DOES THE 'ENVIRONMENTAL KUZNETS CURVE' EXIST? AN APPLICATION OF LONG-RUN STRUCTURAL MODELLING TO SAUDI ARABIA*

1. Introduction: motivation and objective of the study

There is an increasing move by developing and emerging economies to address their environmental issues. In the last few decades, we have witnessed an unprecedented state of global warming. Many scientists have argued that increasing carbon dioxide (CO_2) emissions produce a massive build-up of greenhouse gas, which significantly contributes to warming global temperatures and associated climatic instability (IPCC, 1996). Some countries have signed to the Kyoto protocol in a bid to follow guidelines in reducing their emission levels by investing in infrastructure under the Clean Development Mechanism (CDM). The CO_2 emissions levels in developing countries cannot be reduced dramatically without sacrificing industrial output, which in turn dampens economic growth. For a country like Saudi Arabia, where 90% of exports come from crude oil and petroleum related products, the need to reduce the CO_2 from fossil fuels and cement production is even greater. The ecological nature of the country means there are not many trees to absorb some of the CO_2, so technology that captures and reuses emissions is critical. The idea is for developing countries to have CO_2 and other pollutants capture mechanisms and continue to experience sustainable growth levels. The costs of implementing such mechanism can burden governments and private institutions. So some help and cooperation from the industrialized countries are crucial.

Saudi Arabia's CO_2 emissions have risen by about 40% over the past decades and Saudi Arabia currently is responsible for about

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1.3% of the world total fossil fuelled-based CO_2 emissions (ranking 19th in the world in 2003). Saudi Arabia ratified the Kyoto protocol as a 'non-Annex I state' in December 2004. As there are no specific commitments for greenhouse gas reductions, Saudi Arabia has called for research to improve technology to recover greenhouse gases at the point of production of fossil fuels, in order to ease the potential impact of possible future environmental measures on oil exporters. A historical summary of CO_2 emissions from fossil fuel use in Saudi Arabia is shown in the table below. That implies that the relationship between emissions and income is initially positive.

Component	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
CO_2 from coal	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
CO_2 from natural gas	88.1	92.2	97.4	103.4	90.3	94.0	90.7	98.3	105.2	111.1	117.7
CO_2 from petroleum	144.0	146.1	136.1	145.0	162.8	162.2	171.2	189.9	194.2	198.1	209.8
Total CO_2 from all fossil fuels	232.1	238.3	233.4	284.4	253.1	256.2	262.0	288.2	299.4	309.2	327.4

Source: DOE/IEA.
Note: CO_2 from natural gas includes contribution from gas flaring.

In this paper, we explore for the first time the well-established theory of Kuznets (1955) curve in relation to the environment in Saudi Arabia. We test the Environmental Kuznets Curve (EKC) hypothesis by establishing a relationship between CO_2 emissions *per capita* and *per capita* GDP using the Saudi Arabian data. The hypothesis is that environmental degradation first increases with *per capita* gross domestic product (GDP) and then declines after a certain income level is reached, resulting in an inverted U-shaped Environmental Kuznets Curve (EKC). The World Bank (1992) explains that this hypothesis is based on the existence of positive income elasticity for environmental quality, or in other words, that the demand for environmental quality increases as a country becomes more developed.

In the current context, it may be that Saudi Arabia and other neighbouring countries that ratified the Kyoto Protocol have reached a level of economic growth, which affords them the ability and desire to reduce CO_2 emissions. This tenet, however, calls for a careful examination of the relationship between economic growth and carbon dioxide emissions. To our knowledge, this study is the first on an individual oil producing country as most studies focus on industrialised economies like Canada (Lantz and Feng, 2006) or on highly populated economics like India, China and Brazil (Focacci, 2005). With the majority of the CO_2 emissions in Saudi Arabia coming from petroleum related products, this is certainly a first step in modelling the stochastic properties on emissions and growth. Secondly, the findings of this study will give some idea of whether economic growth is the cure for reduction in CO_2 emissions or will there be a point somewhere where the government will have to intervene on the expansionary path of Saudi Arabia. The government could put systems in place that penalises firms that pollute or give subsidies to organizations to have technology in place that captures or stores greenhouse gas emission (GHG).

1.1 The Pollution and Growth Debate

In the 1970s, studies focused on the pollution and growth nexus showed evidence that industrial activity was the main cause of pollution and encouraged the policy makers to have systems in place that would reduce the pollution levels for industrialized and developing countries. The view that pollution is an inexorable by-product of industrialization and that increasing material affluence will entail a decreasingly attractive world was challenged in the early 1990s. The view was considered increasingly pessimistic since it neglects the possibility of technological change, education, economic and political structure that might mitigate the environmental problems. Taking into account that with economic growth society could react and possibly restore environmental difficulties, Beckerman (1992) says that everything will work out in the end. We quote the following:

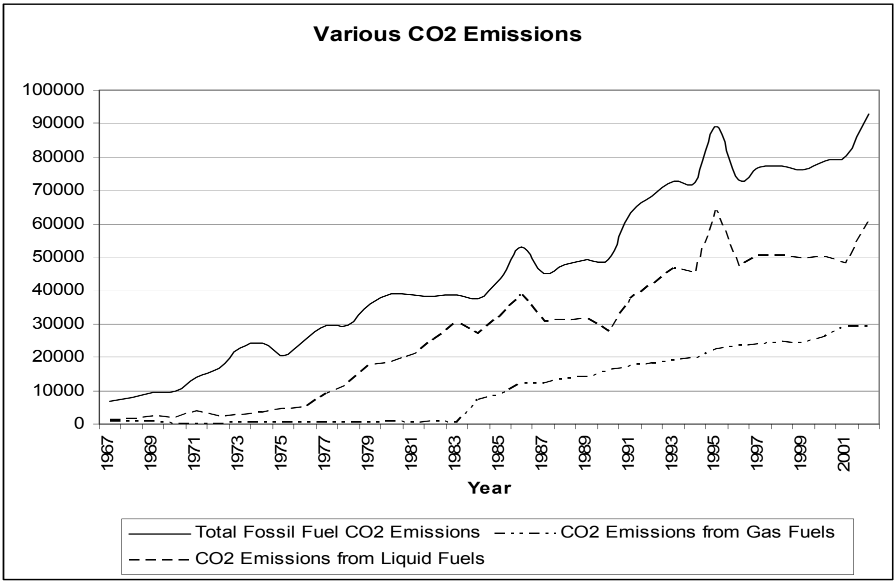
> "There is clear evidence that although economic growth leads to environmental degradation in the early stages of the process, in the end the best and probably the only way to attain a decent environment in most countries is to become rich".

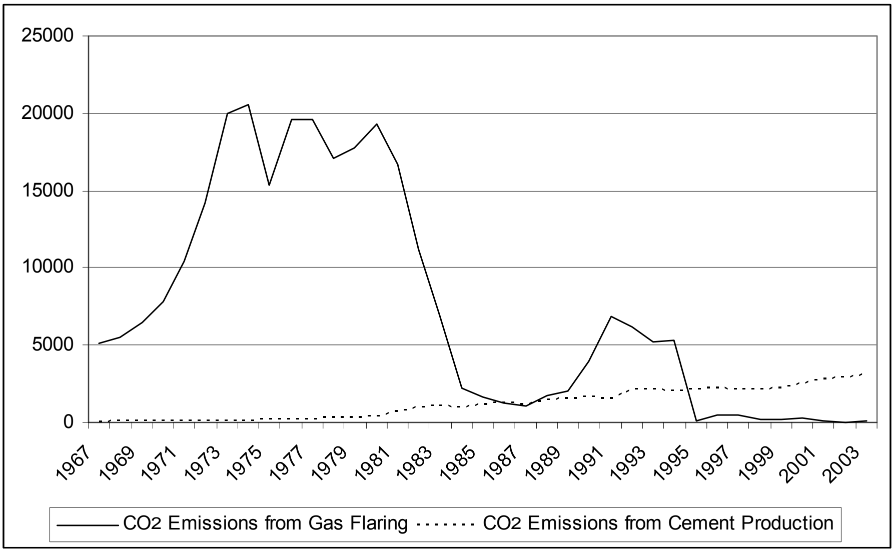
There is visual evidence from this statement for countries like Singapore who have paid a great deal of attention to pollution levels as they have become rich since the 1970s.

Saudi Arabia had low growth rates from the 1980s to the late 1990s and with 90% of exports made of crude oil, the fluctuation of oil prices tend to weigh in on the government revenues. With the uncertainty in the oil price, the Saudi Arabia government had to take cautious approach when planning on projects relating to the environmental concerns. Saudi Arabia had a budget deficit for almost 2 decades since the 1980s and it is only in 2004 that higher oil prices contributed to a budget surplus. The continuation of higher oil prices has given Saudi Arabia the means to address the environmental degradation issue at large and the move forward in implementing CDM is much welcomed. The stage is now set to invest in technologies that will reduce emission levels without the need to reduce growth.

1.2 CO_2 Emissions from Fossil Fuels

Saudi Arabia ranked nineteenth among nations based on 2003 fossil-fuel CO_2 emissions with 83 million metric tons of carbon. Saudi Arabia is the world's second largest oil producer. In 2002 Saudi Arabia ranked sixteenth in the world for CO_2 emissions, so a jump up by three places is most welcoming news indeed. Even though Saudi Arabia is the world's largest exporter of oil, not surprisingly consumption of petroleum products represents the bulk of the country's fossil-fuel CO_2 emissions (65.6% in 2002 and 59% in 2003). Use of natural gas has become increasingly important since the mid 1980s and now accounts for 31.3% of total fossil fuel CO_2 emissions. We have seen an increase in gas production since 2002, and in 2003 CO_2 emissions from gas increased from 31.3% to 37.1%. The striking feature of the time series for Saudi Arabia is the emissions resulting from flaring gas in the oil fields. In 1974, gas flaring accounted for 85% of Saudi Arabia's fossil-fuel emissions. As new technologies were incorporated into the oil fields and it became possible to refine or reinject these gases, CO_2 emissions from gas flaring fell sharply and now account for less than 1% of total emissions. *Per capita* emissions have grown ten-fold since 1950; at 3.64 metric tons of carbon per person, they are well above the global average. Saudi Arabia has no coal production and it is neither a producer nor a consumer of coal, so our total CO_2 emissions are comprised of only two fossil fuels, petroleum and gas products. The following diagram shows three different sources of CO_2 emissions for Saudi Arabia.





The Middle East composed of 15 nations may contribute a large fraction of the world's oil production but through their own energy consumption produce only 5.7% of global CO_2 emissions from fossil fuels and cement. The Middle East, due to the CO_2 emitted during the Kuwaiti oil field fires, exhibited a dramatic singularity of CO_2

emissions for 1991. The 1991 Kuwaiti oil field fires resulted in 130 million metric tons of carbon being emitted to the atmosphere, more than the 2002 total fossil-fuel CO_2 emissions of the 9th largest national emitter, South Korea. The three major fuel consumers discharge 68% of the region's CO_2: Iran, 98.1 million metric tons of carbon in 2002; Saudi Arabia, 92.8 million metric tons of carbon; and Turkey, 56.7 million metric tons of carbon. Gas flaring has been a major source of regional emissions, and in a few years during the early 1970s, before infrastructure was available for gas use and re-injection, flaring accounted for almost half of the total fossil-fuel CO_2 emissions. Growth has been nearly continuous since 1950, although it started from a very low base. *Per capita* emissions underwent rapid growth until 1973, changed little during the late 1970s and 1980s, and have grown during the 1990s to exceed the global average. Qatar has the second highest national *per capita* CO_2 emission rate in the world for 2002, 16.53 metric tons of carbon per person.

Given the above background of the growing CO_2 emissions, this study is aimed at investigating the relation between CO_2 emissions and income within the theoretical framework given by the Environmental Kuznets Curve (EKC). Saudi Arabia is taken as a case study.

2. Literature Review

Evidence in supporting the EKC hypothesis is well documented by Shafiq and Bandyopadhyay (1992) and also Shafik (1994) in a panel study. The other literature is well documented in Selden and Song (1994), Holtz-Eakin and Selden (1995), Tucker (1995), Sengupta (1996), Roberts and Grimes (1997), Panayotou (1997), Shmalensee *et al*. (1998), Galeotti and Lanza (1999), Agras and Chapman (1999), Auffhammer *et al*. (2000), Neumayer (2002), and Shi (2003). There is an excellent survey paper on the Environmental Kuznets Curve hypothesis (Dinda, 2004).

Grossman and Krueger (1991) were the first to posit a relationship between environmental quality and *per capita* income. They argue that as economic development proceeds, increasingly intensive and extensive economic activity initially leads to a sullying of the environment. Later, at higher income levels, changes in the composition and techniques of production may be strong enough to offset the greater level of economic activity, leading eventually to an improvement in environmental quality. This would imply that countries might be able to outgrow environmental problems Holtz- Eakin and Selden (1995).

Grossman and Krueger (1991) found that for a number of types of urban air pollution, concentrations first rise with *per capita* income, then fall. In subsequent work, this finding of an inverted U-shaped relationship became known as the Environmental Kuznets Curve (EKC)[1]. In the analysis of Grossman and Krueger (1991), in general the 'turning points' occurred around $5,000 for most air pollutants[2]. While there was some evidence of a second turning point (which would make the relationship more of an N shape than an inverted U-shape), Grossman and Krueger (1991) considered it not to be especially compelling.

Very quickly, a large literature emerged that supported the EKC hypothesis. Hettige *et al*. (1992) found evidence of an EKC using data on toxic intensity of industrial production. Selden and Song (1994) showed similar results for four measures of national air quality, with turning points in the neighborhood of $10,000. Shafik (1994) expanded the analysis to include other measures of environmental quality, including deforestation, various measures of water quality, and solid wastes *per capita* in addition to air quality indicators. He, too, found broad support for an EKC relationship, with turning points ranging from about $3,000 to about $6,000. For some measures, Shafik (1994) found evidence of an N-shaped relationship: the fecal coliform content of rivers increases until *per capita* income levels of about $1,375 are reached, then declines up to $11,400, after which it rises again. List and Gallet (1999) find both inverted U-shaped and N-shaped curves for cross sectional state pollution data in the U.S. Wang *et al*. (1998) find an inverted U-shaped curve for hazardous waste sites in the U.S. Like Shafik (1994), Cropper and Griffiths (1994) reported an EKC relationship with respect to deforestation. Grossman and Krueger (1995) updated their earlier work to include many different measures of air and water quality. Once again, for most pollutants there seemed to be either an inverted U-shaped or an N-shaped relationship with *per capita* income, with lower turning points around $8,000. Hilton and Levinson (1998) found evidence of an inverted U-shaped curve for automotive lead emissions for a

[1] Simon Kuznets did not himself work in this area. The EKC relationship invokes his name because Kuznets (1955) found a similar shape for the relationship between income inequality and *per capita* income.

[2] Except where noted otherwise, researchers have used PPP-adjusted income figures (in 1985 international dollars) from Summers and Heston (1991).

panel data set across countries. Torras and Boyce (1998) controlled for political rights, literacy, and income inequality in their study. For most measures, an N-shaped relationship was found to exist with peaks in the range of \$3,000 to \$11,000 and troughs generally around \$15,000.

Early work in this literature was very cautious about the policy implications of such findings. For example, Shafik (1994, p. 770) stated:

> "The evidence suggests that it is possible to 'grow out' of some environmental problems. But there is not necessarily anything automatic about this – in most countries, environmental improvement has required policies and investments to be put into place to reduce degradation".

In a similar vein, Grossman and Krueger (1995, p. 372) noted

> "... that there is nothing inevitable about the relationships that have been observed in the past".

As a result, several critiques of the EKC literature emerged, followed by several empirical studies that called into question the existence of an EKC relationship. Arrow *et al*. (1995) pointed out that while earlier studies may indicate a correlation between economic growth and improvements in certain environmental indicators, there is no indication of a causal relationship. Arrow *et al*. (1995) also noted that earlier work had not considered system-wide effects, and had thus ignored the possibility that environmental degradation is simply being transferred to middle-income countries. That is, the EKC result may be obtained when using cross-sectional data because the poorest countries mainly import their manufactures and so tend to not heavily pollute. At the same time the wealthier countries tend to import the 'dirtier' industrial products from middle income economies, thereby lowering the local environmental impact. Stern *et al*. (1996) and de Bruyn *et al*. (1998) made similar critiques of the EKC literature and also raised some econometric concerns about the earlier literature. Ekins (1997) and Munasinghe (1999) argued that only determined environmental policy can make future economic growth environmentally sustainable.

A number of empirical works called into question the results of the earlier literature. Several, including Suri and Chapman (1998) and Rothman (1998) take international trade into account. When such factors are considered, the turning points rise to very high levels (approximately \$50,000 per person); this effectively means there is no EKC relationship. Using a chaos theory argument, Unruh and

Moomaw (1998) found that CO_2 turning points were reached not because countries hit an income threshold but because of a common historical event (e.g., oil price shocks). Given that such future shocks cannot be anticipated, the authors conclude that it would not be reasonable to count on environmental problems taking care of themselves as economic development proceeds.

3. Theoretical underpinnings

The EKC concept attracted attention in the early 1990s with the seminal study of Grossman and Krueger (1991) on the possible impacts of NAFTA and also with the background study of Shafik and Bandyopadhyay (1992) for the World Development Report (1992). According to the EKC hypothesis, if there is no change in the economic structure (such as, the output mix or input mix) or in the state of technology, then mere growth in the scale of the economy i.e., growth in national income, would result in a proportional growth in pollution. This is known as the 'scale effect'. The traditional view that economic growth and environmental quality are not compatible reflects the 'scale effect' alone. In other words, the traditional view is based on the static assumptions of economic structure and state of technology. However,

> "at higher levels of development, structural change towards information-intensive industries and services, coupled with increased environmental awareness, enforcement of environmental regulations, better technology and higher environmental expenditures, result in levelling off and gradual decline of environmental degradation" (Panayotou, 1993).

In other words, at the higher stage of development the 'scale effect' of increased pollution is likely be more than offset by the 'pollution-reducing time effects'. That explains the inverted U shape of EKC.

The inverted U shape of EKC is a simple relationship between only two variables (i.e., the *per capita* emissions and *per capita* income) and is based on the assumptions that all other factors remain constant. The EKC implicitly assumes that there are no interactions among the variables over time and that CO_2 is the endogenous (or dependent) variable and the variables representing income are exogenous (or independent). We test the EKC by postulating the following relationship between CO_2 *per capita* and income *per capita*:

$$\ln(E/P) = \alpha + \beta\ln(GDP/P) + \delta\ln(GDP/P)^2 + \gamma\ln(GDP/P)^3 + \varepsilon_t \quad (1)$$

(i) $\beta=\delta=\gamma=0$. A flat pattern or no relationship between the dependent and independent variables.
(ii) $\beta>0$ and $\delta=\gamma=0$. A monotonic increasing relationship or a linear relationship between the variables.
(iii) $\beta<0$ and $\delta=\gamma=0$. A monotonic decreasing relationship between the variables.
(iv) $\beta>0, \delta<0$ and $\gamma=0$. An inverted U-shaped relationship, i.e., EKC.
(v) $\beta<0, \delta>0$ and $\gamma=0$. A U-shaped relationship.
(vi) $\beta>0, \delta<0$ and $\gamma>0$. A cubic polynomial or N-shaped figure.
(vii) $\beta<0, \delta>0$ and $\gamma<0$. Opposite to the N-shaped curve.

4. The methodology used

Mostly cross-sectional or pooled cross-section timeseries approaches have been adopted to test the Environmental Kuznets Curve's inverted U-shape hypothesis (Dinda, 2004; Stern, 1998). The cross-sectional approach has major shortcomings in testing any relationship. Firstly, they are not appropriate in capturing the dynamics of the variables involved. Secondly, a major assumption of the cross-sectional studies is that the slope parameters are homogeneous or equal across units/countries (Perman and Stern, 2003). This assumption is not realistic in the context of developing countries with different institutions, structures, and stages of development. Finally, it is difficult to draw any policy conclusions on a particular country on the basis of results of a group of countries. Moreover, in the case of pooled cross section-timeseries, the data in the time-series dimension are likely to be non-stationary and require estimation methods which will take care of the non-stationary nature.

The time-series studies of individual countries over time are more appropriate for testing the relationship between variables (Dinda, 2004; Friedl and Getzner, 2003). In time-series studies, however, the traditional regression approach has been mostly applied in environmental studies. The application of the traditional regression methodology in time-series data has the following major limitations.

It has, by now, become almost a standard procedure (helped by easy access to standard software packages) that any regression analysis should start off, not mechanically, but by testing the stationarity and cointegration properties of the time series involved. It is, by now, well established that most economic time series are non-stationary in their original level form. If the variables are non-stationary, the conventional statistical tests (such as R^2, t, etc.) are not valid.

If the variables are non-stationary but cointegrated, the ordinary regression without the error-correction term(s) derived from the cointegrating equation is mis-specified. However, if the variables are non-stationary but not cointegrated, then an ordinary regression with different variables (which will be stationary) can be estimated but the conclusions drawn from such an analysis will be valid only for the short run and no conclusions can be made about the (long run) theoretical relationship among the variables, since the theory has typically nothing to say about the short run relationship. This is due to the fact that the differenced time-series variables have no information about the long run relationship between the trend components of the original series since these have, by definition, been removed. The long run co-movement between the variables cannot be captured by differenced variables.

Hence on the one hand, if the variables taken are non-stationary at their original level forms, the conventional statistical tests are not valid because the variances of these variables are changing and the relationship estimated will be spurious. On the other hand, if the variables taken are turned stationary by first-differencing, the long-term information contained in the trend element in each variable has been, by definition, removed and the relationship estimated gives only the short run relationship between the variables and the regression does not test any theory.

Hence the regression analysis that has been applied for many decades in time-series studies is now considered to have either estimated a spurious relationship (if the original level form of the variables was non-stationary) or estimated a short-run relationship (if the variables were differenced to make the original variables stationary).

This damaging limitation of the traditional regression analysis (i.e., either spurious or not testing theory) has been addressed by the recent and ongoing cointegration time series techniques. The significant contributions made by the time series cointegration techniques starting with the publication of the seminal paper by Engle and Granger (1987) has been recognized through the recent award of the Nobel Prize in Economic Science to Engle and Granger in 2003 [for further details see Diebold (2003, 2004) and Granger (2003)].

The recent time-series studies based on cointegration have applied either vector error-correction and/or variance decomposition methods for testing the long run relationship among variables. Although these time series techniques are an improvement on the cross-sectional studies and the traditional regression approach in testing relationship over time, one of the major limitations of error-correction/variance decompositions methods is that they are based on the estimates of the cointegrating vectors which are atheoretical in nature. The most recently developed 'Long run structural modelling' (LRSM) technique (Pesaran and Shin, 2002) takes care of that major limitation of the conventional cointegrating estimates.

LRSM endeavours to estimate theoretically meaningful long-run (or cointegrating) relations by imposing on those long-run relations (and then testing) both identifying and over-identifying restrictions based on theories and *apriori* information of the economies. For testing each restriction the results are presented in tables and one should check the LR statistic in each case whether the null of restrictions should be rejected or accepted.

Hence to test the relationship between CO_2 and income over time we would apply the following most recent procedures based on Long run structural modelling (LRSM).

After examining the unit root tests and the order of the VAR, the Johansen cointegration tests will be applied. The test of cointegration is designed to examine the long run theoretical or equilibrium relationship and to rule out spurious relationship among the variables. The cointegrating estimated vectors will then be subjected to exactly identifying and overidentifying restrictions based on theoretical and *apriori* information of the economy. The evidence of cointegration, however, cannot tell us the direction of Granger-causality among the variables, i.e., which variable is leading and which variable is lagging. That can be done by the test of vector error-correction model (VECM) that can indicate the direction of Granger-causality both in the short and long run. The VECM, however, cannot tell us which variable is relatively more exogenous or endogenous. The variance decomposition (VDC) technique is designed to indicate the relative exogeneity/endogeneity of a variable by decomposing (or partitioning) the variance of the forecast error of a variable into proportions attributable to shocks (or innovations) in each variable in the system including its own. The proportion of the variance explained by its own past shocks can determine the relative exogeneity/endogeneity of a variable. The variable that is explained mostly by its own shocks (and not by others) is deemed to be the most exogenous of all. If required, the variance decompositions can also be equivalently represented by the impulse response functions. They are designed to map out the dynamic response path of a variable due to a one-period standard deviation shock to another variable. The IRF is a graphical way of exposing the relative exogeneity or endogeneity of a variable. Finally, one could find out the persistence profiles. They are designed to estimate the speed with which the variables get back to equilibrium when there is a system-wide shock to the long run equilibrium (unlike the IRF which traces out the effects of a variable-specific shock on the long run relationship).

5. Data, empirical results and discussions

The data used in our study is annual and spans from 1975 to 2003. The CO_2 emission data is from the Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory in Oak Ridge, Tennessee[3]. Our GDP and population data are from the Datastream. Although the data on CO_2 emission span back to late 1930s, our population and GDP data are only available from 1975.

The variables taken to test the EKC are CO_2 *per capita* (CO2PCSI), GDP *per capita* (GDPCAPSI), GDP *per capita* squared (SGDPCAPSI), and GDP *per capita* cubed, (CGDPCAPSI). All the variables are transformed into logarithms to achieve stationarity in variance.

We tested the unit roots of all the variables and found that they could be taken as I(1) on the basis of ADF and PP tests. We also found that the optimal order of the VAR could be taken as three on the basis of AIC and SBC criteria. We applied the standard Johansen cointegration test (Table 1) and found them to have one cointegrating vector at 95% significance level on the basis of maximal eigen value and trace statistics. An evidence of cointegration implies that the relationship among the variables is not spurious, i.e., there is a theoretical relationship among the variables and that they are in equilibrium in the long run. However, in order to make the coefficients of the cointegrating vector consistent with the theoretical and *apriori* information of the economy, we applied the 'long run structural modelling' procedure. Since the number of the cointegrating relationship is one, we imposed an exact identifying restriction of unity on the coefficient of CO_2 (Table 2,

[3] http://cdiac.ornl.gov/ftp/trends/emissions/sau.dat.

Panel A). If the relationship is written in an equation form (with the CO_2 variable as the dependent variable), all coefficients of the cointegrating vector appear to be significant at 1% probability level. GDP *per capita* will have the positive sign, GDP *per capita* squared will have the negative sign and GDP *per capita* cubed will have a positive sign. That implies that the EKC curve initially demonstrates a positive relationship between CO_2 and *per capita* income, followed by a negative relation, but finally a positive relationship again. In other words, the EKC curve appears to be of cubic 'N-shape' (rather than of 'inverted U-shape'). It implies that a policy of increasing *per capita* income is not going to reduce CO_2 *per capita*. There is need for a pro-active Government policy to reduce CO_2 emissions.

TABLE 1 - *Johansen ML Results for Multiple Cointegrating Vectors – CO_2 per capita, GDP per capita, GDP per capita Squared and GDP per capita Cubed (1975-2003)*

H_0	H_1	Statistic	95% Crit	90% Crit
Maximum Eigen value Statistics				
$r = 0$	$r >= 1$	38.95	31.79	29.13
$r <= 1$	$r >= 2$	19.66	25.42	23.10
Trace Statistic				
$r = 0$	$r >= 1$	74.30	63.00	59.16
$r <= 1$	$r >= 2$	35.35	42.34	39.34

The underlying VAR model is of order 3 and is computed using 29 annual observations.

Note: The statistics refer to Johansen's log-likelihood maximal eigenvalue and trace statistics based on cointegration with unrestricted intercepts and restricted trends in the VAR. From the above results, we select one cointegrating vector based on both the eigenvalue and trace statistics.

In order to test whether the curve is inverted U-shaped or cubic N-shaped, we imposed an over-identifying restriction of zero on the coefficient of GDP *per capita* cubed but the zero restriction was strongly rejected by the chi-square statistic (Table 2, Panel B). That implies that the traditional 'inverted U-shaped EKC' does not hold in the context of Saudi Arabia at least during the period under review. The curve appears to be of cubic N-shaped.

Cointegration, however, cannot tell us the direction of Granger-causality between the variables as to which variable is leading and

TABLE 2 - *Exact and Over Identifying Restrictions on the Cointegrating Vector*

	Panel A	Panel B
CO_2PCSI	1.00 (*None*)	1.000 (*None*)
GDPCAPSI	-460.36* (126.61)	-28.06 (20.17)
SGDPCAPSI	308.21* (85.34)	9.42 (6.82)
CGDPCAPSI	-68.41** (19.07)	0.000 (*None*)
Trend	0.000 (0.001)	0.010 (0.009)
Log Likelihood	322.91	317.05
Chi-Square	None	11.708 [0.001]

The output above shows the maximum likelihood estimates subject to exactly identifying (Panel A) and over identifying (Panel B) restrictions. The 'Panel A' estimates show that all the variables are significant (standard errors are in parentheses). * Indicates significance between 5% and 1% and ** indicates significance at 1% level or less. All the coefficients have the correct signs. However, the over-identifying restriction on GDP *per capita* cubed equal to zero is rejected (with a p-value of only 0.001 error while rejecting the null) and as a result we proceed with 'Panel A' for the remainder of the paper.

which variable is lagging (i.e., which variable is exogenous and which variable is endogenous). For discerning the endogeneity/exogeneity of the variables, we applied the vector error-correction modelling technique (Table 3).

Looking at the significance or otherwise at the coefficient of the error-correction term we find that the CO_2 variable is the only endogenous variable, whereas all the income variables are exogenous. That tends to indicate that the CO_2 variable responds to the income variable. The error-correction term in the CO_2 equation is significant. It implies that the deviation of the variables (represented by the error-correction term) has a significant feedback effect on the CO_2 variable that bears the burden of short-run adjustments to bring about the long-term equilibrium. The error-correction model also helps us to distinguish between the short term and long term Granger-causality. The error-correction term stands for the long-term relations among the variables. The impact of each variable in the short term is given by the 'F' tests of the joint significance or insignificance of the lags of each of the differenced variables. The speed of short-run adjustment to bring about the long term equilibrium is given by the coefficient of the error-correction term. The results tend to indicate that if the long term equilibrium between the variables is disturbed by any shocks, it will take about two years and a half to restore the equilibrium.

TABLE 3 - *Error Correction Models – CO_2 per capita, GDP per capita, GDP per capita Squared and GDP per capita Cubed, Assuming One Cointegrating Vector*

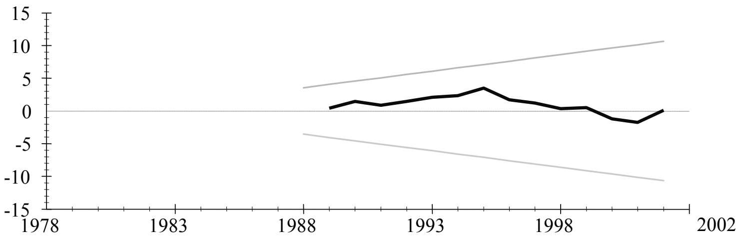
Dependent Variables	*CO_2PCSI*	*GDPCAPSI*	*SGDPCAPSI*	*CGDPCAPSI*
DCO_2PCS (-1)	-0.380* (0.291)	0.374 (0.441)	1.133 (1.333)	2.584 (3.041)
DGDPCAPSI(-1)	-80.396 (60.320)	34.338 (91.419)	45.762 (276.192)	-20.025 (630.042)
DSGDPCAPSI(-1)	54.462 (40.296)	-21.775 (61.071)	-27.475 (184.506)	19.5011 (420.890)
DCGDPCAPSI(-1)	-12.176 (8.922)	4.654 (13.522)	5.682 (40.853)	-5.001 (93.193)
DCO_2PCS (-2)	-0.344 (0.236)	0.393 (0.357)	1.055 (1.080)	2.106 (2.462)
DGDPCAPSI(-2)	-42.602 (51.931)	-5.309 (78.705)	-47.752 (237.778)	-176.684 (542.417)
DSGDPCAPSI(-2)	28.535 (34.211)	3.549 (51.850)	32.103 (156.647)	118.998 (357.339)
DCGDPCAPSI(-2)	-6.355 (7.481)	-0.835 (11.338)	-7.316 (34.255)	-26.969 (78.141)
ECM(-1)	-0.411* (0.195)	0.103 (0.296)	0.157 (0.893)	0.041 (2.037)
Chi-sq SC(1)	0.258 [0.612]	0.085 [0.771]	0.040 [0.841]	0.013 [0.908]
Chi-sq FF(1)	0.001 [0.974]	2.163 [0.141]	1.539 [0.215]	1.055 [0.304]
Chi-sq N(2)	0.266 [0.876]	11.429 [0.003]	11.678 [0.003]	11.551 [0.003]
Chi-sq Het(1)	0.401 [0.527]	0.152 [0.696]	0.116 [0.733]	0.076 [0.783]

Standard errors are given in parentheses. * Indicates significance at the 5% level or less. The diagnostics are chi-squared statistics for: serial correlation (SC), functional form (FF), normality (N) and heteroskedasticity (Het) and indicate that the equations are well specified. In the case of 'diagnostics', 'p' values are in parentheses.

The diagnostics of all the equations of the error-correction model (testing for the presence of serial correlation, functional form, normality, and heteroscedasticity) tend to indicate that the equations are well-specified. We also checked the stability of the coefficients of the CO_2 equation by the CUSUM and CUSUM SQUARE tests (Figure 1) which indicate that they are stable.

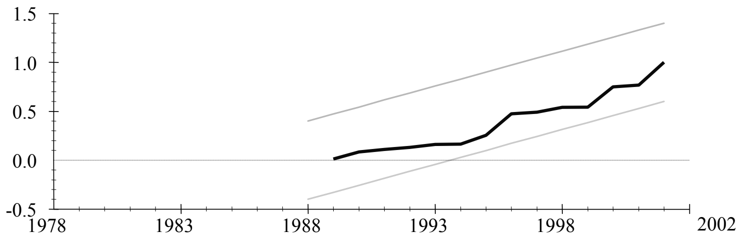
FIGURE 1 - *CUSUM / CUSUMSQ for CO_2 per capita as Dependent Variable in VECM*

Plot of Cumulative Sum of Recursive Residuals



The straight lines represent critical bounds at 5% significance level

Plot of Cumulative Sum of Squares of Recursive Residuals



The straight lines represent critical bounds at 5% significance level

The stability of the coefficients of the function is tested and the function appears to be stable since the residuals fall within the upper and lower bounds.

Although the error-correction model tends to indicate the endogeneity/exogeneity of a variable, we had to apply the generalized variance decomposition technique (Table 4) to discern the relative degree of endogeneity or exogeneity of the variables. The relative exogeneity or endogeneity of a variable can be determined by the proportion of the variance explained by its own past. The variable

TABLE 4 - *Generalized Variance Decompositions*

		Percentage of Forecast Variance Explained by Innovations in:			
		ΔCO_2PCSI	$\Delta GDPCAPSI$	$\Delta SGDPCAPSI$	$\Delta CGDPCAPSI$
Years	Relative Variance in ΔCO_2PCSI				
1		60.84	11.76	13.02	14.39
3		50.85	15.46	16.37	17.32
5		46.48	17.25	17.84	18.43
10		39.28	19.65	20.25	20.82
15		37.88	20.15	20.72	21.24
	Relative Variance in $\Delta GDPCAPSI$				
1		3.77	32.17	32.13	31.93
3		5.63	31.62	31.51	31.25
5		6.41	31.39	31.25	30.95
10		6.81	31.27	31.11	30.81
15		6.97	31.22	31.06	30.75
	Relative Variance in $\Delta SGDPCAPSI$				
1		4.01	31.96	32.05	31.98
3		5.67	31.49	31.49	31.35
5		6.45	31.28	31.23	31.04
10		6.86	31.16	31.10	30.89
15		7.02	31.12	31.04	30.82
	Relative Variance in $\Delta CGDPCAPSI$				
1		4.27	31.75	31.96	32.02
3		5.73	31.35	31.47	31.44
5		6.50	31.16	31.21	31.12
10		6.91	31.05	31.08	30.96
15		7.08	31.01	31.02	30.88

Generalized variance decompositions indicate the relative endogeneity or exogeneity of the variables. Figures in the first column refer to horizons (i.e., number of years). The above analysis indicates, for example, at the end of the forecast horizon number 10, about 39% of the forecast error variance of CO_2 is explained by its own shocks and the remaining 61% is explained by all the income variables taken together. But in the case of the income variables, only about 6% of the variance of each income variable is explained by the variance of CO_2 variable. That tends to further strengthen the earlier results of error-correction model that CO_2 variable is mostly income-driven and not the other way around.

which is explained mostly by its own shocks (and not by others) is deemed to be the most exogenous of all. In our table, at the end of the forecast horizon number 10, we find that 39% of the forecast error variance of CO_2 is explained by its own shocks and the remaining 61% is explained by all the income variables taken together. But in the case of the income variables, only about 6% of the variance of each income variable is explained by the variance of CO_2 variable. That tends to indicate that it is the CO_2 variable that is driven by the income variables and not the other way around.

These out-of-sample variance forecast results given by the generalized variance decompositions further strengthen our earlier within-sample results given by the error-correction model that the CO_2 variable lags (rather than leads) the income variables.

Both techniques tend to indicate that the income variable is relatively more exogenous or leading and the CO_2 relatively more endogenous or follower.

6. Conclusions and policy implications

This study is motivated by the recent heightened world concern over global warming pollution. It is an initial attempt in the context of Saudi Arabia to test the Environmental Kuznets Curve (EKC) which postulates that the curve relating the environmental pollution (say, CO_2 emission) and income on a *per capita* basis is of inverted U-shape. If this hypothesis is tested to be valid, there is no need for any direct intervention by the Government to reduce the pollution level since the growth in *per capita* income would automatically take care of that problem.

In contrast to the above, our study, based on a recently developed rigorous time series technique known as the Long run structural modelling (LRSM) (Pesaran and Shin, 2002), tends to indicate that at least in the context of Saudi Arabia during the period under review, the EKC possesses a cubic-N shape. This implies that although increasing *per capita* income may indeed be associated with decreasing *per capita* CO_2 emission for a certain period, in the long run the trend will reverse and it will again be associated with increasing *per capita* CO_2 emission. This empirical finding of our study has a significant policy implication in that increases in *per capita* income alone are not enough to reduce *per capita* CO_2 emission, but should be supported by a proactive industrial/technological policy that tackles related causes and also, since CO_2 emission is evidenced to be income-driven, policies should be focused on environment-friendly GDP growth. Moreover, not only the production of GDP but also the consumption of GDP, in particular the tastes and preferences of high-income individuals need to be environment-friendly, since the curve is found to be N-shaped.

According to Hecksher-Ohlin trade theory, under free trade, developing countries would have a comparative advantage to specialize in the production of those goods that are intensive in the factors they are mostly endowed with. Since Saudi Arabia would have a comparative advantage in energy-intensive industries, the CO_2 emission stemming from the energy-intensive industries is likely to have an increasing trend unless the Government policies are pro-active in containing the emission level by resorting to environmental regulations and technological innovations. Through proper policy measures, such as, input mix, and output mix, the scale effects of pollution could be reduced (Stern, 2004; Auci and Becchetti, 2006). The Clean Development Mechanism (CDM), emissions trading, carbon capture and storage in which CO_2 is removed from petroleum and then injected into empty oil fields to enhance oil recovery; can play a useful role in reducing emissions. A well planned policy of emissions-reducing technological change (or the time effect) could outweigh the scale effect of rising income *per capita* on emissions (Stern, 2004; Perman and Stern, 2003). Dasgupta *et al*. (2002) give evidence that the environmental improvements are quite possible in the developing countries and there is also evidence that the peak levels of environmental degradation could be lower than that experienced in the developed countries in the past. Much of Dasgupta *et al*.'s evidence is based on China. There is also evidence that China reduced sulfur emissions and even carbon emissions over the recent years (Diesendorf, 2003). China is also adopting European Union standards for pollution emissions from cars with about 8/10-year lag (Gallagher, 2003). These are only some of the lessons that are worth considering by other developing countries, such as, Saudi Arabia.

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ABSTRACT

This study examines the relationship between income and CO_2 emission on a *per capita* basis in Saudi Arabia during 1975-2003. It is motivated by the recent heightened world concern over global warming pollution which resulted in the formulation of the Kyoto protocol and its rapid ratification by a majority of countries in the late 1990s. There have been many attempts to explain the increase in *per capita* CO_2 emission by relating it to *per capita* income growth in a country via the 'Environmental Kuznets Curve' (EKC). The curve is named after Kuznets (1955) who hypothesized that income inequality in a country first rises and then falls as economic growth progresses. The EKC is usually postulated to have an inverted-U shape, which means that *per capita* income growth is initially associated with an increase in *per capita* CO_2 emission. However, beyond a certain point, the relationship reverses and further *per capita* income growth is associated with a decrease in *per capita* CO_2 emission. The practical implication of an EKC with inverted-U shape is that a continued increase of *per capita* income alone would ultimately reduce *per capita* CO_2 emission, thus obviating the need for proactive political intervention.

In contrast to the above, our study, based on a recently developed rigorous time series technique known as the Long Run Structural MODELLING (LRSM) (Pesaran and Shin, *Econometric Reviews*, 2002), indicates that at least in the context of Saudi Arabia (1975-2003) the EKC possesses a cubic-N shape. This implies that although increasing *per capita* income may indeed be associated with decreasing *per capita* CO_2 emission for a certain period, in the long run the trend will reverse and it will again be associated with increasing *per capita* CO_2 emission. This empirical finding of our study has a significant policy implication in that increases in *per capita* income alone are not enough to reduce *per capita* CO_2 emission, but should be supported by a proactive industrial/technological policy that tackles related causes and also, since CO_2 emission is evidenced to be mainly income-driven, policies should be focused on environment-friendly GDP growth. Moreover, not only the production but also the consumption of GDP, in particular the tastes and preferences of high-income individuals need to be environment-friendly. These findings have profound policy implications for both the developing and the developed economies of the world.

Keywords: Environmental Kuznets Curve, Long Run Structural Modelling

JEL Classification: C22, Q56

RIASSUNTO

La Curva di Kuznets esiste? Un'applicazione LRSM al caso dell'Arabia Saudita

Questo studio esamina la relazione tra reddito procapite ed emissioni di CO_2 in Arabia Saudita nel periodo 1975-2003. La scelta di questo argomento è dovuta all'aumentato interesse mondiale circa l'inquinamento causato dal riscaldamento globale e tradotto nell'impegno assunto con la sottoscrizione del Protocollo di Kyoto alla fine degli anni '90. Si è tentato più volte di spiegare l'incremento delle emissioni procapite di CO_2 mettendole in relazione con l'aumento del reddito di un paese, così come indicato dalla 'Curva ambientale di Kuznets' (EKC). Generalmente la curva di Kuznets viene rappresentata con una U inversa, il che significa che la crescita del reddito procapite è inizialmente associata ad un incremento delle emissioni procapite di CO_2. Oltre un certo livello però, la relazione si inverte ed ulteriori aumenti del reddito procapite sono associati a diminuzioni delle emissioni di CO_2. Quindi, secondo le implicazioni pratiche della curva di Kuznets a U inversa, la continua crescita del solo reddito procapite porta in ultima istanza ad una diminuzione delle emissioni procapite di CO_2, evitando in tal modo la necessità di interventi politici preventivi.

Contrariamente a quanto sopra esposto, questo studio, che si basa su un modello *time series* formulato di recente da Pesaran e Shin (2002) e conosciuto con il nome di Long Run Structural Modelling (LRSM), indica che almeno per quanto riguarda l'Arabia Saudita nel periodo 1975-2003 la curva di Kuznets ha un andamento diverso. Sebbene un aumento del reddito procapite può essere associato, per un certo periodo, ad una diminuzione delle emissioni procapite di CO_2, nel lungo periodo la tendenza si invertirà e tale aumento nel reddito sarà di nuovo associato ad un aumento nelle emissioni di CO_2. Questo risultato ha importanti implicazioni politiche in quanto gli incrementi del reddito procapite da soli non sono sufficienti a ridurre le emissioni di CO_2, ma devono essere affiancati da politiche industriali e tecnologiche preventive che affrontino le cause del problema e, posto che le emissioni sono trainate dal reddito, da decisioni mirate ad una crescita del PIL sostenibile dal punto di vista ambientale. Inoltre non solo la produzione ma anche i consumi (specialmente i gusti e le preferenze di persone con alto reddito) devono essere sostenibili.

Queste conclusioni rivestono notevole importanza sia per le economie in via di sviluppo che per quelle sviluppate.