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RESEARCH ARTICLE

Does the environmental Kuznets curve reliably explain a developmental issue?

Muhammad Iftikhar Ul Husnain[1] · Azad Haider[2] · Muhammad Aamir Khan[1]

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Abstract

This study aims to achieve two main objectives; first, it provides a brief but critical description of the empirical literature on the environmental Kuznets curve (EKC) in terms of history, origin, micro-foundations, measurement of environmental degradation, methodologies and samples. Second, it examines the curious attraction of the EKC despite considerable criticism it has attracted over time. The motivation stems from the mixed results probably due to different econometric techniques, sample periods, country-specific factors and environmental indicators used to test EKC. The study concludes that of course, the EKC has attracted a great deal of criticism, but its survival power is undeniable. Different taxonomies of the approaches to explain income-environment nexus have been established by various commentators producing different results under different scenarios. It is still equally important among researchers to interpret the relationship between income and pollution due to its charismatic characteristics; therefore, the empirical literature on EKC continues to grow despite criticism on its validity and assumptions. However, we should not be convinced that economic growth on its own will solve environmental ills. The proposition that affluent countries will invest heavily to level off and gradually contain their environmental pollution should not be persuaded. Therefore, policymakers must not encourage unlimited economic growth to cure environmental problems.

Keywords Environment · Kuznets · Growth · Economic · Hypothesis · Relationship: U-shaped

Introduction

In this modern age, to attain a certain level of economic growth and sustainable development is threatened by the controversial issues of the environment (Alege et al. 2016). For the implementation of effective and efficient environmental control policies, it is critical to understand how economic expansion and environmental degradation are linked (Altıntaş and Kassouri 2020). The use of energy in an economic expansion is crucial as energy consumption is positively associated with overall economic output (Apergis and Payne 2011; Apergis and Payne 2010; Paramati et al. 2018; Apergis and Payne 2014; Apergis and Danuletiu 2012). At the same time, the use of energy increases CO_2 emissions and causes damage to environmental quality. The association between environmental quality and economic output is explained by the EKC that states this relationship is inverted *U*-shaped (Apergis et al. 2017). However, empirical conclusions show that the EKC is not valid for all economies (Ozcan et al. 2018; Adu and Denkyirah 2019; Destek et al. 2018; Monserrate et al. 2018).

This has attracted great attention from researchers particularly after the ground-breaking work of Simon Kuznets (1955) who in the 1950s found an inverse *U*-shaped relationship between income inequality and per capita GDP and raised the hypothesis called the Kuznets curve (Sun bo 2011). In recent times, economists working in the field of environmental economics have extended this notion to establish the same type of hypothesis that links expansion in economic activity and environmental quality famously known as the EKC (Bhattarai and Hammig 2001).

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✉ Muhammad Iftikhar Ul Husnain
iftikharhusnain@comsats.edu.pk

Azad Haider
azad.haider@smu.ca

Muhammad Aamir Khan
m.aamir.khan@comsats.edu.pk

[1] Department of Economics, COMSATS University Islamabad, Islamabad, Pakistan

[2] Department of Economics, Sobey School of Business, Saint Mary's University, Halifax, Canada

An abiding empirical and theoretical interest in the relationship between income and pollution represents an important characteristic of the current debate on the sustainability of the planet. Voluminous literature is available in this area and a significant portion of this literature has been devoted to finding the nature of the causal association between GHGs emissions and economic activity (e.g., Alege et al. 2016; Alkhathlan and Javid 2013). Due to the vast and varied nature of this literature, we cannot determine how far our knowledge of the subject has progressed. The results vary from monotonic to *N*-shaped between income and pollutants. Indeed, a significant difference of hypothesis can be seen on the validity of the EKC in a different context. Of course, EKC has attracted a great deal of criticism, but its survival power is undeniable. For instance, the EKC pays too much attention to production (Kaika and Zervas 2011). Empirical literature finds the EKC tipping point considering the average level of income of different economies (Dinda 2004; Lieb 2004), under the assumption of the normal distribution of world income, which indeed is highly skewed (Milanovic 2002). Therefore, it is unrealistic to find the tipping point of the EKC considering mean income. Furthermore, the EKC hypothesis can only be demonstrated for a few selected pollution indicators due to data availability. Even in developed countries, data is not available for some toxic and unregulated pollutants. According to Liu (2012), inconsistency in data availability remains a serious hurdle in estimating the EKC for industrial pollution. Another drawback associated with the EKC is that most of the studies employ data about pollution indicators since the 1970s, whereas the developed nations have turned their EKC before the 1970s; therefore, conclusions drawn based on this data period cannot be considered reliable. Likewise, environmental problems like underground water pollution and soil erosion are impossible to empirically estimate; therefore, findings of the EKC cannot be generalized (Vincent 1997).

The advent of the EKC changed the debate from environmental resource scarceness to an inevitable role of income growth in improving environmental quality. The EKC hypothesis has significantly changed the economic policy framework in the developing and developed world along with its strong impact on the priorities and policies of the World Bank and IMF that reflects their pro-growth stance. To reduce unemployment and poverty, the developing countries are perusing fast economic growth without considering the vulnerabilities of the environment (Gill et al. 2018). According to Webber and Allen (2004), the EKC hypothesis has an important proposition for developing nations. Instead of implementing environment-friendly measures, they should focus on fast economic growth as the latter can attain both economic and environmental objectives, whereas policies targeting economic growth just result in slow economic activity.

Different taxonomies of the approaches to explain income-environment nexus have been established by various commentators that identify various sources of variation in results that include the country-specific studies (Stern and Common 2001; Lee et al. 2010; Carson et al. 1997; Kaufmann et al. 1998), sample period (Harbaugh et al. 2002; Auci and Becchetti 2006), econometric methodology (Wang 2013; Schmalensee et al. 1998; Perman and Stern 2003), parameter homogeneity (Vollebergh et al. 2009; List and Gallet 1999), spatial influence among regions and countries (Maddison 2006; Hosseini and Kaneko 2013) and common time effect (Stern 2010). Yang et al. (2015) identify as many as 141,312 model formulations emerging from various combinations of the dependent variable, the independent variable, the order of the polynomial (linear, quadratic and cubic), control variables and the use of level versus log specifications.

Pragmatically, EKC is a relationship that traces the pollution path that countries followed during the process of economic development. It describes the relationship between income and pollution indicators (Unruh and Moomaw 1998). At the early stages of economic expansion, pollution level increases with an increase in per capita income, while pollution indicators follow a downward trend when income level crosses a certain threshold level. This relationship is best explained by a bell-shaped curve that relates growth in income to environmental deterioration. Despite the fact that the EKC has helped in analyzing the linkages between the economic development of countries and environmental degradation, it does have some serious policy drawbacks. Countless studies have shown that EKC does not apply to all pollutants or environmental degradation. It implies that even some pollution indicators do decline over time, the other pollutants persistently increase with income growth (Stern 2004b). According to Clausen and York (2008), the notion that wealthy nations will lead the campaign for environmental reforms is naive as most modern nations are responsible for increasing environmental damage.

This mixture of hypothesis, taxonomies and results has led us to write a precise note on the curious attraction and empirical explanation of the EKC hypothesis. The goal of this note is to study, analyse, inspect and investigate that how the EKC relationship evolved, what type of methods have been used to test this relationship, what shortcomings these technique face, how results depend on the choice of environmental degradation indicator and what future lines need to be followed to further study this association. The prime goal of this article is to critically analyse the EKC literature and present input that will help in understanding the most fascinated EKC hypothesis that might be valuable for practitioners working in this field. It should be noted that due to the exploratory nature of the study, we followed the general approach and focused on only major approaches adopted to explain the EKC hypothesis. However, we have tried to include all the important aspects of the EKC like estimation methods, sample period,

country-specific factors, the sensitivity of the results to model specification and measures of pollution.

The paper is structured as follows: the "History and nature of the EKC" section overviews history and nature of EKC; the "Previous studies" section provides a brief summary of most recent studies on the EKC; the "Micro-foundations of EKC" section discusses micro-foundations of EKC; "The measure of environmental degradation" section inspects different measures of environmental degradation; the "Determinants of environmental degradation" section enlists different determinants of environmental pollution; the "Data series, the order of polynomial and output" section highlights different data series used in the EKC literature and output of these studies; the "Methodologies" section provides a critical analysis of the methodologies used to study the EKC hypothesis; the "Some critics of the EKC" section briefly provides some criticism of the EKC and the "Conclusions" section concludes with some policy insights.

History and nature of the EKC

The possible association between economic activity and pollution has been a topic of long debate for many years (Dinda 2004). Beckerman (1992) states that there is "clear evidence that, although economic growth usually leads to environmental deterioration 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". The *U*-shaped relationship between per capita income and environmental quality postulated by Grossman and Krueger (1992) has been a key instrument to understand the meaning of development in two decades (Paudel and Schafer 2009; Nasir and Rehman 2011) and due to its similar shape to Kuznets curve, this statistical relationship was called EKC.

According to the materials balance paradigm, from the 1970s to the 1980s, it was firmly believed that economic growth causes environmental degradation, thus limited growth was the famous conclusion (Koehler 1974). Since the 1990s and onwards, the Kuznets curve became the main tool to describe the association between income and environmental quality. Empirically, the first time nonlinear inverse *U*-shaped relationship between income and pollution was identified by Shafik and Bandyopadhyay (1992) and Grossman and Krueger (1992). EKC hypothesis consists of two stages: in the first stage, income and pollution are positively linked because of industrialization and urbanization that occur in the initial phases of development (Gill et al. 2018). In the second part, the association between per capita income and environmental quality reverses to negative as improved and environment friendly technology replaces the traditional way of producing goods and services (Panayotou 1993). At higher income levels, people start valuing the environment and demand a quality environment because the environmental quality is a normal good (Beckerman 1992; World Bank 1992). With the rise in income, citizen's demand for improvement in environmental quality is positively responded by political systems (Barrett and Graddy 2000). Economic commentators believe that environmental issues will be automatically solved in the later stages of economic development; hence, economic development is no threat to the environment. The EKC hypothesis changed the concept of the limited capacity of the planet to absorb wastes and predicted the inevitability of income growth to combat environmental problems. The fundamental hypothesis of the EKC is "grow first clean later" as Webber and Allen (2004) argued that instead of implementing pro-environment policies, poor countries need to focus on economic growth as pollution will decrease at the higher stages of development. Currently, EKC has become a vehicle for expressing the association between environmental degradation and per capita income.

An observed inverse *U*-shaped association between economic activity and environmental degradation can be explained in several ways. First, Arrow et al. (1995) state that during the process of economic expansion economies move from a clean agrarian to polluting industrial to clean service economies. Second, the role of advanced institutions plays a critical role in collective decision-making to internalize externalities spilling from pollution. Jones and Manuelli (1995) employ the overlapping generation model to show that collective decision-making by the younger generation plays a key role in framing pollution laws. The decisions adopted by institutions determine the type of income-environment relationship ranging from monotonic to sideways mirrored S. Third, some believe that pollution level decreases with the rise in income at a higher stage of development some constraints become nonbinding. In the first phase of economic development, only the dirtiest technologies are used but as the income achieves a threshold level, pro-environment technologies are available (Stokey 1998). Finally, John and Pecchenino (1994) show that a country that is at the corner solution of zero environmental investment will experience a decline in its environmental quality with economic development and then environmental quality will improve at a point at which positive environmental investment is required.

The EKC hypothesis has influenced policies of developing and developed nations and fast economic growth without consideration of environmental degradation appeared on the major agenda of developing countries. The "grow now clean latter" agenda proposed by the EKC hypothesis led to massive environmental changes like an increase in GHGs emissions and climate change which have threatened the survival of human life.

Previous studies

Due to its immense importance, the association between economic expansion and environmental degradation has been

extensively tested in the context of the environmental Kuznets curve. The literature on EKC has increased exponentially over the last 20 years, yet no serious consensus has been achieved (Prieur 2009). The major culprit for environmental pollution is carbon dioxide (CO_2) emissions (Xu et al. 2016); therefore, many studies have examined the relationship between CO_2 emissions and economic development (see Shahbaz and Sinha (2019) since the seminal work of Kraft and Kraft (1979), Shafik and Bandyopadhyay (1992) and Holtz-Eakin and Selden (1995). By keeping in view, the brevity and nature of this article, we summarize the most recent studies on the EKC in Table 1.

Micro-foundations of EKC

Microeconomic explanation, considering cost and revenue analysis proposed by microeconomics, of the EKC differs from the traditional macroscopic view (Wang et al. 2017; Husnain et al. 2018). Climate change was considered a major element of environmental change (Arnell 2004). To understand the environmental change process, different geological sediments were studied on a wide temporal scale (Overpeck and Zielinski 1997). The advent of the EKC entirely changed the notion about the nexus between economic development and environmental quality as its proponents considered it probably the most suitable and the only way to achieve a decent environment in most economies (Beckerman 1992). On the other hand, dissidents questioned the appropriateness of the econometrics and explanation of the EKC in the context of neoclassical production (Stern 2004b). The EKC hypothesis was explained in three ways. Firstly, the scale of production describes that increased production was associated with economic development while environmental degradation and resource consumption were the outcomes of the economy of scale. Secondly, as technology improves, emission per unit of output decreases (Stern et al. 1996). Thirdly, higher environmental awareness, the emergence of information-intensive industries and services and enforcement of environmental regulations relieve environmental degradation (Panayotou 1993). Unlike the common perception that the EKC hypothesis is a macro-level phenomenon, it rests on several assumptions that have roots in microeconomics. For example, it is related to changes in the behaviours and attitudes of rich country citizens and it is concluded that these two variables are weakly linked to national income. Furthermore, even if with an increase in GDP, environmental worries also increase, which does not imply actual greener attitudes or high standards of political pro-environment activism. In general, it can be said that some doubts may undermine the relevancy of the micro-level foundations on which the EKC hypothesis has been established. For example, He et al. (2007) identifies the mismatch between reality in most developing countries and micro assumptions of the EKC's and warns of turning points appearing at the later stage due to factors like inequality, corruption and institutional efficiency.

The measure of environmental degradation

The sensitivity of the findings is attributable to the choice of different pollution proxies. Shafik and Bandyopadhyay (1992) record various shapes and forms of the EKC depending upon the measure of pollution and state that some pollutants improve with a rise in income, others deteriorate and then improve, and others worsen steadily. Empirical literature reveals that the nexus between income and pollution may take various forms of which the EKC is most widely supported and tested empirically on various pollutants (Kaika and Zervas 2013). The dependent variable in the EKC hypothesis is environmental degradation that is measured by various indicators of environmental degradation ranging from very narrow definition such as those sulphur and carbon to wider definitions as GHG emissions. Different proxies of environmental quality used in empirical studies are CO_2 (Shafik and Bandyopadhyay 1992; Narayan and Narayan 2010; Carson et al. 1997; Moomaw and Unruh 1997; Friedl and Getzner 2003; Roca et al. 2001; Jalil and Mahmud 2009 Borhan et al. 2012; Al Sayed and Sek 2013; Ali et al. 2014; Al Mulali et al. 2015; Khan et al. 2016; Benavides et al. 2017; Solarin et el. 2017; Wang et al. 2017); CH_4 (Wang et al. 2017; Roca et al. 2001); N_2O (Roca et al. 2001; Zambrano-Monserrate and Fernandez 2017; Wang et al. 2017; Haider et al. 2020); NO_2 (Luo et al. 2014); NOx (Roca et al. 2001; Och 2017); SO_2 (Roca et al. 2001; Perman and Stern 2003; Jayanthakumaran and Liu 2012; Luo et al. 2014; Wang et al. 2016); NMVOC (Roca et al. 2001); COD (Jayanthakumaran and Liu 2012); SOx (Kaufmann et al. 1998; Stern and Common 2001; Shen 2006; Akbostanci et al. 2009; Fodha and Zaghdoud 2010; Fosten et al. 2012; Wang et al. 2016); GHGs (Kubicová 2014; Cho et al. 2014); PM10 (Luo et al. 2014); ecological footprint (Alola et al. 2019; Yilanci and Ozgur 2019; Altıntaş and Kassouri 2020;Danish et al. 2020) and coal consumption (Tiwari et al. 2013; Yin et al. 2015). The choice of pollutants depends on the relative importance of the pollutant which has led to a high number of EKC studies based on carbon emissions. Our selection of different studies using different proxies of environmental quality is based on heterogeneity in terms of time, sample data and results; however, this list is not exhaustive, and many more articles can be referenced.

The empirical evidence on the EKC is sensitive to different measures of environmental pollution as an inverted *U*-shaped relationship is observed between local pollutants and income, while global emissions (such as CO_2) are not (Moosa 2017) and the EKC estimates for sulphur emissions show a high

Table 1 A summary review of recent studies validating/invalidating the EKC hypothesis

Study	Country	Time frame	Methodology	Variables used	Conclusion
Ozcan et al. (2018)	Turkey	1961–2013	Bootstrap rolling window causality	Ecological footprint, GDP	EKC hypothesis not confirmed
Atwi et al. (2018)	182 countries	1992–2011	SEM, FE, SLM	CO_2 emissions, GDP	EKC hypothesis confirmed
Olale et al. (2018)	Canada	1990–2014	Fixed effect and random effect model	GHGs emissions, GDP, trade, time trend	EKC hypothesis confirmed
Cetin (2018)	Emerging and developed markets	1990–2011	PMG	CO_2 emissions, GDP per capita, renewable energy consumption	Mixed findings
Destek et al. (2018)	15 countries of the EU	1980–2013	MG-FMOLS, MG-DOLS, DCCEMG	GDP, ecological footprint, trade, energy consumption	EKC hypothesis not confirmed
Barra and Zotti (2018)	120 countries	2000–2009	GMM	CO_2 emissions, per capita GDP	EKC hypothesis confirmed
Armeanu et al. (2018)	28 EU countries	1990–2014	Pooled OLS, fixed effect	GDP, GHGs emissions, CPI, energy consumption, R&D expenditure	EKC hypothesis confirmed
Monserrate et al. (2018)	Peru	1980–2011	ARDL, VECM	CO_2 emissions, GDP, electricity and petroleum consumption	EKC hypothesis not confirmed
Kong and Khan (2019)	29 countries	1977–2014	GMM	GDP, agriculture land, military expenditure, inflation, exports	EKC hypothesis confirmed
Koilo (2019)	11 emerging Eastern European and Central Asian countries	1990–2014	Hodrick Prescott-filter	CO_2 emissions, energy use, trade, FDI	EKC hypothesis confirmed
Liu et al. (2019)	Chinees provinces	1996–2015	Fixed effect	CO_2 emissions, GDP, FDI, trade, energy consumption	EKC hypothesis confirmed
Hassan and Nosheen (2019)	37 high-income nations	1990–2017	Panel GMM	CO_2 emissions, N_2O emissions, GDP, FDI, trade, energy use	Railways EKC hypothesis confirmed
Yilanci and Ozgur (2019)	G7 countries	1970–2014	Bootstrap panel causality test in rolling windows	GDP, forest products, cropland, fishing	Mixed findings
Aydin et al. (2019)	26 countries of the EU	1990–2013	PSTR	Ecological footprint, GDP	Mixed findings
Adu and Denkyirah (2019)	West African countries	1970–2013	Fixed effect and random effect models	Environmental quality, GDP per capita, official exchange rate	EKC hypothesis not confirmed
Haider et al. (2020)	33 countries	1980–2012	PMG	N_2O emissions, GDP, exports, agriculture land use	EKC hypothesis confirmed
Ng et al. (2020)	76 countries	1971–2014	CCEMG, AMG, PMG	CO_2 emissions, GDP, energy consumption	Mixed findings
Ongan et al. (2020)	US	1990–2019	ARDL	CO_2 emissions, per capita GDP	Mixed findings
Erdogan (2020)	OECD countries	2000–2015	FMOLS	Ecological footprint, GDP, investment on rail and road infrastructure	EKC hypothesis confirmed
Altıntaş and Kassouri (2020)	14 EU countries	1990–2014	Fixed effect model, DCCE	CO_2 emissions, GDP, ecological footprint, renewable energy, fossil fuel	EKC hypothesis confirmed
Raza et al. (2020)	BRICS and Next-11 countries	1990–2015	FMOLS, heterogeneous panel causality test	CO_2 emissions, GDP, residential energy consumption, financial development	Residential energy EKC hypothesis confirmed
Beyene and Kotosz (2020)	12 East African countries	1990-2013	PMG	CO_2 emissions, per capita income, FDI, population density	EKC hypothesis confirmed
Mania (2020)	98 countries	1995–2013	GMM, PMG	CO_2 emissions, GDP, export diversification	Augmented EKC hypothesis confirmed

level of sensitivity to the sample choice due to internalization of local pollutants in a single region or economy and can push for environmental policies aimed at correcting externalities that affect pollution victims before such policies become active to externalize problems globally. Yang et al. (2015) conclude that the EKC hypothesis cannot be verified for any of the seven emission indicators they employ in their analysis.

Determinants of environmental degradation

It is an empirically established fact that the EKC expresses a relationship of some sort between economic development, proxied by GDP, GDP growth rate and GDP per capita, and environmental degradation. Therefore, income appears in the list of independent variables in all the EKC studies (Wang et al. 2017). It is noteworthy that GDP per capita income is still the most widely used economic proxy thus far despite the popularity of GDP and GDP growth rate variables (Ang 2007; Ahmed and Long 2012; Fosten et al. 2012; Culas 2012; Tiwari et al. 2013; Elliott et al. 2013; Kohler 2013; Alkhathlan and Javid 2013; Shahbaz et al. 2013b; Chandran and Tang 2013; Shahbaz et al. 2013c; Shahbaz et al. 2014; Flores et al. 2014; Omri et al. 2014; Bernard et al. 2015; Tutulmaz 2015; Wang et al. 2015; Yaduma et al. 2015; Lacheheb et al. 2015; Liddle 2015; Nasr et al. 2015; Heidari et al. 2015; Jebli et al. 2015; Ahmed et al. 2015; Shahbaz et al. 2015; Shahbaz et al. 2016; Disli et al. 2016; Hao et al. 2016; Javid and Sharif 2016; Li et al. 2016a; Li et al. 2016b; Rafindadi 2016; Stern and Zha 2016). Also, some studies test the EKC between environmental degradation and corruption with its direct impact on the environment and indirect impact through the channel of income (Lopez and Mitra 2000; Cole 2004; Leitão 2010; Biswas et al. 2012; Sahli and Rejeb 2015). Corruption has the potential to influence the nexus between development and the environment (Lopez and Mitra 2000). Furthermore, Torras and Boyce (1998) use income, inequality and pollution to reassess the EKC while Bhattarai and Hammig (2001) found the EKC-type link between income and deforestation. In addition, many proxies of environmental degradation have been used in EKC empirical literature which include growth in the different economic sectors (Li et al. 2016a; Ren et al. 2014; Bernard et al. 2015; Culas 2012; Al Mamun et al. 2014): exports[1] (Culas 2012; Ren et al. 2014; Jebli and Youssef 2015; Lacheheb et al. 2015; Rafindadi 2016); time (Borhan et al. 2012); industry shares of different sectors in GDP (Apergis and Ozturk 2015; Pata 2018); labour force (Al Mulali et al. 2015); population density (Apergis and Ozturk 2015; Borhan et al. 2012; Ahmed and Long 2012; Panayotou 1997; Selden and Song 1994); population growth (Begum et al. 2015); land (Apergis and Ozturk 2015); foreign direct investment[2] (Pao and Tsai 2011a; Chandran and Tang 2013; Kubicová 2014; Yin et al. 2015; Tang and Tan 2015; Koilo 2019; Sarkodie and Strezov 2019; Liu et al. 2018; Solarin and Al-Mulali 2018); institutional quality (Apergis and Ozturk 2015; Sarkodie and Adams 2018); urbanization (Arouri et al. 2014; Dogan and Turkekul 2016; Omri et al. 2014; Ozturk and Al-mulali 2015; Kasman and Duman 2015; Disli et al. 2016; Al Mulali et al. 2015; Wang et al. 2015; Azam and Khan 2016; Jebli et al. 2015; Wang et al. 2016; Li et al. 2016b ; Al-Mulali et al. 2016; Solarin et al. 2017; Danish et al. 2020; Pata 2018; Sarkodie and Adams 2018); opening ratio (Basarir and Arman 2014); human development index (Basarir and Arman 2014); financial openness (Shahbaz et al. 2013b; Al Mulali et al. 2015); agriculture land use (Zambrano-Monserrate and Fernandez 2017; Haider et al. 2020; Aziz et al. 2020; Agboola and Bekun 2019; Gokmenoglu et al. 2019); human capital accumulation (Ulucak and Bilgili 2018; Sapkota and Bastola 2017); infrastructure investments (Pereira and Pereira 2017; Erdogan 2020; Georgatzi et al. 2020; Neves et al. 2017) and energy consumption (Ahmed and Long 2012; Saboori et al. 2012; Shahbaz et al. 2013a; Akpan and Apkan 2012; Arouri et al. 2014; Jebli and Youssef 2015; Basarir and Arman 2014; Jung and Won 2014; Jebli et al. 2016; Azam and Khan 2016).

The abovementioned long list of control variables is another source of reaching different conclusions about the EKC hypothesis. Robalino-López et al. (2015) argue that economic development, population growth, technological change, international trade, lifestyles institutional structures, resource endowments and transport models can affect the level of CO_2 emissions. The inclusion of a large number of independent variables in the regression model is a way to prove almost anything and achieve conclusions in line with the prior beliefs (Leamer 1983). Leamer commenting on the work of his contemporaries argues that "hardly anyone takes data analysis seriously". He further states that conventionally reported empirical results overstate and disrupt the precision of estimates.

Data series, the order of polynomial and output

The choice of data series also leads to varying conclusions about the EKC hypothesis. Both time series and panel data series have been employed to examine the EKC. The country

[1] International trade appears in many of the empirical studies as it is one of the most important factors that can explain the EKC. Trade causes pollution by increasing the size of the economy. However, many economists contradict this argument (Birdsall and Wheeler 1993; Jones and Manuelli 1995). However, trade can increase pollution through scale effect and improve environmental quality through composite effect.

[2] As a primary means of technology acquisition, many developing countries heavily depend on technology transfers through FDI and set environmental standards that mismatch efficiency levels and thus become pollution haven (Dean 2004; Neumayer 2003; Wheeler 2000). These environmental friendly technologies reduce pollution level; however, increasing concern about environment globally can disrupt these investments flows (Xing and Kolstad 1995; Letchumanan and Kodama 2000).

data consists of developed countries and countries in the process of development (Fodha and Zaghdoud 2010, Tunisia; Saboori and Sulaiman 2013, Malaysia; Alkhathlan and Javid 2013, Saudi Arabia). The panel data studies focus on a group of countries that have some common characteristics like the Middle East (Ozcan 2013); MENA (Ozturk and Akaravci 2011; Farhani et al. 2014); Asia (Bhattarai and Hammig 2001; Apergis and Ozturk 2015); ASEAN (Borhan et al. 2012); North America (Bhattarai and Hammig 2001); Africa (Bhattarai and Hammig 2001) and BRICS (Pao and Tsai 2010, 2011b) countries. The purpose of these studies is to compare countries' results. One might be tempted to replicate advanced countries' work on developing countries and vice versa yet the other may content this is of interest to know whether this proposition has more extensive applicability. Critical thinking would suggest that it would not be a fruitful line of inquiry and there should be unorthodox thinking in the testing of the EKC hypothesis.

Three forms of a polynomial (linear, quadratic and cubic) are common in EKC literature and each form is supported by different arguments. For example, Van Alstine and Neumayer (2010) support the inclusion of cubic term on the basis that a second tipping point may exist. Canas et al. (2003) find support for an inverse *U*-shaped curve when they use both quadratic and cubic terms in the function; however, they suggest that great caution is required while viewing robust results. On the contrary, Zhang (2012) states that an inverse *U*-shaped curve may be a result of a restrictive functional form while *N*-shaped or an even more flexible shape may exist. Yang et al. (2015) use linear, quadratic and cubic forms of the model without mentioning which specifications is more plausible.

In addition to the order of the polynomial majority of the economist advocate that variables should be used in logarithmic form rather than in level form. For instance, Stern (2003) supports the use of log-log specification on the basis that the process of economic development produces wastes and regressions that assume the level of indicators equal to zero are not appropriate. Likewise, the use of the log-log form with panel data is also supported by Schmalensee et al. (1998) as the combination of country and year fixed is more suitable than additive effects, given the heterogeneity of countries in the panel. On the other hand, Van Alstine and Neumayer (2010) use the model in levels with no logs while Holtz-Eakin and Selden (1995) use both specification and found no significant differences. The above discussion shows that log models and non-log models may lead to different findings and provide support for prior perception which is quite common in the empirical literature.

The output of the EKC studies is not consistent and has led to different types of relationships between pollution and income. The results produced by this empirical literature consists of the non-existence of the EKC (Roca et al. 2001; Kubicová 2014; Fujii and Managi 2016; Ozcan et al. 2018; Destek et al. 2018; Monserrate et al. 2018; Adu and Denkyirah 2019); *U*-shaped (Ozcan 2013; Khan et al. 2016); inverted *U*-shaped (Ahmed and Long 2012; Ozcan 2013; Shahbaz et al. 2013a; Apergis and Ozturk 2015; Khan et al. 2016; Jebli et al. 2016; Apergis 2016; Wang et al. 2016; Solarin et al. 2017; Ali et al. 2017; Zambrano-Monserrate and Fernandez 2017; Haider et al. 2020; Altıntaş and Kassouri 2020; Erdogan 2020); *N*-shaped (Vincent 1997; Omay 2013) and wave shaped (Wang et al. 2017).

Methodologies

According to Stern (2003), the empirical work on the EKC is econometrically weak which makes empirical evidence on the EKC far from clear. Based on the theoretical explanation of the original EKC hypothesis, at least six combinations can be formed of various dependent and independent variables with the main objective in each case whether the data set supports the specification. Based on different statistical tests available in the literature, it is not surprising to conclude that some studies report significant while the other insignificant results meaning the existence and non-existence of the EKC hypothesis.

The following general reduced form model is applied to test the EKC hypothesis in the empirical literature (Dinda 2004).

$$y_{it} = \alpha_i + \beta_1 x_{it} + \beta_2 x_{it}^2 + \beta_3 x_{it}^3 + \beta_4 Z_{it} + e_{it}$$

i 1,…. N countries
t 1….., T years

where y is the dependent variable representing environmental pollutant, x is the independent variable used as a proxy for income, z is a vector of other control variables that can affect y, α is the intercept, β_i are the estimated regression coefficients and e is the error term. The inclusion of the cubic term of x tries to examine an *N*-shaped rather than an inverted *U*-shaped relationship between income and environmental degradation. Many studies use the above-reduced form model in the logarithmic form (Stern 2004b; Adu and Denkyirah 2019; Koilo 2019; Haider et al. 2020; Ng et al. 2020; Erdogan 2020; Altıntaş and Kassouri 2020). The functional form that best fits the data and has higher explanatory power inside the data range is selected (Lieb 2003). The model is estimated and tested for significance of parameters, i.e. β_i. Dinda (2004) states that the following seven possible outcomes may emerge;

i. If all β_i are simultaneously equal to zero, then no relationship exists between x and y.

ii. If β_1 is positive while β_2 and β_3 are equal to zero, then either monotonic increasing or linear relationship exists between x and y.
iii. If β_1 is negative while β_2 and β_3 are equal to zero, then either monotonic decreasing relationship exists between x and y.
iv. If β_1 is positive, β_2 negative and β_3 is equal to zero, then an inverse U-shaped relationship exists between the variables.
v. If β_1 is negative, β_2 positive and β_3 equals zero, then a U-shaped relationship exists between the variables.
vi. If β_1 and β_3 are positive while β_3 equals zero, then there exists an N-shaped relationship.
vii. If β_1 is negative while β_2 and β_3 are positive, then there exists an N-shaped relationship.

The only case iv is the EKC relationship.

Due to the short data series available for analysis, sophisticated statistical tests have emerged, but it does not mean that relatively simple statistical approaches are less important. Modern methodologies are the results of well-known issues linked with multiple regressions. More sophisticated approaches intend to address these deficiencies. Approaches, like cointegration that attempts to examine the long-run relationship among the variables, may not be useful in the case of EKC hypothesis testing as it does not produce consistent results when variables are related in a nonlinear way. If the objective is to verify the long-run association among the variables, then cointegration is the most suitable technique. The Johansen cointegration test (Abdallah et al. 2013; Saboori and Sulaiman 2013b; Tiwari et al. 2013; Farhani et al. 2014; Ahmed 2014; Shahbaz et al. 2014; Tutulmaz 2015; Azam and Khan 2016); vector error-correction model (VECM) (Ang 2007; Acaravci and Ozturk 2010; Alkhathlan and Javid 2013; Chandran and Tang 2013; Burnett et al. 2013; Ahmed 2014; Ahmed et al. 2015; Wang et al. 2015; Jebli and Youssef 2015; Dogan and Turkekul 2016; Monserrate et al. 2018) and the autoregressive distributed lag (ARDL) bounds testing approach to cointegration (Ahmed and Long 2012; Saboori et al. 2012; Alkhathlan and Javid 2013; Tiwari et al. 2013; Farhani et al. 2014; Ahmed et al. 2015; Jebli and Youssef 2015; Al-Mulali et al. 2016; Dogan and Turkekul 2016; Javid and Sharif 2016; Rafindadi 2016; Baek 2016; Hervieux and Darne 2016; Mrabet and Alsamara 2017; Amri 2018; Bello et al. 2018; Monserrate et al. 2018) being popular choices. Consistency in a small sample is one of the celebrated advantages of the ARDL approach. The empirical literature mainly focuses on whether the statistical method was applied appropriately to specific data sets, yet it camouflages the original theoretical hypothesis. To find the turning point of the EKC, authors apply ARDL (Saboori and Sulaiman 2013) bounds testing approach.

However, we can find other techniques as well in empirical literature on EKC like GMM (Taguchi 2012; Apergis and Ozturk 2015; Al Mulali et al. 2015; Ozturk and Al-mulali 2015; Khan et al. 2016; Barra and Zotti 2018; Kong and Khan 2019; Mania 2020); fixed effect and random effect model for panel data (Akpan and Apkan 2012; Jayanthakumaran and Liu 2012; Al Sayed and Sek 2013; Yin et al. 2015; Olale et al. 2018; Liu et al. 2019); OLS (Pao and Tsai 2010; Armeanu et al. 2018); 2SLS (Borhan et al. 2012: Ozturk and Al-mulali 2015); FMOLS (Ozcan 2013; Cho et al. 2014); Larsson, Lyhagen and Löthgren (LLL) cointegration test (Bella et al. 2014); MOLS (Alper and Onur 2016); Hidden Markov regression models (Martinez-Zarzoso and Maruotti 2013); DOLS (Song et al. 2008; Apergis and Ozturk 2015); Grey prediction model (Pao and Tsai 2011b; Pao et al. 2012); bootstrap panel causality test (Ozcan et al. 2018; Ozcan and Ozturk 2019); Stock-Watson-Shin cointegration test (Esteve and Tamarit 2012); continuous wavelet approach (Bilgili et al. 2019); panel smooth transition regression (Aydin et al. 2019); ECM bootstrap cointegration (Westerlund 2007); panel cointegration (Churchill et al. 2018); bootstrap panel rolling window causality (Yilanci and Ozgur 2019); bivariate model and panel non-causality test (Sarkodie and Strezov 2018); pooled mean group (Haider et al. 2020; Beyene and Kotosz 2020); dynamic common-correlated effects (Chudik and Pesaran 2015); common-correlated effects (Apergis et al. 2017) and Markov switching equilibrium correction model (Charfeddine and Mrabet 2017). Some studies use the Granger causality test to examine the direction of the relationship between income and environmental degradation (Benavides et al. 2017; Roca et al. 2001; Alper and Onur 2016; Acaravci and Ozturk 2010; Kubicová 2014) and Toda Yamamoto Dolado Lütkepohl (Saboori et al. 2016).

The above discussion reveals three prominent features. First, various pollutants and different control variables are used to test EKC empirically since the celebrated work of Grossman and Krueger (1992). However, despite the use of different pollution indicators and control variables, empirical findings are inconclusive. Secondly, usually, CO_2 emissions have been the focus of empirical literature on EKC which may lead to unreliable and inconsistent estimates as aggregate carbon emissions are inflated due to a shift in mix effluent from sulphur and nitrogen oxides to carbon (Ulucak and Bilgili 2018). To avoid bias emerging from the upward trend of CO_2 emissions, researchers should focus on a more inclusive pollution indicator like an ecological footprint. Finally, time series and panel data econometric techniques are used which may not produce robust estimates in the omitted variable case and do not cater for the possible cross-country/section dependencies and heterogeneity (Narayan et al. 2016). In light of the above insights, it mandates the use of econometric techniques to test EKC which can potentially deal with these different issues (Altıntaş and Kassouri 2020). The methodologies used to test the EKC are criticized for not detecting long-run relationships and it is not clear what inference can be deduced from this literature and omitted variable bias likely to be cause

for this problem referred to as spurious regression Stern (2004a). The presence of unit root does not necessarily lead to cointegration. Also, when cointegration is found, the form of the EKC varies significantly across countries (Moosa 2017) which has led Van Alstine and Neumayer (2010) to conclude the possibility of spurious results. The first difference form models solve the problem yet cointegration is superior; however, few studies apply cointegration to test the EKC hypothesis (Perman and Stern 2003). The aforementioned discussion undoubtedly shows the application of several methodologies to test the EKC empirically. Different econometric methodologies applied to different periods for a range of countries do not produce conclusive results.

Some critics of the EKC

Since its advent, the EKC per see has unleashed conflicting reactions (Chen et al. 2019). Critics of the EKC assert that it supports economic expansion ignoring the cost to the environment, and the notion that ultimately the environment will improve as a result of economic growth is highly problematic. Insufficient evidence is available that the EKC holds for all environmental problems particularly in the case of climate change. However, proponents of the EKC believe that the environmental damage resulting from economic growth can be cleaned up as it happened in the case of many highly industrialized nations. They have reached a general conclusion that: "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 high environmental expenditures, result in leveling off and the gradual decline of environmental degradation" (Proops and Safonov 2004). Therefore, economic growth and improved environment are compatible. However, the causal relationship that an increase in income level will eventually improve the environment has not been consistently demonstrated (Kong and Khan 2019). Furthermore, Dasgupta et al. (2002) state that industrialization continues to create new and toxic pollutants even some of the pollutants follow the EKC hypothesis. Mills and Waite (2009) conclude that the goals of economic expansion and biodiversity are incompatible as species are disappearing 1000 times faster than in all of history due to increased human business activity.

The environmental Kuznets curve is criticized on several grounds. Its implicit assumptions about the direction of causality running from income to environmental degradation (Arrow et al. 1995), normal distribution of income (Stern et al. 1996) and different estimates derived on the pollutant in use (Lieb 2003) are questioned. Severe criticism is placed on the methodological issues, estimation problem and targeting the production side while ignoring consumption evolution (List and Gallet 1999; Aslanidis and Iranzo 2009).

The mainstream economic literature, using either cross-sectional or panel data sets, considers average income as the only explanatory variable that is linked to environmental quality and normally distributed. However, world income distribution is highly skewed (Stern 2004a; Stern et al. 1996) that makes estimating a turning point income level of little importance. Previous empirical literature establishes that world income is not normally distributed (Sala-i-Martin 2006; Milanovic 2002). The EKC postulates that developing economies follow the development path of developed countries and both groups of economies find themselves in different phases of the EKC (Vincent 1997). In reality and empirically proven, due to many constraints like their colonial history, unfavourable links with foreign banks and corporations and the raw nature of exports that earn low price, developing countries cannot follow the growth patterns of developed nations (Grimes and Roberts 1997). Further pollution heaven hypothesis incentivizes developing countries to import from the regions with less strict environmental regulations instead of producing domestically with less environmentally friendly technology. Therefore, there is no guarantee that poor economies will follow the historical path of developed countries. The EKC is also criticized for its reliance on the supply side ignoring the consumption patterns (Rothman 1998). The economic activity involves both the production and consumption process; therefore, the studies should also focus on the income elasticity of demand for pollution-intensive goods. Any positive effect of improvement in production technologies may be counterbalanced by an increase in the demand for pollution-intensive goods. According to Panayotou (2003), an increase in municipal waste and CO_2 shows that consumption patterns in developed countries are still unsustainable. Therefore, the EKC studies need to focus on both patterns to avoid misleading and incomplete conclusions (Kaika and Zervas 2013). The choice of pollutants by many EKC studies is also open to criticism due to its local versus global relevance and short-run versus long-run impacts. According to Arrow et al. (1995), the EKC get some validity in empirical literature when pollutants in question are related to short-run and local abatement cost. Being a local phenomenon, the effects of these pollutants are easily recognizable by local communities (Dinda 2004). These pollutants include sulphur dioxide and fecal coliforms (Lieb 2003). On the other hand, no evidence of the EKC can be found when the long-run effects of pollutants are considered (Arrow et al. 1995). Many of the empirical studies dealing with CO_2 emissions and greenhouse gases report a positive relationship rather than an inverted *U* relationship (Ansuategi and Escapa 2002). Econometric methodologies used in empirical studies on the EKC are severely criticized by different authors with major criticism on data used, as data on pollutants is of poor quality (Stern et al.

1996). Furthermore, empirical findings are seriously restricted due to the unavailability of sufficient long data for all the countries. The unavailability of long-time series data forces researchers to study EKC by using panel data (List and Gallet 1999). Therefore, the findings reached for the whole sample does not imply the similar outcomes will emerge in the case of an individual country. Therefore, the EKC hypothesis should be tested by employing longer time series data (Dijkgraaf and Vollebergh 2001, 2005). List and Gallet (1999) point out that opposite outcomes are reached when panel and time series data are used in the same sample. Some other econometric drawbacks associated with empirical methodologies used to test the EKC include omitted variable bias (Stern 2004b), lack of any test on heteroscedasticity (Stern et al. 1996) and least focus on the spatial effect of emissions. This criticism on econometric methods leads us to conclude that statistical analysis carried out in the EKC studies is not robust; hence, the structural model should be preferred to reduce form models to form reliable and appropriate policies.

Omitted variable bias is another weak aspect of the EKC as Stern and Common (2001) states that the EKC suffers from significant omitted variable bias and is an incomplete model despite these models have time trend variable that accounts for time-varying omitted variable and stochastic shock (Stern 2003). Potential omitted variable bias arises from testing different variables individually and the role of other additional variables like trade remains unclear given the poor statistical properties of the most EKC model (Stern 1998). Being the deterministic nature of the time variable in the EKC equation, it is unable to capture the effect of missing variables particularly stochastic shocks. As an unexhaustive list of variables can be found that can be introduced in the EKC models, one way to account for missing variable bias has been identified in the EKC literature is to use an unobserved component model that is estimated in a time-varying parametric framework (Moosa 2017). Socially deprived areas are more vulnerable to the environment (Li et al. 2018), and the EKC is more applicable to developed economies with the colonial history and superiority in trade (Grimes and Roberts 1997). On the other hand, the less developed world of today may not follow the path proposed by the EKC hypothesis (Nahman and Antrobus 2005). The problem with the EKC studies is not using this or that method but there are so many possibilities that results can be obtained for or against the EKC by using any data set. It might still be argued that whatever method one uses to test, the EKC holds grounds based on its consistency with a particular interpretation.

The above discussion reveals that the main drawback of the EKC hypothesis is its inability to acknowledge that the resilience of the environment limits economic growth. Contrary to this, the EKC favors unchecked economic growth as it ambitiously assumes that the environmental damage is eventually repairable. This supposition is seriously dangerous (He 2007). The fallacy of environmental remediation camouflages the fantasy achieved by the EKC hypothesis. In addition, EKC mistakenly posits that economies can grow infinitely without considering that natural resources are finite. Worse, the EKC overlooks the fact that some environmental problems like animal extinction are irreversible and permanent, and therefore, after its happening, it cannot be rectified with any among of money or time (Karsch 2019).

Conclusions

The motivation for this study was to explore the state of the art in the area of EKC. We investigated issues that need to be studied within existing EKC literature. Departing from the current EKC literature which typically tests the relationship between environmental quality and economic activity, this paper concentrates on the curious attraction of the EKC and critically analyses the empirical literature on the criteria of pollutant selected, the methodology used, data selected and implicit assumption of the EKC like normal distribution of world income and the perception that developing countries will follow the path of developed nations to achieve a high level of economic development.

The literature on the EKC is quite large, and the results are at best mixed. The study concludes that different shaped (monotonic, inverted *U*, *N*, wave, etc.) relationships exist between environmental indicators and economic development. Some empirical studies reported the non-existence of the EKC hypothesis. No feedback from environmental pollutants to economic development is found as an income factor that is assumed as an exogenous variable and it does not reduce economic activity (Arrow et al. 1996). The turning point of the EKC is sensitive to the variations in various pollutants, data and model selection. Our series of criticisms of the testing of the EKC hypothesis is not free from the bias of "omission" meaning loose definition of environmental degradation and "commission" in danger associated with econometric "overkill" which has marred the theoretical spirit of the original EKC. In the end, the study concedes that a cardinal change in the definition of environment in several of the countries can change policy significantly ranging from active to passive. However, due to a lack of expertise in psychology, the authors cannot demonstrate the ever-increasing fascination of the EKC hypothesis for econometricians that have different objectives than policymakers. Perhaps this hypothesis is being tested as it happens to be there. Others articulated models of income-environment nexus may deserve attention.

The paper concludes that despite large criticism, the EKC studies continue to appear in empirical literature with regular intervals. The EKC remains the best tool to express the relationship between pollutants and economic development among researchers. Our findings reveal that the EKC curve

is empirically tested while using panel data and CO_2 emissions that do not help to generalize the results and conclusion change within the same sample when the EKC is tested for individual countries. Therefore, there is a need to apply longer time series data to test EKC for a country and other pollutants may also provide useful information in the policy framework. Our analysis of the EKC is useful to help understand some of the controversial issues discussed in the empirical literature. The warning from Stern (2003) still equally valid that when econometric considerations are addressed, there is rare evidence of the EKC and most indicators of environmental degradation are monotonically rising in income.

In brief, the EKC cannot be described as a universal law as overwhelmingly for or against the EKC results can be obtained from the same data. Therefore, fragile results obtained in the EKC studies are a characteristic of the empirical literature on the EKC. Seldom do many agree on the precise solutions to environmental pollution, but we should not be convinced that economic growth on its own will solve these issues. We should not be persuaded that affluent countries will invest heavily to level off and gradually contain their environmental pollution. It is uncertain whether they will adopt cleaner technology, effectively enforce environmental laws or allocate huge sums of money to conserve the environment. Therefore, policymakers must not encourage unlimited economic growth to cure environmental problems.

Authors' contributions M.I.H. conceived the concept and wrote "Introduction", "Some critics on EKC", "Previous studies" and "Conclusion" sections. A.H. wrote the "Micro-foundation of EKC", "Methodologies" and "History and nature of the EKC" sections. M.A.K. prepared "The measure of environmental degradation", "Determinants of environmental degradation" and "Data series, the order of polynomial and output" sections.

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