0.0069	
Adj R^2	0.0281	0.0365	0.0048	

[a] EKC equation includes fixed effects.

[b] $*$ implies rejection of the null hypothesis at 5%.

Table 6: Countries list

Asia	Africa	America	Europe
Bangladesh	Burkina Faso	Antigua	Austria
Bhutan	C. African	Argenitna	Belgium
Brunei	Congo	Bahamas	Denmark
Cambodia	Ethiopia	Barbados	Finland
China	Gabon	Belize	France
N. Korea	Gambia	Benin	Germany
Hong Kong	Ghana	Bermuda	Greece
India	Guinea	Bolivia	Iceland
Indonesia	Kenya	Brazil	Ireland
Japan	Madagascar	Canada	Italy
S. Korea	Malawi	Chile	Luxembourg
Lao	Mali	Colombia	Netherlands
Macau	Mauritania	Costa Rica	Norway
Malaysia	Mozambique	Cuba	Portugal
Maldives	Niger	Dominica	Spain
Mongolia	Nigeria	Dominican rep.	Sweden
Nepal	Sierra Leone	Ecuador	Switzerland
Pakistan	S. Africa	El Salvador	U.K.
Philippine	Tanzania	Grenada	
Singapore		Guatemala	
Srilanka		Honduras	
Taiwan		Jamaica	
Thailand		Mexico	
		Nicaragua	
		Panama	
		Paraguay	
		Peru	
		ST. Lucia	
		ST. Vincent	
		Suriname	
		Trinidad	
		Uruguay	
		USA	
		Venezuela	