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Revisiting the Environmental Kuznets Curve: A New Evidence on the Relationship Between Marine Degradation and Global Economic Activities

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Abstract

Oceans and seas have an important impact on economic growth, environmental sustainability, and human wellbeing. Unfortunately, marine ecosystem services are exploited due to marine degradation, such as plastic pollution, ocean acidification, and dumping of industrial chemical but it is most and severely affected by oil spills. The current study attempts to check the validation of Environmental Kuznets Curve Hypothesis for global marine degradation by using time series econometrics techniques with structural breaks. The world level data time series data on oil spillage, oil consumption and GDP per capita is used, covering the time period of 50 years from 1970 to 2019. The results concluded that there is an existence of inverted U-shaped between marine degradation and global economic activities. The turning point has already appeared in the dataset, most probably, due to the shifting trend from non-renewable energy to renewable energy as well as various conventions and laws being introduced on the prevention of marine oil spillage.

Keywords: Environment Kuznets Curve, Crude oil consumption, Oil spillage, marine pollution, structural breaks, unit root

JEL: O44, Q5

Introduction

The recent concern of natural scientists as well as policy analysts, both at national and international level, is the sustainability of environment and perseverance of natural capital. Human consumption activities and industrial wastes are the main causes of environmental degradation. Long-term ecosystem protection requires intergenerational decisions that reduce pollution and promote renewable energy. The focus of past literature has always remained on global warming, dumping of industrial waste, air pollution and depletion of natural resources. The environmental degradation in term of marine pollution has

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been dealt with very scantly in the theoretical as well as empirical literature. United Nations Conference on Sustainable Development also highlights the importance of oceans and seas for sustainable development (Leggett and Carter 2012). The very first importance to marine ecosystem was initiated in 1992 under United Nations Conference on Environment and Development (UNCED); agenda 21 highlighted the importance of marine ecosystem services. The importance of marine ecosystems cannot be ignored as it plays an important role in carbon cycle by absorbing 30% of the carbon emission[1]. In addition, the global seafood industry contributed to $358.68 billion in 2023 which is projected to grow to $ 837.17 billion by the year 2032[2]. Thus, increasing marine degradation could possibly reduce the absorption capacity of carbon emissions as well as adversely affect the seafood industry. In addition, the natural capital from marine ecosystem provides inputs for various industrial applications.

Fisheries, mariculture, tourism, and recreational activities are an important source of livelihood and significantly contributes towards coastal economies. Regrettably, human activities and climate change has generated many types of pollution in the ocean, which has adversely affected marine ecosystem. The marine ecosystem services are exploited due to marine degradation resulting from plastic pollution, ocean acidification, and dumping of industrial wastes but it is most severely affected by oil spillage (Denchak 2018). This pollution has the most drastic impact which occurs through accidental spills during offshore drilling. The offshore drilling began in the early 1890s starting from shallow fresh water to deep salt waters during late 1930s. The offshore oil production is challenging due to remoteness, harsh environment, larger investment, and wastage as compared to land-based production.

Although oil spillage can occur through natural causes, anthropogenic causes have been the main reasons of oil spillage. Anthropogenic oil spill is encountered due to accidents which may occur during extraction and storage, handling and transfer operation, accidental rupture of transportation vessels and routine maintenance activities. Anthropogenic causes are directly linked with global economic activities and consumption of crude oil as it increases the direct demand for more oil production. It is not just the accidental spillage, but also the produced water and the drilling fluid discharged during well-drilling that adds a considerable amount of oil in maritime environment. Historically, there has been some major oil spills like diesel fuel spills in Baja California from Tampico Marui in 1957, oil discharge from Area Prima in Puerto Rico in 1962, oil spill in 1976 on Argo Merchant and Exxon Valdez in 1989.

Spillage of crude oil pollutes marine ecosystem as it comprises dangerous organic compounds, hydrocarbons, that are detrimental to life and the blue economy. The direct impact of oil spill on human health occurs through inhalation and emitted odors and declined sea food production. The indirect impact occurs through consumption of

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1 Rohr. T, Richardson, A. & Shadwick, E. (2023, June 15). Oceans absorb 30% of our emissions, driven by a huge carbon pump. Tiny marine animals are key to working out its climate impacts. The Conversation. Retrieved from https://theconversation.com/oceans-absorb-30-of-our-emissions-driven-by-a-huge-carbon-pump-tiny-marine-animals-are-key-to-working-out-its-climate-impacts-207219

2 Source: https://www.fortunebusinessinsights.com/industry-reports/seafood-market-101469

contaminated food, as well as negative effects on blue growth economy in terms of declined coastal livelihoods, declining marine property value and reduced coastal tourism (IPCC 2013). The global market value of marine and coastal resources adds up to the total value of $3 trillion per year. Moreover, 3 billion people depend upon marine ecosystem for their livelihoods.[3] Therefore, marine degradation is an important concern for environmentalists and environmental economists. Consequently, the impact of economic activities on marine degradation needs to be addressed which have been under the theoretical discourse on several international forums.

The Environmental Kuznets Curve (EKC) is a modern version of inverted-U hypothesis that studies the relationship between economic growth and environmental degradation. The framework was developed by Grossman and Krueger (1995). The EKC hypothesis is simple and instinctive which states that environmental degradation has a positive relationship with economic growth and after reaching a turning point the negative relationship tends to prevail. This declining trend could be attributed to technological change and diminishing returns as explained by the Green Solow model (Brock and Taylor 2010). Figure 1 provides a graphical illustration on the relationship between world oil spillage and world GDP per capita for actual figures and with backward forecasting. The graphs depict that there tends to exist an inverted-U shaped relationship between world oil spillage and world GDP per capita. In addition, from 1970's onwards the turning point has already started to appear, and the negative relationship is more pronounced at higher levels of world GDP per capita.

Many of the previous studies have empirically examined the EKC for air pollution (emission such as carbon dioxide, carbon monoxide, nitrogen oxide and sulfur dioxide) which is used as a proxy for environmental degradation (Bruyn and Bergh 1998; Shahbaz, Jalil and Dube 2010; Esteve and Tamarit 2012; Tiwari et al. 2013; Saboori and Sulaiman, 2013a, b; Tutulmaz 2015). The current study contributes to extant literature by considering marine pollution as an indicator of environmental degradation. The relationship

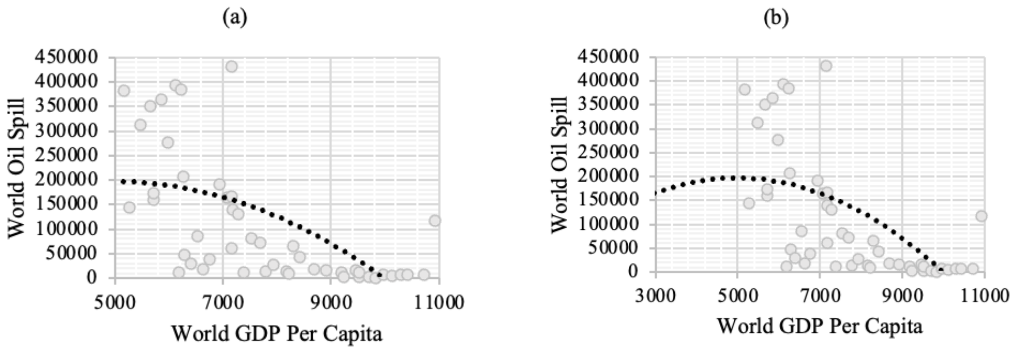


Figure 1. Graphical relationship between world oil spillage and GDP per capita, (a) actual figures between 1970-2019 and (b) with backward forecasting

Source: Author's compilation using data from WDI and ITOPF. The world GDP per capita is measured in constant US dollars and oil spill is measured in tonnes.

3 https://www.worldbank.org/en/topic/oceans-fisheries-and-coastal-economies

between environmental degradation and economic growth for global marine ecosystem is studied by taking oil spillage as an indicator of marine degradation. However, there are other indicators of marine degradation, such as ocean acidification, trash in the ocean and ocean noise, but there is limitation of data availability for these variables. The relationship is tested with global economic activities measured in terms of world GDP per capita and world crude oil consumption per capita. The world GDP per capita and marine degradation (oil spills) is expected to vary positively with each other because crude oil is not only a vital energy source but an important input for gasoline, diesel fuels, jet fuels, coal oil, lubricating oil and hydraulic oil used for industrial purposes. Therefore, increased global economic activities will be a demand-pull factor for more offshore drilling. The increased oil storage in underground tankers and its handing may cause crude oil to leak and drip in marine waters. Moreover, oil spillage is likely to increase during transportation to coastlines to cater for the increased demand for crude oil which may adversely affect the marine ecosystem. The environmental economists have developed a strong connection of a turning point in environment degradation at higher levels of economic growth in terms of EKC. Therefore, the current study re-examines the EKC hypothesis for marine degradation as the turning point in oil spillage is likely to occur due to technological progress and structural modification in energy consumption towards renewable energy sources. In addition, strict adherence to marine degradation laws is becoming more pronounced in recent times as every country is taking a strong stance for protection of global environment and green economic policy such as UNCED Agenda 21 and SDGs.

Literature Review

Literature on time series analysis

The Environmental Kuznets Curve (EKC) has been tested by existent literature on both time series and panel data. Bruyn and Bergh (1998) have used traditional model of EKC by using time series data set of four countries i.e. the Netherlands, West Germany, the UK, and the USA. A strong correlation between environmental indicators i.e., CO_2 emission, Nitrous Oxide, SO_2 and economic growth was found, mainly due to structural and technological change in the economy. Shahbaz et al. (2010) studied energy consumption, urbanization and trade openness under the time series framework for Portugal and found the long run as well as the short run relationship between income and CO_2 emission, but trade openness showed insignificant result. Using the same variables except urbanization, Shahbaz et al. (2012) investigated the existence of nonlinear relationship for Pakistan. Furthermore, unidirectional causality was found between economic growth and CO_2. Moreover, trade openness showed a significant negative impact on CO_2 emission in the long run. Similarly, Esteve and Tamarit (2012) showed that CO_2 monotonically rises with income and elasticity of income found to be less than one, which implies that if EKC does exist then growth path starts declining after a turning point.

Shahbaz et al. (2013) examined the EKC hypothesis for Romania by augmenting energy consumption in the traditional model of EKC. The study revealed the existence of the EKC relationship and concluded that democratic regimes, effective policy implication and environment-friendly projects reduced CO_2 emissions in Romania. Tiwari et al. (2013) found the dynamic relationship between income and CO_2 emission in the case of India by including trade openness and coal consumption in the estimated equation. Saboori and Sulaiman (2013a) used the traditional model and examined the long-run relationship for Malaysia and suggested unidirectional causality between income and CO_2 emission. Similarly, Saboori and Sulaiman (2013b) analyzed the EKC hypothesis for the Association of South Asian Nations (ASEAN) for the period 1971-2009 by using energy consumption as an additional variable in the model. The study revealed that EKC hypothesis held only for Singapore and Thailand. Shahbaz et al. (2014; 2012) found similar results for Tunisia and Pakistan Furthermore, the robustness of causality analysis was checked by using a technique of the Innovative Accounting Approach (IAA). The study has confirmed the existence of EKC and suggested that a country should implement more environment-friendly regulatory projects to overcome pollution. Studies have found evidence of a positive relationship between financial development and sustainable energy consumption (Rafindadi, 2016; Rafindadi, Isah, & Usman, 2023). Furthermore, a significant impact of electricity consumption on economic growth is found in literature (Rafindadi & Usman, 2019) with a feedback effect (Rafindadi & Ozturk, 2016; Rafindadi & Ozturk, 2017). In addition, the existence of a feedback effect suggests focusing on entrepreneurial development for productive and efficient energy consumption (Rafindadi, Aliyu & Usman, 2022). A positive but asymmetric effect was found in the case of Brazil (Rafindadi, & Usman, 2021). On the other hand, a negative relationship was found between economic growth and natural gas consumption in the case of Malaysia (Rafindadi & Ozturk, 2015).

Baek (2015) found little evidence on the existence of EKC in the case of Arctic countries. The author used the same variables and econometric methodology that was used by Saboori and Sulaiman (2013b) for ASEAN countries. The result showed that energy consumption worsened the effect on pollution by increasing the CO_2 emission. Moreover, Robalino-López et al. (2014) examined the relationship by using historical data as well as the future projections in the case of Venezuela. It was found that Venezuela is on the path of achieving environmental stabilization and the EKC hypothesis does not apply for this country. Hence, changes in the energy matrix and productive sectoral structure prove helpful for environment stabilization. Likewise, Tutulmaz (2015) analyzed the EKC hypothesis for Turkey and Ahmad et al. (2016) checked the robustness and consistency of EKC for Croatia. The relationship was found to be significant. Rafindadi (2016) found that natural disaster is a strong causative factor for EKC along with a deteriorating impact of energy consumption on environment. Badulescu et al. (2020) investigated the EKC hypothesis for the European Union by examining the relationship between environmental spending and GDP. Demissew Beyene and Kotosz (2020) tested the EKC hypothesis for the East African countries by examining the impact of GDP per capita, GDP per capita square, globalization, FDI, pollution density, and political variables on CO_2 emissions. The results supported an inverted-U relationship in the short run but a bell-shaped curve in the long run. This is due to the implementation of efficient environmental policies and adoption of green technologies. Zhang (2021) concluded an N-shaped EKC in the case of China and observed a positive impact of energy consumption and a negative effect of urbanization on CO_2 emissions.

Literature on panel data analysis

Shafik and Bandyopadhyay (1992) tested EKC for three environmental indicators i.e., deforestation, per capita carbon dioxide emission and water. The analysis was done on a panel of 149 countries and a time period from 1961 to1986. The study concluded that carbon dioxide emission increased monotonically with economic growth. Using the same methodology, Haltz-Eakin and Selden (1995) examined the relationship between per capita CO_2 emission and per capita GDP for 130 countries covering the time period from 1951 to 1986. The results showed that quadratic model followed the inverted U-shaped relationship, but cubic model portrayed that CO_2 increased by exhibiting N-shaped relationship. Same findings were also concluded by Mooman and Unruh (1997) who analyzed the relationship between CO_2 emission and GDP per capita on panel data set of 16 OECD industrial countries for the period 1950 to 1992. Stern, Common and Barbier (1996) have critically examined the global impact of EKC by forecasting the individual income of the countries and accumulated incomes over countries. It was concluded that global emission of sulfur dioxide (SO_2) would continue to increase by 2050. Cole, Rayner and Bates (1997) tried to overcome the weaknesses in the estimation of EKC as pointed out by Stern et al. (1996). Using the panel dataset, the study showed the existence of EKC for local air pollution in urban zones, while other global and indirect indicators of air pollution increased monotonically with income. In addition to that, the turning point has been predicted at a very high level of income with greater impact of transport generated pollutants than the total emissions per capita. Similarly, Torras and Boyce (1998) empirically tested that more equitable distribution of power to improve the quality of air and water can be achieved by enhancing the effects on policy that bear the cost of pollution instead of those who get a benefit from pollution generating activities. In addition, literacy, political rights and civil liberties have a strong influence on environmental quality particularly in low-income countries. Additionally, Agras and Chapman (1999) suggested that EKC is the quadric model of income and pollution, but it ignores other explanatory variables, and the most important omitted variable is the price of energy. Galeotti and Lanza (1999) have empirically examined the relationship between CO_2 and GDP per capita for a panel of 110 countries from 1971 to 1996. The results showed that there is an inverted U-shaped relationship between CO_2 emission and GDP for all non-OECD and OECD countries. Moreover, through forecasting it was revealed that the average world growth of CO_2 between 2000 to 2020 would be 2.2% per year. Ravallion, Heil and Jalan (2000) analyzed the relationship between CO_2 emissions and GDP per capita population and the Gini coefficient for the panel data set of 42 countries between the year 1975 to1992. The analysis revealed insignificant results for cubic function, but the estimations for quadratic function showed significant results. Similarly, Borghesi (2000) used the same relationship but instead of GDP per capita, the author used GDP per capita in PPP for 126 countries for the period 1988 to 1995. It was found that CO_2 monotonically increased with income but slightly decreased as income inequality increased.

Furthermore, Andreoni and Levinson (2001) used static model on micro foundations to test the relationship between income and pollution. The study showed that there exists a technological link between reduction of the undesirable byproduct and the consumption of the desirable product. This link is consistent with market failure and efficiency, but it does not depend upon the dynamics of growth, political institution, and externalities. Similarly, Roca et al. (2001) argued that economic growth could not solve the problem of environmental issues directly as the relationship between income and pollutants depend upon other factors as well. Therefore, the EKC hypothesis cannot be generalized globally. Gangadharan and Valenzuela (2001) studied the interrelationship among income, environment, and health. This relationship was empirically examined by a two stage least square to check the impact of income and environment on health status. The results showed that environmental degradation had a significant but negative impact on health status whereas income showed a significant positive impact.

Most of the pessimistic views explain that EKC is just a snapshot and illusionary because in industrialized countries new pollutants continue to be added as old pollutants are controlled. However, Dasgupta et al. (2002) provided an optimistic view about EKC and argued that the shape of EKC becomes flat and moves toward the left. It is proposed that economic liberalization, clean technology, international assistance, diffusion and follow-up of the new methods of pollution resistor technology are the main drivers to control environmental degradation. Furthermore, Narayan and Narayan (2010) presented an evidence of the EKC hypothesis which was analyzed for a panel dataset consisting of 43 developing nations from 1980 to 2004. The results were significant for South Asian and Middle East countries. Hao et al. (2016) used spatial econometrics to test EKC in the case of coal consumption for 29 Chinese provinces from 1995 to 2012. The analysis showed that spatial correlation exists between coal consumption and economic growth. Similarly, Özokcu and Ozdemir (2017) suggested that environmental degradation would not be solved spontaneously by economic growth. The analysis was done for 26 OECD countries and 52 emerging countries for the period from 1980 to 2010. Using the cubic functional form, the results showed that there exists an inverted N-shaped relationship. Another panel data study for 50 US States is undertaken by Atasoy (2017). Rafindadi, Muye, and Kaita (2018) examined the pollution mitigating effect of FDI on GCC countries which prevails due to technique effect, but energy consumption had a deteriorating effect on environment due to scale effect. Gill, Viswanathan and Hassan, (2018) critically evaluated EKC hypothesis. The study recommends that developing countries should focus on other growth paths instead of EKC but keep in mind that the growth path must be viable and less injurious. Moreover, the study proposed that energy is the main determinant of pollution.

Hove and Tursoy (2019) used GMM estimations to investigate EKC and observed that the higher level of real GDP per capita reduces carbon dioxide emissions and fossil fuel energy consumption but at the cost of an increase in nitrous oxide from industry value addition. Similarly, the findings by Kong and Khan (2019) supported the EKC for solid, liquid, and gas pollutants resulting from industrial waste and construction. No direct relationship was found with weapons imports and coal rent. Moreover, Majeed and Mazhar (2020) reinvestigated the EKC for ecological footprints by using the first- and second-generation panel data methods. The sample was drawn from 20 high-income nations, 36 middle-income nations, and 20 low-income nations. The findings suggested that global environmental strategies must be matched with diverse groups of people. Sen and Abedin (2020) examined the individual and panel-level EKC for China and India. It was found that high energy consumption will decline China's environmental quality at a slower rate than that of India in the long run. However, a growth in per capita GDP over a certain threshold level will benefit India's environment.

The Model

The inverted U-shaped relationship between economic growth and income inequality is famously known as the Kuznets Curve Hypothesis (Kuznets 1955). Later, this viewpoint has been modified into an Environmental Kuznets Curve (EKC) Hypothesis which detects an inverted-U relationship between environmental degradation and economic growth (Grossman and Krueger 1995). It is suggested that at the initial stage of economic development, countries tolerate environmental degradation but at later stages of economic development the environmental degradation tends to fall. The Green Solow Model (Brock and Taylor 2010) further elaborates that pollution per unit output increases prodigiously when the economy is far away from its balance growth path and suggests a humped-shape EKC. As the economy enters a balanced growth path, environmental degradation falls. The convergence property of the Green Solow Model results from technological progress and is not conventionally related to strict environmental policies.

The traditional model of the Environmental Kuznets Curve was first popularized by Grossman and Krueger (1995) using a simple empirical approach by regressing environmental degradation with GDP per capita and GDP per capita square. Extant literature based on empirical approach on EKC has used carbon dioxide, nitrogen oxide, carbon monoxide and sulphur dioxide emissions as proxies to measure environmental degradation (Stern et al. 1996; Shafik 1994; De Bruyn and Bergh 1998; Shahbaz et al. 2010; Esteve and Tamarit 2012; Tiwari et al. 2013; Saboori and Sulaiman 2013; Tutulmaz 2015). The modified version of the EKC hypothesis incorporates some additional controlled variables in the estimated equation (Shahbaz, Jalil and Dube 2010; Esteve and Tamarit 2012; Saboori and Sulaiman 2013a; Özokcu and Ozdemir 2017).

The present study aims to revisit the EKC hypothesis for marine degradation and takes world oil spillage as a proxy indicator to measure marine pollution. The global indicator of marine pollution is considered because this proxy cannot be measured in segregation as its effects are spillover in the marine ecosystem. The marine pollution in terms of oil spillage has a long-lasting effect as compared to other kinds of pollution since the petroleum hydrocarbons in marine environment cannot be recycled easily. Sometimes oil spillage results into an irretrievable destruction of maritime environment. Therefore, the present study serves to determine the impact of global economic activities on stock pollutants which has a prolonged damaging impact on marine resource capital. The world GDP per capita is taken to measure the overall economic prosperity and world crude oil consumption per capita is taken as a control variable.

Both theses variables reflect the increased economic activities globally.

The baseline equation of the model to test the EKC hypothesis for marine pollution is presented below:

$$\mathrm{WOSP_t} = \alpha + \beta_1\mathrm{WGDPPC_t} + \beta_2\mathrm{WDGPPC^\wedge 2_t} + \beta_3\mathrm{WCROCPC_t} + \mathcal{E}_t \quad (1)$$

Where WOSP = world oil spillage per capita, WGDPPC = world GDP per capita, WDGPPCˆ2 = world GDP per capita square, WCROCPC = world crude oil consumption per capita and $\mathcal{E}_t$ is the error term. Equation (1) is taken in log-linear form to measure the percentage change in oil spillage to one unit change in regressors. The conditions for the validity of inverted-U relationship are that the sign of β_1 must be positive and β_2 must be negative to hold true the EKC hypothesis. The traditional versions of the EKC have been criticised due to the omission of covariates such as trade openness, globalization and manufacturing sector production and few studies have also brought back income inequality in the estimated equation (Shahbaz et al. 2010; Esteve and Tamarit 2012; Saboori and Sulaiman 2013b; Özokcu and Ozdemir 2017). The present study takes world crude oil consumption per capita (WCROCPC) as control variable as higher demand will pull-up the offshore drilling of crude oil production which may increase the chances of accidental oil spillage.

Variables and Data Sources

The data covers a time series from 1970 to 2019. The data is extracted from World Development Indicators and the Statistical Review of World Energy, The description of variables is provided in Table 1.

Methodology

The study uses standard procedures of time series analysis by including the higher order of integration system as well as the possible structural breaks in determining the long-run relationship. The parameters obtained under each estimation technique provide a robust analysis along with strong evidence of the existence of EKC for marine environment degradation. The first step in a time series analysis is the unit root test to

Table 1. Description of Variables

Variable	Description
World oil spillage per capita (WOSP)	It is used as proxy variable for marine pollution, is measured in tonnes. It includes accidental spills of crude oil from tankers except resulting from act of war. The International Tanker Owners Pollution Federation (ITOPF) publishes annual reports on Oil Tanker Spill Statistics. ITOPF compiles data on world oil spillage by collecting information from shipping press, other specialist publications, vessel owners, vessel insurers and ITOPF's experiences. These oil spills have usually occurred from collisions, grounding, structural damage, fires, and detonations.
World GDP per capita (WGDPPC)	It reflects the global economic activities and measured in constant US dollars.
World crude oil consumption per capita (WCROCPC)	It is measured in tonnes and consist of the inland demand along with the demand by marine bunkers and aviation. It excludes the consumption of biodiesel and bio-gasoline, but the derivatives of coal and natural gas are included.

check for random walk in the variables. The time span included for our analysis comprise 50 years, therefore the possibility of structural breaks is also considered. Andrews and Zivot (1992) unit root test include single structural break. The general representation for a time series (Y_t) with the inclusion of both intercept and trend is given below:

$$\Delta Y_t = \alpha + \beta t + \rho Y_{t-1} + \lambda DI_t + \gamma DT_t + \sum_{i=1}^{k} n_i \Delta Y_{t-i} + \mu_t \qquad (2)$$

In equation (2) the term Δ is the difference operator. ΔY_{t-i} is the lagged value of the variable determined by Akaike Information lag length criterion (AIC). The μ_t is the normally distributed white-noise error term. The two dummy variables DI_t and DT_t captures the shift in intercept and shift in time trend, respectively, at time break date (TB). For time break (TB) at time t =1, 2, 3 ... T, the dummy variables take the values as follows:

$DI_t = 1$ if t > TB and $DI_t = 0$ if t < TB and DT_t = t-TB if t > TB and $DT_t = 0$ if t < TB

The null hypothesis is $H_0: \rho = 0$ indicating that the variable (Y) has a unit root. The null hypothesis is rejected if t-statistic of ρ is greater than the critical value. The Clemente, Montanez and Reyes (1998) unit root test allows for two optimal structural breaks. This test further proposes two models i.e., the innovative outlier (IO) model and additive outlier (AO) model that makes a distinction on how the impact of the break dummy varies over time. The AO model assumes an abrupt change in the time series whereas IO model assumes that the effect of structural change is gradual over time. The historical data on oil spillage has shown a sudden change as well a long-lasting impact of some large oil spills such as the Exxon Valdez oil tanker spill in 1989 and the Deepwater Horizon oil spill in the Gulf of Mexico in 2010. So, both models are applied for unit root analysis. The equation to be estimated for IO model (Vogelsang and Perron 1998) with two break dates in both intercept and trend for a time series (Y_t) is given below:

$$\Delta Y_t = \alpha + \beta t + \rho Y_{t-1} + \lambda_1 DI_{1t} + \lambda_2 DI_{2t} + \gamma_1 DT_{1t} + \gamma_2 DT_{2t} + \pi_1 DTB_{1t} + \pi_2 DTB_{2t} + \sum_{i=1}^{k} n_i \Delta Y_{t-i} + \mu_t \qquad (3)$$

In equation (3), the intercept dummy for two structural breaks is presented by DI_1 and DI_2. TB1 and TB2 represents the two unknown break dates which are endogenously determined. DI_1=1 if $t > TB_1$ and zero otherwise. Similarly, DI_2=1 if $t > TB_2$ and zero otherwise. The slope dummies for two unknown structural breaks are DT1 and DT2. The minimum value of pseudo t-statistic is obtained for different combinations of break date. The null hypothesis of unit root is rejected if the absolute value of t-statistic is greater than the critical value. The AO model (Perron 1989; Vogelsang and Perron 1998) is a two-step procedure. First, the series is de-trended by regressing on constant term, time rend and dummy break as given below:

$$Y_t = \alpha + \beta t + \gamma DT_t + \widetilde{Y}_t \qquad (4)$$

$\widetilde{Y}_t$ is the de-trended series. Equation (4) assumes that the structural break affects only the slope coefficient. The equations tests for all possible values of time breaks (TB) such as TB = k+2, …,T-1 for a total of T observations. The break date is endogenously determined. The second step uses the residual of first step to test for a change in the slope coefficient as presented below:

$$\widetilde{Y}_t = \vartheta \widetilde{Y}_{t-1} + \sum_{i=1}^{k} n_i \Delta Y_{t-i} + \mu_t \qquad (5)$$

The null hypothesis of unit root is rejected if the absolute value of t-statistic for ϑ is greater than the corresponding critical value.

To estimate the long-run relationship, a conventional cointegration approach such as Engle-Granger and Johansen cointegration does not consider the optimal structural break and does not provide reliable results (Wooldridge 2001; Baltagi 2009). Gregory and Hansen (1996) Structural Break Cointegration analysis incorporates a single structural break while determining the long-run relationship. The model can be represented as a level shift, a level shift with trend and regime shifts as given below:

$$\mathrm{WOSP_t} = \alpha_0 + \alpha_1\sigma_t + \beta_1\mathrm{WGDPPC}_{\mathrm{t}} + \beta_2 WDGPPC^2{}_{\mathrm{t}} + \beta_3\mathrm{WCROCPC_t} + \mu_{\mathrm{t}} \quad (6)$$

Where, α_0 is the intercept before shift and α_1 is the intercept after shift at the time break. σ_t is a dummy variable for break point assuming that it affects only the intercept. σ_t gets the value 1 if t > nτ and 0 if t < nτ where τ belongs to the relative timing of break. The level shift with trend is represented as below where the ϕ coefficient of trend, t.

$$\mathrm{WOSP_t} = \alpha_0 + \alpha_1\sigma_t + \phi_1 t + \beta_1\mathrm{WGDPPC}_{\mathrm{t}} + \beta_2 WDGPPC^2{}_{\mathrm{t}} + \beta_3\mathrm{WCROCPC_t} + \mu_{\mathrm{t}} \quad (7)$$

The regime shift model affects both the intercept and slope coefficients as represented below:

$$\mathrm{WOSP_t} = \alpha_0 + \alpha_1\sigma_t + \beta_1\mathrm{WGDPPC}_{\mathrm{t}} + \beta_{11}\sigma_t\mathrm{WGDPPC_t} + \beta_2 WDGPPC^2{}_{\mathrm{t}} + \beta_{22}\sigma_t WDGPPC^2{}_{\mathrm{t}} + \beta_3\mathrm{WCROCPC_t} + \beta_{33}\sigma_t\mathrm{WCROCPC_t} + \mu_{\mathrm{t}} \quad (8)$$

The cointegrating slope coefficients before the regime shift are β_1, β_2 and β_3. The change in slope coefficient after a structural break are denoted by β_{11}, β_{22} and β_{33}. Alternatively, the model of regime shift with trend can be written as:

$$\mathrm{WOSP_t} = \alpha_0 + \alpha_1\sigma_t + \phi_1 t + \phi_2 t\,\sigma_t + \beta_1\mathrm{WGDPPC_t} + \beta_{11}\sigma_t\mathrm{WGDPPC_t} + \beta_2 WDGPPC^2{}_{\mathrm{t}} + \beta_{22}\sigma_t WDGPPC^2{}_{\mathrm{t}} + \beta_3\mathrm{WCROCPC_t} + \beta_{33}\sigma_t\mathrm{WCROCPC_t} + \mu_{\mathrm{t}} \quad (9)$$

The intercept, slope and trend coefficient before regime shift are α_0, β_1, β_2, β_3 and ϕ_1. Where as α_1, β_{11}, β_{22}, β_{33} and ϕ_2 are the corresponding changes in the coefficients after the break. The Gregory and Hansen (1996) Structural Break Cointegration test demands for the same order of integration. Alternatively, the autoregressive distributed lag (ARDL) model (Pesaran et al. 2001) has an advantage that it determines the long-run relationship among variables that are of different integrated order. The drawback of the ARDL approach is that it does not allow a higher order integrating system. To incorporate higher order of integration, the paper estimates the relationship through dynamic ordinary least square (DOLS) as suggested by Stock and Watson (1993). The DOLS method is a parametric approach that includes lags and leads of the first-differenced integrated regressor on the right-hand-side of equation (1), as represented below:

$$\begin{aligned}\mathrm{WOSP_t} = \alpha &+ \beta_1 \mathrm{WGDPPC_t} \\ &+ \beta_2 WDGPPC^2{}_{\mathrm{t}} \\ &+ \beta_3 \mathrm{WCROCPC_t} \\ &+ \sum_{j=-q}^{p} \sigma_1\, \Delta\mathrm{WGDPPC}_{\,\mathrm{t-j}} \\ &+ \sum_{j=-q}^{p} \sigma_2\, \Delta WDGPPC^2{}_{\mathrm{t-j}} \\ &+ \sum_{j=-q}^{p} \sigma_3\, \Delta\mathrm{WCROCPC}_{\,\mathrm{t-j}} \\ &+ \varepsilon_{\mathrm{t}} \qquad (10)\end{aligned}$$

The optimal number of lags and leads is selected according to the Schwarz information criterion. During estimations, the break dummies are included which were obtained from our preliminary analysis of Gregory and Hansen (1996) Structural Break Cointegration test. Lastly, to check the robustness of our analysis, the structural change regression is applied to determine the long-run relationship and the Chow test (Chow 1960) is computed to test the significance of each possible break date. The test considers a single known break date at a time. So, the optimal break dummies are added sequentially during the estimations of equation (1).

Empirical Results

The present study undertakes rigorous time series analysis by including possible structural breaks in the model. The empirical estimations provide us with a robust analysis and provide strong evidence of the existence of EKC in the case of marine degradation. The estimation begins with unit root analysis. Table 2 provides the results of Andrews and Zivot (1992) unit root test with the inclusion of a single structural break. The test concludes that WOSP and WCROCPC are stationary variables whereas WDGPPC and WDGPPCˆ2 are of integrated order 1.

The stationarity of the variable is again tested by including two optimal structural breaks in the series (Clemente, Montanez and Reyes 1998) as shown in Table 3. The additive outlier model concludes WOSP as stationary. The variable WCROCPC is stationary at first difference whereas both WDGPPC and WDGPPCˆ2 are stationary at second difference. On the other hand, the results of the innovative outlier model conclude that all variables are of integrated order 3 except WCROCPC which is stationary at level.

Table 2. Zivot-Andrews unit root test with one structural break (with both trend and intercept)

Variable	Optimal Breakpoints (Level)	t-statistics	Optimal Breakpoints (first difference)	t-statistics	Order of Integration
WOSP	2008	-6.908**	-	-	I(0)
WGDPPC	1998	-4.030	2009	-6.261**	I(1)
WDGPPC^2	1998	-3.138	2009	-6.650**	I(1)
WCROCPC	1980	-6.982**	-	-	I(0)

Note: ** denotes stationarity in the presence of structural break. Critical value of t-statistics is -5.08 at 5 % level of significance. Lag method: Akaike information criterion (AIC). Source: Author’s calculations using Stata.

Table 3. Clemente-Montanes-Reyes unit root test with two structural breaks (with both trend and intercept)

Variable	***Additive Outlier Model***				
	Optimal Breakpoints (Level)	t-statistics	Optimal Breakpoints (first/ second difference)	t-statistics	Order of Integration
WOSP	1995[a], 2005[a]	-6.983**	-	-	I(0)
WGDPPC	1991[a], 2008[a]	-3.175	1989, 2007	-5.578**	I(2)
WDGPPC^2	1972[a], 2009[a]	-2.641	1989, 2007	-5.50**	I(2)
WCROCPC	1981[a], 2009[a]	-2.240	1979[a], 1983[a]	-7.232**	I(1)
	Innovative Outlier Model				
	Optimal Breakpoints (Level)	t-statistics	Optimal Breakpoints (third Difference)	t-statistics	Order of Integration
WOSP	1993[a], 2006[a]	-3.678	1982, 1996	-8.269**	I(3)
WGDPPC	1993[b], 2009[b]	-1.907	2006[a], 2009[a]	-5.60**	I(3)
WDGPPC^2	1993, 2009	1.506	2006[a], 2009[a]	-5.97**	I(3)
WCROCPC	1974[b], 1978[a]	-8.362**	-	-	I(0)

Note: Critical value of t-statistics is -5.490 at 5 % level of significance. ** denotes stationarity in the presence of structural break. a denotes the significance of structural break dummy at 5% significance level. b denotes the significance of structural break dummy at 10% significance level.

Source: Author's calculations using Stata.

Table 4. Determining the optimal structural breaks using Gregory-Hansen cointegration approach

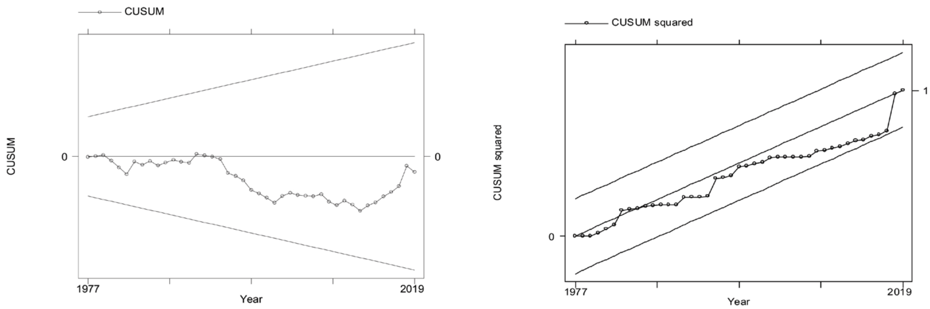
Model	ADF	Break Date	Z_t	Break Date
Level shift	-7.30**	1987	-7.37**	1987
Level shift with trend	-7.04**	1986	-7.48**	1986
Regime shift	-9.16**	1989	-9.24**	1993
Regime shift with trend	-9.65**	1987	-9.99**	1993

Note: ** denotes rejection of null hypothesis of no cointegration at 5%. Source: Author's calculations using Stata.

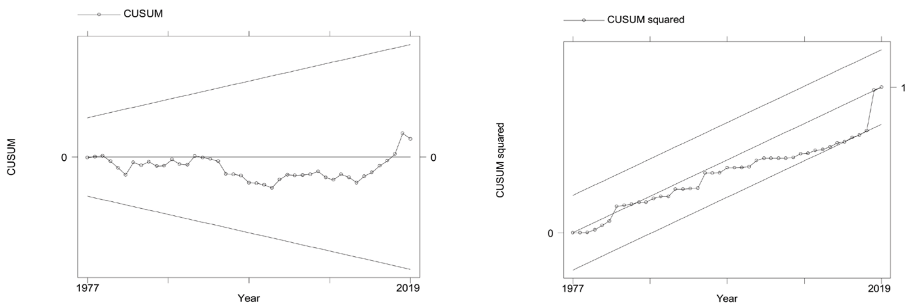
The application of the unit root test under the different assumptions of structural breaks provides us with mixed results. All the variables are of different integrated order along with the presence of higher order of integration. Before proceeding with DOLS estimations, the optimal structural breaks are determined using the Gregory and Hansen (1996) Structural Break Cointegration as provided in Table 4. In all the four models, the cointegration results show the presence of long-run relationship and optimal break dates are recognized in the years 1987, 1986 and 1993 based on Z_t statistics.

The parameter stability tests under each of these break dates are provided in Figure 2. The CUSUM and CUSUMsq graphs are within the established critical bounds which conclude that the long-run relationship is stable.

(Break Point: 1986)



(Break Point: 1987)



(Break Point: 1993)

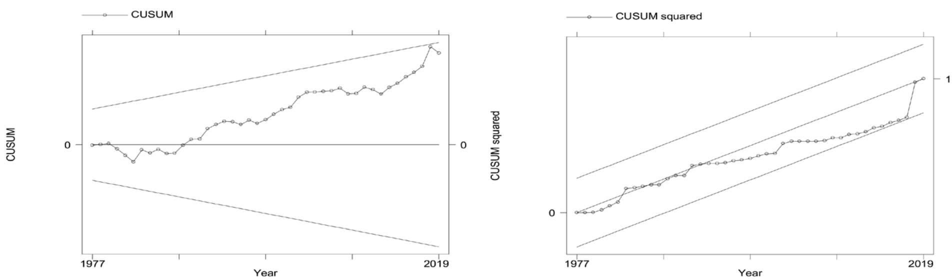


Figure 2. Parameter stability test (CUSUM and CUSUMsq graph)
Source: Author's calculations using Stata.

Table 5 shows the estimated results for DOLS with the inclusion of break dummies as determined through the Gregory-Hansen approach. The break dummies for 1986, 1987 and 1993 are included based on the results of Phillips-Z test (Z_t statistics). The break dummies of 1987 and 1993 are statistically significant at 10%. The break dummy of 1987 reveals a positive shock on oil spillage whereas the break dummy of 1993 shows a negative impact. In addition, the coefficient sign of WDGPPC is positive and negative in the case of WDGPPCˆ2. This indicates the presence of a non-liner relationship between world oil spillage and world economic activities. Thus, there is an existence of an inverted-U shaped relationship of EKC in the case of marine pollution. The relationship of WCROCPC is positive with oil spillage as more crude oil consumption will increase the demand for offshore drilling which may increase the chances of greater oil spill. Due to increased demand the size of oil tanker also becomes large for storage purposes and the chances of oil spills increases during tanker handling and its transportation. The value of R^2 shows that 67 percent variation in the dependent variable is explained by the explanatory variables.

In order to check the robustness of our analysis, structural change regression is applied. The results are provided in Table 6. The F-statistic shows that the estimated model is significant for the structural break dummy of 1993 and insignificant in the case of 1987 and 1986. The coefficient attached with each of the explanatory variables also has the expected signs. The significant break dummy has a negative sign indicating that the turning point of EKC has already started. The significance of the structural dummy for 1993 is also supported by the Chow test as

Table 5. Dynamic ordinary least square (DOLS) estimation with structural break dummies

Variable	Coefficients	t-statistics
WGDPPC	0.0027***	2.808
WDGPPC^2	-0.0000021***	-3.533
WCROCPC	0.017***	3.190
Break (1986)	-1.525	-1.202
Break (1987)	2.097*	1.833
Break (1993)	-1.18*	-1.995

Note: Dependent variable is WOSP. *** and * denote that coefficients are significant at 1% and 10%, respectively. R2 = 0.67. The lead and lags specification based upon Schwarz information criterion (SIC). Maximum length included is 3. Source: Author's calculations using Stata.

Table 6. Estimated results for structural change regression and Chow Test

Variable	Break (1993)		Break (1987)		Break (1986)	
	Coefficient	p-values	Coefficient	p-values	Coefficient	p-values
WGDPPC	0.0023***	0.000	0.0012*	0.088	0.0012	0.115
WDGPPC^2	-0.00000161***	0.000	-0.0000011**	0.011	-0.0000015**	0.018
WCROCPC	0.016***	0.000	0.024***	0.000	0.024***	0.000
Break Dummy (D)	-1.147*	0.059	0.989	0.158	0.937	0.203
F-statistic	3.74*		2.06		1.66	
Diagnostics (Null hypothesis=no structural change)						
Chow Test	(0.059)*		(0.158)		(0.2035)	

Note: Dependent variable is WOSP. ***, ** and * indicates significance at 1%, 5% and 10%. p-values are given in brackets ( ). Source: Author's calculations using Stata.

indicated by its p-value which is significant at a 10% level.

Our analysis provides robust results which reveal the existence of the Environmental Kuznets Curve for marine degradation. Furthermore, it is observed that the turning point of EKC has already started to appear in 1992. The Earth Summit held in Rio de Janeiro, discussed Agenda 21 devoted solely to the ocean.[4] The protection of marine environment is also one of the agenda items under SDG (Goal 14). The conventions on the prevention of marine oil spillage have been launched since the 1950's (Mensah 1976). For prevention of operational discharges, there has been a convention such as The International Convention for the Prevention of Pollution of the Sea by Oil (1954), with its 1962 Amendments; the amendments to the 1954/62 Convention adopted in 1969 and 1971; International Convention for the Prevention of Pollution from Ships (1973). The conventions on the prevention of accidental oil spillage include The International Convention on Safety of Life at Sea (1960) with its amendments of 1966, 1967, 1968, 1969, 1971 and 1973; The International Regulations for Preventing Collisions at Sea (1960); The International Convention on Load Lines (1966); The Convention on the International Regulations for Preventing Collisions at Sea (1972); and The International Convention on Safety of Life at Sea (1974). Similarly, the conventions held in 1975 deal with the establishment of arrangements during the occurrence of accidents and issuance of liabilities and compensations for the damages (Mensah 1976).

On the other hand, the Green Solow Model explains that the decline in pollution occurs due to diminishing returns and environmental technological change. The technological change and marine degradation laws are the major factors responsible for a declining trend in marine oil spillage. The control of marine degradation is becoming a focal point of discussions at various international forums.[5] The technological change factor is the development of long-term environmental monitoring programs as preventive measures to eliminate the likelihood of oil spillage (Dalsimer 1992; Commitee 2015). For this purpose, the safe production techniques are being adopted along with safe transportation. The technological advancement is focusing on elimination of human errors, improving the offshore facilities like vessel designs and drilling methods, pipeline systems and better transportation from offshore to land. In addition to these technological developments, the reduction in marine degradation is also resulting from the change in the demand for energy sources, which is transitioning from non-renewable to renewable energy sources. Moreover, the recent past trends of crude oil extraction shows that the world demand for drilling rigs, used for extraction at offshore locations, is declining. This implies that the production at offshore sites has declined which might also be a contributing factor to less oil spillage.

4 "Protection of the Oceans, all kinds of seas, including Enclosed and Semi enclosed Seas and Coastal Areas and the Protection Rational Use and Development of their Living Resources".

5 In 1972, the Declaration on Human Environment and Action Plan has discussed about the global environmental issues with special emphasis on marine pollution. Principle 7 places responsibility on states for marine pollution and requires preventive measures. Principle 22 states that it is the liability to reimburse marine pollution damage. (UNCHE, 1972).

Conclusion

The study empirically validates the existence of the Environmental Kuznets Curve for marine degradation. A time series analysis is undertaken by including possible structural breaks. The world oil spillage is used as a proxy indicator for marine pollution. However, the trendline of oil spillage data reveals that the turning point has already started to appear which is also empirically tested by employing long-run cointegration analysis with structural breaks. The turning point is occurring due to the global trends towards increased demand of renewable energy sources as well as structural change to cater the requirement of SDGs. The study proposes the term of 'Marine Kuznets Curve' as the previous studied have not examined the EKC hypothesis for marine ecosystem. Although marine degradation is on the improvement side as oil spillage is declining but there is still a need for much human intervention through the introduction of methods to remove oil from the oceans and seas immediately, whenever oil spills occur as it has a long lasting impact on marine environment.

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