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Carbon Dioxide Emissions and the Macroeconomy: Evidence from the ASEAN Region

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This paper examined the effects of income, trade, and foreign direct investments (FDI) on carbon dioxide (CO_2) emissions in the Association of Southeast Asian Nations (ASEAN) member countries for the period of 1970–2011 using the panel corrected standard errors (PCSE) estimation method. The results of the study were consistent with the environmental Kuznet's curve (EKC) hypothesis – CO_2 emissions increase as *per capita* GDP increases up to a certain income threshold, beyond which further increase in income is accompanied by lower emissions. However, the threshold *per capita* GDP (estimated to be USD 20,017) is way above the income levels of the ASEAN countries (with the exception of Brunei and Singapore). This suggests that most of the ASEAN region will still be in the upward-sloping portion of the EKC for several more years, and this necessitates an economic growth strategy that includes a stringent program to curb CO_2 emissions. Nonetheless, both trade and FDIs do not significantly contribute to CO_2 emissions in the ASEAN region, auguring well for the trade- and FDI-oriented development strategies adopted by most ASEAN member countries. Since low-carbon technologies and production methods are owned by high-income investing countries, trade and FDI can also be encouraged to facilitate and hasten the transfer of low-carbon technologies to the fast-developing countries of the ASEAN region.

Keywords: carbon dioxide emissions, environmental Kuznets curve, panel corrected standard errors, pollution haven hypothesis, trade openness

INTRODUCTION

Human activities – such as the burning of fossil fuels to produce electricity and other forms of energy, agricultural production, and consumption that produce waste, and deforestation among others – result in excessive emissions of greenhouse gasses (GHG) that contribute to global warming. The main GHG that causes global warming is CO_2, which makes up 64% of emissions. Global temperature is found to be closely correlated with CO_2 concentration (IPCC 2013). From the pre-industrial period (about 1860) to 2011, average global concentrations of CO_2 increased by 140% to 390.9 parts per million while average surface temperature had risen by 0.65 °C to 0.85 ºC (WMO 2012). The natural consequences of global warming include rising sea levels (with the melting of land-based glaciers and ice sheets); coastal erosion and flooding leading to rising water tables and saltwater intrusion in fresh surface water bodies and aquifers; increased incidence, intensity, and duration of droughts; higher frequency and severity of typhoons;

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and species population reduction and extinction (Cline 1992). Ecological systems, human health, and important socioeconomic sectors such as food production and services (*e.g.* agriculture, fisheries, tourism, construction, *etc.*), water resources, coastal systems, and human settlements are all sensitive to climate change (IPCC WG I 2001).

The ASEAN region is considered to be highly vulnerable to the negative impacts of climate change because of its geographical location, topography, economic structure, population density, and social and political structures (Lee *et al.* 2013). Mendelsohn (2003) argues that tropical countries are likely to suffer large damages from climate change. The numerous islands and long coastlines in the region expose many of its lands and people to the dangers of stronger tropical storms and flooding. Increased occurrence of extreme weather disturbances can lead to lower productivity in agriculture, fisheries, and tourism – the major sources of livelihood in most of the ASEAN countries. With ASEAN being the fourth most populated region in 2008, lower productivity in key production sectors means less income, less supply of food, and higher food prices for the growing ASEAN population.

Although ASEAN countries are not the biggest CO_2 emitters, accounting for just about 4% of the world's emissions in 2011 (US EIA 2011), their emissions are rapidly increasing (Lee *et al*. 2013) due to accelerating economic activities. Among the ASEAN member countries, Brunei Darussalam had the highest *per capita* emissions, followed by Singapore. Brunei, the third-largest oil producer in Southeast Asia and the fourth-largest producer of liquefied natural gas in the world, was the worst CO_2 emitter *per capita*. Its huge emissions may also be attributed to its lack of framework legislation on its environment (Neal *et al*. 2010). Singapore had high *per capita* CO_2 emissions but the trend had been decreasing since 1998, with an average annual growth of only 0.24%. CO_2 emissions had been on an increasing trend in Malaysia, Thailand, and Indonesia (Figure 1).

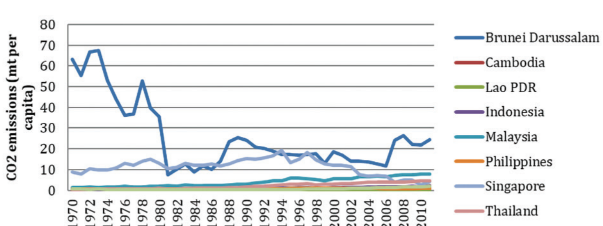

Figure 1. CO_2 emissions of ASEAN member countries (1970–2011).

ASEAN is currently one of the fastest-growing economic regions in the world. Its real GDP *per capita* almost doubled from USD 2,882 in 2000 to USD 5,581 (purchasing power parity) in 2011, while its trade in goods and services more than doubled from USD 260.9 billion to USD 598.2 billion (ASEAN 2012). The ASEAN region also attracts substantial FDIs, with net inflows ballooning from USD 21.81 billion in 2000 to USD 114.08 billion in 2011 (ASEAN 2012). Figure 2 shows that *per capita* GDP was on a generally increasing trend in all ASEAN countries, except Brunei. With its economy heavily dependent on the oil and gas sector, it was vulnerable to oil price fluctuations, thus the fluctuation in its GDP *per capita*.

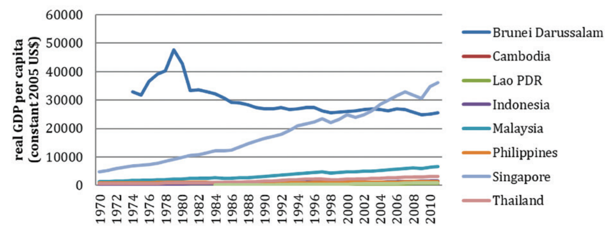

Figure 2. Real *per capita* GDP of ASEAN member countries (1970–2011).

The macroeconomic variables – GDP, trade, and FDIs – are often associated with CO_2 emissions. According to the EKC hypothesis, initially, emissions increase with income growth but at a certain income level, the impact of economic activities on emissions is reversed. The pollution haven hypothesis, on the other hand, suggests that FDIs may lead to higher emissions as they bring in dirty industries in the less environment policy-stringent, developing host countries. Likewise, trade accelerates the transport of goods and services that entails substantial energy use and, hence, increases CO_2 emissions. Previous empirical studies of these relationships yield mixed results, suggesting that the relationships between macroeconomic variables and CO_2 emissions vary depending on the underlying social and political contexts of the country or region. Thus, empirical evidence for a specific country or region is crucial to guide development planners to make sound policy choices regarding long-run economic growth and environmental strategies and trajectories.

This paper aims to investigate the impact of macroeconomic variables – specifically GDP, FDI, and trade – on CO_2 emissions using unbalanced panel data for nine ASEAN countries – namely, Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, the Philippines, Thailand, Singapore, and Vietnam during the period of 1970–2011 (Myanmar is not included because of lack of sufficient data).

Ever since its use in the World Bank Development Report in the 1990s, a number of EKC studies have been carried out – some have found an inverted-U relationship between certain pollutants (*e.g.* CO_2, sulfur dioxide, dark matter, nitrogen oxide, carbon monoxide, suspended particulate matter, fecal coliform) and income (Shafik and Bandyopadhyay 1992; Selden and Song 1994; Han and Lee 2013; Adu and Denkyirah 2017; Liu *et al.* 2019; Kusumawardani and Dewi 2020; Sun *et al*. 2020; Malik *et al*. 2020; Tiba and Belaid 2020; Ridzuan *et al*. 2020). Others, however, do not support the EKC hypothesis (Harbaugh *et al*. 2002; Carson 2010; Boopen and Vinesh 2011; Xue *et al.* 2012; Palanca-Tan *et al*. 2016; Hübler 2017; Rafindadi *et al*. 2018; Beyene and Kotosz 2019); some others have mixed results (Grossman and Krueger 1991; Ertugrul *et al*. 2016; Bakhsh *et al*. 2017). The scope of existing literature on the EKC ranges from single-country, single-pollutant to multiple-country, multiple-pollutant studies. For the case of the ASEAN region, three studies – namely, those of Lean and Smyth (2010), Saboori and Sulaiman (2013), and Chandran and Tang (2013) – have been undertaken, but all three cover only the ASEAN-5 countries and exclude the equally relevant and interesting cases of Brunei, Cambodia, Laos, and Vietnam. The addition of these four countries in this paper expands the range of values of the macroeconomic variables necessary for a more insightful analysis. Further, the inclusion of FDI and trade openness in the analysis sets this paper apart from the three earlier studies that are focused instead on energy consumption in different production sectors as direct drivers of CO_2 emissions.

METHODOLOGY

Conceptual Framework

Environment vs. economic growth: the EKC. The EKC proposes an inverted U-relationship between economic growth and environmental degradation. The EKC suggests that environmental degradation such as pollution (*e.g.* CO_2 emissions) increases in the early stages of development, reaches a maximum at some income level, and then decreases with further income expansion (Panayotou 1993). As a country starts to develop, environmental degradation worsens due to the increase in the production of commodities. The decline in environmental damage as the country reaches a certain income level results from the shift in economic structure from the polluting manufacturing industries to the relatively clean services and information sectors, technological innovations in pollution and environmental damage control, and greater availability of public funds for environmental investments. Further, with greater wealth, there is a greater demand for environmental quality. A scale effect on economic activities may also arise. As income rises, population growth rates drop and approach replacement levels (Glover 1999). The EKC hypothesis may trivialize the issue of environmental degradation as it is seen to be temporary with development, eventually leading to a better environment (Andreoni and Levinson 2001).

Environment and FDI: pollution haven hypothesis. The pollution haven hypothesis suggests that FDI may cause more pollution. High-income economies tend to relocate polluting industries to countries with less stringent environmental policies in order to save on production costs (Levinson and Taylor 2008). If the pollution haven hypothesis applies, then FDI in developing countries may be expected to increase CO_2 emissions. When industrialized nations transition towards becoming fully developed nations, the country's economic activity shifts away from manufacturing towards services. Developed countries also impose more stringent environmental policies that require a shift to more environmentally friendly technologies that can raise the cost of production. Hence, heavily polluting firms are compelled to move production bases towards low-cost, less environmental policy-stringent, low-income countries.

Environment and trade. Trade entails the movement of goods and services and, hence, greater energy consumption and more CO_2 emissions (Naranpanawa 2011). Further, with many developing countries having a comparative advantage in pollution-intensive goods, more of these goods are produced in low-income countries as a consequence of trade liberalization or more trade openness. Anderson *et al*. (2009), as cited by Hossain (2011), found that trade plays an important role in generating CO_2 emissions in the transport sector and that greater emissions are attributable to exports than imports.

Appendix I summarizes the results of empirical studies on the impact of the three macroeconomic variables – *per capita* GDP, FDI, and trade – on CO_2 emissions.

Empirical Model and Estimation Procedure

The econometric model used to investigate the relationship between CO_2 emissions and *per capita* gross domestic product (GDP and GDPSQ), trade openness (TO), and FDI is specified as follows:

$$CO2_{i,t} = \alpha_0 + \alpha_1 GDP_{i,t} + \alpha_2 GDPSQ_{i,t} + \alpha_3 FDI_{i,t} + \alpha_4 TO_{i,t} + \varepsilon_{i,t}$$

The subscripts i and t refer to a particular country and year; α_0, α_1, α_2, α_3, and α_4 are the coefficients to be estimated and $\varepsilon_{i,t}$ is the error term. The inverted U-shaped EKC entails that the coefficient of GDP is greater than zero ($\alpha_1 > 0$) and the coefficient of the squared value of GDP (GDPSQ) is less than zero ($\alpha_2<0$), while the pollution haven hypothesis implies that the coefficient of FDI is greater than zero ($\alpha_3 > 0$). As discussed in the conceptual framework, the coefficient of trade openness is also expected to be greater than zero ($\alpha_4 > 0$).

Four regression procedures were tried to run the empirical model – pooled ordinary least squares (OLS), fixed effects (FE), random effects (RE) and PCSE. In pooled OLS, the longitudinal or panel aspect of the data set is ignored and observations are treated as if they are cross-sectional. The results from pooled OLS can possibly suffer from heterogeneity bias because it imposes a common constant term (Wooldridge 2010). The Breush-Pagan/Cook-Weisberg heteroscedasticity test and the variance inflation factor (VIF) multicollinearity test are undertaken to identify possible econometric problems.

FE and RE are the estimation methods particularly used for panel data, such as the ones set for this study. The FE procedure cannot capture the effects of independent variables whose values do not change across time. The procedure controls the effect of time-invariant variables with time-invariant effects (Wooldridge 2009). The assumption is that the individual-specific effect is correlated with the independent variables. Thus, FE cannot be used to investigate time-invariant causes of the dependent variables (Torres-Reyna 2007). On the other hand, the RE method assumes that the variations across entities (unobserved variables) are random and uncorrelated with the observed independent variables (Torres-Reyna 2007) and, thus, can estimate the effects of time-invariant variables on the dependent variable. However, the estimates can be biased because there is no control for omitted variables (Wooldridge 2009). The Hausman test can be run to determine which of the two (FE or RE) is more appropriate for a particular data set. In addition, three other diagnostic tests are done: 1) Breusch-Pagan Lagrange multiplier (LM) test of independence for cross-sectional dependence, 2) modified Wald heteroscedasticity test by Greene (2007), and 3) the Wooldridge test for autocorrelation. Baltagi (2008) claims that cross-sectional dependence is a problem in macro panels with long series of over 20–30 years that can lead to test results bias termed as contemporaneous correlation (Torres-Reyna 2007). The Breusch-Pagan LM procedure tests the null hypothesis that the residuals across entities are not correlated. Heteroscedasticity, which implies that the variances of regression disturbances are not constant across observations, can invalidate the statistical test of significance (Greene 2007). The modified Wald procedure tests the null hypothesis of constant variance (or homoscedastic). Finally, autocorrelation – the correlation among error terms – can occur in time-series studies if the error associated with a given time period carries over into future time periods. Autocorrelation causes the standard errors of the coefficients to be smaller than they actually and the value of R-squared to be higher (Wooldridge 2010).

The PCSE procedure is done to address the above-mentioned econometric issues that may arise from FE and RE. Developed by Beck and Katz (1995), PSCE corrects cross-sectional dependence, heteroscedasticity, and autocorrelation. Time-series, cross-section data are characterized by having repeated observations over time on some units (*e.g.* country) and, hence, usually have contemporaneous correlations across units as well as unit-level heteroscedasticity, which can result in incorrect or spurious inferences from standard errors estimates of OLS. PSCE can account for the deviations from these spherical errors and allows for better inference from linear models using time-series, cross-section data (Bailey and Katz 2011). In PSCE, the OLS parameter estimates is retained and the OLS standard errors are replaced with PCSE. Using Monte Carlo analysis, it has been shown that PSCE estimates of sampling variability are highly accurate, even with the presence of complicated panel error structures (Beck and Katz 1995).

Data

The study uses unbalanced panel data for nine ASEAN countries – Brunei Darussalam (with observation for the years 2001–2011), Cambodia (1993–2011), Lao PDR (1988–2011), Indonesia (1981–2011), Malaysia (1970–2011), the Philippines (1970–2011), Singapore (1970–2011), Thailand (1975–2011), and Vietnam (1986–2011). The unavailability of data for some variables in some years for certain countries constrains the study to use an unbalanced panel data set. Table 1 lists the variables used in the study with their definitions and descriptive statistics. CO_2 emissions data are obtained from the Carbon Dioxide Information Analysis Center,

Table 1. Variables and descriptive statistics.

Variable	Definition (unit)	Mean	Standard deviation		
			Overall	Between	Within
CO2	*Per capita* carbon dioxide emissions (metric tons)	3.75	5.20	6.33	2.09
GDP	*Per capita* gross domestic product (constant 2005 US$)	4,993.14	8,265.40	9,443.54	3,666.01
GDPSQ	Squared value of *per capita* gross domestic product	9.30e+07	2.37e+08	2.49e+08	1.43e+08
FDI	Net foreign direct investment inflows measured as a share of GDP (%)	4.01	4.37	3.11	2.85
TO	Trade openness, exports, and imports of goods and services measured as a share of gross domestic product (%)	129.31	100.60	87.70	34.63

FDI from International Financial Statistics and Balance of Payments of the International Monetary Fund; and all the other data sets from the World Bank Economic Indicators online publication in 2015.

Table 1 reveals that mean CO_2 emissions of the nine ASEAN countries in the sample is 3.75 mt *per capita* per year. It can be noticed that the standard variation across countries for all variables is higher than the within the country variation.

RESULTS AND DISCUSSION

Regression Results
The results of the four regression runs are presented in Table 2. Results of the pooled OLS regression (column 2) indicate that the coefficients of GDP and GDPSQ follow the hypothesized signs and are statistically significant. The coefficient of TO is also significant but is negative. The result of the Breush-Pagan/Cook-Weisberg test indicates that the data-set is heteroscedastic and the VIF test indicates the presence of multicollinearity.

Columns 3 and 4 of Table 2 present the results of the FE and RE estimation methods. RE yields the same results as the pooled OLS in terms of significance and signs of the coefficients. The result of the FE run differs from the pooled OLS and RE only in that the coefficient of TO becomes insignificant. The Hausman test result indicates that FE is the more appropriate procedure for the data set. Findings from the three diagnostic tests reveal the presence of cross-sectional dependence, heteroscedasticity, and autocorrelation – necessitating a re-estimation of the model using the PCSE method.

The results of the PCSE run are given in column 5 of Table 2. Like the FE results, only the coefficients of GDP and GDPSQ are significant (and have the hypothesized signs), while the coefficients of TO and FDI are insignificant (please refer to Appendices IIA–D for the details of the regression and test results.)

DISCUSSION

Data for the nine ASEAN countries of the study provide empirical evidence for the EKC hypothesis. This result is consistent with findings of earlier studies on the smaller group of ASEAN-5 countries consisting of Indonesia, Malaysia, the Philippines, Singapore, and Thailand (Lean and Smyth 2010; Chandran and Tang 2013; Saboori and Sulaiman 2013) as well as with findings for mostly middle-income countries [see, for instance, the findings of Arouri *et al.* (2012) and Farhani *et al*. (2013) for the Middle East and North African (MENA) countries, Tamazian and Rao (2010) for a group of 24 transition economies, Shahbaz *et al*. (2013) for Indonesia, and Boutabba (2014) for India].

On the other hand, the study finds that both FDI and trade do not contribute to CO_2 emissions in the nine ASEAN countries.

The result of this study implies that the pollution haven hypothesis does not apply in the ASEAN sample of this study. Cole and Elliott (2005) emphasize the role of capital in explaining why pollution havens may not be widespread. They argue that countries with lax environmental standards typically do not have the level of accumulated capital that is necessary to attract capital-intensive investment. Hoffman *et al*. (2005) find that the pollution

Table 2. Regression results.

Variable	Coefficient			
	Pooled OLS	FE	RE	PCSE
Constant	–0.49997	0.17676	–0.04999	1.73044**
GDP	0.00209***	0.00149***	0.00209***	0.00182***
GDPSQ	–5.42e–08***	–4.34e–08***	–5.42e–08***	–4.55e–08***
FDI	–0.00586	0.11357	–0.00586	–0.01943
TO	–0.01232***	0.00082	–0.01232***	–0.01209
R^2	0.9085			0.7267
Adjusted R^2	0.9071			
R^2 within		0.6367	0.5591	
R^2 between		0.8906	0.9846	
R^2 overall		0.8459	0.9085	

***Significant at 1% level; **significant at 5% level haven hypothesis applies only to low-income countries as they lack the infrastructure and skilled labor that attract FDI as well as the financial capability to implement and monitor environmental regulation, thus becoming "innocent" pollution havens. Except for Cambodia, all ASEAN countries included in this study fall under the middle to high-income category. Brunei Darussalam and Singapore are both high-income countries. Malaysia and Thailand belong to upper-middle-income category while Indonesia, Lao PDR, the Philippines, and Vietnam are under the lower-middle-income group. Similarly, the conclusion that FDI has no significant effect on CO_2 emissions was reached by Chandran and Tang (2013) for ASEAN-5, Chen and Huang (2013) for N11 or Next11 (the group of 11 countries – Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, the Philippines, Turkey, South Korea, and Vietnam – with emerging markets that could potentially become some of the world's largest economies), and Ozturk and Acaravci (2013) for Turkey.

Trade openness has also been found to have no significant effect on CO_2 emissions in the studies of Farhani *et al*. (2013) for the MENA region and Boutabba (2014) for India. Al-Mulali and Low (2014), in their study of 189 countries from six different regions, likewise found a non-significant relationship between trade and CO_2 emissions for countries in the early development stages and whose trade does not account for a large proportion of GDP.

Using the PCSE coefficients, the threshold income or turning point, *i.e.* the *per capita* GDP at which further increases in income will lead to lower CO_2 emissions, is estimated to be USD 20,017 *per capita*. Seven (namely, Cambodia, Indonesia, Lao PDR, Malaysia, the Philippines, Thailand, and Vietnam) out of nine countries included in this study are still way below this threshold income. This implies that economic growth in these seven countries must be pursued with much effort to curb the levels of CO_2 emissions.

CONCLUDING REMARKS

Eyed as one of the economic growth centers in the world, governments of the ASEAN member countries are posed to pursue aggressive development strategies. Despite the finding that the EKC hypothesis applies to the ASEAN countries, the estimated threshold income – the income at which CO_2 emissions will decrease with increases in income – is rather very high, with *per capita* GDP of USD 20,017 almost twice the lower bound of the World Bank's high-income country category (USD 12,276) in 2011. Except for two (namely, Singapore and Brunei), all ASEAN member countries have *per capita* income way below this threshold income. This implies that most of the ASEAN region will still be in the upward-sloping portion of the EKC for several more years, *i.e.* as they increase their GDP, their CO_2 emissions increase as well. Hence, most ASEAN member countries will need to pursue an economic growth strategy that includes a stringent program to curb CO_2 emissions. While pushing for accelerated development, ASEAN countries must pursue an economic model that is based on small energy consumption, efficient utilization of energy, and low-carbon or clean energy alternatives (such as hydropower, solar power, and wind power).

Nonetheless, both trade and FDIs do not significantly contribute to CO_2 emissions in the ASEAN region. These findings augur well for the trade- and FDI-oriented development strategies adopted by most ASEAN member countries. Further, as the low-carbon technologies are owned by the advanced, high-income countries, trade and FDI can play key roles in the transfer of these low-carbon technologies to the fast developing countries in the ASEAN region (Ockwell *et al*. 2008).

NOTES ON APPENDICES

The complete appendices section of the study is accessible at http://philjournsci.dost.gov.ph

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APPENDICES

Appendix I. Summary of findings from past studies.

Author and year of publication	Country/region (period)	Findings			
		GDP	GDP^2	FDI	TO
Tamazian and Rao 2010	24 transitional economies (1993–2004)	+	–	–	+
Lean and Smyth 2010	ASEAN 5 (1980–2006)	+	–		+
Arouri *et al.* 2012	12 MENA countries (1981–2005)	+	–		
Chandran and Tang 2013	ASEAN-5	+	–	ns	
Chen and Huang 2013	Next 11 (the group of 11 countries – Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, Philippines, Turkey, South Korea, and Vietnam) (1981–2009)	+			
Farhani *et al.* 2013	11 MENA countries (1980–2009)	+	–		ns
Ozturk and Acaravci 2013	Turkey (1960–2007)	+	–		+
Saboori and Sulaiman 2013	Selected ASEAN countries (1971–2009)	+	–		
Shahbaz *et al.* 2013	Indonesia (1Q 1975–4Q 2011)	+			–
Al-Mulali and Low 2014	189 countries from six different regions (1990–2011)				+
Boutabba 2014	India (1971–2008)	+	–		ns
Ertugrul *et al.* 2016	Thailand Turkey India South Korea Brazil Indonesia China (1971–2011)	ns + + + ns ns +	ns – – ns ns –		ns + + ns ns + +
Palanca-Tan *et al.* 2016	Philippines (1971–2010)	+		+	
Zhang and Zhou 2016	China (1995–2010)	+		–	
Adu and Denkyirah 2017	West Africa (1970–2013)	+	ns		+
Bakhsh *et al.* 2017	Pakistan (1980–2014)	–		–	
Hübler 2017	Developing and developed countries	+		+	+
Mutascu 2018	France (1960–2013)				+
Rafindadi *et al.* 2018	Nigeria (1990–2014)	–	–	–	
Beyene and Kotosz 2020	East Africa (1990–2013)	–	+	–	+
Liu *et al.* 2019	China (1996–2014)	+			
Kusumawardani and Dewi 2020	Indonesia (1975–2017)	+	–		

Author and year of publication	**Country/region (period)**	**Findings**			
		GDP	GDP^2	FDI	TO
Mahadevan and Sun 2020	China Belt and Road countries (2003–2014)	+ +		ns +	ns –
Malik *et al.* 2020	Pakistan (1971–2014)	+	–	+	
Tiba and Belaid 2020	27 African countries (1990–2013)	+	–	+	
Ridzuan *et al.* 2020	Malaysia (1978–2016)	+	–		
Sun *et al.* 2020	CCEMG approach OECD Belt and Road Global AMG approach OECD Belt and Road Global (1992–2015)	 + + + ns + +	 – – – ns – –		

Note: ns – not significant

Appendix IIA. Results of using fixed effect and random effect estimation methods.

```
. xtreg CO2 GDPpc GDPpc2 TrOp FDI, fe

Fixed-effects (within) regression               Number of obs      =       274
Group variable: ID                              Number of groups   =         9

R-sq:      within  = 0.6367                     Obs per group: min =        11
between = 0.8906                                               avg =      30.4
overall            = 0.8459                                    max =        42

F(4,261)                                                           =    114.37
corr(u_i, Xb)      = 0.5834                     Prob > F           =    0.0000

------------------------------------------------------------------------------
         CO2 |      Coef.   Std. Err.      T    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       GDPpc |   .0014949   .0000955    15.66   0.000     .0013068    .0016829
      GDPpc2 |  -4.34e-08   2.35e-09   -18.50   0.000    -4.81e-08   -3.88e-08
        TrOp |   .0008195   .0028648     0.29   0.775    -.0048216    .0064606
         FDI |   .0113568   .0348488     0.33   0.745    -.0572639    .0799774
       _cons |   .1767635   .3201665     0.55   0.581    -.4536746    .8072016
-------------+----------------------------------------------------------------
     sigma_u |  3.1405183
     sigma_e |  1.2886733
         rho |  .85588806   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(8, 261) =    18.32           Prob > F = 0.0000

. xtreg CO2 GDPpc GDPpc2 TrOp FDI, re

Random-effects GLS regression                   Number of obs      =       274
Group variable: ID                              Number of groups   =         9

R-sq:      within  = 0.5591                     Obs per group: min =        11
between = 0.9846                                               avg =      30.4
overall            = 0.9085                                    max =        42

Wald chi2(4)                                                       =   2669.91
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0000

------------------------------------------------------------------------------
         CO2 |      Coef.   Std. Err.      Z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       GDPpc |   .0020942   .0000655    31.97   0.000     .0019658    .0022226
      GDPpc2 |  -5.42e-08   2.07e-09   -26.21   0.000    -5.82e-08   -5.01e-08
        TrOp |  -.0123244   .0021721    -5.67   0.000    -.0165816   -.0080672
         FDI |  -.0058645   .0390538    -0.15   0.881    -.0824086    .0706796
       _cons |  -.0499969   .1629193    -0.31   0.759     -.369313    .2693191
-------------+----------------------------------------------------------------
     sigma_u |          0
     sigma_e |  1.2886733
         rho |          0   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Appendix IIB. Result of Hausman specification test.

```
. hausman fe re

Note: the rank of the differenced variance matrix (3) does not equal the number of
        coefficients being tested (4); be sure this is what you expect, or there may
        be problems computing the test. Examine the output of your estimators for
        anything unexpected and possibly consider scaling your variables so that the
        coefficients are on a similar scale.

                  ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |      fe           re          Difference          S.E.
-------------+----------------------------------------------------------------
       GDPpc |   .0014949     .0020942       -.0005993        .0000695
      GDPpc2 |  -4.34e-08    -5.42e-08        1.07e-08        1.11e-09
        TrOp |   .0008195    -.0123244        .0131439         .001868
         FDI |   .0113568    -.0058645        .0172213               .
------------------------------------------------------------------------------
                           b = consistent under Ho and Ha; obtained from xtreg B
            = inconsistent under Ha, efficient under Ho; obtained from xtreg

    Test:  Ho:  difference in coefficients not systematic

                  chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =       54.13
                Prob>chi2 =      0.0000
                (V_b-V_B is not positive definite)
```

HO: Random effect is more appropriate
HA: Fixed effect is more appropriate

Appendix IIC. Results on different diagnostic tests.

Cross-section dependence test (Breusch-Pagan LM test of independence)

```
. xttest2

Correlation matrix of residuals:

          __e1      __e2      __e3      __e4      __e5      __e6      __e7      __e8
__e1    1.0000
__e2   -0.6515    1.0000
__e3   -0.8380    0.8667    1.0000
__e4    0.0727    0.3272    0.0189    1.0000
__e5    0.4766   -0.3903   -0.5501   -0.0348    1.0000
__e6   -0.6735    0.9706    0.9356    0.2138   -0.4444    1.0000
__e7    0.4067   -0.5997   -0.5992    0.2128    0.0385   -0.6078    1.0000
__e8   -0.4520    0.2629    0.1233    0.4577    0.1083    0.1162    0.0822    1.0000
__e9    0.5308   -0.7030   -0.8389    0.2138    0.6234   -0.8098    0.6579    0.3654

          __e9
__e9    1.0000

Breusch-Pagan LM test of independence: chi2(36) =     111.701, Pr = 0.0000
Based on 11 complete observations    over panel units
```

HO: there is cross-section independence
HA: there is cross-section dependence

Heteroscedasticity test (modified Wald test)

```
. xttest3

Modified Wald test for groupwise heteroskedasticity
in fixed effect regression model

H0: sigma(i)^2 = sigma^2 for all i

chi2 (9)  =      6.3e+05
Prob>chi2 =       0.0000
```

HO: Data is homoscedastic
HA: Data is heteroscedastic

Autocorrelation test (Wooldridge test)

```
. xtserial CO2 GDPpc GDPpc2 TrOp FDI

Wooldridge test for autocorrelation
in panel data H0: no first-order
autocorrelation F( 1, 8) = 30.955
Prob > F = 0.0005
```

HO: There is no autocorrelation
HA: There is autocorrelation

Appendix IID. Results of using PCSE estimation method.

```
. xtpcse CO2 GDPpc GDPpc2 TrOp FDI, correlation(psar1)
(note: estimates of rho outside [-1,1] bounded to be in the range [-1,1])
(note: the number of observations per panel, e(n_sigma) = 11,
       used to compute the disturbance of covariance matrix e(Sigma)
       is less than half of the average number of observations per panel,
       e(n_avg) = 30.444444; you may want to consider the pairwise option)

  Prais-Winsten regression, correlated panels corrected standard errors (PCSEs)

Group variable:    ID                            Number of obs       =       274
Time variable:     Year                          Number of groups    =         9
Panels:            correlated (unbalanced)       Obs per group: min =         11
Autocorrelation:   panel-specific AR(1)                         avg =   30.44444
Sigma computed by casewise  selection                           max =         42
Estimated covariances        =         45        R-squared           =    0.7267
Estimated autocorrelations   =          9        Wald chi2(4)        =    103.70
Estimated coefficients       =          5        Prob > chi2         =    0.0000

------------------------------------------------
             |           Panel-corrected
         CO2 |      Coef.   Std. Err.      z    P>|z|      [95% Conf. Interval]
-------------+----------------------------------
       GDPpc |   .0018216   .0002651     6.87   0.000      .0013021    .0023411
      GDPpc2 |  -4.55e-08   6.66e-09    -6.83   0.000     -5.86e-08   -3.25e-08
        TrOp |  -.0120912   .0076519    -1.58   0.114     -.0270886    .0029061
         FDI |  -.0194318   .0470206    -0.41   0.679     -.1115905    .0727269
       _cons |   1.730438   .8334625     2.08   0.038      .0968815    3.363995
------------------------------------------------
  more
```