

# **ACTUARIAL SCIENCE HONOURS 2016 RESEARCH PROJECT**

## **AN INVESTIGATION INTO THE RELATIONSHIP BETWEEN ECONOMIC GROWTH AND CARBON DIOXIDE EMISSIONS**

**By B Rubin and SM M Yang**

### **ABSTRACT**

As intergovernmental organisations attempt to mitigate the supposed trade-off between economic growth and the use of environmentally damaging fuels, theorists have yet to categorically agree on the dynamics of the relationship between economic growth and anthropogenic environmental damage. This paper investigates the afore-mentioned relationship with particular focus on the anthropogenic environmental damage caused by the emissions of carbon dioxide. The paper models the relationship between economic growth and anthropogenic environmental damage, represented by carbon dioxide emissions, over time for 23 developed countries using data from the World Bank. The analysis shows that the developed countries have shown a number of different patterns of carbon dioxide emissions as a function of economic growth through time. The patterns cannot be described as automatic or systematic since a standard pattern does not necessarily hold for all countries. It is argued that the precise shape of the curve is heavily dependent on government environmental policy in a particular country, among other external factors. Hence, the paper concludes that the relationship between economic growth and anthropogenic environmental damage cannot be generalised across countries and therefore, developing countries' environmental policy should not be informed by the environmental performance of already developed countries.

### **KEYWORDS**

Anthropogenic environmental damage; economic growth; developed countries; developing countries; GDP; Kuznets curve

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### **1 INTRODUCTION**

1.1 In 1997, in an historic meeting in Kyoto, Japan, the United Nations (UN) established an international protocol that compels state parties to reduce greenhouse gas emissions (Huang, Lee & Wu, 2007). In doing so, the UN acknowledged the anthropogenic impact (the impact originating from human activity) of past economic growth on carbon dioxide (CO<sub>2</sub>) emissions, which form a large part of greenhouse gas emissions, and its ultimate contribution towards global warming (Grubb, 2004). The Kyoto Protocol reignited the concern and research over the precise relationship between economic progress and environmental protection (Huang, Lee & Wu, 2007). Many theories have been postulated as a result of both theoretical and empirical analysis over this relationship and implications have been considered from the varying viewpoints (Galeotti & Lanza, 1999).

1.2 More recently, at the 21st Congress of the Parties (COP21), representatives of 160 nations provisionally agreed to actively attempt to keep global temperatures from rising above 2 degrees Celsius<sup>1</sup>. The agreement implies that the countries involved will commit to reducing the usage of fuels that can be shown to have a harmful impact on the environment. Since COP21, participating countries have committed to nationally-determined restrictions, in which the countries aim to reduce their relative use of environmentally harmful fuels, and specifically carbon-intensive fuels. Stern (2004) proposes that it is important to consider the impact of targeting a reduction of carbon-intensive fuels on economic growth. In particular, Stern refers to how the change away from carbon-intensive practices should, *ceteris parabus*, result in a decline in output relative to the output that would be achieved in a business-as-usual scenario (*ibid.*). Is there a way for an economy to sustain economic growth while reducing consumption of carbon-intensive fuels? Or as is there necessarily a trade-off between the two?

1.3 Aluaddin (2013) posits that economic development is a necessity for all developing countries. However, it is now widely accepted that the drivers of past economic growth, such as fossil fuel consumption, have had direct and damaging effects on the environment. This paper aims to establish if a certain relationship between economic growth and CO<sub>2</sub> emissions per capita necessarily holds and if it arises automatically. The results obtained will allow for an informed discussion as to whether, as Munasinghe (1995) and Panayotou (1997) discussed, developing countries may learn from the experiences of developed countries in this regard. The implications are relevant for both developed and developing economies but the results may indicate that the two have different roles to play in the name of sustainable growth. Reddy & Thomson (unpublished) asked if human activity, as practised today, could "sustain environmental... and economic well-being, and if not, how can we change economic activity so that the environment and society can sustain it?" The results and conclusions of this paper may provide a framework in which we could begin to address these issues.

1.4 The aim will be addressed by investigating the following primary research question and subsequent auxiliary research question. In the past, have countries displayed the ability to grow economically while reducing CO<sub>2</sub> emissions per capita? If indeed there is an identifiable pattern in the relationship between economic growth and carbon dioxide emissions for different countries, can we generalise the pattern and use it to predict the future global relationship between the two?

1.5 Section 2 of this paper will provide a review of literature that aims to establish the relationship between economic growth and anthropogenic environmental damage. Section 3 expands the discussion into the issue of the significance of this problem to developing countries. Section 4 develops a methodology for modelling the relationship for a group of specific developed countries across time in a longitudinal analysis. Section 5 lays out the results of the analysis. Section 6 includes the interpretations and implications of the results obtained in order to establish whether economic growth can be maintained in the presence of a diminishing reliance on the use of carbon-intensive fuels.

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<sup>1</sup> United Nations, Intended Nationally Determined Contributions, 2015.  
[http://unfccc.int/focus/indc\\_portal/items/8766.php](http://unfccc.int/focus/indc_portal/items/8766.php), 10/06/2016

## **2. LITERATURE REVIEW**

2.1 In the previous section, we introduced the aims of the research and presented the recent developments in the area of environmental awareness. We now aim to provide a compilation of the history of the research regarding the relationship between economic growth and anthropogenic environmental damage. This section looks at the gradual development in the understanding of this topic by discussing past empirical and theoretical studies. We identify the major contributions in this area and proceed to investigate the shortcomings of previous research and isolate inadequacies of past analyses. The next section then goes on to discuss some works that explored the implications of the findings on government policy. In particular, we consider how the implications of the research may affect developing countries.

2.2 In the late 1960's, Ezra Mishan introduced the world to the "unintended spillover effects" and environmental "costs" of economic expansion in his seminal paper titled "The Cost of Economic Growth" (Mishan, 1967). While the notion began to gain credence in the academic sphere, it seemed not to affect the hierarchy of objectives for governing bodies across the world (Beckerman, 2001). In general, maximising economic expansion was prioritised above reducing environmental costs (*ibid.*). A breakthrough paper, written by Grossman & Krueger, was published in 1991 which propagated the concept of the Environmental Kuznets Curve (EKC) hypothesis (Grossman & Krueger, 1991). In that paper, Simon Kuznets's theory of the relationship between income inequality and economic growth was adapted by Grossman and Krueger to explain the relationship between environmental damage and economic growth. The EKC theme was popularised by the World Bank's World Development Report in 1992 (Stern, *op. cit.*). The traditional EKC hypothesis conjectures that harmful pollutant emissions are directly dependent on the level of economic development (Huang, Lee & Wu, *op. cit.*). According to the hypothesis, at the early stages of development, emissions rise firstly in increasing marginal amounts and then subsequently in diminishing marginal amounts as economic growth increases. This is due to agriculture and industry intensifying at the early stages of development (causing increasingly more pollution) and subsequently increasing but at a decreasing rate (*ibid.*). As economic growth increases, an economy should eventually reach a point after which, environmentally harmful outputs (or emissions) decline with subsequent economic growth due to the natural expansion of the service sector and other less pollution-causing practices (*ibid.*). This hypothesised systematic relationship between economic growth and environmental damage has become known as the inverted-U shape relationship (Yandle, Bhattacharai, & Vijayaraghavan, unpublished). The relationship is illustrated in Figure 1.

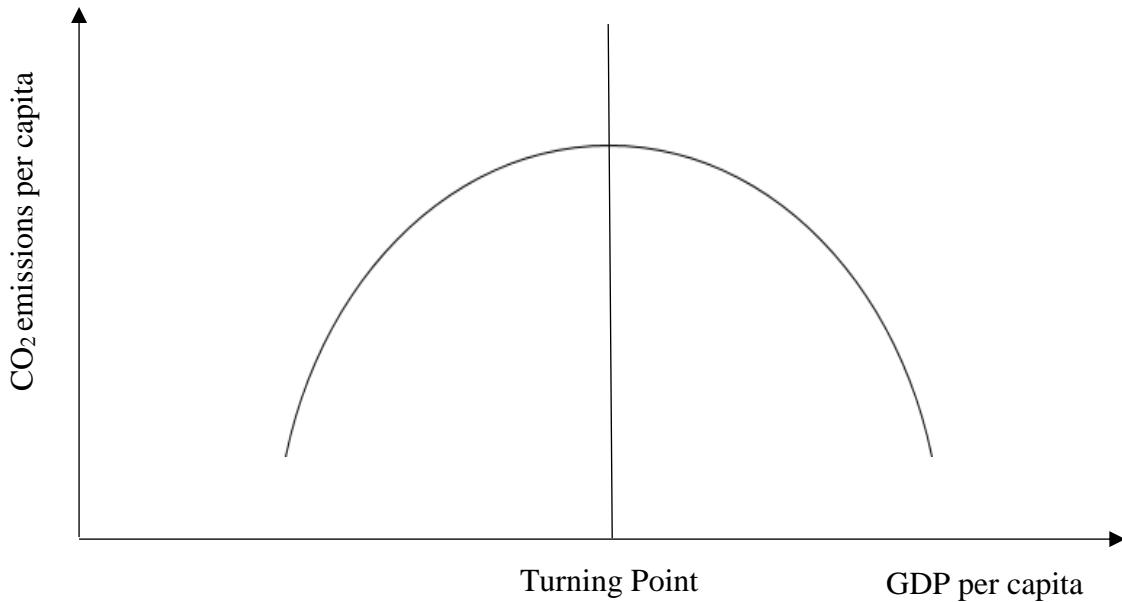


Figure 1. EKC graph

2.3 The traditional and still dominant technique in EKC literature is to investigate the behaviour of a particular pollutant (usually measured in emissions per capita) using a linear regression model. The dependent variable under investigation is the per capita emissions of a particular pollutant, which is used as a proxy for anthropogenic environmental damage. This paper uses carbon dioxide emissions as the dependent variable and the reasons behind this decision are discussed in ¶4.2. As such, the purpose of the model is to determine the "environmental performance of a country as it develops" (Stern, *op. cit.*). The results achieved should then provide insight when predicting the future environmental performance of similar countries or countries that lag behind in terms of economic development. Historically, GDP per capita has been used as the proxy for economic growth.

2.4 The air pollutants that have been modelled in past literature include sulfur dioxide, carbon dioxide, carbon monoxide, nitric oxide and, to a lesser extent, some other volatile organic compounds. Grossman et al. (1994), Seldon & Song (1994), Panayotou (1995), Stern & Common (2001) are among the notable researchers who empirically showed that the EKC relationship holds for sulfur dioxide. However, their respective calculated turning points (the point of economic growth after which further economic growth results in decreasing environmental damage per capita) vary widely. Fewer studies have been conducted using nitric oxide as the pollutant, with the vast majority of empirical studies showing that the EKC relationship holds. However, the estimated turning points again vary dramatically among the different studies. Galeotti & Lanza (*op. cit.*) argue that carbon dioxide (CO<sub>2</sub>) emissions are the most appropriate pollutant to use as the dependent variable. According to the United States Environmental Protection Agency, 80.9% of CO<sub>2</sub> emissions in the United States in 2014 were anthropogenic in nature. It is widely agreed that CO<sub>2</sub> is the primary greenhouse gas emitted through human activity (Galeotti & Lanza, *op. cit.*). In 1995, Holtz-Eakin & Selden established, via econometric methods, showed that an EKC relationship does exist between carbon dioxide emissions and GDP per capita (Holtz-Eakin & Selden, 1995). Their analysis was based on data from 13 high-income countries from 1951 to 1986. However, they concluded that only when per capita income reached US\$8 million, a turning point would occur (*ibid.*). This per capita income level is not obtainable in a pragmatic sense (*ibid.*). More recent studies have obtained turning points within a range of observable income levels using

more complex modelling techniques (Panayotou, unpublished). Galeotti & Lanza (op. cit.) and other major studies have obtained an inverted-U shaped relationship in their respective empirical studies based on broad data samples, with the turning points being realistic in terms of feasible income per capita levels. However, the majority of past empirical studies suggest that CO<sub>2</sub> emissions per capita increase monotonically with increases in income per capita. Shafik & Bandyopadhy (1992) and Heil & Seldon (2001) published prominent papers that empirically argued the monotonic increasing relationship.

2.5 An accumulation of empirical results shows that the validity of the EKC and the necessary existence of a turning point is a point of contention. As discussed above, results vary widely between studies and it is clear that "unequivocal evidence for the EKC relationship is scant" (Elkins, 1997). There is also dispute over whether the EKC relationship or the monotonically increasing relationship, discussed in ¶2.4, is the dominant relationship. As such, "whether economic growth will be beneficial or harmful to the environment in the long run remains a matter of belief" according to Nauymayer (1998). However, if anything, the fact that there is no consensus means that further research is required on the topic. The relationship between economic growth and environmental damage will necessarily determine the future welfare of the planet (*ibid.*). This idea will be fully explored in ¶3.2 by means of two examples but one of the main reasons for the previous statement is because government policy is largely dictated by targeting a level of economic growth (which is usually represented by GDP per capita). In particular, the perspective of relevant governing agencies on this issue will prescribe growth and trade opportunities for developing economies (*ibid.*).

2.6 A number of critical papers have been published, questioning the validity and relevance of EKC theory both theoretically and econometrically (Stern, op. cit.). This next section will briefly outline and contextualise the main criticisms of the theory. Before structuring the criticisms, it is important to reiterate the objective of applying the EKC theory. Everett, Ishwaran, Ansaloni & Rubin (2010) identify the main objective of the EKC theory as being the ability to predict the "environmental performance of a country as it develops", where performance refers to the amount of environmental damage that can be attributed to the development. Stern (op. cit.) and Ekins (2000) focus on the lack of reliability and robustness of the econometric framework of most EKC models. They argue that results have been shown to be significantly impacted by the choice of model. Stern also discusses the importance of the choice of pollutant being modelled as the dependent variable (Stern, op. cit.). In particular, he emphasises that greater significance should be placed on the results that follow from estimating global pollutants such as CO<sub>2</sub>. Magnani (2000) draws attention to the fact that countries with similar levels of wealth do not necessarily contribute similarly to environmental damage (over a range of environmental damage proxies). Everett, Ishwaran, Ansaloni & Rubin add that this may indicate a lack of systematic signs of behaviour. Yandle, Bhattacharai & Vijayaraghavan (op. cit.) stated categorically that "there is no single relationship that fits all pollutants for all places and times". Stern writes that the "impression produced by early studies seem slow to fade in the political, academic and business communities." Despite the evident shortcomings within the theory, influential decisions by policy-makers continue to be dictated by the impression that the inverted-U shape, that was suggested in the earliest studies, necessarily holds (Stern, op. cit.). The relationship proposed in early studies often seem to be treated as an anchor, with subsequent findings attaining less traction in the political, academic and business communities. Yandle, Bhattacharai & Vijayaraghavan (op. cit.) conclude that the reduction in environmental damage after the turning point is not automatic but rather that it is a result of policies and institutions. They add that economic growth allows for reduction in environmental damage only insofar as it allows for the supply of the

necessary resources and allows for the demand of improved environmental quality. (*ibid.*). However, a problem with EKC theory is that it may be misleading in the sense that it indicates that environmental damage automatically decreases when a certain GDP per capita level is reached. But a more informed argument says that the extent to which environmental damage is actually reduced depends critically on "government policies, social institutions and the completeness and functioning of markets" (Panayotou, *op. cit.*). The implications of basing policy on the potentially misleading theory of EKC will be further explored in the following sub-sections (¶3.1 and ¶3.2).

### **3. SIGNIFICANCE TO DEVELOPING ECONOMIES**

This section considers the two essentially global concerns of firstly ensuring economic growth in the developing world and secondly of reducing anthropogenic environmental damage. We discuss how addressing the two issues may be in direct conflict with one another.

#### **3.1 WHICH PROBLEM SHOULD BE PRIORITISED**

3.1.1 By definition, countries categorised as developing have experienced less economic growth to date compared to developed countries. Therefore, developing countries have contributed less towards environmentally harmful outputs than developed countries (Grossman & Krugman, 1991). Past literature has shown a division in thinking regarding the role of developing economies in reducing environmentally harmful emissions in the short term.

3.1.2 Kenny (unpublished) argues that "cheap and reliable" fossil-fuels are critical to development in low-income and middle-income nations. Economic growth in developing countries (and the resulting reduction in poverty) is imperative and is a global concern (*ibid.*). From that position, it follows that developing nations should not be impeded in their attempt to grow economically. However, a politically-enforced reduction in emissions and an implementation of coping mechanisms to reduce harmful environmental outputs could cause "negative short-term impacts" on the economic growth of developing economies (Ludena, de Miguel, & Schuschny, unpublished). The reduction of greenhouse gas emissions is also essentially a global problem and hence requires a combined commitment from all governments across the world (*ibid.*).

3.1.3 So we have that developing economies should not be impeded in their attempt for economic expansion. Conversely, we have that all economies (including developing) should aim to reduce environmentally harmful output, which may impact negatively on economic growth. So how can the two points of view be reconciled? Should developing economies bear the brunt of dealing with the consequences of targeting low emissions by being impeded in their attempt to achieve desirable levels of economic expansion? Alternatively, should the responsibility be shared globally, disregarding levels of economic development? The issue is exacerbated since, according to Kenny (*op. cit.*), global carbon emissions increases since 2000 have been largely due to developing countries' rapid growth and increased energy consumption.

#### **3.2 THE PRIORITY DEPENDS ON SHAPE OF THE CURVE**

3.2.1 The answers to these philosophically challenging questions are not straightforward. Before attempting to answer the questions above, we must consider the issues introduced in ¶2.6. The role of developing countries can be shaped, to some extent, by the underlying relationship between economic growth and environmental damage. Moreover, and as introduced in ¶2.5, the relationship between economic growth and environmental damage is

critical in determining the future welfare of the planet. The implications of two differently shaped relationships are considered below.

3.2.2 Let us firstly consider the case in which it is true that environmental damage automatically increases monotonically as an economy grows, as claimed by Shafik & Bandyopadhy (1992) and Heil & Seldon (2001). In this case it is accepted that a marginal increase in GDP per capita will necessarily result in an increase in CO<sub>2</sub> emissions per capita at all levels. It then follows logically that policies aimed at maximising economic growth would ultimately also lead to maximised levels of CO<sub>2</sub> emissions. In the extreme, that would eventually necessitate extremely high levels of CO<sub>2</sub> emissions and ultimately to the associated negative environmental consequences. For that situation to be avoided, it would be necessary for all economies to reduce carbon emissions and hence to reduce the rate of economic expansion.

3.2.3 However, let us now consider the situation in which the inverted-U relationship exists and materialises automatically at a specific point in the development of an economy. In this case, it may be argued that developing economies should commit to targeting economic expansion in the short term with the end goal of overcoming the turning point. If the inverted-U relationship is necessarily true, then targeting GDP growth can be justified in order to reach the GDP per capita level where environmental damage will begin to decrease.

3.2.4 The above arguments are further compounded by the issue of inter-generational equity (Lieb, unpublished). Should today's generations (especially in developing countries) aim to reduce the consumption of harmful energy supplies and hence sacrifice the probability of attaining desirable levels of economic growth in order to allow for the future possibility of long term sustainability? Will future generations even be able to thrive if today's generations do not sacrifice harmful energy consumption in the short term? This discussion is outside the scope of the paper; however, the issues will be alluded to when discussing the implications of the results from the empirical analysis in Section 6.

## 4 METHODS

### 4.1 MEASURING ECONOMIC GROWTH

GDP per capita is used as a measure of economic growth because it is a wide-spread measure used globally and hence provides readily available and relevant data (Schepelmann, Goossens, & Makipaa, unpublished). Per-capita data is used to standardise for the effects of population growth over time. Furthermore, the use of GDP is advantageous in the sense that it is transparent and universally well-defined in terms of its calculation (*ibid.*).

### 4.2 MEASURING CARBON-INTENSIVE FUEL USAGE

CO<sub>2</sub> emissions per capita is used as a measure for the use of carbon-intensive fuels in a country. As with GDP, per-capita data is used for CO<sub>2</sub> emissions to standardise for the effects of population growth over time. We also justify the use of CO<sub>2</sub> since it is the primary greenhouse gas emitted through human activity (Galeotti & Lanza, *op. cit.*) and extensive research has been done on the irreversible effects of anthropogenic CO<sub>2</sub> emissions on climate change. It is argued that the effects of climate change as a result of increased emissions are irreversible for 1000 years (Solomon, Plattner, Knutti, & Friedlingstein, unpublished).

Understanding the effect of GDP growth on CO<sub>2</sub> emissions is therefore of significant importance. The use of CO<sub>2</sub> emissions per capita is also advantageous because it is one of the proxies for dirty fuel usage that the World Bank frequently collects.

### 4.3 DEVELOPMENT CLASSIFICATION SYSTEM

At the moment, there is no consensus between the UN, World Bank and IMF on strict categorisation criteria for developing, transitioning and developed countries (Nielsen,

unpublished). This is primarily due to a lack of consensus in the economic community on what constitutes a development threshold or benchmark and the normative nature of such a task (*ibid.*). However, since the purpose of this paper is not to gauge this development threshold, we cannot comment on which classification system is better. That being said, since the majority of this paper will utilise data from the World Bank, we will also use the World Bank's definition of developing, transitioning and developed for the sake of consistency.

#### 4.4 DATA SOURCES

4.4.1 The three datasets required to carry out the research in this paper are, the World Bank's economic classification of countries, CO<sub>2</sub> emissions per capita for each country, and GDP per capita for each country. All of these datasets were collected from the World Bank's website.<sup>2</sup>

4.4.2 Only data from high-income countries will be analysed. The underlying assumption for doing so is that high-income economies will display a more holistic spectrum of the relationship between economic growth and dirty fuel usage. As a result of this assumption, the data from developing and transitioning economies is not useful for the purposes of this study. This is because these economies will not have had enough time to develop a satisfactorily complete spectrum of the relationship between GDP per capita and CO<sub>2</sub> per capita.

4.4.3 The World Bank dataset for CO<sub>2</sub> per capita starts in 1960 and ends in 2011, where CO<sub>2</sub> per capita is measured in Metric Tons per capita under the Imperial System of measurements.

4.4.4 The World Bank dataset for GDP per capita starts in 1960 and ends in 2014. All GDP per capita values are in real 2014 dollar terms in order to adjust for the effects of inflation.

4.4.5 The frequency of GDP per capita and CO<sub>2</sub> per capita data is annual.

#### 4.5 TESTING FOR THE CO<sub>2</sub> AND GDP RELATIONSHIP

4.5.1 The traditional and still most widely used method of testing the EKC is to use the following relationship (Lieb, *op. cit.*):

$$y_{it} = \alpha_i + b_1 x_{it} + b_2 x_{it}^2 + b_3 x_{it}^3 + \mathbf{b}_4 \mathbf{z}_{it} + e_{it};$$

where:

$y_{it}$  represents the CO<sub>2</sub> emissions per capita of country  $i$  at time  $t$ ;

$x_{it}$  represents for the GDP per capita of country  $i$  at time  $t$ ;

$\mathbf{z}_{it}$  represents a vector that accounts for other variables that might affect environmental degradation;

$\alpha_i$  is the theoretical CO<sub>2</sub> emissions per capita when GDP per capita is equal to 0;

$b_1, b_2, b_3$  and  $\mathbf{b}_4$  represent the coefficients of  $x, x^2, x^3$  and  $\mathbf{z}_{it}$  respectively;

$i$  represents the index for the country;

$t$  represents an index for time.

4.5.2 For the purposes of this research,  $\mathbf{z}_{it}$  will be set to  $\mathbf{0}$  because we are only looking at the effect that GDP per capita has on CO<sub>2</sub> per capita.

4.5.3 There are multiple methods of estimating the above general form and three that stand out are panel data analysis, ordinary least squares and generalised least squares. (Lieb, *op. cit.*) For the purposes of this study we eliminate the use of generalised least squares and panel

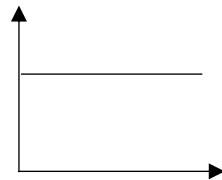
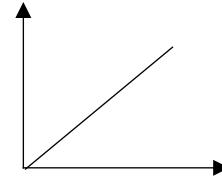
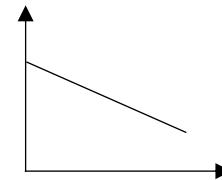
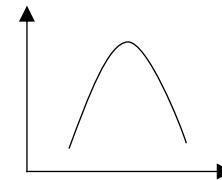
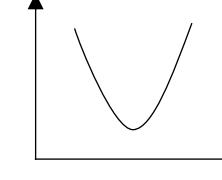
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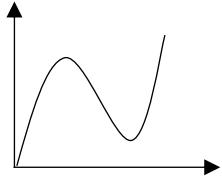
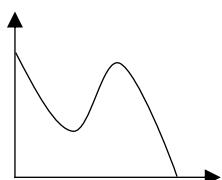
<sup>2</sup> World Bank, Work Bank Database, 2016. <http://data.worldbank.org/>, 04/03/2016

data analysis because there are gaps in the data from the World Bank. That is to say that there are some countries where CO<sub>2</sub> emissions per capita or GDP per capita were not recorded for certain years. We therefore estimate the above equation for countries individually using ordinary least square techniques.

4.5.4 Under this form, there are 7 possible shape outcomes which are summarised in TABLE 1.

TABLE 1. The 7 different possible shapes taken from Dinda (2004)

Shape	Coefficient conditions for shape to hold	Implications of shape	Graphical illustration
Flat pattern	$b_1=b_2=b_3=0$ .	No relationship between x and y.	
Straight line increasing relationship between x and y	$b_1>0$ and $b_2=b_3=0$	Country needs to sacrifice economic growth in order to reduce CO <sub>2</sub> emissions.	
Straight line decreasing relationship between x and y	$b_1 < 0$ and $b_2=b_3=0$	Country can constantly grow while decreasing CO <sub>2</sub> emissions.	
Inverted-U relationship between x and y	$b_1 > 0$ , $b_2 < 0$ and $b_3=0$	Environmental Kuznets Curve. Economy needs to use more carbon-intensive fuels in order to fuel growth until it reaches a turning point. After the turning point, economy can grow while reducing CO <sub>2</sub> emissions.	
U-shaped relationship between x and y	$b_1 < 0$ , $b_2 > 0$ and $b_3=0$	Economy reduces CO <sub>2</sub> per capita while achieving economic growth until it reaches a turning point. After the turning point the economy emits more CO <sub>2</sub>	

		per capita as it grows.	
N-shaped relationship between x and y	$b_1 > 0, b_2 < 0$ and $b_3 > 0$	Inverted U, but with another turning point at higher GDP level. After second turning point economy emits more CO <sub>2</sub> emissions per capita to achieve economic growth.	
Inverted N-shaped relationship between x and y	$b_1 < 0, b_2 > 0$ and $b_3 < 0$	U shape, but with another turning point at higher GDP level. After second turning point country emits less CO <sub>2</sub> emissions per capita to achieve economic growth.	

(Dinda, 2004)

4.5.5 It is important to note that the cubic model misidentifies some shapes. For example, if there is a monotonically increasing shape where CO<sub>2</sub> emissions per capita approaches some asymptotic value, the cubic graph will categorise this as an N-shape that monotonically increases after the second turning point. Similarly, this misidentification also holds true for the quadratic and linear models, which are special cases of the cubic model, and will be discussed further in ¶5.2.

#### 4.6 ELIMINATION OF COUNTRIES FOR LACK OF DATA

4.6.1 As justified in ¶4.4.2, only countries in the World Bank's high-income category were chosen for analysis. This totaled 80 high income countries as of 31 May 2016.

4.6.2 Of these 80 countries, countries without sufficient data points were left out of the analysis. Frank Harrell (2015) has suggested a rule of thumb whereby 10 to 20 data points are needed for each covariate when using regression (Harrell, 2015). The cubic model has three covariates (GDP, GDP squared and GDP cubed), so 30 data points was used as our cut-off point criteria for including a specific country in the analysis. This left us with 50 countries, out of the original 80 countries, on which we conducted analysis.

#### 4.7 METHOD FOR DATA ANALYSIS

4.7.1 As justified in ¶4.4.2, the analysis only took high-income countries into account. The underlying assumption of using high-income economies was that high-income economies have experienced sufficient growth in their economies to display the full range of the relationship between GDP per capita and CO<sub>2</sub> per capita. As mentioned in ¶4.3, The World Bank's classification of high-income economies was used.

4.7.2 We took the full range of CO<sub>2</sub> per capita and GDP per capita data from the World Bank, which ran from 1960 to 2011.

4.7.3 Ordinary least squares regression was used to fit a cubic model, quadratic model and linear model to each of the 50 high-income countries. We chose these three models because, depending on the coefficient of the model, the model should fall under one of these three shapes (see TABLE 1).

4.7.4 At this stage we had 150 models, 3 for each country. For each country, the adjusted R-squared was used to find the model with the best fit out of the linear, quadratic and cubic model, leaving us with a best fitting model for each country. We use the adjusted-R squared

because it shows the percentage of variation accounted for by the model, and is therefore a good measure of fit. The model with the highest adjusted R-squared was used to represent the country's experience between GDP per capita and CO<sub>2</sub> per capita. Of these 50 models, we used an adjusted R-squared cut off point of 0.7 to further select models with a good fit. Here, we applied a rule of thumb that stated that an adjusted R-Squared higher than 0.7, meaning that more than 70% of the variation can be explained by the model, provided a good fit for generalised linear models (Moore, 2013).

4.7.5 The Wald test is a test that can be used to test whether the coefficient estimated is significantly different to 0 (see TABLE 1). The Wald test takes on the following form:

$$\frac{\hat{\beta} - \beta_0}{SE(\hat{\beta})} \sim N(0,1);$$

where:

$\hat{\beta}$  is the estimated coefficient;

$\beta_0$  is set to 0 because we want to check if  $\hat{\beta}$  is significantly different to 0;

$SE(\hat{\beta})$  is the standard error of  $\hat{\beta}$ .

The Wald test was performed to check if the coefficients were significantly different to 0. A confidence level of 90% was used to perform these tests. If the coefficient was found to be not significantly different to 0, then the coefficient was set to 0. For the coefficients that were significantly different to 0, the sign of the coefficients were to determine which one of the 7 possible shapes the best fitting model for each country was categorised as (see ¶4.5.3 and TABLE 1). For the countries where the best model was quadratic, it is important to note that  $b_3$  was already preset to 0. Also, for the countries where the best model was linear, it is important to note that  $b_2=b_3$  were preset to 0.

4.7.6 In ¶4.5.4 we noted that the cubic, quadratic and linear models are not able to capture some specific shapes. There was therefore a need to analyse the original plots of data and account for any shapes that our regression models failed to capture. We will henceforth refer to this analysis and use of judgment as a visual classification.

## 5 RESULTS

### 5.1 BEST FIT FOR EACH COUNTRY AND ELIMINATION OF POOR FITS

5.1.1 As described in ¶4.7.4, the adjusted R-squared is used to find each country's best fitting model out of the linear, quadratic and cubic regression models. These adjusted R-squared values for all 50 countries are tabulated in the TABLE 1a of the APPENDIX.

5.1.2 As set out in ¶4.7.4, countries where the model has an adjusted R-squared less than 0.7 are eliminated due to poor fit. Of the 50 countries, 23 achieved our criteria of good fit (see ¶4.7.4). No further results were drawn from the remaining 27 countries because the purpose of this paper is to determine whether a dominant relationship between GDP per capita and CO<sub>2</sub> per capita exists, and these countries have already demonstrated a weak relationship from their poor fit.

### 5.2 FURTHER SHAPES

5.2.1 As pointed out in ¶4.7.6, there are some forms that the cubic, quadratic and linear models fail to account for and from the visual classification that we performed on each of the 23 countries' best fitting models, there are 3 shapes in particular that these models didn't take into account.

5.2.2 One of these shapes is a shape that starts off looking like an inverse quadratic, but then tends to some asymptotic value of CO<sub>2</sub> per capita as GDP per capita increases. The shape looks like an inverted L and this is how we will refer to this shape for the rest of this

paper. Note that for countries that do exhibit such a relationship, the best fit usually came out as cubic with an N-shape. It is necessary to differentiate this relationship from the straight-line increasing relationship (Table 1) because the two imply different behaviours in the upper tails of GDP per capita. More specifically, the inverted-L relationship implies that GDP per capita tends off to an asymptotic level of CO<sub>2</sub> per capita. One country that exhibits this relationship is Australia, and has been included for illustration purposes in Figure 2 below.

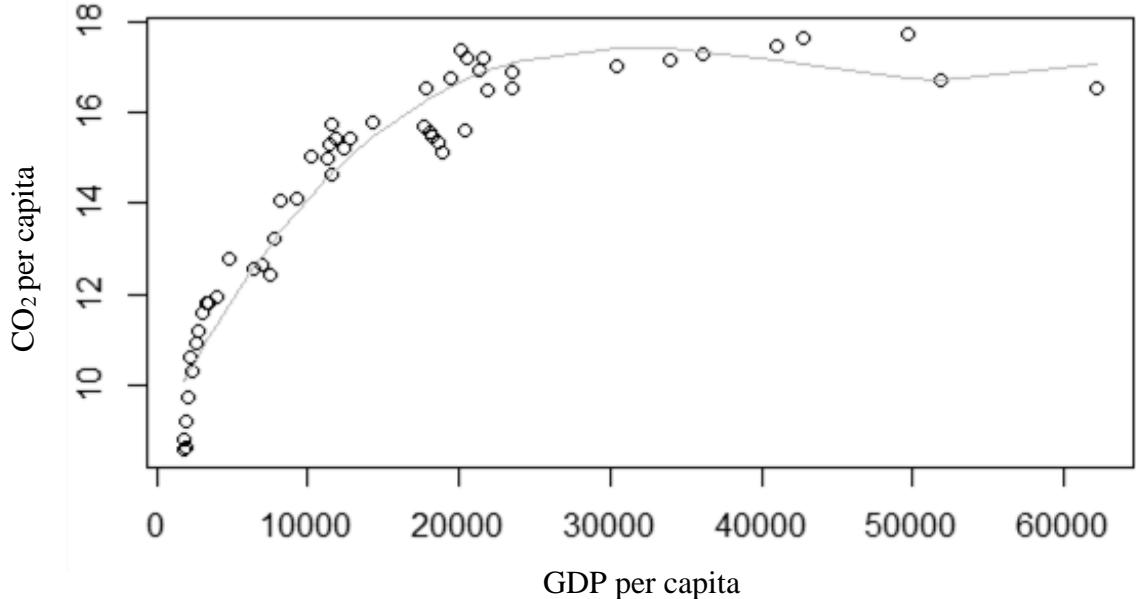


Figure 2. Plot of CO<sub>2</sub> per capita vs GDP per capita for Australia with the model of best fit

5.2.3 The second shape is the inverse of the shape above that looks like an L. This relationship is more plausible than the linearly decreasing relationship (Table 1) because negative CO<sub>2</sub> emissions per capita do not make sense in reality. It is therefore important to separately account for this relationship. One country that exhibits this relationship is the United Kingdom, which can be found in Figure 3 below.

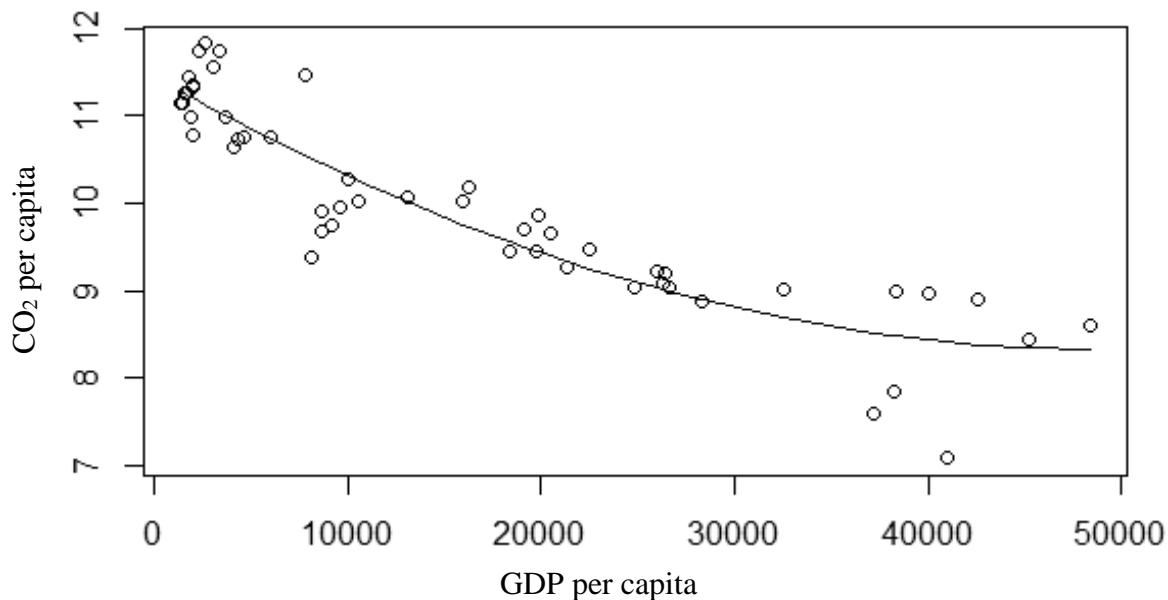


Figure 3. Plot of CO<sub>2</sub> per capita vs GDP per capita for United Kingdom with the model of best fit

5.2.4 The third shape that is not captured is a relationship that is monotonically increasing, but not necessarily in a straight line. This monotonically increasing relationship also differs to the inverted L relationship that appears in ¶5.2.2 because CO<sub>2</sub> emissions per capita do not seem to tend to an asymptotic value as GDP per capita increases. The relationship therefore needs to be separately accounted for and will be referred to as the monotonically increasing relationship. An example of such a country that exhibits this behavior is Korea.

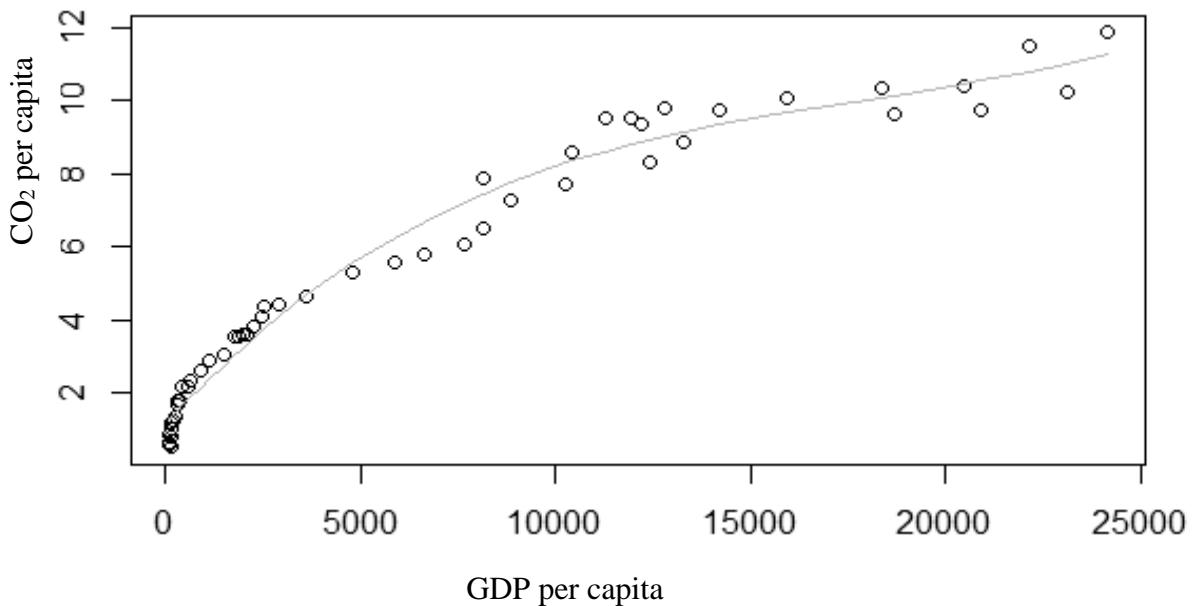


Figure 4. Plot of CO<sub>2</sub> per capita vs GDP per capita for Korea with the model of best fit

### 5.3 MODELLING RESULTS

5.3.1 Of the 23 countries that had a good fit, 14 countries were best fitted by the cubic model, 8 countries were best fitted by the quadratic model and 1 country, Barbados, was best fitted by the linear model. As explained in ¶5.1.2, the remaining countries were disregarded because of poor fit.

5.3.2 Applying the Wald Test to categorise all the models into one of the 7 possible shapes (Table 1), we get the following proportion of shapes: 48% N, 26% Inverted U, 9% Inverted N, 9% U, 4% Constant, and 4% Linearly Increase.

5.3.3 We note that there are no linearly decreasing relationships. We also note that a large proportion of 48% of countries resemble an N-shape and only 6 of our 23 countries resemble the EKC's inverted-U.

5.3.4 However, as pointed out in ¶4.5.4 and ¶5.2, there is a need to do a final visual classification on the shapes above to account for the L, inverted-L and monotonically increasing shapes that are not accounted for by our regression models. We apply this visual classification on the 23 countries with good fit and find that the proportions are revised as follows: 43% Inverted-L, 22% Monotonically Increasing, 22% Inverted-U, 9% L, 4% Linearly Increasing.

5.3.5 We note that after the visual classification, there are no more N-shape relationships. Most of the countries that were best modelled by an N-shape rather resembled an inverted-L shape, which our regression models fail to account for. The U, N and flat relationships also fall away and are instead replaced by one of the three shapes that the regression models failed

to account for. The inverted-U EKC is still the second most prominent relationship after the inverted-L shape.

5.3.6 Also note that all the shapes apart from the L-shape are increasing at low levels of GDP per capita. This shows that when these high-income developed countries were still developing, there was an inevitably higher volume of CO<sub>2</sub> emissions per capita emitted as their economy grew.

## 6. IMPLICATIONS

6.1 In the previous section, we presented the results of our analysis. In the following section, we use our results in order to address the issues raised earlier in the paper (see ¶1.4 and ¶3.2). In ¶1.4, we laid out the following questions. In the past, have countries displayed the ability to grow economically while reducing carbon dioxide emissions per capita? If indeed there is an identifiable pattern in the relationship between economic growth and carbon dioxide emissions for different countries, can we generalise the pattern and use it to predict the future global relationship between the two? In the remainder of this section we will discuss the results that were expected based on past literature, the results that were actually seen from this paper's investigation and additionally, the reasons behind any discrepancies between the two.

### 6.2 REDUCING EMISSIONS WHILE GROWING ECONOMICALLY

6.2.1 As discussed in ¶2.2, the traditional EKC hypothesis conjectures that damaging pollutant emissions are directly dependent on the level of economic development (Huang, Lee, & Wu, op. cit.). According to the hypothesis, at the early stages of development, emissions rise in diminishing marginal amounts as economic growth increases. As economic growth increases, an economy should eventually reach a point after which, environmentally harmful outputs (or emissions) decline with subsequent economic growth (*ibid.*). However, the majority of past empirical studies suggest that carbon dioxide emissions per capita increase monotonically with increases in income per capita. Shafik & Bandyopadhyay (op. cit.) and Heil & Seldon (op. cit.) published prominent papers that empirically argued the monotonic increasing relationship.

6.2.2 From the discussion of the results in the previous section, it was seen that only 22% of the countries were considered to have reached a turning point in GDP per capita, after which CO<sub>2</sub> emissions per capita started to marginally decrease. This is a critical observation with regard to the primary research question because it implies that, according to our investigation, only a minority of countries have displayed the ability to grow economically while reducing carbon emissions.

6.2.3 In addition to the 22% that displayed inverted-U relationships, 43% of the countries exhibited inverted-L shaped curves. So in aggregate, 65% of the countries that were examined reached a point, in GDP per capita terms, after which the behaviour of CO<sub>2</sub> emissions per capita changed. The point after which the behaviour of the curve changes is known as the point of inflection. Now according to classical EKC theory, the curve should decrease after this point as the country should be able to grow economically while decreasing per capita CO<sub>2</sub> emissions. However, our results show that the more likely outcome is that CO<sub>2</sub> emissions per capita will remain at a relatively constant level after the point of inflection is reached. This observation is noteworthy for two reasons. Firstly, the past environmental damage that was caused by economic expansion is often irreversible (Lieb, op. cit.). Secondly, the inflection point may only be achieved at a high level of GDP per capita. Hence, once an economy has reached the level of GDP per capita after which CO<sub>2</sub> emissions are supposed to decrease, it is likely that it will continue to emit consistently high levels of CO<sub>2</sub>. For many developing economies, it will ostensibly take a substantial number of years (in

which irreversible damage is caused) to achieve such levels of GDP per capita if they are even achievable at all (Stern, op. cit.).

6.2.4 The remaining countries in our investigation displayed either monotonically increasing or monotonically decreasing curves. In aggregate, 26% of the countries that we analysed suggested that the relationship between GDP per capita and CO<sub>2</sub> emissions per capita is increasing (either in a linear manner or monotonically) as is argued by Shafik & Bandyopadhy (op. cit.) and Heil & Seldon (op. cit.).

#### 6.4 GENERALISING THE RELATIONSHIP

6.4.1 According to our results, it is evident that the empirical relationships between GDP per capita and CO<sub>2</sub> emissions per capita over time and for specific developed economies can be categorised into a variety of distinct shapes. In turn, this implies that there are various possible ways in which the level of CO<sub>2</sub> emissions can behave as GDP per capita increases over time. Hence, our analysis suggests that a systematic and automatic relationship between GDP per capita and CO<sub>2</sub> emissions per capita cannot be identified nor generalised. This result is contrary to classical EKC literature which implies that the relationship is both systematic, in that it is universal to all economies, and automatic, in that it will necessarily and naturally materialise over time. As a consequence, our results suggest that it would not be possible to predict the future behaviour of CO<sub>2</sub> emissions per capita for a particular economy simply by using past relationships as a basis for the projection.

6.4.2 Having concluded that a predefined relationship does not necessarily hold for any one economy, it follows that there is no possibility of generalising any such relationship. Nevertheless, insight can be gained by analysing the possible explanations of the predominant shapes found in our results. Of particular interest, is the nature of the turning points and inflection points in the cases where they do exist. Reiterating an earlier explanation in ¶6.3, a turning point is defined as a GDP per capita value above which CO<sub>2</sub> emissions per capita values start to decrease and a point of inflection is taken to be a GDP per capita value above which CO<sub>2</sub> emissions per capita values become constant. The discussion of these points presupposes that CO<sub>2</sub> emissions per capita increase at GDP per capita values below the point of interest. Although 65% of the countries that we investigated obtained either a turning point or a point of inflection, after which the marginal rate of CO<sub>2</sub> emissions per capita changed, the point was not universal in terms of level of GDP per capita. The results of our analysis suggest that, even when a turning point or a point of inflection exists, it inevitably materialises at an unpredictable level.

6.4.3 Lieb (op. cit.) offers an explanation for this apparent unpredictability of the level at which the turning point or point of inflection occurs (Lieb, op. cit.). Lieb identified the three main empirically validated explanations for the existence of the turning or inflection point. Critically, these three explanations of why pollution may decrease, or at least stop increasing, after the turning or inflection point are almost entirely dependent on government policy (*ibid.*). The first explanation is that demand for environmental welfare rises with income and this demand induces stricter environmental regulation. Satisfying the demand for environmental welfare requires policy measures. The second explanation is that as an economy develops, it eventually reaches a point at which technological progress allows it to produce efficiently with diminishing levels of harmful output. The third explanation is that environmentally harmful practices are simply moved to less developed countries. This migration of dirty industries has become commonplace due to the existing and impending environmental regulation. Policy measures, regulation and financial incentives guide both the technological process and the outsourcing of production discussed in the latter explanations (*ibid.*). Therefore, Lieb concludes that environmental policy is the most important determinant of whether an inflection point will exist for a particular country and if so, at what

level it will exist. He claims that "for a given pollutant, an EKC (relationship) will only exist when policy measures are taken but (the curve) will be monotonically rising if the government remains inactive" (*ibid.*). The logic behind Lieb's theory aids understanding in examining why each country in the investigation has a unique curve. The model that was used to investigate the relationship does not exhibit sufficient robustness to take government policy into account (Stern, *op.cit.*). Notably, our results support Magnani's (*op. cit.*) findings that countries with similar levels of wealth do not necessarily contribute similarly to environmental damage.

## 6.5 SIGNIFICANCE TO DEVELOPING ECONOMIES

We posed the question of whether developing economies (countries with current low levels of GDP per capita) should be burdened by restrictions on CO<sub>2</sub> per capita emissions. We claimed that the answer depended on if a systemic relationship between GDP per capita (economic growth) and environmental damage (CO<sub>2</sub> emissions per capita) could be found. Illustrative hypothetical scenarios were discussed in ¶3.2. However, as discussed in the preceding sub-section, no systematic relationship can be identified through traditional EKC theory. Our analysis and research suggests that government policy should not be influenced or guided by the possible existence of an automatic EKC inverted-U relationship. As discussed in ¶2.6, influential decisions by policy-makers continues to be dictated by the impression that the inverted-U shape, that was suggested in the earliest studies, necessarily holds (Stern, *op. cit.*). The principal problem with basing decisions on EKC theory is that it presupposes that environmental damage necessarily and automatically decreases when a certain GDP per capita level is reached. This presupposition is in direct conflict with the results obtained in this paper. Our analysis indicated that the more likely outcome is that CO<sub>2</sub> emissions per capita will remain at a relatively constant level after the point of inflection is reached if that point is reached at all. In pragmatic terms, basing decisions on EKC theory means that governments of developing economies may endeavour to implement policies that work towards achieving a certain level of GDP per capita in the hope that CO<sub>2</sub> emissions per capita will eventually decrease. According to the results of the analysis, 21 of the 23 countries exhibited an increasing CO<sub>2</sub> per capita emissions rate in the early stages of development (low levels of GDP per capita). Hence the decision to pursue business-as-usual economic expansion, in the vast majority of cases, leads to an increase in CO<sub>2</sub> per capita emissions and the irreversible environmental damage that comes with it. Furthermore, empirical evidence indicates that the attainment of the turning point will not necessarily lead to decreased per capita CO<sub>2</sub> emissions (Lieb, *op. cit.*). Among others, Everett, Ishwaran, Ansaloni & Rubin (*op. cit.*) posit that policy should aim to reduce CO<sub>2</sub> emissions, regardless of the stage of economic development of the country. This argument is confirmed by our results' implied corollary that without structural change in the development stage, it can be expected that countries that are currently developing will continue to increase CO<sub>2</sub> emissions per capita. Yandle, Bhattacharai & Vijayaraghavan (*op. cit.*) conclude that the reduction in environmental damage after the turning point is not automatic but rather that it is a result of policies and institutions and our results substantiate this type of conclusion.

## 7. CONCLUSIONS

7.1 The objective of the paper was to assess whether a relationship between economic growth, represented by GDP per capita, and anthropogenic environmental damage, represented by CO<sub>2</sub> emissions, exists and whether the relationship can be generalised. Through empirical analysis of 23 developed countries, along with a compilation of past studies, it was found that countries displayed 5 different and distinct relationships between GDP per capita and CO<sub>2</sub> per capita. Notably, 15 of the 23 countries exhibited the existence of

either a turning point or a point of inflection, after which CO<sub>2</sub> emissions per capita either decreased or remained relatively constant with marginal increases in GDP per capita. Increasing curves were exhibited by 6 of the countries while 2 countries exhibited monotonically decreasing curves.

7.2 According to Lieb (op. cit.), the fact that each country has a unique curve (representing a unique relationship between CO<sub>2</sub> emissions per capita and GDP per capita) is indicative of the claim that the environmental performance of a country is intrinsically linked and dependent on government environmental policy. This claim is not consistent with classical EKC theory which posits that the relationship is a certain shape (inverted-U) and materialises independently of external policy and hence is universal across different economies.

7.3 The shape of the curve cannot be categorically generalised according to our investigation and furthermore, our results suggest that it is plausible that the curve is determined by external factors such as technology and government policies. Consequently, this conclusion highlights that it is dangerous for countries to target GDP growth in the hope of reaching a point where carbon emissions decrease while the economy still grows. This idea of a turning point that was introduced by the EKC has been disproven on multiple occasions for carbon emissions (Stern, op. cit.). As emphasised in ¶4.2, the damage that carbon emissions have on climate change is irreversible. Hence, it is dangerous to be stuck in the paradigm of thinking propagated by the EKC as irreversible anthropogenic damage is caused in the pursuit of the attainment of the fabled turning point and it defers government action on initiating structural change. Rather, there is a need for further research on government policies and technologies that can be invested in to reduce carbon emission levels regardless of economic status.

7.4 Finally, our results serve as a potential argument for developed countries to aid developing countries in reducing carbon emissions. As pointed out in ¶6.5, when the developed countries in our study were still in the early developmental stages, they have almost always produced increasing amounts of carbon emissions to achieve growth. It could therefore be argued that it is the responsibility of developed countries, who have already benefited from increasing consumption of carbon-intensive fuels to develop their economies, to aid developing countries in reducing carbon emissions. This notion was embraced during COP21, especially by leaders of developing nations. Chinese president Xi Jinping pleaded for "continued dialogue and the exchange of best practices for mutual learning amongst countries" while India's minister of state for environment, Prakash Javadekar, claimed that the key to addressing climate change in developing countries will be the "funding of technology transfers with respect to intellectual property rights."<sup>3</sup>

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<sup>3</sup> Triple Pundit, Perspectives of Developing Nations at COP21, 2015.

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## APPENDIX

TABLE 1a. Adjusted R<sup>2</sup> for linear, quadratic and cubic fit of 50 countries with sufficient data

Country	Adjusted R <sup>2</sup> Cubic	Adjusted R <sup>2</sup> Quadratic	Adjusted R <sup>2</sup> Linear	Max Adjusted R <sup>2</sup>
Antigua and Barbuda	0.1699	0.1481	0.1546	0.1699
Argentina	0.5158	0.4569	0.4606	0.5158
Australia	0.9297	0.8888	0.5715	0.9297
Austria	0.6124	0.5901	0.4733	0.6124
Bahamas	0.3228	0.2316	0.239	0.3228
Bahrain	0.4019	0.348	0.3592	0.4019
Barbados	0.8241	0.8218	0.8277	0.8277
Belgium	0.3142	0.3011	0.2806	0.3142
Bermuda	0.5528	0.4258	0.09093	0.5528
Brunei Darussalam	0.05917	0.05411	0.03491	0.05917
Canada	0.4326	0.3746	0.0826	0.4326
Chile	0.8151	0.8166	0.7764	0.8166
Cyprus	0.9506	0.9359	0.7153	0.9506
Denmark	0.3144	0.2853	0.04984	0.3144
Finland	0.6161	0.5653	0.3614	0.6161
France	0.5365	0.3878	0.3979	0.5365
French Polynesia	0.746	0.7366	0.6551	0.746
Greece	0.9678	0.9333	0.6701	0.9678
Greenland	0.04884	0.06613	-0.01685	0.06613
Hong Kong	0.9525	0.9208	0.7517	0.9525
Iceland	0.1757	0.00682	-0.01601	0.1757
Ireland	0.8427	0.8169	0.4997	0.8427
Israel	0.9077	0.9093	0.7855	0.9093
Italy	0.772	0.7208	0.495	0.772
Japan	0.7172	0.6992	0.5774	0.7172

Country	Adjusted R^2 Cubic	Adjusted R^2 Quadratic	Adjusted R^2 Linear	Max Adjusted R^2
Korea	0.9758	0.9709	0.8961	0.9758
Kuwait	0.2406	0.1002	-0.02195	0.2406
Luxembourg	0.7553	0.7105	0.4808	0.7553
Macao	0.7705	0.4999	-0.01898	0.7705
Malta	0.8847	0.8777	0.5823	0.8847
Netherlands	0.4052	0.2338	0.05999	0.4052
New Caledonia	0.3815	0.4002	0.3788	0.4002
New Zealand	0.845	0.8482	0.5662	0.8482
Norway	0.6231	0.5811	0.5046	0.6231
Oman	0.8274	0.8343	0.8148	0.8343
Portugal	0.9591	0.9615	0.7258	0.9615
Qatar	0.007968	-0.01263	-0.0006523	0.007968
Saudi Arabia	0.5987	0.5928	0.5455	0.5987
Seychelles	0.8742	0.8678	0.8661	0.8742
Singapore	0.6771	0.422	-0.01733	0.6771
Spain	0.7912	0.7676	0.5759	0.7912
St Kitts and Nevis	0.939	0.9397	0.9329	0.9397
Sweden	0.5979	0.5343	0.5726	0.5979
Switzerland	0.5317	0.3987	0.02281	0.5317
Trinidad and Tobago	0.9148	0.916	0.8997	0.916
United Arab Emirates	-0.02699	-0.009267	0.006833	0.006833
United Kingdom	0.8328	0.836	0.8002	0.836
United States	0.1512	0.1163	-0.01464	0.1512
Uruguay	0.2195	0.1388	0.02062	0.2195
Venezuela	0.03472	0.04693	0.05833	0.05833