N-shaped Environmental Kuznets Curve: A Note on Validation and Falsification

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Abstract: The empirical testing of Environmental Kuznets Curve (EKC) hypothesis plays a significant role in designing a macroeconomic model for sustainable economic development. In doing so, we have chosen the N-shaped EKC, i.e., cubic specification of EKC, and have shown the validation criteria by checking the first order differentiation of the empirical model(s). Then, we have selected several studies in which these particular validation criteria have not been followed and have shown how the models derived in those studies are falsified. This research note may have a significant implication for studies to be carried out based on the EKC hypothesis by ensuring a certain level of model validation, which is sometimes ignored by researchers.

Keywords: Environmental Kuznets Curve, Validation, Falsification

I. Introduction

The Environmental Kuznets Curve (EKC) hypothesis is a well-established hypothesis in the existing literature of energy and environmental economics. While assessing the relationship between economic growth and environmental degradation, Grossman and Krueger (1991) found its similarity with the findings of Simon Kuznets (1955), and they named this association the Environmental Kuznets Curve hypothesis. Since then, by either supporting or disproving this hypothesis, a wide body of literature has been published on various contexts and for various pollutants.[1]

The mathematical model of EKC should comply with certain conditions, which will determine the shape and turnaround points and thereby validate the empirical model. Through analysis of the literature, we discovered many studies that commented on the shape and turnaround points of the EKC without validating the mathematical model derived by them. In this study, we focus on the N-shaped and inverted N-shaped EKCs. The reason for choosing these two specifications is that the first order conditions of these two specifications are in the quadratic form, and therefore, it will be possible for us to show the validation criteria for these EKCs. For inverted U-shaped EKCs, these validation criteria do not hold, as the first order condition in this case will be linear, and the maxima or minima value will be independent of income or the squared explanatory variable. In this case, the validation of the model can be performed by looking at the signs of the coefficients of squared income or any other proxy of economic growth.[2] At level, a cubic mathematical model can result in the quadratic first order condition, and this is the only reason for choosing N-shaped and inverted N-shaped EKCs. For both of these cases, the turnaround points must be real, and they should be derived from the first order condition. Therefore, the first

[1] Moomaw and Unruh (1997), Roberts and Grimes (1997), Roca and Alcántara (2001), Galeotti et al. (2006), Sinha (2015, 2016), Sinha and Bhattacharya (2016, 2017), Alam et al. (2016), Shahbaz et al. (2012, 2013 a, b, 2016 a, b, c).

[2] Let us assume that X is the indicator of pollution and that G is the indicator of economic growth. Then, a standard U-shaped / inverted U-shaped EKC takes the following mathematical form:

$$X = b_0 + b_1 G + b_2 G^2 + \epsilon;$$

$$\text{Or, } \frac{dX}{dG} = b_1 + 2b_2G$$

$$\text{Or, } \frac{d^2X}{dG^2} = 2b_2$$

$b_2 < 0$ implies the presence of local maxima, thereby indicating the evidence of inverted U-shaped EKC
$b_2 > 0$ implies the presence of local minima, thereby indicating the evidence of U-shaped EKC

differentiation of an EKC model must fulfill the basic validity criterion, and this aspect has been ignored by some researchers while estimating the EKCs.

In this study, we have demonstrated how non-fulfillment of the validity condition for an EKC might lead to the falsification of that particular EKC. We have identified a number of studies that failed to consider this criterion. For example, Pal and Mitra (2017) estimated the EKCs for CO_2 emissions in India and China over the period 1971-2012. They found the shape of EKCs to be N-shaped only by looking at the sign of the coefficients of production: "The outcome shown in Table–4 indicates that for both the countries the coefficients associated with level values of production (Y_t) was positive, squared values of production (Y_t^2) was negative and cubic values of production (Y_t^3) was positive. This supports the presence of N-shaped EKC hypothesis…" (Pal and Mitra, 2017, p. 11, line 4). It is evident from this example that the authors commented on the shape of the EKC only by looking at the signs of the coefficients of production and without testing the first and second order conditions of the mathematical model used by them. This is where our study contributes to the existing literature by introducing the necessary condition for an N-shaped EKC to be valid. First, we have noted the results derived by the authors, validated the models by employing the data used by them in those studies, and then falsified those studies based on the validation criterion. In the existing literature of energy and environmental economics, we have not come across any study that has validated the estimated EKCs from the mathematical point-of-view. From that perspective, the present study is a contribution to the existing literature in terms of reinstating the validations of a standard N-shaped EKC model.

II. The estimation problem

Let us assume that P is the indicator of pollution and Y is the indicator of economic growth. Then, a standard N-shaped EKC takes the mathematical form as per equation-1:

$$P = a_0 + a_1 Y + a_2 Y^2 + a_3 Y^3 + \epsilon \quad (1)$$

From equation-1, we obtain the following specifications, which denote specific functional forms:

(a) $a_1 = a_2 = a_3 = 0$; no growth-pollution association

(b) $a_1 > 0$, $a_2 = a_3 = 0$; linearly increasing growth-pollution association

(c) $a_1 < 0$, $a_2 = a_3 = 0$; linearly decreasing growth-pollution association

(d) $a_1 > 0$, $a_2 < 0$, $a_3 = 0$; inverted U-shaped growth-pollution association

(e) $a_1 < 0$, $a_2 > 0$, $a_3 = 0$; U-shaped / monotonically increasing growth-pollution association

(f) $a_1 > 0$, $a_2 < 0$, $a_3 > 0$; N-shaped growth-pollution association

(g) $a_1 < 0$, $a_2 > 0$, $a_3 < 0$; inverted N-shaped growth-pollution association

The necessary condition for the EKC to be N-shaped is that a_1, $a_3 > 0$ and $a_2 < 0$. Similarly, for the EKC to be inverted N-shaped, the necessary condition is a_1, $a_3 < 0$ and $a_2 > 0$. However, this condition is not sufficient for commenting on the nature of the EKC, as this condition does not reflect anything about the validity of the model. To check the validity of the model, the model should be differentiated to the first order. The first order differential of equation-1 is given by

$$\frac{dP}{dY} = a_1 + 2a_2Y + 3a_3Y^2 = 0 \qquad (2)$$

For the EKC to be N-shaped or inverted N-shaped, equation-1 must have local maxima and minima at two distinct values of Y[3]. The condition for equation-1 having local maxima and minima is given by equation-3:

$$a_2{}^2 - 3a_1a_3 > 0 \qquad (3)$$

To find the values of the maxima and minima, arriving at the second order condition is required. The second order condition, derived from equation-2, takes the following form:

$$\frac{d^2P}{dY^2} = 2a_2 + 6a_3Y = \pm\sqrt{4a_2^2 - 12a_1a_3} \qquad (4)$$

The validity of the second order condition is also given by equation-3. Therefore, it can be stated that equation-3 is the sufficient condition for an N-shaped or an inverted N-shaped EKC to be

[3] The local maxima and minima can be found at $Y = \left(-2a_2 \pm \sqrt{4a_2^2 - 12a_1a_3}\right)/6a_3$, or, $Y = \left(-a_2 \pm \sqrt{a_2^2 - 3a_1a_3}\right)/3a_3$. These are derived by solving the first order condition given in equation-2.

valid.[4] Therefore, for an N-shaped EKC, the two conditions are (i) a_1, $a_3 > 0$, $a_2 < 0$, and (ii) $a_2^2 - 3\ a_1\ a_3 > 0$. Similarly, for an inverted N-shaped EKC, the two conditions are (i) a_1, $a_3 < 0$, $a_2 > 0$, and (ii) $a_2^2 - 3\ a_1\ a_3 > 0$. If it is found that for any given model the first condition holds, but the second condition does not hold, then the EKC can never be estimated, as the turnaround points will not be real. However, in the literature of energy and environmental economics, there are several instances where researchers commented on the shape of the EKC by looking at the first condition only.

We have identified a number of studies where the researchers stated the models to be valid, but they failed to fulfill the second condition. We have tested the models derived by the authors, and found that $a_2^2 - 3\ a_1\ a_3$ comes out to be less than zero, as indicated in Table-1. Non-fulfillment of these conditions will lead to the turnaround points, which are imaginary in nature, as has been identified by some researchers (Abid 2016, Sebri 2016).

III. Conclusion

The present study analyzed the validity of EKC studies conducted by several authors, and in some instances, the established EKC studies have been found to be invalid. We computed the basic validity criteria of an EKC study from the mathematical formulation of a cubic EKC model, and we checked the same condition for several EKC studies. We have identified a number of studies that have commented on the shape of EKC only by the sign of the coefficients without pursuing further validation.

Considering the context of growth-emissions association, the EKC hypothesis still garners much discussion in the energy and environmental economics literature, and therefore, the researchers must perform due diligence in testing the empirical model and interpreting the results. As the policy recommendations provided by the researchers are extremely critical for the particular context of the study, any mistake in the results can create a substantial issue for those contexts. To avoid those mistakes, we recommend that the researchers address these basic validation criteria before commenting on the shape of EKC and associated policy recommendations.

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[4] $Y_{maxima} > Y_{minima}$: EKC is N-shaped.
$Y_{maxima} < Y_{minima}$: EKC is inverted N-shaped.
$Y_{maxima} = Y_{minima}$: EKC is U shaped / inverted U-shaped.

Table-1: Evidence of the Falsified EKC Studies

Author(s)	*Model derived by author(s)*	*Reported Verdict*	$a_2{}^2 - 3a_1a_3$	*Our Verdict*
Martínez-Zarzoso and Bengochea-Morancho (2004)	$LC = 94.1*LY - 12.43*LY^2 + 0.56*LY^3$	N Shaped EKC	-3.5831	Invalid model
Dijkgraaf and Vollebergh (2005)	$C = -142.2*Y + 5.05*Y^2 - 0.19*Y^3$	Inverted U Shaped EKC	-55.5515	Invalid model
Galeotti and Lanza (2005)	$LC = 4.435*LY - 0.394*LY^2 + 0.012*LY^3$	N Shaped EKC	-0.0044	Invalid model
Galeotti et al. (2006)	$C = 7.2*Y - 0.74*Y^2 + 0.03*Y^3$	Model can't be rejected	-0.1004	Invalid model
	$C = 17.62*Y - 2.14*Y^2 + 0.09*Y^3$	Model can't be rejected	-0.1778	Invalid model
Bagliani et al. (2008)	$EF = 0.0006*Y - 2.26E\text{-}08*Y^2 + 2.94E\text{-}13*Y^3$	N Shaped EKC	-1.844E-17	Invalid model
	$EF = 0.0004*Y - 1.34E\text{-}08*Y^2 + 1.57E\text{-}13*Y^3$	N Shaped EKC	-8.84E-18	Invalid model
	$EF = 0.0002*Y - 8.51E\text{-}09*Y^2 + 1.25E\text{-}13*Y^3$	N Shaped EKC	-2.58E-18	Invalid model
Brajer et al. (2008)	$LS = 8.78*LY - 0.899*LY^2 + 0.031*LY^3$	N Shaped EKC	-0.0083	Invalid model
Mazzanti et al. (2008)	$PM_{10} = 4.675*VA - 1.008* VA^2 + 0.074* VA^3$	N Shaped EKC	-0.0218	Invalid model
Akbostancı et al. (2009)	$C = 3.5597*Y - 2.3475*Y^2 + 0.54145*Y^3$	N Shaped EKC	-0.2714	Invalid model
	$LC = 3.3647*LY - 6.2111*LY^2 + 3.82435*LY^3$	N Shaped EKC	-0.0256	Invalid model
Lee et al. (2009)	$C = 0.324*Y - 0.012*Y^2 + 0.00015*Y^3$	N Shaped EKC	-1.8E-06	Invalid model
	$C = 0.349*Y - 0.013*Y^2 + 0.000172*Y^3$	N Shaped EKC	-1.108E-05	Invalid model
	$C = 0.341*Y - 0.013*Y^2 + 0.000166*Y^3$	N Shaped EKC	-8.18E-07	Invalid model
Mohapatra and Giri (2009)	$N = 0.0031*Y - 3.963E\text{-}07*Y^2 + 1.853E\text{-}11*Y^3$	N Shaped EKC	-1.961E-14	Invalid model
	$N = 0.0156*Y - 9.193E\text{-}07*Y^2 + 1.815E\text{-}11 *Y^3$	N Shaped EKC	-4.307E-15	Invalid model
He and Richard (2010)	$C = 3.4950*Y - 0.1060*Y^2 + 0.0012*Y^3$	N Shaped EKC	-0.0013	Invalid model
	$C = 3.1698*Y - 0.1011*Y^2 + 0.0011*Y^3$	N Shaped EKC	-0.0002	Invalid model
Lipford and Yandle (2010)	$C = 131.99*Y - 0.0054*Y^2 + 0.0000000818*Y^3$	N Shaped EKC	-0.00000323	Invalid model
	$C = 75.1*Y - 0.003*Y^2 + 0.0000000483*Y^3$	N Shaped EKC	-0.00000188	Invalid model
	$C = 138.22*Y - 0.0058*Y^2 + 0.00000011*Y^3$	N Shaped EKC	-0.00001197	Invalid model
	$C = 1159.12*Y - 0.00417*Y^2 + 0.000000525*Y^3$	N Shaped EKC	-0.00180823	Invalid model
	$C = 3452.24*Y - 1.0887*Y^2 + 0.000121*Y^3$	N Shaped EKC	-0.06789543	Invalid model
	$C = 0.00146*Y - 0.000000064*Y^2 + 1.06E\text{-}12*Y^3$	N Shaped EKC	-5.468E-16	Invalid model
	$C = 0.00149*Y - 0.0000000758*Y^2 + 1.45E\text{-}12*Y^3$	N Shaped EKC	-7.358E-16	Invalid model
	$C = 0.00295*Y - 0.000000972*Y^2 + 1.08E\text{-}10*Y^3$	N Shaped EKC	-1.101E-14	Invalid model
Brajer et al. (2011)	$LS = 8.796*LY - 0.946*LY^2 + 0.034*LY^3$	N Shaped EKC	-0.0022	Invalid model
Sinha Babu and Datta (2013)	$EDI = 12.919*DBI - 18.52538* DBI^2 + 8.975398* DBI^3$	N Shaped EKC	-4.6698	Invalid model
Onafowora and Owoye (2014)	$LC = 5.034*LY - 0.813*LY^2 + 1.042*LY^3$	N Shaped EKC	-15.0753	Invalid model
	$LC = 3.489*LY - 0.615*LY^2 + 0.605*LY^3$	N Shaped EKC	-5.9543	Invalid model
	$LC = 9.605*LY - 1.710*LY^2 + 0.630*LY^3$	N Shaped EKC	-15.2294	Invalid model
	$LC = 3.275*LY - 0.535*LY^2 + 0.566*LY^3$	N Shaped EKC	-5.2747	Invalid model
	$LC = 4.728*LY - 0.677*LY^2 + 0.405*LY^3$	N Shaped EKC	-5.2862	Invalid model
	$LC = 4.895*LY - 0.781*LY^2 + 0.659*LY^3$	N Shaped EKC	-9.0675	Invalid model

Balibey (2015)	$LC = 240.4722*LY - 27.17071*LY^2 + 1.027006*LY^3$	N Shaped EKC	-2.6517	Invalid model
Dong et al. (2016)	$C = 0.142*Y - 2.36E\text{-}6*Y^2 + 1.36E\text{-}11*Y^3$	N Shaped EKC	-2.24E-13	Invalid model
Uddin et al. (2016)	$EF = 0.32*Y - 1.23*Y^2 + 9.81*Y^3$	N Shaped EKC	-7.9047	Invalid model
	$EF = -1.53*Y + 2.98*Y^2 - 4.92*Y^3$	Inverted N Shaped EKC	-13.7024	Invalid model
	$EF = 3.49*Y - 3.23*Y^2 + 4.96*Y^3$	N Shaped EKC	-41.4983	Invalid model
	$EF = 13.96*Y - 2.47*Y^2 + 5.16*Y^3$	N Shaped EKC	-209.9999	Invalid model
	$EF = -5.06*Y + 1.13*Y^2 - 0.97*Y^3$	Inverted N Shaped EKC	-13.4477	Invalid model
	$EF = -1.706*Y + 0.049*Y^2 - 0.046*Y^3$	N Shaped EKC	-0.2330	Invalid model
Abid (2017)	$C = 11.142*Y - 1.186*Y^2 + 0.043*Y^3$	N Shaped EKC	-0.0307	Invalid model
Boamah et al. (2017)	$C = 3.00*Y - 0.41*Y^2 + 0.02*Y^3$	N Shaped EKC	-0.0119	Invalid model
das Neves Almeida et al. (2017)	$CIEP = 5.9825739*Y - 9.352259*Y^2 + 5.0266098*Y^3$	N Shaped EKC	-2.7514	Invalid model
Pal and Mitra (2017)	$LC = 7.8345*LY - 2.8164*LY^2 + 3.3789*LY^3$	N Shaped EKC	-71.4843	Invalid model

Note: C = CO_2 emissions, LC = log(CO_2 emissions), N = NO_2 emissions, LN = log(NO_2 emissions), S = SO_2 emissions, LS = log(SO_2 emissions), EF = Ecological Footprint, PM_{10} = Particulate Matter, VA = Value Added, CIEP = Composite Index of Environmental Performance, EDI = Environmental Degradation Index, DBI = Development Balance Index

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