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Environmental Kuznets Curve: An Empirical Analysis in the Indian Context

Sakshi Gambhir*

ABSTRACT

The relationship between economic growth and environmental quality has been much under dispute. According to the EKC (Environmental Kuznets Curve) hypothesis, environmental damage increases in the early stages of economic growth, but diminishes once nations reach higher levels of income. While the notion EKC is well established, there is controversy about its shape, incidence and determinants. In this paper, we model EKC with the variables of GDP and CO₂ emissions (aggregate and per capita) using alternative model specifications to bridge the gap between conventional and modern EKC literature. We also place the theoretical construct of EKC into a policy-oriented framework by incorporating the impact of four global policy periods namely, liberalisation, globalisation, world recovery and global financial crisis. We substantiate a cubic form of EKC in the Indian context for the time period 1991 to 2014. With aggregate CO₂ emissions as the dependent variable, the linear, quadratic and cubic terms are all significant with the expected signs, which confirm an N-shaped EKC for India. Even with per capita emissions as the dependent variable, existence of an N-shaped EKC is established. In this case however, evidence on the cubic term is rather weak which points towards the difference in socio-psychological factors that influence the revival of upturn in the case of India. The policy period analysis does not show any distinct results, which could be due to contradictory effects on different variables and volatility in these variables.

Keywords: *Environmental Kuznets Curve; Environment; Development; Trade; Growth.*

1.0 Introduction

Since 1991, when economists first reported a systematic relationship between income changes and environmental quality, the relationship known as the Environmental Kuznets Curve (EKC) has become standard fare in technical conversations about the environment policy. Central to discussions on development and environment has been

*Assistant Professor, Janki Devi Memorial College, University of Delhi, Delhi, India. (Email id: gambhir_sakshi@yahoo.co.in)

the dimension of trade and investment liberalisation resulting in the entire development debate being revisited from the point of view of trade, development and the environment.

The defenders of free trade have often relied on the EKC hypothesis and argued that trade generated resources, in particular the financial resources, would enable economies to make investments for environment protection and conservation, which would otherwise be unaffordable. They further contend that trade can improve environmental outcomes by encouraging greater efficiency, diffusing abatement technologies and raising environmental awareness. The opponents, on the other hand, posit that environmental problems proliferated in the process of global integration achieved through trade and investment liberalisation could be irreversible, with possible destabilising effects for the developing economies.

It has been believed and learnt from experience that trade and investment liberalisation could stimulate economic growth and foster greater welfare. But the sustainability of such growth and welfare has been questioned on several occasions. At the heart of such sustainability concerns lies the complex and highly debated relationship of trade and environment. The implications of falling cross-border trade and investment barriers on environment are far too significant to ignore. With national economies merging and pressure on ecosystems mounting, this trade-environment interface is often characterized as a conflicting one, but the possibilities of conciliation between the two are also not ruled out. The Environmental Kuznets Curve challenges the instinctive dichotomy between development and environment as it offers greater economic growth as a means to solve environmental problems. In this work, we are specifically examining carbon dioxide (CO₂) emissions, which are a major indicator of environmental degradation and Gross Domestic Product (GDP), a proxy of economic development. These variables enable us to analyze the existence of EKC in the Indian context. The original EKC literature restricts itself to a quadratic form of the relationship between GDP and CO₂ emissions, in aggregate or per capita terms. This is on account of the delinking hypothesis. The new literature challenges this quadratic form of EKC where it is clearly established that the EKC shows up as an N-shaped curve. We, therefore, attempt to model this relationship between GDP and CO₂ emissions (aggregate and per capita) with alternative model specifications to bridge the gap between conventional and modern EKC studies.

1.1 Objectives

It is in the light of this, that the following objectives are set.

- (i) To test for the different forms of Environmental Kuznets Curve in the Indian context for the time period 1991 to 2014.

- (ii) To assess the impact of structural breaks caused due to the advent of WTO, the period of world recovery and the global financial crisis on the EKC analysis.

1.2 Hypotheses

Against this backdrop, we formulated the following primary hypotheses:

- There is not enough evidence to validate the construct of Environmental Kuznets Curve in the Indian context.
- The exogenous structural breaks caused due to WTO, world recovery and crisis; do not have any impact on the EKC analysis.

The rest of the study is organized as follows. Section 2 lays down the conceptual framework for EKC highlighting some of the crucial dimensions of the trade-environment relationship. Section 3 provides a brief review of the extant literature on EKC along with a critical analysis of the same. Section 4 discusses the data sources and the methodology employed. Section 5 presents the analysis and results. Section 6 concludes.

2.0 Conceptual Framework

The debate on growth and development has largely been argued during the seventies and eighties the world over. There were two identifiable strategies of economic development mainly meant for developing economies, namely the import-substitution strategy and the export-oriented strategy. Subsequent to the eighties, in the nineties the concern shifted towards the global environment through the emphasis on pollution and other forms of environmental degradation. Thereafter, the entire development debate has been revisited from the point of view of trade, development and the environment. This awareness has come about following the sudden rise in environmental variables, particularly CO₂ emissions and has been further strengthened by global phenomenon such as global warming, which is caused by accumulation of greenhouse gases (GHG) (mainly carbon dioxide) in the atmosphere. This entire gamut of environmental factors is clearly identifiable with the sudden growth and development of both incomes as well as trading volumes.

Furthermore, in recent times, an added dimension has been the substitution of trade with investment. This phenomenon complicates the relationship between trade, development and environment. Although the initial impetus came globally during the late eighties, in India it happened in 1991. During this period, the Indian economy was deregulated wherein various controls such as industrial licensing, exchange rates and interest rates were deregulated. There is a clear association between opening up, *liberalisation*, deregulation, growth in trade and the international business environment.

Hence, it was expected that during this phase growth would be promoted. The implications for the environment however are a derivative of the broader growth pattern.

Also, *globalisation* has been initiated in the form of setting up of WTO. In general, globalisation refers to the establishment of a common international business environment. The three main principles that seek to ensure such commonness are MFN (Most favored nation), level playing field and national treatment. Jointly, these three principles ensure that all countries across the world have an equal opportunity to trade as well as invest in any other country of the world on equal terms. This is largely facilitated by the removal of tariff and non-tariff barriers and the establishment of certain agreements, mainly TRIPS (Trade Related Aspects of Intellectual Property Rights) and TRIMs (Trade Related Investment Measures). The expectation therefore is that, with the advent of WTO a new era had begun whereby there would be a narrowing down of the divergence between the developed and developing countries.

Against this backdrop, the global economy has exhibited a pattern of growth and development in the past three decades. However, as a precursor to the period of liberalisation, since 1987 there had been some attempts at liberalisation both in the Indian economy and the global economy. The global economy witnessed rapid growth in the period from 1987 to 1997 but it slowed down during the period 1997 to 2001. This was because of the Asian Financial Crisis and the withdrawal of portfolio investment after this crisis. This crisis had a cascading effect in the form of the Y2K bug and the dot com bubble because of which the world economy witnessed a near disaster. However, the world economy showed resilience and witnessed an upsurge in a couple of years starting from 2002. There was a near boom situation, which led to positive growth trends across the world. Thus, the period from 2002 up to 2007 is considered in the literature to be the period of *world recovery*.

What also needs to be emphasised is that the United States hugely over-invested in housing during this period from 2002 to 2007. Financial institutions then packaged the loans in ways that hyper charged what could have been an ordinary downturn in the United States housing market into a *global financial crisis*. In other words, loss of confidence by U.S investors in the value of sub-prime mortgages caused a liquidity crunch, which in turn resulted in the U.S Federal Bank injecting a large amount of capital into the financial markets. By late 2008, the crisis had worsened as stock markets around the globe crashed and became highly volatile. Governments around the world struggled to rescue giant financial institutions as the fallout from the housing and the stock market collapse worsened. Since then, home economies across the globe have been facing numerous economic difficulties affecting their ability to produce in their own country, inducing them relocate to the developing world.

On the whole, each of these policy periods namely, liberalisation, globalisation, world recovery and global financial crisis, have had considerable implications for the global investment patterns, developmental policies and the state of the environment. Our approach has been to enter into the debate on trade and environment through a policy period analysis. This helps in placing the theoretical construct of EKC into a policy-oriented framework. The existing literature looks at EKC as a theoretical concept; therefore it fails to relate it to the different policy periods globally.

2.1 Environmental Kuznets Curve (EKC)

According to the EKC hypothesis, environmental damage increases in the early stages of economic development, but diminishes once nations reach higher levels of income, suggesting that the relationship between income (economic development) and environmental degradation takes the shape of an inverted U (Figure 1). This happens because developed countries have the necessary technologies for pollution abatement and also the necessary capital for implementing such technologies. The curve is named after Nobel laureate Simon Kuznets, who purported an inverted-U shaped relationship between economic growth and income inequality. He propounded that income inequality increases over time and then after a threshold becomes more equal as per capita income increases (Kuznets, 1955).

Figure 1: A Hypothetical Global EKC

Source: Murthy and Bhasin, 2016

In the early stages of economic growth, primary production dominates, there is an abundance of natural resources and limited generation of wastes but in the course of development and through industrialization, economies experience natural resource depletion and waste accumulation. During this phase, there is a positive relationship between economic growth and environmental degradation. With further economic growth, services, improved technology and information diffusion limit the material bias of an economy and result in reduced environmental degradation (Panayotou, 2003). The turning point in Figure 1 represents that level of income beyond which environmental degradation gets delinked from the process of economic growth. This is called the threshold level.

2.2 The de-linking and re-linking hypothesis

Some explanation for the EKC downturn is the explanation that comes from literature emanating from the developed countries themselves. It is argued that technology and capital, both of which developed countries have in abundance, are the main reason for establishing the de-linking hypothesis. De-linking refers to decoupling of environmental impacts from economic growth. In other words, it is the process whereby aggregate economic activity gives rise to reduced environmental impacts (Vehmas et al., 2003). The argument is that developed countries have the capital because they are capital intensive and that capital can buy green technologies. This leads to de-linking in the sense, when the developed countries go beyond a threshold, they can afford to harness such technologies, which are expensive but effective in reducing environmental degradation.

As against this, developing countries neither possess the technology nor do they have the necessary resources so as to implement these technologies. Meanwhile, developing overpopulated economies are purported to have two very negative features that are likely to aggravate the environmental problem; these are poverty and overpopulation. It is, therefore argued that developed countries alone have the potential to delink pollution from growth. In the first place, developing countries are not able to come out of the low-level equilibrium trap, secondly even if they are able to do so, they do not have the resources, both technological and capital so as to effect such a delinking.

However, even if the de-linking hypothesis holds true, one could still doubt if the observed improvements in environmental quality would sustain in the long run. If such improvements could not be extrapolated into the future, delinking would only be a temporary phenomenon. This implies that there might come an income level, where there would be technological and economic upper bounds to improvements in environmental efficiencies, at least until further breakthroughs in research and development occur or a more intensive application of environmental policy checks is implemented. At this stage the de-linking conditions would not hold any more and environmental degradation and

economic growth would be relinked again. This is referred to as the re-linking hypothesis (De Bruyn and Opschoor, 1997). Re-linking could be defined as the empirical validation of a process in which pollution intensity has been stabilized or starts to rise again (Vehmas et al., 2003).

This entire process signifies that EKC would not hold in the long run. What one could foresee is an N-shaped curve, which exhibits the same inverted-U shaped pattern initially but after a certain level of income is reached, the relationship between economic development and pollution becomes positive again (Pezzey, 1989; de Bruyn et al., 1998).

3.0 Literature Review

Shafik and Bandyopadhyay (1992) examined the relationship between economic growth and environmental quality by analysing the evolution of eight indicators of environmental quality in response to economic growth across 149 countries for the period 1960-90. They concluded that as income rises, most environmental indicators deteriorate initially and many indicators tend to improve as countries approach middle-income levels. Environmental friendly policies and investments are worthwhile and action needs to be taken where there are generalized local costs and substantial private and social benefits.

Holtz-Eakin and Selden (1995) use global panel data between CO₂ emissions and per capita income, and then use the estimated trajectories to forecast global emissions of CO₂. Evidence suggested a diminishing marginal propensity to emit CO₂ as economies develop despite which global CO₂ emissions shall continue to grow at an annual rate of 1.8 per cent, a result that is not sensitive to average output growth. Moreover, economic and population growth will be most rapid in the lower-income nations that have the highest marginal propensity to emit CO₂.

Jha and Murthy (2004) established that a certain 'type of development' that characterizes high consumption countries is primarily responsible for Global Environmental Degradation (GED). They shifted the focus to consumption in the growth-environment debate with the help of a consumption-based HDI and estimated a Global EKC by examining over 174 countries. They concluded that urbanized, open, high income and high-energy use economies had a clear association with a high degree of environmental degradation. Also, the Global EKC did not seem to have an inverted-U shape. A cubic representation of the same appeared to be the most appropriate with high-consumption countries contributing excessively to GED. The middle-consumption countries were contributing slightly less while the low consumption countries were contributing insignificantly, or even negatively, to GED. Therefore, a certain type of

development led to high incomes and consequently high consumption, which resulted in environmental degradation.

Murthy and Bhasin (2016) examined the theories of EKC and pollution haven hypothesis while looking at the type of economic development through GNI per capita, degree of urbanization, energy use and FDI flows. With a panel study for 69 countries, they emphasized the shortcomings of the traditional EKC concept, which captures only the level of economic development. They found clear evidence of an inverted-U shaped EKC for the low-income and middle-income countries; and a U-shaped EKC pattern for the high-income countries. Jha and Murthy (2003) estimated a Global EKC by relating an aggregate index of environmental degradation to a better measure of economic development (in comparison to per capita income). With a panel study of 174 countries, they validated the existence of an inverse N-shaped Global EKC. They highlighted the prevalence of extreme inequalities in absolute terms in worldwide distribution of environmental degradation by pointing out how U.S alone had an adverse influence on all the six environmental degradation indicators considered. They emphasized the need for considering absolute level of environmental degradation in different countries to understand the linkages between economic development and environmental degradation.

Babu and Datta (2013) undertook a pooled data analysis involving comparison of a wider assessment of environmental pressure defined by EDI (Environmental Degradation Index) with modified measures of growth (using separate models), for twenty-two developing countries from Asia, Latin America and Sub-Saharan Africa, covering the period 1980 to 2008. From the EDI and GDP model, they found evidence of an N-shaped EKC for Asia and Sub-Saharan Africa but inverted-U shape for Latin America. Meanwhile, from the EDI and DBI (Development Balance Indicator) model, they found evidence for an N-shaped EKC across all three regions. They concluded that increasing state of development index was unable to mitigate environmental degradation beyond a critical level of economic development, as evidenced by an N-shaped relation.

Pao and Tsai (2011) investigated the relationship among real GDP, energy consumption, FDI and emissions in BRIC (Brazil, Russian Federation, India and China) countries in order to assess the impact of economic growth and financial development on environmental degradation. In long run equilibrium, emissions appeared to be FDI inelastic and energy consumption and GDP elastic, if GDP was less than 1.174, while GDP inelastic if GDP was greater than 1.174. Hence, emissions were found to be highly responsive to changes in both energy consumption and real GDP but not in FDI. Also, emissions were found to be initially increasing with the level of income, then stabilizing and subsequently declining, thereby rendering support to the EKC hypothesis. They also validated pollution haven and halo and scale effects among BRIC countries. Zhao et al. (2013) have tested the

validity of the EKC hypothesis for long term historical CO₂ emissions by using the traditional EKC equation and a new linear model attempting to identify EKC patterns at individual country, region and global scales with different development stages. It was concluded that different countries with different economic development stages witnessed different EKC patterns, with very rapid increase in CO₂ emissions in the early industrialization stages but slower decrease in emissions during the later development stages, resulting in an asymmetric curve, which could not be explained by the traditional EKC theory alone. This meant that the overall EKC curve was hierarchic and scale-dependent, and composed of many parts of smaller EKCs. Also, the overall development of a country or region might not follow an overall EKC pattern, but the EKC hypothesis could still be justified during different periods of economic growth.

Kanjilal and Ghosh (2013) examined the cointegrating relationship between carbon emissions, energy use, economic activity and trade openness for India to test the EKC hypothesis in the context of possible regime shifts in the long run relationship of the underlying variables, for the period 1971 to 2008. The threshold cointegration tests ascertained a long-run relationship between carbon emission, energy use, economic activity and trade openness with two endogenous structural breaks, which were attributed to the economic crisis of 1990-1991 and the external oil price shocks witnessed by India. The EKC hypothesis was validated for India and the elasticity of CO₂ emissions with regard to energy use and per capita income was found to be high.

Jayanthakumaran et al. (2012) examined the relationship between emissions, growth, energy use, trade and endogenously determined structural breaks for India and China to test for the existence of EKC over the period 1971 to 2007. The findings validated the EKC hypothesis for China and India. In case of China, a 1 per cent increase in per capita income led to a 1.62 per cent increase in per capita CO₂ emissions and a 1 per cent increase in per capita income squared led to a 0.13 per cent decrease in per capita CO₂ emissions. As far as India was concerned, a 1 per cent increase in per capita income led to a large 7.85 per cent increase in the per capita CO₂ emissions and a 1 per cent increase in per capita income squared led to a 0.66 per cent decrease in the per capita CO₂ emissions. India's heavy reliance on domestic production/consumption was cited as one of the reasons for the high level of emissions. With cumulative emissions (as against per capita emissions) as the dependent variable, EKC hypothesis was validated for China in the long run but no long run relationship was found for India.

3.1 Critical Analysis of the Literature

The literature on EKC is devoted to two phenomena: first, testing for existence of an inverted-U shaped relationship between income (per capita) and select environmental

degraders, and second, determination of the threshold level or the turning point, that is, the level of income beyond which environmental quality begins to improve. The early EKC estimates showed that some important indicators of environmental quality such as the levels of sulfur dioxide and particulates in the air actually improved as incomes and levels of consumption went up. Since then, this theory has been tested and validated for certain countries using specific indicators of environmental degradation. But, there have been some key concerns:

- The inverted-U shape of EKC is taken for granted and empirically examined for countries by relating individual degraders with individual indicators of economic development. But, linking individual pollutants to the level of per capita income (as done in most cases) could produce misleading conclusions as pollutants could be related to each other and to other indicators of environmental degradation. Also, a country's per capita income maybe only an imperfect indicator of its development (Jha and Murthy, 2003).
- There are several econometric concerns. To begin with, the earliest studies were simple quadratic functions of the levels of income, which seemed rather inappropriate. Some studies used a cubic EKC in levels and found an N-shaped pattern. The standard EKC regression model assumed same income elasticity across all countries at a given level of income. Most studies used panel data attempting to estimate both the fixed and random-effects models, but only fixed effects could be estimated consistently. This implied that results based on a particular sample of data could not be extrapolated to other samples (Stern, 2004). Further, issues such as heteroskedasticity, simultaneity, omitted variables bias and cointegration, have rendered the EKC literature econometrically weak.
- Most empirical EKC studies have attempted to estimate the level of average income that would correspond to the threshold level of the typical EKC pattern, with the implicit assumption that world income is normally distributed. However, world income distribution is highly skewed with much larger number of people below world mean income than above it. Therefore, it is the median rather than mean income that is the relevant variable (Stern et al., 1996).
- The early-EKC literature implicitly assumed a uni-directional causality running from income to environmental degradation, thereby ignoring the rebound effects of energy efficiency (Kaika and Zervas, 2013). They don't seem to acknowledge the possibility of environmental degradation having a reverse effect on the process of economic growth.

- Also, validity of the EKC pattern has been contingent on the type of pollutant considered. The inverted-U shape has been supported mostly when the pollutants in question were associated with low and local short-term abatement costs such as sulfur dioxide, particulates, etc. No apparent patterns could be found for pollutants with long-term effects such as CO₂ emissions. Moreover, most EKC studies have focused only on flow and not stock pollutants (Kaika and Zervas, 2013).
- EKC studies have not given consideration to the consumption side of the economy. The forces sufficiently explaining EKC such as structural changes, technological advancements or international trade pertain to the production side. Hence, if the needs of domestic consumption were satisfied by imports, then this effect would not be taken into account in an EKC analysis focusing only on domestic production (Rothman, 1998; Cole, 2004; Jha and Murthy, 2004).

In the light of the aforesaid concerns, the validity of EKC as a universal phenomenon has remained questionable. Empirical analysis has revealed that it may apply to select pollutants and to certain countries assuming different forms (inverted-U, U shaped, N-shaped or monotonic). Therefore, there are bounds to its validity. Also, it is possible that the overall development of a country or region might not exhibit an overall EKC pattern, but the EKC hypothesis could still be justified during different periods of economic growth (Zhao et al., 2013).

4.0 Data and methodology

4.1 Data

Data for the study were sourced from the World Development Indicators, World Bank. Time series data were collected for our two sets of variables; the dependent variable, namely aggregate CO₂ emissions (kt) in model A and CO₂ emissions per capita (metric tons) in model B along with the independent variables, namely, GDP (current US\$) in model A, and GDP per capita (current US\$) in model B, for the time period 1991 to 2014. We also test for structural breaks caused due to the advent of WTO, the period of world recovery and the global financial crisis using dummy variables.

4.2 Methodology

The EKC literature purports a quadratic form of the relationship between GDP and CO₂ emissions. We attempt to model this relationship with different model specifications. Conventionally, EKC is measured either through aggregate CO₂ emissions or per capita CO₂ emissions (Murthy and Bhasin, 2016). The expected functional form is one where the underlying pattern of emissions is quadratic. The original literature restricts itself to such a

form. This is on account of the delinking hypothesis. Such a relationship has been tested by various authors (Grossman and Krueger, 1993; Shafik and Bandyopadhyay, 1992; Grossman and Krueger, 1995; Cole et al., 1997, etc.). Sometimes the specifications in these works are couched in terms of per capita emissions (Selden and Song, 1994; Shafik, 1994; Holtz-Eakin). The essential hypothesis in all such studies is based on the notion that the demand for environmental quality increases as economic growth takes place. This demand is met by two types of responses, one through technology and the other through investment. Cleaner technologies supposedly replace polluting technologies. Secondly, as economic growth takes place, it is assumed that consumption needs reduce more than proportionately so as to allow greater savings and hence, investment, presumably in such cleaner technologies. This is a Keynesian phenomenon. Many of such studies are cross-sectional in nature (Jha and Murthy, 2003). Such an EKC depicts the phenomenon at a point of time. It appears as though countries that are lower down on the curve would eventually move up the curve leading to an increase in CO₂ emissions. Thus, CO₂ emissions are an after-effect of economic development. Continuing further, it is expected that around the range of middle-income countries, the downturn begins to happen because of the reasons stated. Later, this delinking is complete when we visit the developed economies.

Our study is a one-country study. Therefore, the analysis requires slightly different treatment. Coming back to the question of the form of the equation, some of the studies question the quadratic form by arguing that the so-called delinking is followed by a phase of relinking (Jha and Murthy, 2003). This gives rise to an N-shaped EKC due to the relinking hypothesis. What literature does not state with some exceptions (Jha and Murthy, 2006), is that this relinking is not due to technology and investment but it is due to consumption, which increases disproportionately due to socio-psychological factors.

Moreover, some of the arguments about the behavior of the EKC are couched in value terms and in terms of the impact of population. But, Jha and Murthy (2006) have measured the EKC in real terms, which obviates the question of value and in per capita terms, which obviates the issue of population. Consequently, the new literature challenges the quadratic form of the EKC, meaning thereby that the delinking hypothesis operates at a lower level of income than earlier thought of. The purported high-income level, which is supposed to bring the downturn, manifests at a lower level of income. This perhaps implies the presence of cleaner technologies, since they become affordable at the middle-income level. However, in the new literature, it is clearly established that the EKC shows up as an N-shaped curve. This cubic form can be explained through three phases. In the first phase, poorer countries, which have a lower level of consumption, lead to pollution because they cannot afford cleaner technologies. In the second phase, the middle-income level, the investment in cleaner technologies manifests in the form of a dip in the emissions. In the

third phase, which is achieved at relatively higher levels of income, the benefit from cleaner technologies is outweighed by the degradation caused due to excessive consumption. This type of behaviour can only be explained by a cubic form of the equation.

4.3 Analysis for structural breaks

For the purpose of our analysis we have divided our entire time period (1991 to 2014) to account for the impact of the four identifiable phases of trade and development, namely

- 1991 to 1994 (the advent of liberalisation in India)
- 1995 to 2001 (the period of globalisation)
- 2002 to 2007 (the period of world recovery)
- 2008 to 2014 (the period of global financial crisis)

To account for the impact of these four periods, we incorporate three dummy variables in our growth model, namely D_1 (for the period of globalisation), D_2 (for the period of world recovery) and D_3 (for the period of global financial crisis).

D_1 would take on the value one for the period 1995 to 2001 and the value zero for the periods 1991 to 1994, 2002 to 2007 and 2008 to 2014.

D_2 would assume the value one for the period 2002 to 2007 and the value zero for the period 1991 to 1994, 1995 to 2001 and 2008 to 2014.

D_3 would take the value one for the period 2008 to 2014 whereas the value zero for the period 1991 to 1994, 1995 to 2001 and 2002 to 2007.

So, after introducing the dummy variables, the regression equation can be written as follows:

$$\ln Y = a_1 + b_1t + b_2D_1 + b_3D_2 + b_4D_3 + b_5D_1t + b_6D_2t + b_7D_3t + \mu t$$

where

$\ln Y$ = natural log of variable Y

a_1 = intercept at the I policy period

b_1 = growth rate in the I policy period

b_2 = difference in the intercept of II and I policy period

b_3 = difference in the intercept of III and I policy period

b_4 = difference in the intercept of IV and I policy period

b_5 = difference in the growth rate of II and I policy period

b_6 = difference in the growth rate of III and I policy period

b_7 = difference in the growth rate of IV and I policy period

μt = error term.

Hence, with the help of the above written regression equation, we can easily find out the intercept as well as growth rate for different policy periods as follows:

Policy Period	Intercept	Slope
I (Liberalisation)	a_1	b_1
II (Globalisation)	$a_1 + b_2$	$b_1 + b_5$
III (World Recovery)	$a_1 + b_3$	$b_1 + b_6$
IV (Global Financial Crisis)	$a_1 + b_4$	$b_1 + b_7$

In case the initial period does not display any significant growth rate, the slope dummy for the second and the third period shall be their own slopes as such and they need not be added to the initial slopes. Conversely, if either the intercept or the slopes of the subsequent periods were not significant, they would indicate that there is no structural break, respectively, in the intercept or the slope that is, in the level or the growth rate, compared to the base period. In this way by introducing dummies, we can find out the growth rate and the intercept for different policy periods.

All these aspects have been addressed in the framework presented in Table 1.

Table 1: Framework for analysing EKC in the Indian context

Dep. Var. Model No.	Aggregate Carbon dioxide emissions (CO ₂) (in kilotons) (A)	Per Capita Carbon dioxide emissions (CO ₂ PC) (in metric tons) (B)
1	Quadratic EKC	Quadratic EKCPC
2	Cubic EKC	Cubic EKCPC
3	Cubic EKC with breaks in GDP	Cubic EKCPC with breaks in GDPC

In line with the above stated framework, we formulated the following estimating equations.

4.3.1 Aggregate carbon dioxide emissions (CO₂) (in kilotons) as the dependent variable

(a) Quadratic EKC

Functional form: $CO_{2t} = f(GDP_t, GDP_t^2)$

Estimating equation

$$CO_{2t} = \alpha_1 + \beta_1 GDP_t + \beta_2 (GDP_t^2)_t + e_{1t} \quad \dots(1)$$

where

α_1 = intercept (initial level of aggregate CO₂ emissions)

β_1 and β_2 = indicators for testing the existence of a quadratic form of the relationship between aggregate CO₂ emissions and GDP, that is, a quadratic EKC. The expected sign of β_1 is positive while that of β_2 is negative. If these coefficients turn out to be significant with these expected signs, it would confirm the existence of an inverted-U shaped relationship between aggregate CO₂ emissions and GDP for India over the time period 1991 to 2014

(b) Cubic EKC

Functional form: $CO_{2t} = f(GDP_t, GDP_t^2, GDP_t^3)$

Estimating equation

$$CO_{2t} = \alpha_2 + \beta_3 GDP_t + \beta_4 (GDP_t^2) + \beta_5 (GDP_t^3) + e_{12} \quad \dots(2)$$

where

α_2 = intercept (initial level of aggregate CO₂ emissions)
 β_3, β_4 and β_5 = indicators for testing the existence of a cubic form of the relationship between aggregate CO₂ emissions and GDP, that is, a cubic EKC. The expected sign of β_3 and β_5 is positive while that of β_4 is negative. If these coefficients turn out to be significant with these expected signs, it would confirm the existence of an N-shaped relationship between aggregate CO₂ emissions and GDP for India over the time period 1991 to 2014

(c) Cubic EKC with breaks in GDP

Functional form: $CO_{2t} = f(D_1, D_2, D_3, GDP_t, GDP_t^2, GDP_t^3, D_1GDP_t, D_2GDP_t, D_3GDP_t)$

Estimating equation

$$CO_{2t} = \alpha_3 + \beta_6 D_1 + \beta_7 D_2 + \beta_8 D_3 + \beta_9 GDP_t + \beta_{10} (GDP_t^2) + \beta_{11} (GDP_t^3) + \beta_{12} (D_1GDP_t) + \beta_{13} (D_2GDP_t) + \beta_{14} (D_3GDP_t) + e_{13} \quad \dots(3)$$

where

α_3 = intercept (level of aggregate CO₂ emissions at the advent of liberalisation)
 β_6 = change in the level of aggregate CO₂ emissions at the advent of globalisation
 β_7 = change in the level of aggregate CO₂ emissions at the advent of world recovery
 β_8 = change in the level of aggregate CO₂ emissions at the advent of global financial crisis

- β_9, β_{10} and β_{11} = indicators for testing the existence of a cubic form of the relationship between aggregate CO₂ emissions and GDP (cubic EKC). The expected sign of β_9 and β_{11} is positive while that of β_{10} is negative. If these coefficients turn out to be significant with these expected signs, it would confirm the existence of an N-shaped relationship between aggregate CO₂ emissions and GDP for India over the time period 1991 to 2014
- B_{12} = difference in the impact of GDP on aggregate CO₂ emissions between the periods of liberalisation and globalisation
- B_{13} = difference in the impact of GDP on aggregate CO₂ emissions between the periods of liberalisation and world recovery
- B_{14} = difference in the impact of GDP on aggregate CO₂ emissions between the periods of liberalisation and global financial crisis

4.3.2 Per capita carbon dioxide emissions (CO₂PC) (in metric tons) as the dependent variable

(a) Quadratic EKPC

Functional form: $CO_2PC_t = f(GDPC_t, GDPC_t^2)$

Estimating equation

$$CO_2PC_t = \alpha_4 + \beta_{15}GDPC_t + \beta_{16}(GDPC_t^2)_t + e_{14} \quad \dots(4)$$

where

- α_4 = intercept (initial level of per capita CO₂ emissions)
- β_{15} and β_{16} = indicators for testing the existence of a quadratic form of the relationship between per capita CO₂ emissions (CO₂PC_t) and per capita GDP (GDPC_t), that is, a quadratic EKPC. The expected sign of β_{15} is positive while that of β_{16} is negative. If these coefficients turn out to be significant with these expected signs, it would confirm the existence of an inverted-U shaped relationship between per capita CO₂ emissions and per capita GDP for India over the time period 1991 to 2014

(b) Cubic EKPC

Functional form: $CO_2PC_t = f(GDPC_t, GDPC_t^2, GDPC_t^3)$

Estimating equation

$$CO_2PC_t = \alpha_5 + \beta_{17}GDPC_t + \beta_{18}(GDPC_t^2)_t + \beta_{19}(GDPC_t^3)_t + e_{15} \quad \dots(5)$$

where

- α_5 = intercept (initial level of per capita CO₂ emissions)

β_{17} , β_{18} and β_{19} = indicators for testing the existence of a cubic form of the relationship between per capita CO₂ emissions and per capita GDP, that is, a cubic EKC. The expected sign of β_{17} and β_{19} is positive while that of β_{18} is negative. If these coefficients turn out to be significant with these expected signs, it would confirm the existence of an N-shaped shaped relationship between per capita CO₂ emissions and per capita GDP for India over the time period 1991 to 2014

(c) Cubic EKCPC with breaks in GDPC

Functional form: $CO_2PC_t = f(D_1, D_2, D_3, GDPC_t, GDPC_t^2, GDPC_t^3, D_1GDPC_t, D_2GDPC_t, D_3GDPC_t)$

Estimating equation

$$CO_2PC_t = \alpha_6 + \beta_{20}D_1 + \beta_{21}D_2 + \beta_{22}D_3 + \beta_{23}GDPC_t + \beta_{24}(GDPC_t^2)_t + \beta_{25}(GDPC_t^3)_t + \beta_{26}(D_1GDPC_t) + \beta_{27}(D_2GDPC_t) + \beta_{28}(D_3GDPC_t) + e_6 \quad \dots(6)$$

where

- α_6 = intercept (level of per capita CO₂ emissions at the advent of liberalisation)
- β_{20} = change in the level of per capita CO₂ emissions at the advent of globalisation
- β_{21} = change in the level of per capita CO₂ emissions at the advent of world recovery
- β_{22} = change in the level of per capita CO₂ emissions at the advent of global financial crisis
- β_{23} , β_{24} and β_{25} = indicators for testing the existence of a cubic form of the relationship between per capita CO₂ emissions and per capita GDP (cubic EKCPC). The expected sign of β_{23} and β_{25} is positive while that of β_{24} is negative. If these coefficients turn out to be significant with these expected signs, it would confirm the existence of an N-shaped relationship between per capita CO₂ emissions and per capita GDP for India over the time period 1991 to 2014
- B_{26} = difference in the impact of per capita GDP on per capita CO₂ emissions between the periods of liberalisation and globalisation
- B_{27} = difference in the impact of per capita GDP on per capita CO₂ emissions between the periods of liberalisation and world recovery
- B_{28} = difference in the impact of per capita GDP on per capita CO₂ emissions between the periods of liberalisation and global financial crisis

In this context, we formulated the following **secondary hypotheses**:

- 1) $H_0: \beta_1 = 0$
 $H_1: \beta_1 > 0$
- 2) $H_0: \beta_2 = 0$
 $H_1: \beta_2 < 0$
- 3) $H_0: \beta_3 = 0$
 $H_1: \beta_3 > 0$
- 4) $H_0: \beta_4 = 0$
 $H_1: \beta_4 < 0$
- 5) $H_0: \beta_5 = 0$
 $H_1: \beta_5 > 0$
- 6) $H_0: \beta_6 =$ There is no difference in the level of aggregate CO₂ emissions between the periods of liberalisation and globalisation
 $H_1: \beta_6 =$ There is difference in the level of aggregate CO₂ emissions between the periods of liberalisation and globalisation
- 7) $H_0: \beta_7 =$ There is no difference in the level of aggregate CO₂ emissions between the periods of liberalisation and world recovery
 $H_1: \beta_7 =$ There is difference in the level of aggregate CO₂ emissions between the periods of liberalisation and world recovery
- 8) $H_0: \beta_8 =$ There is no difference in the level of aggregate CO₂ emissions between the periods of liberalisation and global financial crisis
 $H_1: \beta_8 =$ There is difference in the level of aggregate CO₂ emissions between the periods of liberalisation and global financial crisis
- 9) $H_0: \beta_9 = 0$
 $H_1: \beta_9 > 0$
- 10) $H_0: \beta_{10} = 0$
 $H_1: \beta_{10} < 0$
- 11) $H_0: \beta_{11} = 0$
 $H_1: \beta_{11} > 0$
- 12) $H_0: \beta_{12} =$ There is no difference in the impact of GDP on aggregate CO₂ emissions between the periods of liberalisation and globalisation

- $H_1: \beta_{12} =$ There is difference in the impact of GDP on aggregate CO₂ emissions between the periods of liberalisation and globalisation
- 13) $H_0: \beta_{13} =$ There is no difference in the impact of GDP on aggregate CO₂ emissions between the periods of liberalisation and world recovery
 $H_1: \beta_{13} =$ There is difference in the impact of GDP on aggregate CO₂ emissions between the periods of liberalisation and world recovery
- 14) $H_0: \beta_{14} =$ There is no difference in the impact of GDP on aggregate CO₂ emissions between the periods of liberalisation and global financial crisis
 $H_1: \beta_{14} =$ There is difference in the impact of GDP on aggregate CO₂ emissions between the periods of liberalisation and global financial crisis
- 15) $H_0: \beta_{15} = 0$
 $H_1: \beta_{15} > 0$
- 16) $H_0: \beta_{16} = 0$
 $H_1: \beta_{16} < 0$
- where β_{15} and β_{16} are indicators for testing the existence of a quadratic EKC relationship for per capita CO₂ emissions during 1991 to 2014
- 17) $H_0: \beta_{17} = 0$
 $H_1: \beta_{17} > 0$
- 18) $H_0: \beta_{18} = 0$
 $H_1: \beta_{18} < 0$
- 19) $H_0: \beta_{19} = 0$
 $H_1: \beta_{19} > 0$
- where β_{17} , β_{18} and β_{19} are indicators for testing the existence of a cubic EKC relationship for per capita CO₂ emissions during 1991 to 2014
- 20) $H_0: \beta_{20} =$ There is no difference in the level of per capita CO₂ emissions between the periods of liberalisation and globalisation
 $H_1: \beta_{20} =$ There is difference in the level of per capita CO₂ emissions between the periods of liberalisation and globalisation
- 21) $H_0: \beta_{21} =$ There is no difference in the level of per capita CO₂ emissions between the periods of liberalisation and world recovery
 $H_1: \beta_{21} =$ There is difference in the level of per capita CO₂ emissions between the periods of liberalisation and world recovery
- 22) $H_0: \beta_{22} =$ There is no difference in the level of per capita CO₂ emissions between the periods of liberalisation and global financial crisis
 $H_1: \beta_{22} =$ There is difference in the level of per capita CO₂ emissions between the periods of liberalisation and global financial crisis

<p>23) $H_0: \beta_{23} = 0$
 $H_1: \beta_{23} > 0$</p> <p>24) $H_0: \beta_{24} = 0$
 $H_1: \beta_{24} < 0$</p> <p>25) $H_0: \beta_{25} = 0$
$H_1: \beta_{25} > 0$</p>	$\left\{ \begin{array}{l} \end{array} \right.$	where β_{23}, β_{24} and β_{25} are indicators for testing the existence of a cubic EKC relationship for per capita CO₂ emissions during 1991 to 2014
-
- 26) $H_0: \beta_{26} =$ There is no difference in the impact of per capita GDP on per capita CO₂ emissions between the periods of liberalisation and globalisation
 $H_1: \beta_{26} =$ There is difference in the impact of per capita GDP on per capita CO₂ emissions between the periods of liberalisation and globalisation
- 27) $H_0: \beta_{27} =$ There is no difference in the impact of per capita GDP on per capita CO₂ emissions between the periods of liberalisation and world recovery
 $H_1: \beta_{27} =$ There is difference in the impact of per capita GDP on per capita CO₂ emissions between the periods of liberalisation and world recovery
- 28) $H_0: \beta_{28} =$ There is no difference in the impact of per capita GDP on per capita CO₂ emissions between the periods of liberalisation and global financial crisis
 $H_1: \beta_{28} =$ There is difference in the impact of per capita GDP on per capita CO₂ emissions between the periods of liberalisation and global financial crisis

5.0 Analysis and Results

The results obtained for each model specification are presented below:

5.1 Aggregate carbon dioxide emissions (CO₂) (in kilotons) as the dependent variable

5.1.1 Quadratic EKC

The results for the quadratic EKC are presented in Table 2. The R-square is 0.976, which indicates that our regression line is a good fit of the data.

Estimated equation

$$CO_{2t} = 447761.9 + 1.51E-06 GDP_t - 3.5E-19 (GDP^2)_t + e_{1t} \quad \dots(7)$$

(p-value) (1.0697E-07) (4.3968E-10) (1.3012E-05)

Table 2: Summary Output for Quadratic EKC: Regression Statistics

Multiple R	0.98842
R Square	0.97699
Adjusted R Square	0.97479
Standard Error	72497.13893
Observations	24

	Coefficients	Standard Error	t Stat	P-value
Intercept	447761.9	56894.29	7.87006	1.0697E-07
GDP	1.51E-06	1.39E-07	10.87174	4.3968E-10
GDP ²	-3.5E-19	6.23E-20	-5.65448	1.3012E-05

The first equation is meant to verify an ordinary EKC, which is supposed to be in a quadratic form. The estimated equation shows that the initial level of CO₂ emissions is 447761.9 kilotons. The t-statistic (7.870068) and the p-value (1.0697E-07) show that the intercept is highly significant. The coefficient of GDP (1.51E-06) is rather small; however the t-statistic (10.87174) and the p-value (4.3968E-10) show that it is highly significant. The quadratic GDP variable also has an extremely small coefficient (3.5E-19) but it is highly significant on account of the t-statistic (-5.65448) and p-value (1.3012E-05). The important thing to note is that there is the typical alternation of signs. The linear term has a positive sign while the quadratic term has a negative sign. This is indicative of a bell-shaped curve where initially aggregate CO₂ emissions rise with respect to GDP and later fall with respect to (GDP)². Therefore, we reject our null hypothesis for β_1 and β_2 .

Further, from Figure 2 below, it can be inferred that although aggregate CO₂ emissions do not show a smooth quadratic pattern, in the year 2012 there is a small dip in the level of emissions. Subsequently, since the emissions rise once again, this is an indication of the presence of a cubic form.

5.1.2 Cubic EKC

The results for the cubic EKC are presented in Table 3. The cubic equation has a slightly higher coefficient of determination (0.981) as compared to the quadratic equation (0.976). This shows that the cubic equation is a better fit.

Estimated equation

$$\text{CO}_{2t} = 241680.3 + 2.34\text{E-}06 \text{GDP}_t - 1.2\text{E-}18 (\text{GDP}^2)_t + 2.64\text{E-}31 (\text{GDP}^3)_t + e_{2t} \quad \dots(8)$$

(p-value) (0.0456) (2.14E-05) (0.0098) (0.0531)

Figure 2: Quadratic EKC

The intercept term is also smaller (241680.3) which shows that the cubic equation accounts for more of the explained variation. This also indicates that the cubic form of relationship between aggregate CO₂ emissions and GDP is more appropriate as compared to a quadratic form of relationship between the two variables. In other words, the influence of the cubic term was perhaps being merged in the intercept of the quadratic equation as an omitted variable.

Table 3: Summary Output for Cubic EKC: Regression Statistics

Multiple R	0.99045
R Square	0.98100
Adjusted R Square	0.97815
Standard Error	67500.27777
Observations	24

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	241680.3	113401.7	2.13118	0.04566
GDP	2.34E-06	4.25E-07	5.51241	2.14E-05
GDP ²	-1.2E-18	4.32E-19	-2.85157	0.00986
GDP ³	2.64E-31	1.28E-31	2.05529	0.05314

Moreover, although the coefficient of GDP in the cubic equation is very small ($2.34\text{E-}06$), it is highly significant as indicated by the p-value ($2.14\text{E-}05$). But when we compare the quadratic and the cubic form of equation, the linear term's coefficient in the quadratic equation ($1.51\text{E-}06$) is two-thirds of the linear term's coefficient in the cubic equation ($2.34\text{E-}06$).

Further, both the quadratic terms are extremely small, yet they are significant in both the equations. However, the coefficient of the quadratic term in the cubic equation ($-1.2\text{E-}18$) is about three times the coefficient of the quadratic term in the quadratic equation ($-3.5\text{E-}19$). The implication is that the quadratic term in the cubic equation makes emissions fall faster because it bears a negative sign. In addition to this, the cubic term also has a small ($2.64\text{E-}31$) but significant (0.0531) influence that forces the emissions to rise again.

On the whole, we reject our null hypothesis for β_3 , β_4 and β_5 . This renders evidence for an N-shaped EKC for India during 1991-2014.

Moreover, from Figure 3 below, it can be inferred that the apparent pattern of a cubic EKC is not very different from the quadratic EKC. However, a closer look shows that the predicted CO_2 is closely hugging the actual in the cubic form. It also confirms that 2011 is the peak before which there is a dip in 2012, similar to the quadratic form. On the whole, this confirms the N-shaped EKC as purported in recent literature.

Figure 3: Cubic EKC

5.1.3 Cubic EKC with breaks in GDP

The results for the cubic EKC with breaks in GDP are presented in Table 4.

Table 4: Summary Output for Cubic EKC with breaks in GDP: Regression Statistics

Multiple R	0.99855
R Square	0.99710
Adjusted R Square	0.99488
Standard Error	32663.28
Observations	24

	Coefficients	Standard Error	t Stat	P-value
Intercept	221675.9	223874.4	0.99018	0.34015
GDP	2.12E-06	8.01E-07	2.65052	0.01999
GDP ²	-6.2E-19	5.69E-19	-1.09081	0.29516
GDP ³	7.08E-32	1.39E-31	0.50995	0.61863
D1WTO	-211805	257222.4	-0.82343	0.42511
D2WR	443269.4	300659.4	1.47432	0.16419
D3CRISIS	-13954.7	640147.4	-0.0218	0.98293
D1*GDP	5.57E-07	8.01E-07	0.69521	0.49916
D2*GDP	-8E-07	8.34E-07	-0.96484	0.35223
D3*GDP	-3.1E-07	9.79E-07	-0.31362	0.75878

Estimated equation

$$\begin{aligned}
 \text{CO}_{2t} = & 221675.9 - 211805D_1 + 443269.4D_2 - 13954.7D_3 + 2.12E-06GDP_t - 6.2E-19(GDP^2)_t + \\
 & (p\text{-value}) (0.3401) \quad (0.4251) \quad (0.1641) \quad (0.9829) \quad (0.0199) \quad (0.2951) \\
 & 7.08E-32(GDP^3)_t + 5.57E-07(D_1GDP_t) - 8E-07(D_2GDP_t) - 3.1E-07(D_3GDP_t) + e_3 \dots (9) \\
 & (0.6186) \quad (0.4991) \quad (0.3522) \quad (0.7587)
 \end{aligned}$$

The intercept term (221675.9) is very large but its p-value (0.3401) is not statistically significant. This is because the standard error (32663.28) is extremely large. As a result, the t-statistic (0.9901) is also low. The linear GDP term (2.12E-06) bears the right sign (positive) and is statistically significant (0.0199). Hence, we reject our null hypothesis for β_0 . The GDP² term (-6.2E-19) though bears the right sign (negative), is not statistically significant (0.2951). Also the GDP³ term (7.08E-32) does not show up as being significant (0.6186). As a result, we do not reject our null hypothesis for β_{10} and β_{11} .

As for the dummies, none of them turn out to be significant. The implication is that the aggregate emissions are not so much influenced by the different policy periods. Consequently, we do not reject our null hypotheses for β_6 , β_7 and β_8 (intercept dummies);

and β_{12} , β_{13} and β_{14} (slope dummies). This equation has a very high multiple R (0.9985), R^2 (0.9971) and adjusted R^2 (0.9948). This is because a large number of dummies have been introduced which have added to the explanatory power. Normally, when we add meaningful variables in an analysis, the explanatory power goes up in spite of compromising on the degrees of freedom. This is because the overall explanatory power increases. In this case however, the dummies are not significant. This creates an anomaly because the adjusted R^2 is very high but the partial regression coefficients of the six dummies (D1WTO, D2WR, D3CRISIS, D1*GDP, D2*GDP and D3*GDP) are not statistically significant. The implication is that there is a high degree of multicollinearity. This problem could not be resolved because the time period and the data set are given. Neither could we use panel data.

Figure 4 below confirms that the fit is extremely good because the multiple R (0.9985), R^2 (0.9971) and adjusted R^2 (0.9948) are all extremely high. So, graphically, the predicted CO_2 and the actual CO_2 are almost conjoined.

Figure 4: Cubic EKC with Breaks in GDP

5.2 Per capita carbon dioxide emissions (CO_2PC) as the dependent variable

5.2.1 Quadratic EKCPC

The results for the quadratic EKC are presented in Table 5. The R-square is 0.965, which indicates that the regression line is a good fit.

Estimated equation

$$CO_2PC_t = 0.548287 + 0.001271 GDPC_t - 3.6E-07 (GDPC^2)_t + e_{t4} \quad \dots(10)$$

(p-value) (8.25783E-09) (1.62971E-07) (0.0006)

Table 5: Summary Output for Quadratic EKPC: Regression Statistics

Multiple R	0.98255
R Square	0.96542
Adjusted R Square	0.96212
Standard Error	0.05467
Observations	24

	Coefficients	Standard Error	t Stat	P-value
Intercept	0.54828	0.05963	9.19433	8.25783E-09
GDP	0.00127	0.00016	7.66319	1.62971E-07
GDP ²	-3.6E-07	9.03E-08	-3.99877	0.00065

Now, we consider the quadratic equation with per capita CO₂ emissions as the dependent variable. Once again, we first consider the intercept whose value is 0.54828 metric tons, which is statistically significant (8.25783E-09). This indicates the initial level of per capita emissions. It also implies that two-thirds of the initial emissions (0.83043 in 1991) form the intercept (0.54828), while the intercept as a proportion of the final per capita emissions (1.67872 in 2014) is 0.32660. The situation has reversed because initially two-thirds were being contributed by the intercept, whereas now, only one-third is being contributed by the same. Thus, overtime there have been other determinants, which have aggravated the per capita emissions.

The other factor in this case is clearly identified as GDP. Over the 24-year period (1991 to 2014), GDP has acted as a proxy for economic development. Thus, the quadratic per capita emissions pattern is maintained wherein both the linear per capita GDP term (0.0012) and the quadratic per capita GDP term (-3.6E-07) are statistically significant (1.62971E-07 and 0.0006 respectively). These terms also bear the correct signs such that the linear term is positive while the quadratic term is negative. Consequently, we reject our null hypotheses for β_{15} and β_{16} .

Figure 5 below, shows that the patterns observable in the per capita emissions are quite similar to what were observed for aggregate emissions. The timing of the downturn is also parallel to what was observed for aggregate emissions. The turning point is the same and the impact is also temporary. The small dip that happens around 2012 gets converted into a rising trend very soon. Hence, both the aggregate emissions as well as per capita emissions point towards the need for implementing a cubic equation.

5.2.2 Cubic EKPC

The results for the cubic EKC are presented in Table 6.

Figure 5: Quadratic EKCPC **Estimated equation**

$$CO_2PC_t = 0.32681 + 0.00223 GDPC_t - 1.56E-06 (GDPC^2)_t + 4.3688E-10 (GDPC^3)_t + e_{15} \dots (11)$$

(p-value) (0.0412) (0.0018) (0.0516) (0.1250)

Table 6: Summary Output for Cubic EKCPC: Regression statistics

Multiple R	0.98455
R Square	0.96935
Adjusted R Square	0.96475
Standard Error	0.05274
Observations	24

	Coefficients	Standard Error	t Stat	P-value
Intercept	0.32681	0.14980	2.18163	0.04124
GDPC	0.00223	0.00062	3.58067	0.00187
GDPC ²	-1.56E-06	7.5354E-07	-2.06959	0.05165
GDPC ³	4.3688E-10	2.7285E-10	1.60117	0.12501

The R-square is 0.969, which indicates that the regression is a good fit. A similar cubic equation is constructed for per capita emissions as was constructed for the aggregate emissions. Here, the intercept is smaller (0.32681) than that of the quadratic EKC per capita (0.54828). It reflects the same phenomenon of the cubic term being absorbed in the

intercept in the quadratic equation. Moreover, the linear terms in both the equations are not very further apart (0.00127 in Quadratic EKCPC and 0.00223 in Cubic EKCPC). However, the coefficient of the quadratic term in the cubic equation ($-1.56\text{E-}06$) is around 2.5 times the coefficient of the quadratic term in the quadratic equation ($-3.6\text{E-}07$). This also shows that the cubic function is a better fit because it explains the variation better. Finally, the cubic term ($4.3688\text{E-}10$) in this case bears the right sign (positive) but the p-value is 0.1250, which means that the evidence on relinking hypothesis in per capita terms is weak. Nevertheless, we reject our null hypothesis for β_{17} , β_{18} and β_{19} . However, weak evidence on the cubic term points towards the difference in the socio-psychological factors that influence the revival of the upturn in the case of India. In other words, India might not necessarily behave like the developed countries at later stages of development, unlike the implicit EKC assumption of common developmental patterns of nations.

Moreover, since the cubic term is not so significant, the predicted CO_2 per capita does not perfectly match the actual CO_2 per capita in Figure 6 below. The point of downturn however, is the same as for the equations previously discussed.

Figure 6: Cubic EKCPC

5.2.3 Cubic EKCPC with breaks in GDPC

The results for the cubic EKC with breaks in GDP pc are presented in Table 7. In this case, the results obtained for per capita CO_2 emissions are relatively similar to the results obtained for aggregate CO_2 emissions. The intercept term (0.41299) is very large and its p-value (0.1115) is statistically significant at 15% level.

Estimated equation

$$\text{CO}_2\text{PC}_t = 0.41299 - 0.30899\text{D}_1 + 0.36094\text{D}_2 + 0.11933\text{D}_3 + 0.00153 \text{GDPC}_t - 3.7\text{E-}07(\text{GDPC}^2)_t + 7.98\text{E-}12(\text{GDPC}^3)_t + 0.00083(\text{D}_1\text{GDPC}_t) - 0.00067(\text{D}_2\text{GDPC}_t) - 0.00032(\text{D}_3\text{GDPC}_t) + e_{t6}$$

(p-value) (0.1115) (0.2934) (0.2440) (0.8373) (0.1000) (0.6859)
 (0.9798) (0.3203) (0.4170) (0.7384)
(12)

**Table 7: Summary Output for Cubic EKCPC with Breaks in GDPC:
Regression Statistics**

Multiple R	0.99759
R Square	0.99519
Adjusted R Square	0.99150
Standard Error	0.02589
Observations	24

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	0.41299	0.24189	1.70732	0.11151
GDPC	0.00153	0.00086	1.77066	0.10004
GDPC ²	-3.7E-07	9.04E-07	-0.41359	0.68591
GDPC ³	7.98E-12	3.1E-10	0.02571	0.97987
D1WTO	-0.30899	0.28223	-1.09482	0.29346
D2WR	0.36094	0.29582	1.22015	0.24407
D3CRISIS	0.11933	0.56985	0.20941	0.83737
D1*GDPC	0.00083	0.00080	1.03328	0.32031
D2*GDPC	-0.00067	0.00080	-0.83832	0.41700
D3*GDPC	-0.00032	0.00093	-0.3412	0.73840

However, in comparison to the quadratic form of EKC (0.54828), it is smaller. The linear GDP term (0.00153) bears the right sign (positive) and is statistically significant (0.1000) at 10% level. Hence, we reject our null hypothesis for β_{23} . The GDP² term (-3.7E-07) though bears the right sign (negative), is not statistically significant (0.6859). Also the GDP³ term (7.98E-12) does not show up as being significant (0.9798). Hence, we do not reject our null hypothesis for β_{24} and β_{25} . As far as the dummy variables are concerned, the pattern is very similar in case of per capita emissions and aggregate emissions. In case of per capita emissions too, all the dummies that have been added do not show up as significant factors. In effect, we do not reject our null hypothesis for β_{20} , β_{21} and β_{22} (intercept dummies); and β_{26} , β_{27} and β_{28} (slope dummies). Once again, the multiple R (0.9975), R² (0.9951) and

adjusted R^2 (0.9915) are extremely high while the individual partial regression coefficients of the six dummies are not statistically significant. This implies that this equation also suffers from multicollinearity on account of the multiple dummies.

Graphically, the predicted CO_2PC and the actual CO_2PC are almost conjoined as can be seen in Figure 7 below. This confirms that the fit is extremely good as indicated by the extremely high values of multiple R (0.9975), R^2 (0.9951) and adjusted R^2 (0.9915).

Figure 7: Cubic EKCPC with breaks in GDPC

In effect, it can be inferred that the global policy period analysis has failed to reveal much except that the crisis period bears a negative sign, both in terms of intercept (-13954.7) and slope (-3.1E-07) in the case of aggregate emissions. This could be associated with the slowing down of the global economy. When we examine the per capita emissions, the intercept term associated with crisis is positive (0.11933), which may indicate the bubble effect, preceding crisis. However, in this equation also the growth rate during the crisis period bears a negative sign (-0.00032), which confirms the slowing down effect. Nevertheless, the overall conclusion is that the policy period analysis has not shown any distinct results in the final models explaining EKC.

6.0 Conclusion

The original EKC literature restricts itself to a quadratic form of the relationship between GDP and CO_2 emissions, in aggregate or per capita terms. This is on account of

the delinking hypothesis. The new literature challenges this quadratic form of EKC where it is clearly established that the EKC shows up as an N-shaped curve. We have modeled the relationship between GDP and CO₂ emissions (aggregate and per capita) with alternative model specifications to bridge the gap between conventional and modern EKC studies. Our analysis of the alternative model specifications (with aggregate CO₂ emissions as the dependent variable) has substantiated a cubic form of EKC in the Indian context. The linear (2.34E-06), quadratic (-1.2E-18) and cubic (2.64E-31) terms were all significant with the right signs, which confirmed an N-shaped EKC as has been purported in the recent literature. Even with per capita emissions as the dependent variable, the N-shaped EKC was established. However, in this case, evidence on the cubic term was rather weak (p-value = 0.1250), which points towards the difference in the socio-psychological factors that influence the revival of the upturn in the case of India. Nevertheless, our study substantiates that a cubic form of relationship between aggregate CO₂ emissions and GDP is more appropriate as compared to a quadratic form of relationship between the two variables. In other words, India exhibits an N-shaped EKC pattern during 1991 to 2014, which implies that at relatively higher levels of income, the benefit from cleaner technologies is outweighed by the degradation caused due to excessive consumption. Hence, we reject our primary hypothesis that there is not enough evidence to validate the construct of Environmental Kuznets Curve in the Indian context.

In the policy period analysis, none of the dummy variables turned out to be significant both in case of aggregate and per capita models analyzing EKC. Though the dummies added to the explanatory power as indicated by extremely high values of multiple R, R square and Adjusted R, their partial regression coefficients were not significant. This was attributed to a high degree of multicollinearity among the dummy variables. Because of contradictory effects on different variables and volatility in these variables, the policy period analysis has not shown distinct results in the final models explaining EKC. Hence, we do not reject our primary hypothesis that the exogenous structural breaks caused due to WTO, world recovery and crisis; do not have any impact on the EKC analysis.

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