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Peaks of transportation CO_2 emissions of 119 countries for sustainable development: Results from carbon Kuznets curve

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Abstract

Transportation has significantly boomed energy consumption and carbon dioxide (CO_2) emissions. Understanding and forecasting the dynamic statuses of transportation CO_2 emissions is a necessary step before making strategies to decrease CO_2 emissions. Carbon Kuznets curve (CKC) hypothesis has been frequently validated properly to present the changing statuses of CO_2 emissions in the literature. This study tests the CKC hypothesis using the data recording the CO_2 emissions of transportation sectors of 119 countries over the period of 1995–2014, then turning points (TPs) are calculated for the countries where CKC hypothesis is turned out supported. Based on the CKC models, this study identifies different types of TPs, i.e. TP of carbon intensity (TP_{CI}), TP of per capita CO_2 emissions (TP_{PC}), and TP of total CO_2 emissions (TP_{TC}) of the countries whose data support the CKC hypothesis. According to the earliness of the turning years (TYs) (TY_{CI}, TY_{PC} and TY_{TC}) – the years when CO_2 emissions peak – of individual countries, this study identified a step-wise decoupling strategy for different countries, i.e. (1) first to reach the TP_{CI}, (2) then to reach the TP_{PC}, and (3) finally to reach the TP_{TC}. As a result, the CKC hypothesis was supported by the data of 58 countries, among which, there are still seven countries having not reached any of the three TPs, 23 countries have reached the first-step TP (TP_{CI}), 9 countries have reached the second-step TP (TP_{PC}), and 19 countries have reached the third-step TP (TP_{TC}).

KEYWORDS

carbon Kuznets curve, CO_2 emission reduction, Sustainable development, Transportation, Turning points

1 | INTRODUCTION

Over the past sixty years, the world has experienced incomparable economic globalization development. The global gross domestic product (GDP) has soared from around 1.367 to 80.684 trillion dollars in past sixty years – approximately an increase of 59 times totally or 7.4% annually (World Bank, 2017). While the dramatic economic development has brought not only benefits such as more job opportunities, increase of income and technologic development, but also drawbacks particularly those raised by global warming (Dong, Sun, Li, & Liao, 2018; Wang, Wang, Du, Li, & He, 2019; Zha, Tan, Yuan, Yang, & Zhu, 2019; Zhang et al., 2018). Global warming has aroused worldwide concerns, which has resulted in over 600,000 deaths, 4.1 billion injuries, and loss of over 1.9 trillion dollars in the past twenty years (Chen et al., 2019; Ranganathan & Bali Swain, 2018; World Bank, 2017).

It is widely recognized that carbon emission is the main cause of global warming (Chen, Shen, Shi, Hong, & Ochoa, 2019; Huppmann et al., 2018; Li, Hu, & Zhang, 2018; Szulejko, Kumar, Deep, & Kim, 2017). The total amount of carbon emission at the global level has increased from 9,385.8 to 36,138.3 million tons in the past six decades

– an increase of three times totally or 2.6% annually (World Bank, 2017). Stern (2008) opined that if human beings fail to control CO_2 emission, the over costs for addressing climate change will be equivalent to a loss of 5% of global GDP annually. Specifically, transportation is the large carbon emitter accounting for nearly 20.44% of energy-related carbon emission in 2014 across global countries (World Bank, 2017). The International Energy Agency (IEA) points that global transportation energy use and CO_2 emission will increase by approximately 50% by 2030 (IEA, 2009). In the context of sustainable development, it is therefore urgent to peak the global CO_2 emission in transportation sector as soon as possible.

With this aim, simulating the carbon emission and economic development trajectory with historical data is the first step. Environmental Kuznets curve (EKC) hypothesis presents the nexus between economic and environment (Atici, 2009; Gill, Viswanathan, & Hassan, 2018a; Wu et al., 2019). EKC denotes the inverted U-shaped relationship between per capita income and the environment quality, presenting environmental damage at first increases then declines with per capita GDP (Grossman & Krueger, 1991; Stern, Common, & Barbier, 1996). CO_2 emission was the mostly applied dependent variable in the EKC models, which referred to as Carbon Kuznets curve (CKC) (Dong et al., 2018; Liddle, 2015; Luzzati, Orsini, & Gucciardi, 2018; Wang et al., 2017; Zoundi, 2017). If CKC exists, a turning point (TP) which implies that economic growth can improve both living standards and environmental quality to some extent should exist (Shuai et al., 2017). This theoretical predicted TP provides the relationship between economic growth and carbon emission and vital benchmark as well to governors to make scientific national carbon emission reduction goal rather than the arbitrary and blind decisions.

More importantly, different countries present different carbon emission characteristics (i.e. carbon emission intensity, per capita carbon emission and total carbon emission) (Pal & Mitra, 2017; Shen et al., 2018; Zhang et al., 2019). Based on the different carbon emission characteristics, Shen et al. (2018) found that besides traditional CKC (i.e. CKC of total carbon emission), there are also other two types of CKC, namely CKC of carbon intensity and CKC of per capita carbon emission. More interestingly, the turning points of these three CKCs evolve in a successive pattern. The TP of CKC of carbon intensity (TP_{CI}) reaches first, follows by TP of per capita carbon emission (TP_{PC}), and TP of total carbon emission (TP_{TC}) achieved lastly. If this pattern is validated in the transportation section, it provides even more precise benchmark reference for the decision makers to promote global low-carbon transportation process.

This paper tests the three kinds of CKC based on the various carbon emission characteristics, and predict the TP of different kinds of CKC of transportation sector in individual countries. This study innovatively analyses the CKCs of the transportation sector in 119 individual countries and identifies the gaps between carbon emission status quo and theoretical TPs in the countries where CKC hypothesis is supported. The findings of this study are helpful for effective policymaking to incentivize global low-carbon transportation development. Second, this study provides a new way to analyze the TPs of CKC considering economic development and carbon emission indicators in the transportation sector. By doing so, the results of different kinds of TPs in different countries enable the government to precisely understand the status quo of the national carbon emission and guide carbon emission reduction for sustainable development in the transportation sector.

The rest of the paper is structured as follows. Section 2 is a review of studies on testing CKC hypothesis at country, region and industry levels. Section 3 is a description of the method and data. Section 4 presents the empirical results of CKC. The discussion on the results is presented in Section 5. Section 6 draws conclusions of this study.

2 | LITERATURE REVIEW

For analyzing the TPs of different countries in the transportation sector, the very first thing is to test the CKC hypothesis. Currently, plenty of previous studies have focused on testing the existence of CKC within the scope of a specific country and region. For instance, at the national level, Gill, Viswanathan, and Hassan (2018b) investigated the presence of CKC in Malaysia during the period 1970 to 2011, and confirmed the existence of CKC. Apergis, Christou, and Gupta (2017) validated the CKC hypothesis of 10 states across 48 US States from the period of 1960 to 2010. Ma and Cai (2019) examined the relationship between economic development and carbon emissions generated from China's commercial buildings. The CKC results show that there exists an inverted U-shaped pattern from 2000 to 2015 at the national and municipal levels. Ouyang and Lin (2017) employed the Granger causality test to examine the long-term equilibrium relationship between CO_2 emission and economic growth in China. The empirical results show that there exists an inverted U-shaped relationship between CO_2 emission and economic development. Kivyiro and Arminen (2014) investigated the causal links between CO_2 emission and economic development in six Sub Saharan African countries and validated the CKC hypothesis. Further, Ahmad et al. (2016) employed the autoregressive distributed lag (ARDL) model of cointegration analyses to investigate the long and short-run relationships between CO_2 emission and economic growth during 1971–2014, indicating that CKC has been supported in long run cointegration in India. Alshehry (2015) tested the hypothesis by examining the effects of economic growth and CO_2 emission for the case of the Saudi Arabia over the period 1970–2010 utilizing the structural time-series. Balaguer and Cantavella (2016) validated the long and short-term relationships between CO_2 emission and economic growth in Spain by exploiting long time series (1874–2011).

Others also found evidence of the existence of the CKC at the regional level. For example, Sinha and Sen (2016) studied the causal association between economic growth, CO_2 emission, trade volume, and human development indicator for Brazil, Russia, India, and China (BRIC) during 1980–2013 and the empirical findings validated the existence of CKC. For examining whether the hypothetical CKC exists, Zhang, Liu, and Bae (2017) investigated the causal linkage of CO_2 emission, GDP and trade openness with a sample of ten industrialized countries, which supports the existence of CKC hypothesis. The research by Álvarez-Herránz, Balsalobre, Cantos, and Shahbaz (2017) employed a panel data model to test CKC hypothesis for 28 OECD countries over the period of 1990–2014. By applying the panel smooth transition regression (PSTR) model, Heidari, Katircioğlu, and Saeidpour (2015) examined the validity of the CKC hypothesis in five ASEAN (Association of the South East Asian Nations) countries (Indonesia, Malaysia, Philippines, Singapore, and Thailand), and hypothesis was supported. Nasreen, Anwar, and Ozturk (2017) adopted the cointegration and Granger causality test as well as the ARDL model to check the CKC hypothesis in South Asian countries over the period 1980–2012. Sapkota and Bastola (2017) applied panel fixed and random effects model to examine the relationships of foreign direct investment and income on CO_2 emission for 14 Latin American countries from 1980 to 2010, which concludes the validity of CKC hypothesis.

To date, few researchers examine the CKC hypothesis on the global transportation industry. For example, the research by Talbi (2017) proved the existence of CKC hypothesis in Tunisia's transportation sector during the period of 1980–2014 by using Vector Autoregressive (VAR) model. Azlina, Law, and Mustapha (2014) validated the CKC hypothesis in transportation sector of Malaysia by using time-series data from 1975 to 2011. Further, the study by Xu and Lin (2015) tested the CKC hypothesis by using provincial panel data from 2000 to 2012 in the Chinese transport sector. Chandran and Tang (2013) identified the nexus of transportation sector's CO_2 emission and economic growth for ASEAN countries using the cointegration and Granger causality methods. However, to the best of our knowledge, despite the fact that transportation is a vital industry in terms of CO_2 emission, studies related to the CKC for the transportation sector at global level are absent. Furthermore, a country may be in different carbon emission statuses on the basis of different types of TPs. Therefore, this study aims to (1) examine the CKC hypothesis with the use of the time-series data for the transportation sector in 119 countries over the period of 1995–2014, and (2) identify three types of TPs – TP_{CI}, TP_{PC}, and TP_{TC} – of individual countries where the CKC hypothesis is validated.

3 | METHOD AND DATA

3.1 | The econometric model of CKC hypothesis

CKC quantifies the relationship between economic development and CO_2 emission. It is widely recognized that carbon emission intensity, per capita carbon emission and total carbon emission can all indicate carbon emission characteristics (Bai, Qiao, Liu, Zhang, & Xu, 2016; Shen et al., 2018). Based on the three indicators, Shen et al. (2018) first proposed three types of CKCs between CO_2 emission and economic growth (per capita GDP): (a) CKC of carbon emission intensity (shown in Figure 1a), (b) CKC of per capita carbon emission (shown in Figure 1b), and (c) CKC of total carbon emission (shown in Figure 1c). Therefore, it can be found that there are three types of TPs, namely, TP_{CI} in Figure 1(a), TP_{PC} in Figure 1(b), and TP_{TC} in Figure 1(c).

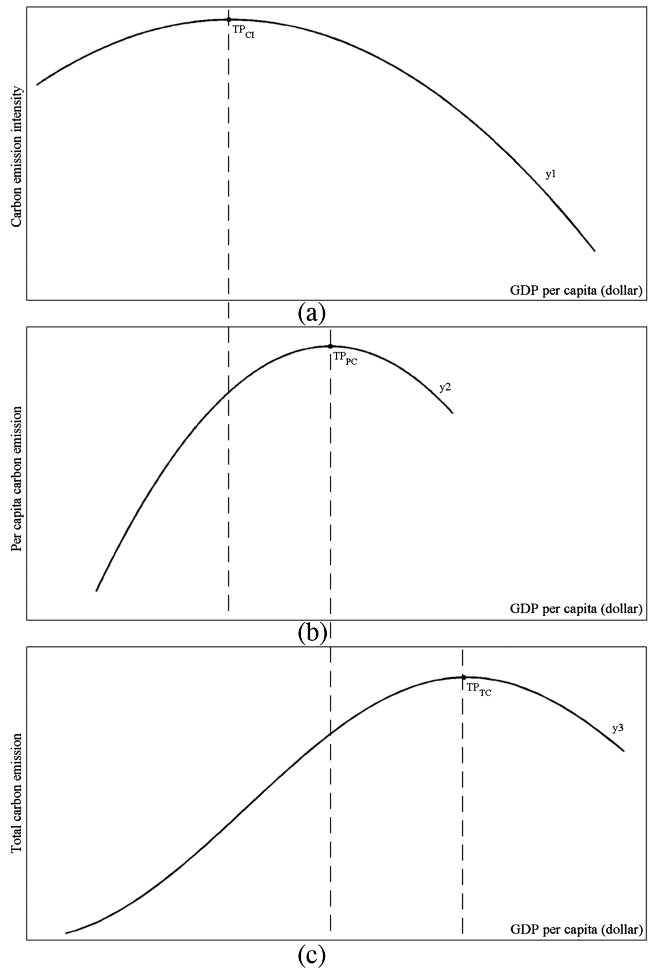

FIGURE 1 Three types of CKCs between carbon emission and per capita GDP (Shen et al., 2018)

A typical CKC model is described as follows:

$$C = f\left(Y, Y^2, Z\right) \tag{1}$$

where C denotes one of the carbon emission characteristics, i.e. TP_{CI}, TP_{PC} or TP_{TC}, Y indicates the income, and Z is other explanatory variables that may influence carbon emission reduction. As one of the main objectives is to identify TP_{CI}, TP_{PC} and TP_{TC} of transportation carbon emission with the increase of the per capita GDP, other additional variables – Z – will not be considered in this model. The estimation model in logarithm form is as follows:

$$lnC_{it} = \beta_0 + \beta_1 lnY_{it} + \beta_2 (lnY_{it})^2 + \varepsilon_{it} \tag{2}$$

where i denotes the sample size of countries (i = 1, 2, 3 … 119), t presents the studied period (t = 1995, 1996, 1997 … 2014). β_0 is a constant, C_{it} is carbon emission of the transportation sector of country i in year t, Y_{it} is per capita GDP of country i in year t, which is measured with the US dollars in 2010, and ε_{it} is the standard error. β_1 and β_2 are the estimated coefficients: when $\beta_1 > 0$ and $\beta_2 < 0$, an inverted

U-shaped CKC exists, and the TP on CKC is calculated by satisfying the following equation:

$$\frac{d}{d(Y_{it})}ln(C_{it}) = \frac{\beta_1}{Y_{it}} + \frac{2\beta_2 lnY_{it}}{Y_{it}} = 0 \quad (3)$$

Thus, per capita GDP at TP is $Y_{it} = exp\left(\frac{-\beta_1}{2\beta_2}\right)$.

If Y_0 and Y_{TY} denote per capita GDP in the base year and in the turning year (TY) respectively, and θ denotes the average annual growth rate of per capita GDP, further calculation can be conducted for estimating TY by the following formula:

$$Y_0 \times (1+\theta)^{TY} = Y_{TY} \quad (4)$$

Similarly, the three types of CKCs can be defined as follows:

$$lnC_{it}^1 = \beta_0 + \beta_1 lnY_{it} + \beta_2 (lnY_{it})^2 + \varepsilon_{it} \quad (5)$$

$$lnC_{it}^2 = \beta_0 + \beta_1 lnY_{it} + \beta_2 (lnY_{it})^2 + \varepsilon_{it} \quad (6)$$

$$lnC_{it}^3 = \beta_0 + \beta_1 lnY_{it} + \beta_2 (lnY_{it})^2 + \varepsilon_{it} \quad (7)$$

where C_{it}^1 is carbon emission intensity of country *i* in year *t*, C_{it}^2 represents per capita carbon emission and C_{it}^3 is total carbon emission.

3.2 | Time-series data

Previous studies have employed time-series analysis to process the dynamic data. Particularly, time-series analysis has been widely used when examining the CKC hypothesis for countries (Akbostancı, Türüt-Aşık, & Tunç, 2009; Ertugrul, Cetin, Seker, & Dogan, 2016; Moghadam & Dehbashi, 2018; Ozatac, Gokmenoglu, & Taspinar, 2017; Pal & Mitra, 2017). Furthermore, Gill et al. (2018b) pointed out that the time-series analysis for a country could provide better framework when the CKC hypothesis is examined. Thus, this paper uses time-series analysis to test the above-mentioned three types of CKC hypotheses of transport sector of the selected 119 individual countries whose data are available. Meanwhile, it is widely recognized that the carbon emission is closely linked to the income level of a country (Shuai, Chen, Wu, Zhang, & Tan, 2019). In order to further examine CKC hypothesis, this study classifies the 119 countries to four income levels – high-income (HI), upper-middle-income (UMI), lower-middle-income (LMI) and low-income (LI) levels.

In order to identify the TP_{CI}, TP_{PC}, and TP_{TC}, the data of transportation sector's carbon emission, GDP and population of the 119 individual countries over the period of 1995 to 2014 are downloaded from the World Bank database (World Bank, 2017). The logarithms of the average values of carbon emission intensity (C^1), per capita carbon emission (C^2), total carbon emission (C^3), and per capita GDP (Y) are resulted as shown in Figure 2 with a scatter plot, distribution overlay, and box chart, which are widely applied for data description in previous studies (Zhang et al., 2019).

Note: The dot denotes the minimum/maximum values, the white square denotes the mean values, the horizontal bar in the box denotes the median values, and the top and bottom edges of the box denote the 75th percentile and 25th percentile, respectively.

4 | RESULTS

This paper adopts Ordinary Least Squares (OLS) technique to calculate the parameters in models (5)–(7) in MATLAB 8. Based on the CKC models in countries where the hypothesis is supported, a TP can be found. The results of transportation carbon emission intensity TP_{CI} of individual countries therefore can be obtained (shown in Table 1), per capita carbon emission TP_{PC} results are shown in Table Appendix 1 and total carbon emission TP_{TC} results are presented in Table Appendix 2. Further, based on model (4), the turning years (TY) of each country are also calculated.

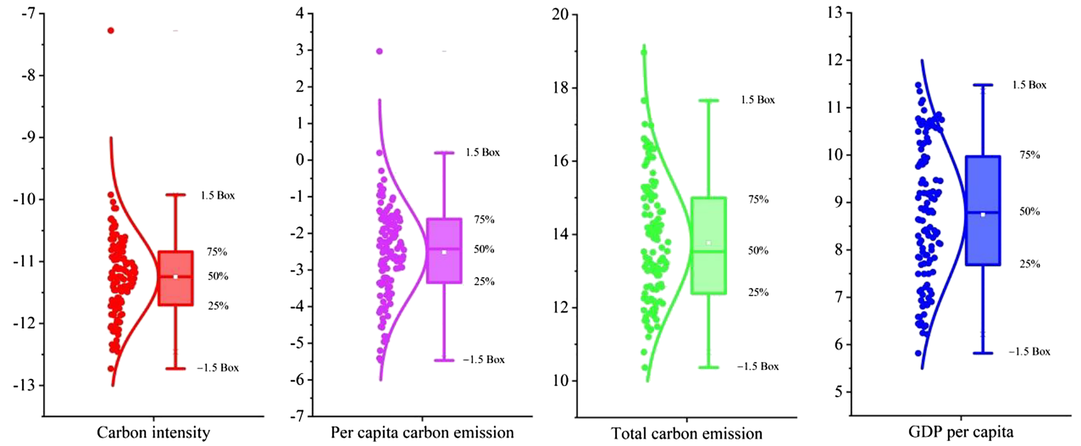

FIGURE 2 Scatter plot, distribution overlay, and box chart of the logarithms of the average annual C^1, C^1, C^1, and Y from 1995 to 2014 of the 119 countries [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Carbon intensity turning points (TP_{CI}) and turning years TY_{CI} of transportation sector in 119 countries

Country	TP_{CI}	TY_{CI}	CKC model	Exists CKC or not
HI-level countries				
Argentina	7447.4	−4	$lnC_{it}^{1} = -1.91808(lnY_{it})^2 + 34.20166lnY_{it} - 163.63714$	√
Australia			$lnC_{it}^{1} = 1.20682(lnY_{it})^2 - 26.79245lnY_{it} + 136.82849$	✗
Austria	42387.5	−9	$lnC_{it}^{1} = -7.48544(lnY_{it})^2 + 159.80844lnY_{it} - 861.75374$	√
Belgium	34768.1	−7	$lnC_{it}^{1} = -2.60009(lnY_{it})^2 + 54.37552lnY_{it} - 296.23605$	√
Brunei Darussalam			$lnC_{it}^{1} = 3.18978(lnY_{it})^2 - 72.19628lnY_{it} + 394.67099$	✗
Canada	34236.9	−25	$lnC_{it}^{1} = -2.17935(lnY_{it})^2 + 45.50941lnY_{it} - 248.81426$	√
Croatia	12528.3	−3	$lnC_{it}^{1} = -0.83153(lnY_{it})^2 + 15.69212lnY_{it} - 85.47554$	√
Cyprus			$lnC_{it}^{1} = 3.59542(lnY_{it})^2 - 73.99538lnY_{it} + 368.81050$	✗
Czech Republic	17229.4	−8	$lnC_{it}^{1} = -6.47417(lnY_{it})^2 + 126.30305lnY_{it} - 627.58440$	√
Denmark			$lnC_{it}^{1} = 2.48018(lnY_{it})^2 - 55.03755lnY_{it} + 292.83718$	✗
Estonia	129.2	−40	$lnC_{it}^{1} = -0.06634(lnY_{it})^2 + 0.84507lnY_{it} - 13.39696$	√
Finland			$lnC_{it}^{1} = 0.33194(lnY_{it})^2 - 7.83116lnY_{it} + 33.61531$	✗
France	35085.0	−16	$lnC_{it}^{1} = -8.28720(lnY_{it})^2 + 173.45993lnY_{it} - 919.68151$	√
Greece			$lnC_{it}^{1} = 0.74166(lnY_{it})^2 - 15.33970lnY_{it} + 67.47413$	✗
Hong Kong SAR, China			$lnC_{it}^{1} = 4.41835(lnY_{it})^2 - 92.36908lnY_{it} + 469.87299$	✗
Hungary	10234.8	−13	$lnC_{it}^{1} = -0.65387(lnY_{it})^2 + 12.37500lnY_{it} - 70.15720$	√
Iceland			$lnC_{it}^{1} = 4.27909(lnY_{it})^2 - 90.80695lnY_{it} + 469.69354$	✗
Ireland	36833.4	−11	$lnC_{it}^{1} = -1.71335(lnY_{it})^2 + 36.02884lnY_{it} - 201.13134$	√
Israel			$lnC_{it}^{1} = 1.06462(lnY_{it})^2 - 22.56298lnY_{it} + 112.13134$	✗
Italy			$lnC_{it}^{1} = 9.65243(lnY_{it})^2 - 202.05863lnY_{it} + 1045.36168$	✗
Japan	34104.3	−41	$lnC_{it}^{1} = -5.47143(lnY_{it})^2 + 114.21248lnY_{it} - 608.03035$	√
Korea, Rep.	7893.1	−30	$lnC_{it}^{1} = -0.55410(lnY_{it})^2 + 9.94475lnY_{it} - 55.73658$	√
Kuwait	40383.4	4	$lnC_{it}^{1} = -7.89178(lnY_{it})^2 + 169.31233lnY_{it} - 909.25889$	√
Latvia			$lnC_{it}^{1} = 0.12492(lnY_{it})^2 - 2.50380lnY_{it} + 1.14978$	✗
Lithuania			$lnC_{it}^{1} = 0.47621(lnY_{it})^2 - 9.04302lnY_{it} + 31.68464$	✗
Luxembourg	103166.8	−1	$lnC_{it}^{1} = -1.57683(lnY_{it})^2 + 36.40613lnY_{it} - 221.39806$	√
Malta			$lnC_{it}^{1} = 7.57433(lnY_{it})^2 - 150.68652lnY_{it} + 737.26812$	✗
Netherlands	25846.7	−20	$lnC_{it}^{1} = -0.75017(lnY_{it})^2 + 15.24337lnY_{it} - 89.43901$	√
New Zealand	16938.3	−45	$lnC_{it}^{1} = -0.88281(lnY_{it})^2 + 17.19241lnY_{it} - 94.79891$	√
Norway			$lnC_{it}^{1} = 3.88365(lnY_{it})^2 - 87.11836lnY_{it} + 476.10133$	✗
Oman	18275.5	5	$lnC_{it}^{1} = -32.71570(lnY_{it})^2 + 642.99915lnY_{it} - 3170.78781$	√
Panama	5869.8	−14	$lnC_{it}^{1} = -1.74047(lnY_{it})^2 + 30.20620lnY_{it} - 142.15442$	√
Poland			$lnC_{it}^{1} = 0.04279(lnY_{it})^2 - 0.77465lnY_{it} - 8.08447$	✗
Portugal			$lnC_{it}^{1} = 0.89302(lnY_{it})^2 - 17.47133lnY_{it} + 73.71541$	✗
Qatar	63174.6	−3	$lnC_{it}^{1} = -17.70938(lnY_{it})^2 + 391.50693lnY_{it} - 2175.08969$	√
Saudi Arabia			$lnC_{it}^{1} = 6.98703(lnY_{it})^2 - 136.88540lnY_{it} + 659.63005$	✗
Singapore			$lnC_{it}^{1} = 5.16816(lnY_{it})^2 - 110.70457lnY_{it} + 579.98626$	✗
Slovenia				✗

(Continues)

TABLE 1 (Continued)

Country	TP_{CI}	TY_{CI}	CKC model	Exists CKC or not
			$lnC_{it}^{1} = 3.92977(lnY_{it})^2 - 78.01913lnY_{it} + 375.72981$	
Spain			$lnC_{it}^{1} = 4.69398(lnY_{it})^2 - 96.30560lnY_{it} + 482.16783$	✗
Sweden	30549.6	−30	$lnC_{it}^{1} = -0.46924(lnY_{it})^2 + 9.69174lnY_{it} - 62.12901$	√
Switzerland	64796.3	−15	$lnC_{it}^{1} = -7.19699(lnY_{it})^2 + 159.47097lnY_{it} - 896.04471$	√
Trinidad and Tobago			$lnC_{it}^{1} = 0.88292(lnY_{it})^2 - 16.63806lnY_{it} + 67.84500$	✗
United Arab Emirates	43398.0	2	$lnC_{it}^{1} = -3.13690(lnY_{it})^2 + 66.99262lnY_{it} - 369.10315$	√
United Kingdom	23081.8	−37	$lnC_{it}^{1} = -1.52312(lnY_{it})^2 + 30.60487lnY_{it} - 165.48976$	√
United States	37652.7	−21	$lnC_{it}^{1} = -3.45154(lnY_{it})^2 + 72.73194lnY_{it} - 394.26783$	√
Uruguay			$lnC_{it}^{1} = 0.03392(lnY_{it})^2 - 0.88462lnY_{it} - 6.39615$	✗
UMI-level countries				
Algeria			$lnC_{it}^{1} = 8.08127(lnY_{it})^2 - 133.61967lnY_{it} + 541.55546$	✗
Azerbaijan			$lnC_{it}^{1} = 0.28012(lnY_{it})^2 - 4.95493lnY_{it} + 10.69504$	✗
Belarus			$lnC_{it}^{1} = 0.76740(lnY_{it})^2 - 13.03640lnY_{it} + 44.55381$	✗
Bosnia and Herzegovina			$lnC_{it}^{1} = 0.61611(lnY_{it})^2 - 9.65143lnY_{it} + 26.68809$	✗
Botswana	6368.1	−6	$lnC_{it}^{1} = -1.53981(lnY_{it})^2 + 26.97460lnY_{it} - 129.25504$	√
Brazil			$lnC_{it}^{1} = 5.37411(lnY_{it})^2 - 99.04914lnY_{it} + 444.68291$	✗
China	2524.3	−10	$lnC_{it}^{1} = -0.18431(lnY_{it})^2 + 2.88769lnY_{it} - 22.62864$	√
Colombia			$lnC_{it}^{1} = 1.92323(lnY_{it})^2 - 33.51735lnY_{it} + 134.50557$	✗
Costa Rica	6752.3	−12	$lnC_{it}^{1} = -3.21094(lnY_{it})^2 + 56.62582lnY_{it} - 260.68573$	√
Cuba	758.6	−51	$lnC_{it}^{1} = -0.47813(lnY_{it})^2 + 6.34136lnY_{it} - 31.98904$	√
Dominican Republic	2614.3	−24	$lnC_{it}^{1} = -1.12246(lnY_{it})^2 + 17.66472lnY_{it} - 80.24667$	√
Ecuador			$lnC_{it}^{1} = 2.71208(lnY_{it})^2 - 45.95888lnY_{it} + 183.88385$	✗
Gabon	11220.3	5	$lnC_{it}^{1} = -5.25192(lnY_{it})^2 + 97.95335lnY_{it} - 468.31037$	√
Guatemala	2690.0	−9	$lnC_{it}^{1} = -12.61891(lnY_{it})^2 + 199.31088lnY_{it} - 798.04974$	√
Iran, Islamic Rep.	5642.1	−5	$lnC_{it}^{1} = -4.86254(lnY_{it})^2 + 84.00537lnY_{it} - 373.21061$	√
Iraq	1555.2	−22	$lnC_{it}^{1} = -0.37994(lnY_{it})^2 + 5.58466lnY_{it} - 30.65047$	√
Jamaica	4751.2	1	$lnC_{it}^{1} = -26.42688(lnY_{it})^2 + 447.46768lnY_{it} - 1905.25383$	√
Jordan	3000.7	−9	$lnC_{it}^{1} = -4.02228(lnY_{it})^2 + 64.40961lnY_{it} - 268.34149$	√
Kazakhstan	2343.6	−27	$lnC_{it}^{1} = -0.20391(lnY_{it})^2 + 3.16449lnY_{it} - 23.47573$	√
Lebanon			$lnC_{it}^{1} = 4.86399(lnY_{it})^2 - 87.91826lnY_{it} + 386.14302$	✗
Libya			$lnC_{it}^{1} = 0.12342(lnY_{it})^2 - 3.11314lnY_{it} + 7.74590$	✗
Macedonia, FYR			$lnC_{it}^{1} = 4.75988(lnY_{it})^2 - 79.74496lnY_{it} + 322.85739$	✗
Malaysia			$lnC_{it}^{1} = 0.77434(lnY_{it})^2 - 14.20587lnY_{it} + 54.35410$	✗
Mauritius	4734.0	−17	$lnC_{it}^{1} = -0.77997(lnY_{it})^2 + 13.20103lnY_{it} - 67.15123$	√
Mexico			$lnC_{it}^{1} = 4.08292(lnY_{it})^2 - 73.59390lnY_{it} + 320.44013$	✗
Namibia	4605.8	−9	$lnC_{it}^{1} = -1.06057(lnY_{it})^2 + 17.89193lnY_{it} - 86.60622$	√
Paraguay	2833.1	−20	$lnC_{it}^{1} = -1.20516(lnY_{it})^2 + 19.15990lnY_{it} - 86.80222$	√
Peru			$lnC_{it}^{1} = 0.21177(lnY_{it})^2 - 3.25445lnY_{it} + 1.12415$	✗

(Continues)

TABLE 1 (Continued)

Country	TP_{CI}	TY_{CI}	CKC model	Exists CKC or not
Romania	2261.4	−41	$lnC_{it}^{1} = -0.28016(lnY_{it})^2 + 4.72773lnY_{it} - 31.48323$	√
Russian Federation			$lnC_{it}^{1} = 0.22542(lnY_{it})^2 - 4.52597lnY_{it} + 11.61702$	✗
South Africa			$lnC_{it}^{1} = 5.67053(lnY_{it})^2 - 100.27580lnY_{it} + 432.19105$	✗
Thailand	2862.1	−27	$lnC_{it}^{1} = -0.58819(lnY_{it})^2 + 9.36324lnY_{it} - 47.82253$	√
Turkey			$lnC_{it}^{1} = 1.99841(lnY_{it})^2 - 37.17482lnY_{it} + 160.89762$	✗
Turkmenistan	3007.5	−12	$lnC_{it}^{1} = -1.22452(lnY_{it})^2 + 19.61395lnY_{it} - 88.31901$	√
Venezuela, RB			$lnC_{it}^{1} = 1.92761(lnY_{it})^2 - 37.67499lnY_{it} + 172.74850$	✗
LMI-level countries				
Angola	3813.4	1	$lnC_{it}^{1} = -0.75092(lnY_{it})^2 + 12.38463lnY_{it} - 62.14074$	√
Bolivia			$lnC_{it}^{1} = 4.37713(lnY_{it})^2 - 66.14886lnY_{it} + 239.50898$	✗
Cambodia			$lnC_{it}^{1} = 1.70671(lnY_{it})^2 - 21.77738lnY_{it} + 58.68403$	✗
Cameroon			$lnC_{it}^{1} = 11.82099(lnY_{it})^2 - 169.61678lnY_{it} + 597.09963$	✗
Congo, Rep.			$lnC_{it}^{1} = 11.62823(lnY_{it})^2 - 180.83916lnY_{it} + 691.68989$	✗
Cote d'Ivoire	1302.2	−16	$lnC_{it}^{1} = -2.05204(lnY_{it})^2 + 30.86816lnY_{it} - 127.54172$	√
Egypt, Arab Rep.	1730.9	−17	$lnC_{it}^{1} = -0.56178(lnY_{it})^2 + 8.37767lnY_{it} - 41.83798$	√
El Salvador	2831.2	−11	$lnC_{it}^{1} = -10.18575(lnY_{it})^2 + 161.92232lnY_{it} - 654.43536$	√
Georgia	2897.5	−4	$lnC_{it}^{1} = -0.51400(lnY_{it})^2 + 8.19484lnY_{it} - 43.31995$	√
Ghana			$lnC_{it}^{1} = 2.69174(lnY_{it})^2 - 38.74874lnY_{it} + 128.35926$	✗
Honduras			$lnC_{it}^{1} = 4.84059(lnY_{it})^2 - 72.51650lnY_{it} + 260.74526$	✗
India			$lnC_{it}^{1} = 0.66165(lnY_{it})^2 - 9.32299lnY_{it} + 21.51784$	✗
Indonesia			$lnC_{it}^{1} = 1.40028(lnY_{it})^2 - 21.55714lnY_{it} + 71.74180$	✗
Kenya			$lnC_{it}^{1} = 4.90590(lnY_{it})^2 - 66.72537lnY_{it} + 215.59430$	✗
Kyrgyz Republic			$lnC_{it}^{1} = 6.25893(lnY_{it})^2 - 81.95160lnY_{it} + 257.92191$	✗
Moldova			$lnC_{it}^{1} = 0.19739(lnY_{it})^2 - 2.88244lnY_{it} - 0.43410$	✗
Mongolia			$lnC_{it}^{1} = 0.79797(lnY_{it})^2 - 12.02353lnY_{it} + 34.45846$	✗
Morocco	2904.2	−2	$lnC_{it}^{1} = -0.57287(lnY_{it})^2 + 9.13608lnY_{it} - 47.39382$	√
Myanmar	113.6	−28	$lnC_{it}^{1} = -0.27078(lnY_{it})^2 + 2.56302lnY_{it} - 16.47074$	√
Nicaragua	346.2	−64	$lnC_{it}^{1} = -0.25404(lnY_{it})^2 + 2.97075lnY_{it} - 18.94382$	√
Nigeria	1620.4	−12	$lnC_{it}^{1} = -5.98542(lnY_{it})^2 + 88.46967lnY_{it} - 337.53967$	√
Pakistan	695.7	−9	$lnC_{it}^{1} = -0.42883(lnY_{it})^2 + 5.61327lnY_{it} - 28.94992$	√
Philippines			$lnC_{it}^{1} = 2.46535(lnY_{it})^2 - 38.88195lnY_{it} + 141.92960$	✗
Sudan	1461.1	−6	$lnC_{it}^{1} = -1.27385(lnY_{it})^2 + 18.56501lnY_{it} - 78.70858$	√
Tunisia			$lnC_{it}^{1} = 0.88728(lnY_{it})^2 - 14.37429lnY_{it} + 47.11549$	✗
Ukraine			$lnC_{it}^{1} = 0.94501(lnY_{it})^2 - 15.45196lnY_{it} + 52.53252$	✗
Uzbekistan	438.1	−30	$lnC_{it}^{1} = -0.90934(lnY_{it})^2 + 11.06198lnY_{it} - 43.13997$	√
Vietnam	1183.2	−5	$lnC_{it}^{1} = -1.03373(lnY_{it})^2 + 14.62932lnY_{it} - 62.24173$	√
Zambia			$lnC_{it}^{1} = 2.49863(lnY_{it})^2 - 36.41934lnY_{it} + 120.57373$	✗
LI-level countries				
Benin	334.6	−62	$lnC_{it}^{1} = 3.28523(lnY_{it})^2 - 38.19268lnY_{it} + 98.62879$	✗

(Continues)

TABLE 1 (Continued)

Country	TP_{CI}	TY_{CI}	CKC model	Exists CKC or not
Haiti	676.0	−2	$lnC_{it}^{1} = -38.97400(lnY_{it})^2 + 507.92349 lnY_{it} - 1665.77780$	√
Mozambique	304.4	−9	$lnC_{it}^{1} = 1.33404(lnY_{it})^2 - 15.25679 lnY_{it} + 32.70539$	✗
Nepal	471.2	−13	$lnC_{it}^{1} = 9.03836(lnY_{it})^2 - 111.26770 lnY_{it} + 330.62060$	✗
Senegal	860.4	−14	$lnC_{it}^{1} = 13.90380(lnY_{it})^2 - 187.90834 lnY_{it} + 623.76015$	✗
Tajikistan	508.0	−15	$lnC_{it}^{1} = 5.76096(lnY_{it})^2 - 71.78749 lnY_{it} + 210.87865$	✗
Tanzania	249.8	−39	$lnC_{it}^{1} = 0.52707(lnY_{it})^2 - 5.81946 lnY_{it} + 4.28904$	✗
Togo	505.0	−1	$lnC_{it}^{1} = -36.84128(lnY_{it})^2 + 458.64065 lnY_{it} - 1437.53974$	√
Zimbabwe	1171.1	2	$lnC_{it}^{1} = -0.62976(lnY_{it})^2 + 8.89947 lnY_{it} - 42.57687$	√

5 | DISCUSSION

Based on the above results, the discussion part is divided into four parts: (1) discussion on the TP_{CI}, (2) discussion on the TP_{PC}, (3) discussion on the TP_{TC}, and (4) discussion on the comparison of three TPs.

5.1 | Discussion on the TPs of carbon intensity

The selected 119 individual countries are classified into three groups including a group that CKC exists and $TY_{CI} > 0$, a group that CKC exists but $TY_{CI} < 0$, and a group that CKC does not exist. These three groups of countries are illustrated on the world map (shown in Figure 3).

As shown in Figure 3, among the 119 countries, there are 58 countries whose transportation sectors accord with the CKC hypothesis. The previous studies support this finding: e.g., Zhang, Liu, Zhang, and Tan (2014) indicated that there is long-term cointegrating nexus between carbon intensity and economic growth in China. And CKC hypothesis of carbon intensity at other countries such as USA, France, UK, Canada (Zhiqiang, Jingjing, & Jiansheng, 2011) and Belgium (Dong, Wang, Su, Hua, & Zhang, 2019) were also accepted. Among the 55 countries, there are 88% countries already reached the TP which indicates their TYs are negative value, such as Argentina, Austria, Belgium, Canada, China, Japan, USA and UK. For example, the TP of transportation carbon intensity in Japan was reached in 1973 owing to the large-scale use of low-carbon technologies in Japanese transportation sector during past three decades such as new energy vehicles (Palmer, Tate, Wadud, & Nellthorp, 2018; Shimada, Tanaka, Gomi, & Matsuoka, 2007). The CO_2 emission reduction strategies of transportation have been promoted and implemented in USA in the past decades such as car sharing and car-pooling, road taxes and parking prices, hybrid and electric cars, and new low-carbon fuels and fuel-efficient propulsion technologies (Javid, Nejat, & Hayhoe, 2014; Lutsey & Sperling, 2009). However, there are also seven countries that have not reached the TP_{CI}, including Angola, Gabon, Jamaica, Kuwait, Oman, United Arab Emirates, and Zimbabwe, which mainly located in Africa and Asia. The reason is that the economic development in these countries is at a low level. For example, Zimbabwe, only has GDP per capita value of 1009 dollars in 2016 (World Bank, 2017). So, the economic development is the priority for these countries, mostly driven by heavy industries. For example, the economic development in Zimbabwe has been mainly driven by manufacturing industry, such as cement manufacturing industry (Zimwara, Mugwagwa, & Chikowore, 2012), oil and

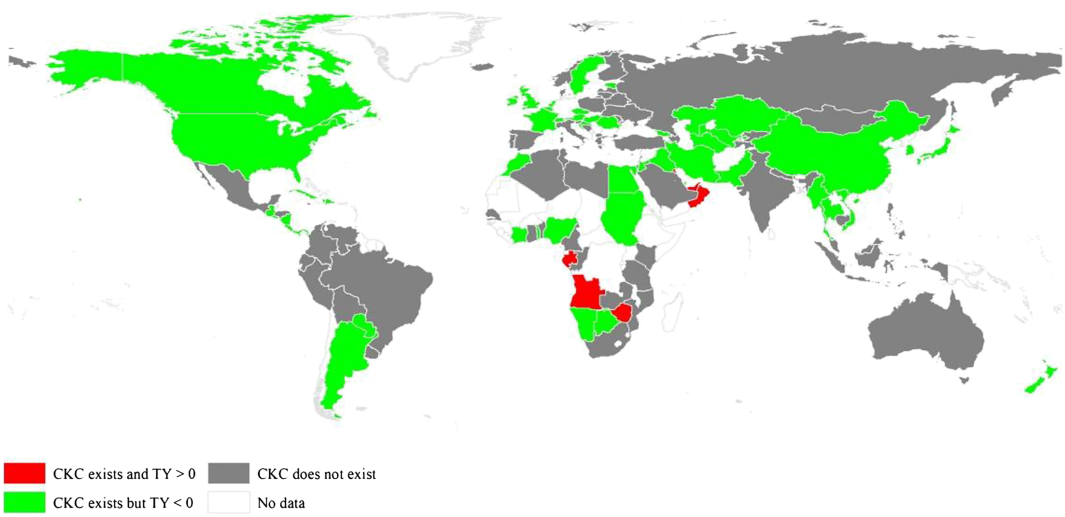

FIGURE 3 The results of TY_{CI} of 119 individual countries [Colour figure can be viewed at wileyonlinelibrary.com]

petrochemical industries in United Arab Emirates and Kuwait (Crystal, 2016; Nyarko, 2010). The extensive development mode leads to the transportation carbon emission grows quickly while the GDP increases relatively slow (Ebohon & Ikeme, 2006). For instance, from 1995 to 2014, the GDP of Oman increased from 35.9 to 67.9 billion dollars (1.9 times' total increment), but the transportation carbon emission surges from 237 to 1,271.4 thousand tons (5.4 times' total increment) (World Bank, 2017).

Notably, the ratio of countries where carbon-intensity CKC exist decreased with the income level (shown in Figure 4).

It can be observed from Figure 4 that the higher income level, the larger proportion of countries have carbon-intensity CKCs. As shown in Figure 4, the proportion is 52.17% at the HI level, 51.43% at the UMI level, 44.83% at the LMI level, and 33.33% at the LI level. This is mainly due to the fact that the main driver for reaching TP is the advanced low-carbon development mechanism. The higher-income-level countries tend to perform better in energy efficiency, industrial structure and renewable energy technology, resulting in more effective carbon emission reduction (Shuai et al., 2017).

5.2 | Discussion on the TPs of per capita carbon emission

Similar with Section 5.1, the selected 119 individual countries are also classified into three groups including a group that CKC exists and $TY_{PC} > 0$, a group that CKC exists but $TY_{PC} < 0$, and a group that CKC does not exist. These three groups of countries are depicted on the world map (illustrated in Figure 5).

As shown in Figure 5, CKC hypothesis of per capita carbon emission is supported in the 58 countries among 119 countries. United States (Stretesky & Lynch, 2009), Japan and France (Dong et al., 2019) also validated the CKC of per capita carbon emission. Among the 58 countries, there are 28 countries having reached their TP_{PC}, e.g., Austria, Canada, Ireland, Netherland and UK. Japan is the country that earliest reached the TP_{PC} in 1984. The reason behind this is that the national per capita carbon emission appears with an obvious decrease trend but the GDP per capita shows with a growth trend. This can be evidenced by the data from World Bank. The GDP per capita of Japan increased from 40,368 dollars in 1995 to 46,484 dollars in 2014, but the transportation carbon emission per capita decreased from 0.2044 to 0.1673 (World Bank, 2017). This may benefit from large transformations of low-carbon technologies in Japan's transport industry, For example, the application and promotion of new-energy vehicle in Japan are earlier than that in other countries (Åhman, 2006).

Notably, there are also 30 countries in the Exist CKC group ($TY_{PC} > 0$), which have not reached the TP_{PC} such as, Angola, Cote d'Ivoire, Vietnam and Zimbabwe. Note that these countries are also mainly located in Africa and Asia, suggesting that the economy in these countries is undeveloped and the carbon emission reduction technique is limited. For example, economic development in Zimbabwe is at a low level and the inflation is excessively serious – poorly performing the concept of low-carbon economy (Funke, Clausen, Ould-Abdallah, Coorey, & Muñoz, 2007). In fact, these countries have started to consider the subject of LCE development in recent years, whereas climate policy has been implemented extensively across European countries over past two decades (Biesbroek et al., 2010). For example, the first Bus Rapid Transit System (BRT), regarded as low-carbon transportation system, was opened in European and North America in 1970, but the first BRT in Africa opened in Nigeria in 2008 (Wikipedia, 2018).

5.3 | Discussion on the TPs of total carbon emission

Similar with Section 5.1 and 5.2, the selected 119 individual countries are classified into three groups including a group that CKC exists and $TY_{TC} > 0$, a group that CKC exists but $TY_{TC} < 0$, and a group that CKC does not exist. These three groups of countries are depicted on the world map (illustrated in Figure 6).

As shown in Figure 6, among the 119 individual countries, there are 51 countries where the CKC hypothesis is supported. The result

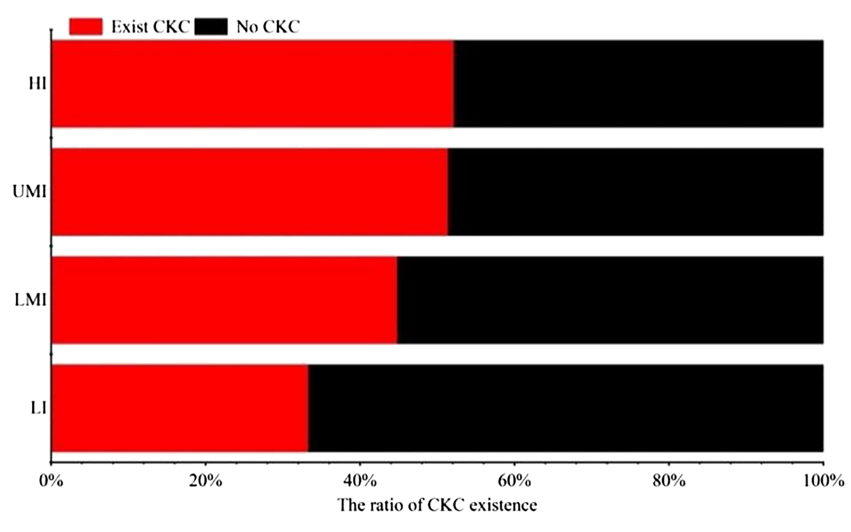

FIGURE 4 The ratios of countries with carbon-intensity CKCs at the four income levels [Colour figure can be viewed at wileyonlinelibrary.com]

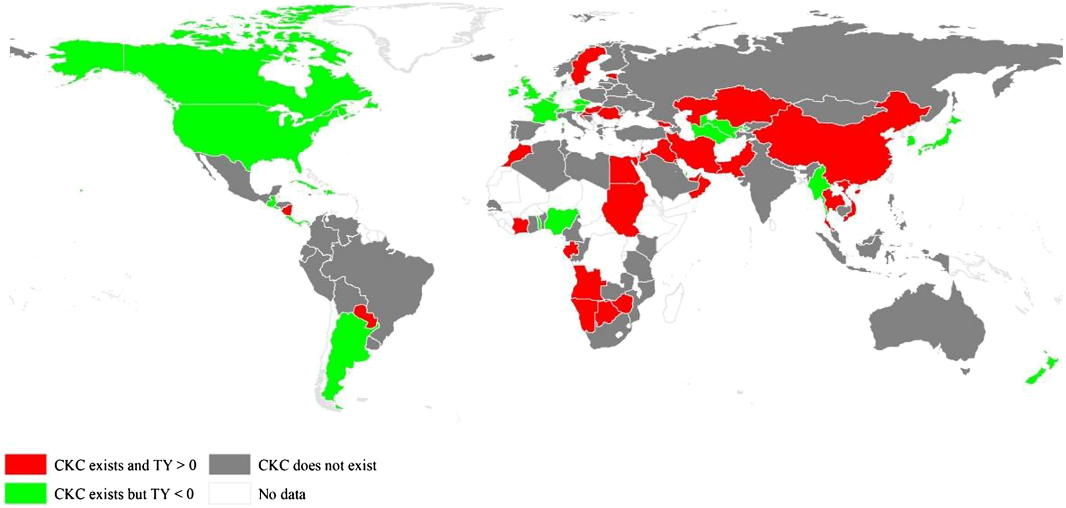

FIGURE 5 The results of TY_{PC} of 119 individual countries [Colour figure can be viewed at wileyonlinelibrary.com]

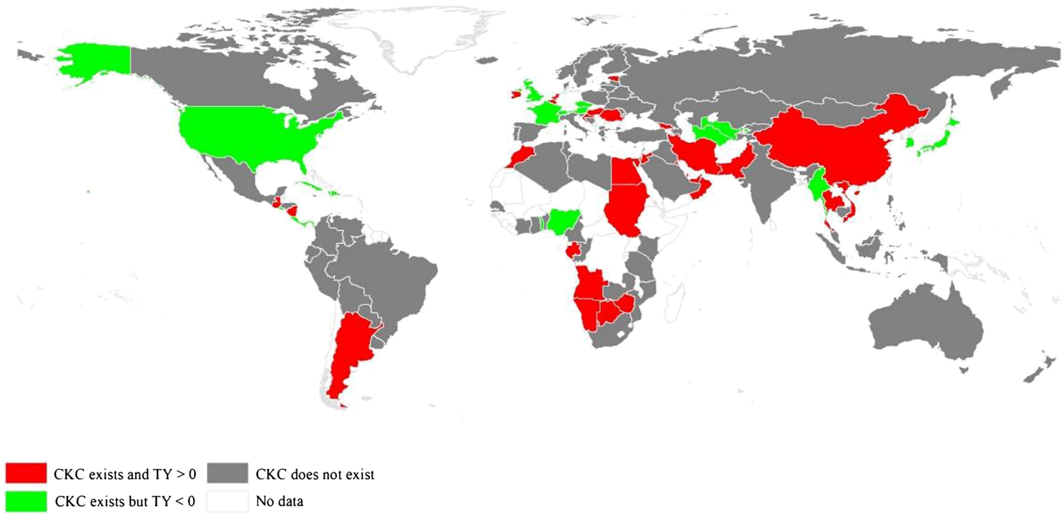

FIGURE 6 The results of TY_{TC} of 119 individual countries [Colour figure can be viewed at wileyonlinelibrary.com]

accords with findings in the literature, for example, the hypothesis is supported in China (Xu & Lin, 2015), Egypt (Abdou & Atya, 2013) and Netherlands (Dong et al., 2019). Among the 51 countries in the Exist CKC group, there are 19 countries have already reached the TP_{TC} with the TY_{PC} less than 0, such as Austria, Japan, UK and USA. Similar with the per capita carbon emission, Japan is the country which earliest reached the TP_{TC}. This is a strong evidence to support that richer countries have more advantages on green-energy and energy-saving technologies in transport industry. For example, it is reported that Japanese government have been devoting great amount of investments and policies to support low-carbon transportation and low-carbon smart electricity systems with electric vehicles (Zhang, Tezuka, Ishihara, & Mclellan, 2012). However, the rest of the CKC-existing countries (32 countries) have not reached the TP_{TC}, which are also mainly located in Africa and Asia (As shown in Figure 6). This means the economic growth process in these countries is pollution intensive, which contributes to the increase of total carbon emission. The results of this study are in line with Esso and Keho (2016), who also found that GDP per capita have positive effects on carbon emission in Africa countries. This finding is similar to the results concluded from the TP_{CI} and TP_{PC}. However, unlike TPs from carbon intensity and per capita carbon emission, most of the countries will spend over two decades in reaching the TPs of total carbon emissions, such as Croatia, Hungary and Pakistan.

Notably, the ratio of countries having total-carbon-emission CKCs decreased with the income level (shown in Figure 7). As shown in Figure 7, there are 45.65% of countries tested accepting the CKC hypothesis at HI level, followed by 42.86% at the UMI level, 41.38% at the LMI level, and 33.33% at the LI level. This finding is similar to that of the existence of carbon-intensity CKCs, which also shows that the higher income level has the larger proportion of countries in which the CKC hypothesis is accepted.

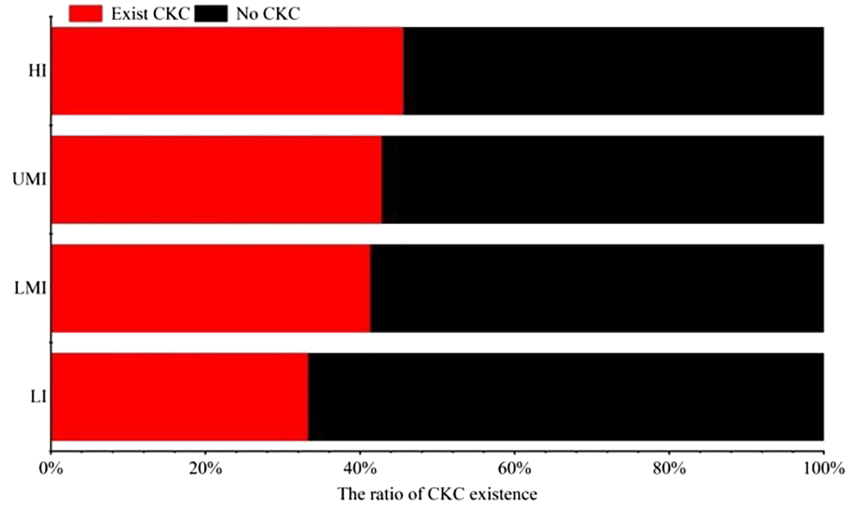

FIGURE 7 The ratios of CKC existence of total carbon emission at the four income levels [Colour figure can be viewed at wileyonlinelibrary.com]

5.4 | Comparison of the three types of TPs

After analyzing the results of TP_{CI}, TP_{PC} and TP_{TC}, this section compares these three types of TPs.

According to results of TP from three carbon emission characteristics, it is interesting to note that the number of countries has reached the TP_{CI} are greater than TP_{PC} and TP_{TC}, meaning countries always reach the TP_{CI} at the first place, followed by TP_{PC} at the second place, and TP_{TC} at the latest place. In other words, it is easier for countries to achieve the carbon intensity peak goal than the other two. Shen et al. (2018) pointed out that carbon intensity is the ratio of total carbon emission to GDP, which is more likely to decrease with the dramatic growth of GDP. This maybe benefit from the economies of scale effect, which leads to the GDP increase faster than carbon emission (Shuai et al., 2019; Wu et al., 2019). On the other hands, according to the CKC model of carbon intensity and per capita carbon emission, we can note that the model (6) is derived from model (5) and the coefficient of model (5) is less than model (6), which leads that TY_{CI} is always smaller than TY_{PC}. In referring to the comparison of the TY_{PC} and TY_{TC}, per capita carbon emission denotes the ratio of total carbon emission to population, which is more easily to decrease since it is more likely that population is increasing in most of countries. This result is consistent with the findings by Dong et al. (2019) and Shuai et al. (2019), which provides that the peak year for CI is smaller than PC, and TC. Furthermore, it is also interesting to note that the TY_{PC} and TY_{TC} are relatively close in many countries. This can be proved by the fact that the total population in many countries is slowly increasing or relatively steady (World Bank, 2017). For instance, the

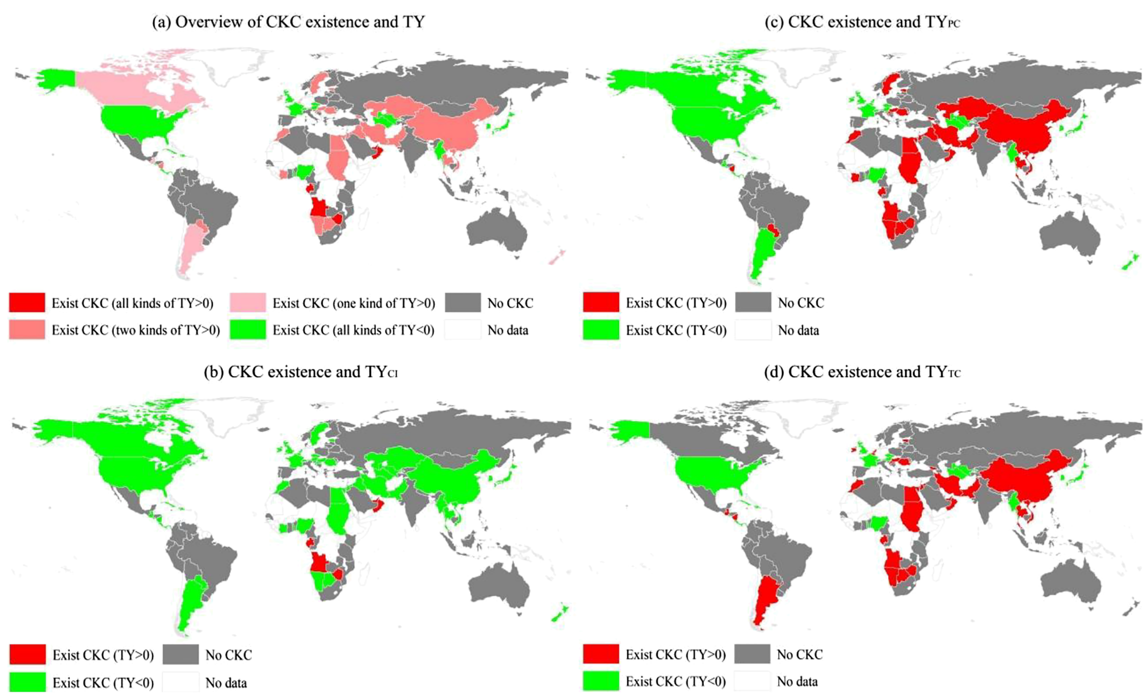

FIGURE 8 CKC existences and TY of 119 countries [Colour figure can be viewed at wileyonlinelibrary.com]

population of Japan increased from 125,439 to 127,276 thousand with an increment of 1,837 thousand from 1995 to 2014, and the population in Bulgaria, Belarus, and Iceland is relatively decline steady. Figure 8 presents the results of transport CKC existence and TY of 119 countries.

As shown in Figure 8 (a), the 119 countries are classified into five groups in considering the situations of CKC and TY: those all kinds of TY are more than 0, those two kinds of TY are more than 0, those only one kind of TY is more than 0, those all kinds of TY less than 0, and those of none CKC existence. Figure 8 (a-d) indicates if a country only has reached one TP, it must be carbon intensity ($TY_{CI} < 0$), which indicates the TP from carbon intensity is at the first place. If a country reaches two TPs, it must be carbon intensity ($TY_{CI} < 0$) and per capita carbon emission ($TY_{PC} < 0$), meaning the TP from per capita carbon emission is the second step. If a country reached the TP_{TC}, it must have reached all the three TPs (all kinds of TY < 0), meaning TP_{TC} is at last. As can be seen in Figure 8, among the 58 CKC-existing countries, there are still seven countries having not reached any of the TP (all kinds TY > 0), 23 countries have reached the first step TP, 9 countries have reached the second step and 19 countries have reached the third step. Thus, it is considered important for different countries to develop different low-carbon economy policies based on their turning point target. For example, if a country only reached TP_{CI}, the governors should focus on the TP_{PC} rather than TP_{TC} target.

6 | CONCLUSIONS

This study investigated the transportation sector's TP of three carbon emission characteristics (i.e., carbon intensity, per capita carbon emission and total carbon emission) using the data of 119 countries over the period 1995 to 2014. After analyzing the three kinds of TYs (TY_{CI}, TY_{PC} and TY_{TC}) of individual countries, this study identified a step-wise TP for different countries, i.e. reaching the TP_{CI} firstly, the TP_{PC} secondly and the TP_{TC} lastly. It was also found that CKC hypothesis was supported by the data of 58 individual countries. Among the CKC-existing countries, there are still seven countries having not reached any of the TPs (i.e. all kinds TY > 0), 23 countries have reached the first step TP, 9 countries have reached the second step and 19 countries have reached the third step. Moreover, after analyzing the CKC existence at four income level, one relationship was discovered, i.e., a larger proportion of the higher-income-level countries have the CKCs compared with that of the lower-income-level countries.

According to the results, the governments can promote the carbon emission reduction based on the step-wise TP, i.e., reaching TPs from carbon intensity, per capita carbon emission and total carbon emission one by one. Furthermore, HI-level countries are suggested to promote the low-carbon economy through reaching TP_{TC}, since most countries at the HI level have already reached TP_{PC}. However, countries at the UMI and LMI levels should spend more efforts on TP_{PC} rather than TP_{TC}. The LI-level countries are suggested to target on reaching TP_{CI}.

Future studies are suggested to investigate the impact factors of reaching the three TPs, which are yet to examined in this paper. Moreover, the step-wise TP identification of other industries, such as manufacturing and construction, can be a direction for further research.

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APPENDIX 1

PER CAPITA CARBON EMISSION TURNING POINTS (TP_{PC}) AND TURNING YEARS (TY_{PC}) OF TRANSPORTATION SECTOR IN 119 COUNTRIES.

Country	TP_{PC}	TY_{PC}	CKC model	Exists CKC or not
HI-level countries				
Argentina	9665.3	−1	$lnC^1_{it} = -1.91808(lnY_{it})^2 + 35.20166lnY_{it} - 163.63714$	√
Australia			$lnC^1_{it} = 1.20682(lnY_{it})^2 - 25.79245lnY_{it} + 136.82849$	✗
Austria	45315.5	−4	$lnC^1_{it} = -7.48544(lnY_{it})^2 + 160.80844lnY_{it} - 861.75374$	√
Belgium	42140.2	−2	$lnC^1_{it} = -2.60009(lnY_{it})^2 + 55.37552lnY_{it} - 296.23605$	√
Brunei Darussalam			$lnC^1_{it} = 3.18978(lnY_{it})^2 - 71.19628lnY_{it} + 394.67099$	✗
Canada	43065.9	−10	$lnC^1_{it} = -2.17935(lnY_{it})^2 + 46.50941lnY_{it} - 248.81426$	√
Croatia	22857.9	20	$lnC^1_{it} = -0.83153(lnY_{it})^2 + 16.69212lnY_{it} - 85.47554$	√
Cyprus			$lnC^1_{it} = 3.59542(lnY_{it})^2 - 72.99538lnY_{it} + 368.81050$	✗
Czech Republic	18612.8	−4	$lnC^1_{it} = -6.47417(lnY_{it})^2 + 127.30305lnY_{it} - 627.58440$	√
Denmark			$lnC^1_{it} = 2.48018(lnY_{it})^2 - 54.03755lnY_{it} + 292.83718$	✗
Estonia	242354.7	21	$lnC^1_{it} = -0.06634(lnY_{it})^2 + 1.84507lnY_{it} - 13.39696$	√
Finland			$lnC^1_{it} = 0.33194(lnY_{it})^2 - 6.83116lnY_{it} + 33.61531$	✗
France	37267.0	−10	$lnC^1_{it} = -8.28720(lnY_{it})^2 + 174.45993lnY_{it} - 919.68151$	√
Greece			$lnC^1_{it} = 0.74166(lnY_{it})^2 - 14.33970lnY_{it} + 67.47413$	✗
Hong Kong SAR, China			$lnC^1_{it} = 4.41835(lnY_{it})^2 - 91.36908lnY_{it} + 469.87299$	✗
Hungary	21987.5	18	$lnC^1_{it} = -0.65387(lnY_{it})^2 + 13.37500lnY_{it} - 70.15720$	√
Iceland			$lnC^1_{it} = 4.27909(lnY_{it})^2 - 89.80695lnY_{it} + 469.69354$	✗
Ireland	49315.1	−3	$lnC^1_{it} = -1.71335(lnY_{it})^2 + 37.02884lnY_{it} - 201.13134$	√
Israel			$lnC^1_{it} = 1.06462(lnY_{it})^2 - 21.56298lnY_{it} + 112.13134$	✗
Italy			$lnC^1_{it} = 9.65243(lnY_{it})^2 - 201.05863lnY_{it} + 1045.36168$	✗
Japan	37367.7	−29	$lnC^1_{it} = -5.47143(lnY_{it})^2 + 115.21248lnY_{it} - 608.03035$	√
Korea, Rep.	19459.8	−6	$lnC^1_{it} = -0.55410(lnY_{it})^2 + 10.94475lnY_{it} - 55.73658$	√
Kuwait	42994.1	6	$lnC^1_{it} = -7.89178(lnY_{it})^2 + 170.31233lnY_{it} - 909.25889$	√
Latvia			$lnC^1_{it} = 0.12492(lnY_{it})^2 - 1.50380lnY_{it} + 1.14978$	✗
Lithuania			$lnC^1_{it} = 0.47621(lnY_{it})^2 - 8.04302lnY_{it} + 31.68464$	✗
Luxembourg	141661.3	4	$lnC^1_{it} = -1.57683(lnY_{it})^2 + 37.40613lnY_{it} - 221.39806$	√
Malta			$lnC^1_{it} = 7.57433(lnY_{it})^2 - 149.68652lnY_{it} + 737.26812$	✗
Netherlands	50334.8	−1	$lnC^1_{it} = -0.75017(lnY_{it})^2 + 16.24337lnY_{it} - 89.43901$	√
New Zealand	29843.1	−11	$lnC^1_{it} = -0.88281(lnY_{it})^2 + 18.19241lnY_{it} - 94.79891$	√
Norway			$lnC^1_{it} = 3.88365(lnY_{it})^2 - 86.11836lnY_{it} + 476.10133$	✗
Oman	18557.0	6	$lnC^1_{it} = -32.71570(lnY_{it})^2 + 643.99915lnY_{it} - 3170.78781$	√
Panama	7823.2	−7	$lnC^1_{it} = -1.74047(lnY_{it})^2 + 31.20620lnY_{it} - 142.15442$	√
Poland			$lnC^1_{it} = 0.04279(lnY_{it})^2 - 0.22535lnY_{it} - 8.08447$	✗
Portugal			$lnC^1_{it} = 0.89302(lnY_{it})^2 - 16.47133lnY_{it} + 73.71541$	✗

(Continued)

Country	TP_{PC}	TY_{PC}	CKC model	Exists CKC or not
Qatar	64983.7	−2	$lnC_{it}^1 = -17.70938(lnY_{it})^2 + 392.50693lnY_{it} - 2175.08969$	√
Saudi Arabia			$lnC_{it}^1 = 6.98703(lnY_{it})^2 - 135.88540lnY_{it} + 659.63005$	✗
Singapore			$lnC_{it}^1 = 5.16816(lnY_{it})^2 - 109.70457lnY_{it} + 579.98626$	✗
Slovenia			$lnC_{it}^1 = 3.92977(lnY_{it})^2 - 77.01913lnY_{it} + 375.72981$	✗
Spain			$lnC_{it}^1 = 4.69398(lnY_{it})^2 - 95.30560lnY_{it} + 482.16783$	✗
Sweden	88669.0	27	$lnC_{it}^1 = -0.46924(lnY_{it})^2 + 10.69174lnY_{it} - 62.12901$	√
Switzerland	69458.0	−8	$lnC_{it}^1 = -7.19699(lnY_{it})^2 + 160.47097lnY_{it} - 896.04471$	√
Trinidad and Tobago			$lnC_{it}^1 = 0.88292(lnY_{it})^2 - 15.63806lnY_{it} + 67.84500$	✗
United Arab Emirates	50897.1	5	$lnC_{it}^1 = -3.13690(lnY_{it})^2 + 67.99262lnY_{it} - 369.10315$	√
United Kingdom	32050.6	−16	$lnC_{it}^1 = -1.52312(lnY_{it})^2 + 31.60487lnY_{it} - 165.48976$	√
United States	43522.1	−11	$lnC_{it}^1 = -3.45154(lnY_{it})^2 + 73.73194lnY_{it} - 394.26783$	√
Uruguay			$lnC_{it}^1 = 0.03392(lnY_{it})^2 - 0.11538lnY_{it} - 6.39615$	✗
UMI-level countries				
Algeria			$lnC_{it}^1 = 8.08127(lnY_{it})^2 - 132.61967lnY_{it} + 541.55546$	✗
Azerbaijan			$lnC_{it}^1 = 0.28012(lnY_{it})^2 - 3.95493lnY_{it} + 10.69504$	✗
Belarus			$lnC_{it}^1 = 0.76740(lnY_{it})^2 - 12.03640lnY_{it} + 44.55381$	✗
Bosnia and Herzegovina			$lnC_{it}^1 = 0.61611(lnY_{it})^2 - 8.65143lnY_{it} + 26.68809$	✗
Botswana		5	$lnC_{it}^1 = -1.53981(lnY_{it})^2 + 27.97460lnY_{it} - 129.25504$	√
Brazil			$lnC_{it}^1 = 5.37411(lnY_{it})^2 - 98.04914lnY_{it} + 444.68291$	✗
China	38043.8	22	$lnC_{it}^1 = -0.18431(lnY_{it})^2 + 3.88769lnY_{it} - 22.62864$	√
Colombia			$lnC_{it}^1 = 1.92323(lnY_{it})^2 - 32.51735lnY_{it} + 134.50557$	✗
Costa Rica	7890.0	−6	$lnC_{it}^1 = -3.21094(lnY_{it})^2 + 57.62582lnY_{it} - 260.68573$	√
Cuba	2158.6	−25	$lnC_{it}^1 = -0.47813(lnY_{it})^2 + 7.34136lnY_{it} - 31.98904$	√
Dominican Republic	4081.4	−12	$lnC_{it}^1 = -1.12246(lnY_{it})^2 + 18.66472lnY_{it} - 80.24667$	√
Ecuador			$lnC_{it}^1 = 2.71208(lnY_{it})^2 - 44.95888lnY_{it} + 183.88385$	✗
Gabon	12341.0	7	$lnC_{it}^1 = -5.25192(lnY_{it})^2 + 98.95335lnY_{it} - 468.31037$	√
Guatemala	2798.8	−6	$lnC_{it}^1 = -12.61891(lnY_{it})^2 + 200.31088lnY_{it} - 798.04974$	√
Iran, Islamic Rep.	6253.1	1	$lnC_{it}^1 = -4.86254(lnY_{it})^2 + 85.00537lnY_{it} - 373.21061$	√
Iraq	5798.5	2	$lnC_{it}^1 = -0.37994(lnY_{it})^2 + 6.58466lnY_{it} - 30.65047$	√
Jamaica	4841.9	1	$lnC_{it}^1 = -26.42688(lnY_{it})^2 + 448.46768lnY_{it} - 1905.25383$	√
Jordan	3397.9	1	$lnC_{it}^1 = -4.02228(lnY_{it})^2 + 65.40961lnY_{it} - 268.34149$	√
Kazakhstan	27214.5	17	$lnC_{it}^1 = -0.20391(lnY_{it})^2 + 4.16449lnY_{it} - 23.47573$	√
Lebanon			$lnC_{it}^1 = 4.86399(lnY_{it})^2 - 86.91826lnY_{it} + 386.14302$	✗
Libya			$lnC_{it}^1 = 0.12342(lnY_{it})^2 - 2.11314lnY_{it} + 7.74590$	✗
Macedonia, FYR			$lnC_{it}^1 = 4.75988(lnY_{it})^2 - 78.74496lnY_{it} + 322.85739$	✗
Malaysia			$lnC_{it}^1 = 0.77434(lnY_{it})^2 - 13.20587lnY_{it} + 54.35410$	✗
Mauritius	8987.3	−1	$lnC_{it}^1 = -0.77997(lnY_{it})^2 + 14.20103lnY_{it} - 67.15123$	√
Mexico	7258.7	−21	$lnC_{it}^1 = 4.08292(lnY_{it})^2 - 72.59390lnY_{it} + 320.44013$	✗
Namibia	7379.9	9	$lnC_{it}^1 = -1.06057(lnY_{it})^2 + 18.89193lnY_{it} - 86.60622$	√

(Continued)

Country	TP_{PC}	TY_{PC}	CKC model	Exists CKC or not
Paraguay	4289.9	9	$lnC_{it}^1 = -1.20516(lnY_{it})^2 + 20.15990lnY_{it} - 86.80222$	√
Peru			$lnC_{it}^1 = 0.21177(lnY_{it})^2 - 2.25445lnY_{it} + 1.12415$	✗
Romania	13472.9	11	$lnC_{it}^1 = -0.28016(lnY_{it})^2 + 5.72773lnY_{it} - 31.48323$	√
Russian Federation			$lnC_{it}^1 = 0.22542(lnY_{it})^2 - 3.52597lnY_{it} + 11.61702$	✗
South Africa			$lnC_{it}^1 = 5.67053(lnY_{it})^2 - 99.27580lnY_{it} + 432.19105$	✗
Thailand	6696.8	7	$lnC_{it}^1 = -0.58819(lnY_{it})^2 + 10.36324lnY_{it} - 47.82253$	√
Turkey			$lnC_{it}^1 = 1.99841(lnY_{it})^2 - 36.17482lnY_{it} + 160.89762$	✗
Turkmenistan	4524.1	−6	$lnC_{it}^1 = -1.22452(lnY_{it})^2 + 20.61395lnY_{it} - 88.31901$	√
Venezuela, RB			$lnC_{it}^1 = 1.92761(lnY_{it})^2 - 36.67499lnY_{it} + 172.74850$	✗
LMI-level countries				
Angola	7421.4	13	$lnC_{it}^1 = -0.75092(lnY_{it})^2 + 13.38463lnY_{it} - 62.14074$	√
Bolivia			$lnC_{it}^1 = 4.37713(lnY_{it})^2 - 65.14886lnY_{it} + 239.50898$	✗
Cambodia			$lnC_{it}^1 = 1.70671(lnY_{it})^2 - 20.77738lnY_{it} + 58.68403$	✗
Cameroon			$lnC_{it}^1 = 11.82099(lnY_{it})^2 - 168.61678lnY_{it} + 597.09963$	✗
Congo, Rep.			$lnC_{it}^1 = 11.62823(lnY_{it})^2 - 179.83916lnY_{it} + 691.68989$	✗
Cote d'Ivoire	1642.8	46	$lnC_{it}^1 = -2.05204(lnY_{it})^2 + 31.86816lnY_{it} - 127.54172$	√
Egypt, Arab Rep.	4215.2	20	$lnC_{it}^1 = -0.56178(lnY_{it})^2 + 9.37767lnY_{it} - 41.83798$	√
El Salvador	2973.7	−7	$lnC_{it}^1 = -10.18575(lnY_{it})^2 + 162.92232lnY_{it} - 654.43536$	√
Georgia	7664.6	10	$lnC_{it}^1 = -0.51400(lnY_{it})^2 + 9.19484lnY_{it} - 43.31995$	√
Ghana			$lnC_{it}^1 = 2.69174(lnY_{it})^2 - 37.74874lnY_{it} + 128.35926$	✗
Honduras			$lnC_{it}^1 = 4.84059(lnY_{it})^2 - 71.51650lnY_{it} + 260.74526$	✗
India			$lnC_{it}^1 = 0.66165(lnY_{it})^2 - 8.32299lnY_{it} + 21.51784$	✗
Indonesia			$lnC_{it}^1 = 1.40028(lnY_{it})^2 - 20.55714lnY_{it} + 71.74180$	✗
Kenya			$lnC_{it}^1 = 4.90590(lnY_{it})^2 - 65.72537lnY_{it} + 215.59430$	✗
Kyrgyz Republic			$lnC_{it}^1 = 6.25893(lnY_{it})^2 - 80.95160lnY_{it} + 257.92191$	✗
Moldova			$lnC_{it}^1 = 0.19739(lnY_{it})^2 - 1.88244lnY_{it} - 0.43410$	✗
Mongolia			$lnC_{it}^1 = 0.79797(lnY_{it})^2 - 11.02353lnY_{it} + 34.45846$	✗
Morocco	6951.4	25	$lnC_{it}^1 = -0.57287(lnY_{it})^2 + 10.13608lnY_{it} - 47.39382$	√
Myanmar	719.9	−7	$lnC_{it}^1 = -0.27078(lnY_{it})^2 + 3.56302lnY_{it} - 16.47074$	√
Nicaragua	2478.2	12	$lnC_{it}^1 = -0.25404(lnY_{it})^2 + 3.97075lnY_{it} - 18.94382$	√
Nigeria	1761.6	−9	$lnC_{it}^1 = -5.98542(lnY_{it})^2 + 89.46967lnY_{it} - 337.53967$	√
Pakistan	2232.4	13	$lnC_{it}^1 = -0.42883(lnY_{it})^2 + 6.61327lnY_{it} - 28.94992$	√
Philippines			$lnC_{it}^1 = 2.46535(lnY_{it})^2 - 37.88195lnY_{it} + 141.92960$	✗
Sudan	2163.5	4	$lnC_{it}^1 = -1.27385(lnY_{it})^2 + 19.56501lnY_{it} - 78.70858$	√
Tunisia			$lnC_{it}^1 = 0.88728(lnY_{it})^2 - 13.37429lnY_{it} + 47.11549$	✗
Ukraine			$lnC_{it}^1 = 0.94501(lnY_{it})^2 - 14.45196lnY_{it} + 52.53252$	✗
Uzbekistan	759.2	−18	$lnC_{it}^1 = -0.90934(lnY_{it})^2 + 12.06198lnY_{it} - 43.13997$	√
Vietnam	1919.2	4	$lnC_{it}^1 = -1.03373(lnY_{it})^2 + 15.62932lnY_{it} - 62.24173$	√
Zambia			$lnC_{it}^1 = 2.49863(lnY_{it})^2 - 35.41934lnY_{it} + 120.57373$	✗

(Continued)

Country	TP_{PC}	TY_{PC}	CKC model	Exists CKC or not
LI-level countries				
Benin			$lnC_{it}^{1} = 3.28523(lnY_{it})^{2} - 37.19268lnY_{it} + 98.62879$	✗
Haiti	684.7	−2	$lnC_{it}^{1} = -38.97400(lnY_{it})^{2} + 508.92349lnY_{it} - 1665.77780$	√
Mozambique			$lnC_{it}^{1} = 1.33404(lnY_{it})^{2} - 14.25679lnY_{it} + 32.70539$	✗
Nepal			$lnC_{it}^{1} = 9.03836(lnY_{it})^{2} - 110.26770lnY_{it} + 330.62060$	✗
Senegal			$lnC_{it}^{1} = 13.90380(lnY_{it})^{2} - 186.90834lnY_{it} + 623.76015$	✗
Tajikistan			$lnC_{it}^{1} = 5.76096(lnY_{it})^{2} - 70.78749lnY_{it} + 210.87865$	✗
Tanzania			$lnC_{it}^{1} = 0.52707(lnY_{it})^{2} - 4.81946lnY_{it} + 4.28904$	✗
Togo	511.9	−1	$lnC_{it}^{1} = -36.84128(lnY_{it})^{2} + 459.64065lnY_{it} - 1437.53974$	√
Zimbabwe	2590.7	11	$lnC_{it}^{1} = -0.62976(lnY_{it})^{2} + 9.89947lnY_{it} - 42.57687$	√

APPENDIX 2

TOTAL CARBON EMISSION TURNING POINTS (TP_{TC}) AND TURNING YEARS (TY_{TC}) OF TRANSPORTATION SECTOR IN 119 COUNTRIES.

Country	TP_{TC}	TY_{TC}	CKC model	Exists CKC or not
HI-level countries				
Argentina	16080.5	5	$lnC_{it}^1 = -0.59429(lnY_{it})^2 + 11.51179lnY_{it} - 40.23637$	√
Australia			$lnC_{it}^1 = 2.95548(lnY_{it})^2 - 62.64684lnY_{it} + 347.73477$	✗
Austria	46547.2	−2	$lnC_{it}^1 = -6.59243(lnY_{it})^2 + 141.71380lnY_{it} - 746.97087$	√
Belgium	71212.6	14	$lnC_{it}^1 = -0.52177(lnY_{it})^2 + 11.65986lnY_{it} - 50.22481$	√
Brunei Darussalam			$lnC_{it}^1 = 0.57023(lnY_{it})^2 - 18.09384lnY_{it} - 50.22481$	✗
Canada			$lnC_{it}^1 = 0.03962(lnY_{it})^2 - 0.28936lnY_{it} + 15.14270$	✗
Croatia	27194.3	27	$lnC_{it}^1 = -0.60312(lnY_{it})^2 + 12.31659lnY_{it} - 49.23032$	√
Cyprus			$lnC_{it}^1 = 0.58911(lnY_{it})^2 - 10.76558lnY_{it} + 60.66046$	✗
Czech Republic	18834.2	−3	$lnC_{it}^1 = -5.98551(lnY_{it})^2 + 117.83590lnY_{it} - 565.59382$	√
Denmark			$lnC_{it}^1 = 2.28294(lnY_{it})^2 - 49.44496lnY_{it} + 281.70731$	✗
Estonia	567445.2	28	$lnC_{it}^1 = -0.06654(lnY_{it})^2 + 1.76328lnY_{it} + 1.51790$	√
Finland			$lnC_{it}^1 = 0.46383(lnY_{it})^2 - 9.49976lnY_{it} + 62.54964$	✗
France	38725.6	−6	$lnC_{it}^1 = -5.30587(lnY_{it})^2 + 112.10518lnY_{it} - 575.73859$	√
Greece			$lnC_{it}^1 = 0.39288(lnY_{it})^2 - 7.18588lnY_{it} + 47.00899$	✗
Hong Kong SAR, China			$lnC_{it}^1 = 4.39256(lnY_{it})^2 - 90.64570lnY_{it} + 480.90888$	✗
Hungary	24004.2	22	$lnC_{it}^1 = -0.72324(lnY_{it})^2 + 14.58923lnY_{it} - 59.31250$	√
Iceland			$lnC_{it}^1 = 4.43182(lnY_{it})^2 - 92.52049lnY_{it} + 493.90383$	✗
Ireland	70379.8	8	$lnC_{it}^1 = -0.98690(lnY_{it})^2 + 22.03094lnY_{it} - 108.84881$	√
Israel			$lnC_{it}^1 = 0.80716(lnY_{it})^2 - 15.68006lnY_{it} + 90.12190$	✗
Italy			$lnC_{it}^1 = 8.27329(lnY_{it})^2 - 172.17380lnY_{it} + 912.00100$	✗
Japan	39290.4	−22	$lnC_{it}^1 = -7.66659(lnY_{it})^2 + 162.20565lnY_{it} - 840.86593$	√
Korea, Rep.	22650.3	−2	$lnC_{it}^1 = -0.52228(lnY_{it})^2 + 10.47471lnY_{it} - 36.49760$	√
Kuwait	46261.3	8	$lnC_{it}^1 = -6.87493(lnY_{it})^2 + 146.70176lnY_{it} - 768.68450$	√
Latvia			$lnC_{it}^1 = 0.05860(lnY_{it})^2 - 0.48617lnY_{it} + 12.01721$	✗
Lithuania			$lnC_{it}^1 = 0.31688(lnY_{it})^2 - 5.33406lnY_{it} + 35.26611$	✗
Luxembourg	901216.6	31	$lnC_{it}^1 = -0.43868(lnY_{it})^2 + 12.02979lnY_{it} - 67.03031$	√
Malta			$lnC_{it}^1 = 7.99994(lnY_{it})^2 - 157.75773lnY_{it} + 788.36964$	✗
Netherlands	73985.5	11	$lnC_{it}^1 = -0.44933(lnY_{it})^2 + 10.07547lnY_{it} - 41.30251$	√
New Zealand			$lnC_{it}^1 = 0.36670(lnY_{it})^2 - 7.014181lnY_{it} + 47.44515$	✗
Norway			$lnC_{it}^1 = 5.47660(lnY_{it})^2 - 121.59825lnY_{it} + 688.94335$	✗
Oman	18674.1	6	$lnC_{it}^1 = -44.61870(lnY_{it})^2 + 877.64017lnY_{it} - 4302.49327$	√
Panama	8432.3	−5	$lnC_{it}^1 = -2.16845(lnY_{it})^2 + 39.20488lnY_{it} - 164.36435$	√
Poland			$lnC_{it}^1 = 0.06989(lnY_{it})^2 - 0.29537lnY_{it} + 11.87079$	✗

(Continued)

Country	TP_{TC}	TY_{TC}	CKC model	Exists CKC or not
Portugal			$lnC_{it}^{1} = 1.34618(lnY_{it})^2 - 25.21187lnY_{it} + 131.96904$	✗
Qatar	74357.7	4	$lnC_{it}^{1} = -28.90567(lnY_{it})^2 + 648.44922lnY_{it} - 3622.49336$	√
Saudi Arabia			$lnC_{it}^{1} = 16.66052(lnY_{it})^2 - 324.64750lnY_{it} + 1597.32695$	✗
Singapore			$lnC_{it}^{1} = 5.46488(lnY_{it})^2 - 115.31991lnY_{it} + 621.48856$	✗
Slovenia			$lnC_{it}^{1} = 4.04548(lnY_{it})^2 - 79.24056lnY_{it} + 400.89204$	✗
Spain			$lnC_{it}^{1} = 4.92266(lnY_{it})^2 - 99.47846lnY_{it} + 518.48337$	✗
Sweden			$lnC_{it}^{1} = 0.50766(lnY_{it})^2 - 10.05727lnY_{it} - 64.03762$	✗
Switzerland	74311.8	−2	$lnC_{it}^{1} = -4.73887(lnY_{it})^2 + 106.30256lnY_{it} - 581.85418$	√
Trinidad and Tobago			$lnC_{it}^{1} = 0.96610(lnY_{it})^2 - 17.12079lnY_{it} + 88.49766$	✗
United Arab Emirates	52650.4	6	$lnC_{it}^{1} = -7.00186(lnY_{it})^2 + 149.24052lnY_{it} - 780.13447$	√
United Kingdom	34721.9	−11	$lnC_{it}^{1} = -0.48348(lnY_{it})^2 + 10.10966lnY_{it} - 36.50640$	√
United States	49952.8	−1	$lnC_{it}^{1} = -2.04041(lnY_{it})^2 + 44.14969lnY_{it} - 219.83795$	√
Uruguay			$lnC_{it}^{1} = 0.08359(lnY_{it})^2 - 0.73397lnY_{it} + 12.23132$	✗
UMI-level countries				
Algeria			$lnC_{it}^{1} = 9.67882(lnY_{it})^2 - 158.36091lnY_{it} + 662.45752$	✗
Azerbaijan			$lnC_{it}^{1} = 0.31005(lnY_{it})^2 - 4.32876lnY_{it} + 27.71482$	✗
Belarus			$lnC_{it}^{1} = 0.78802(lnY_{it})^2 - 12.44117lnY_{it} + 62.58071$	✗
Bosnia and Herzegovina			$lnC_{it}^{1} = 0.59725(lnY_{it})^2 - 8.38306lnY_{it} + 40.89081$	✗
Botswana	9729.6	8	$lnC_{it}^{1} = -1.76278(lnY_{it})^2 + 32.37503lnY_{it} - 136.18745$	√
Brazil			$lnC_{it}^{1} = 3.81456(lnY_{it})^2 - 68.77622lnY_{it} + 326.43583$	✗
China	65229.6	28	$lnC_{it}^{1} = -0.21144(lnY_{it})^2 + 4.38782lnY_{it} - 3.89946$	√
Colombia			$lnC_{it}^{1} = 1.37023(lnY_{it})^2 - 22.47653lnY_{it} + 106.62864$	✗
Costa Rica	8320.3	−3	$lnC_{it}^{1} = -3.92482(lnY_{it})^2 + 70.85434lnY_{it} - 306.59138$	√
Cuba	2466.0	−22	$lnC_{it}^{1} = -0.55170(lnY_{it})^2 + 8.61801lnY_{it} - 21.28082$	√
Dominican Republic	4927.3	−7	$lnC_{it}^{1} = -1.19944(lnY_{it})^2 + 20.39653lnY_{it} - 73.33563$	√
Ecuador			$lnC_{it}^{1} = 2.27497(lnY_{it})^2 - 36.87652lnY_{it} + 163.29353$	✗
Gabon	13246.7	9	$lnC_{it}^{1} = -5.08784(lnY_{it})^2 + 94.58252lnY_{it} - 427.84335$	√
Guatemala	3008.0	1	$lnC_{it}^{1} = -12.44848(lnY_{it})^2 + 199.40070lnY_{it} - 785.10271$	√
Iran, Islamic Rep.	6388.0	2	$lnC_{it}^{1} = -5.80952(lnY_{it})^2 + 101.80814lnY_{it} - 429.60378$	√
Iraq			$lnC_{it}^{1} = 0.46048(lnY_{it})^2 - 6.60768lnY_{it} + 38.01589$	✗
Jamaica	4944.6	2	$lnC_{it}^{1} = -23.24478(lnY_{it})^2 + 394.44269lnY_{it} - 1661.13415$	√
Jordan	3561.5	5	$lnC_{it}^{1} = -7.40462(lnY_{it})^2 + 121.10897lnY_{it} - 481.90174$	√
Kazakhstan			$lnC_{it}^{1} = 0.15502(lnY_{it})^2 - 2.01538lnY_{it} + 19.63081$	✗
Lebanon			$lnC_{it}^{1} = 2.48678(lnY_{it})^2 - 56.75442lnY_{it}242.17121$	✗
Libya			$lnC_{it}^{1} = 0.52516(lnY_{it})^2 - 9.31378lnY_{it} + 55.55671$	✗
Macedonia, FYR			$lnC_{it}^{1} = 4.43353(lnY_{it})^2 - 73.27725lnY_{it} + 314.50148$	✗
Malaysia			$lnC_{it}^{1} = 0.40614(lnY_{it})^2 - 5.85816lnY_{it} + 35.11851$	✗
Mauritius	10367.6	3	$lnC_{it}^{1} = -1.02253(lnY_{it})^2 + 18.60963lnY_{it} - 73.13881$	√
Mexico			$lnC_{it}^{1} = 8.56769(lnY_{it})^2 - 152.64542lnY_{it} + 696.02370$	✗

(Continued)

Country	TP_{TC}	TY_{TC}	CKC model	Exists CKC or not
Namibia	8421.9	14	$lnC_{it}^1 = -1.26659(lnY_{it})^2 + 22.89635lnY_{it} - 91.18523$	√
Paraguay			$lnC_{it}^1 = 0.66678(lnY_{it})^2 - 9.38028lnY_{it} + 45.25248$	✗
Peru			$lnC_{it}^1 = 0.08446(lnY_{it})^2 - 1.43151lnY_{it} + 9.35758$	✗
Romania	16274.5	17	$lnC_{it}^1 = -0.33988(lnY_{it})^2 + 6.59181lnY_{it} - 17.58500$	√
Russian Federation			$lnC_{it}^1 = 0.30073(lnY_{it})^2 - 4.93016lnY_{it} + 36.94120$	✗
South Africa			$lnC_{it}^1 = 5.08539(lnY_{it})^2 - 88.36915lnY_{it} + 399.23768$	✗
Thailand	7657.8	13	$lnC_{it}^1 = -0.63738(lnY_{it})^2 + 11.40086lnY_{it} - 35.07100$	√
Turkey			$lnC_{it}^1 = 1.79316(lnY_{it})^2 - 31.97948lnY_{it} + 157.72293$	✗
Turkmenistan	4846.4	−5	$lnC_{it}^1 = -1.25631(lnY_{it})^2 + 21.32208lnY_{it} - 76.57816$	√
Venezuela, RB			$lnC_{it}^1 = 5.53727(lnY_{it})^2 - 104.10324lnY_{it} + 504.64106$	✗
LMI-level countries				
Angola	8529.4	16	$lnC_{it}^1 = -0.88897(lnY_{it})^2 + 16.09271lnY_{it} - 58.06547$	√
Bolivia			$lnC_{it}^1 = 2.64477(lnY_{it})^2 - 38.31150lnY_{it} + 151.72864$	✗
Cambodia			$lnC_{it}^1 = 1.63036(lnY_{it})^2 - 19.51579lnY_{it} + 70.14312$	✗
Cameroon			$lnC_{it}^1 = 13.66828(lnY_{it})^2 - 193.02771lnY_{it} + 693.90717$	✗
Congo, Rep.			$lnC_{it}^1 = 10.82381(lnY_{it})^2 - 165.03993lnY_{it} + 640.25359$	✗
Cote d'Ivoire			$lnC_{it}^1 = 0.13624(lnY_{it})^2 - 0.51467lnY_{it} + 8.83530$	√
Egypt, Arab Rep.	8166.8	48	$lnC_{it}^1 = -0.54694(lnY_{it})^2 + 9.85346lnY_{it} - 28.21473$	√
El Salvador	3014.5	−6	$lnC_{it}^1 = -11.52011(lnY_{it})^2 + 184.57975lnY_{it} - 726.66521$	√
Georgia	9085.3	12	$lnC_{it}^1 = -0.53974(lnY_{it})^2 + 9.41888lnY_{it} - 28.27786$	√
Ghana			$lnC_{it}^1 = 1.59293(lnY_{it})^2 - 21.43358lnY_{it} + 84.88231$	✗
Honduras			$lnC_{it}^1 = 3.75447(lnY_{it})^2 - 53.91359lnY_{it} + 205.63474$	✗
India			$lnC_{it}^1 = 0.49064(lnY_{it})^2 - 5.66397lnY_{it} + 32.17672$	✗
Indonesia			$lnC_{it}^1 = 1.34628(lnY_{it})^2 - 19.30538lnY_{it} + 84.46725$	✗
Kenya			$lnC_{it}^1 = 4.77180(lnY_{it})^2 - 62.24777lnY_{it} + 215.52776$	✗
Kyrgyz Republic			$lnC_{it}^1 = 6.35090(lnY_{it})^2 - 81.79638lnY_{it} + 274.93267$	✗
Moldova			$lnC_{it}^1 = 0.21980(lnY_{it})^2 - 2.24895lnY_{it} + 16.13858$	✗
Mongolia			$lnC_{it}^1 = 0.77373(lnY_{it})^2 - 10.41851lnY_{it} + 45.99607$	✗
Morocco	11655.4	42	$lnC_{it}^1 = -0.50556(lnY_{it})^2 + 9.46761lnY_{it} - 29.03453$	√
Myanmar	830.5	−5	$lnC_{it}^1 = -0.29416(lnY_{it})^2 + 3.95476lnY_{it} - 0.32241$	√
Nicaragua	2655.0	15	$lnC_{it}^1 = -0.69562(lnY_{it})^2 + 10.96872lnY_{it} - 30.97485$	√
Nigeria	1846.5	−8	$lnC_{it}^1 = -5.65386(lnY_{it})^2 + 85.04614lnY_{it} - 304.27602$	√
Pakistan	6708.6	34	$lnC_{it}^1 = -0.46136(lnY_{it})^2 + 8.13026lnY_{it} - 18.97239$	√
Philippines			$lnC_{it}^1 = 1.37076(lnY_{it})^2 - 20.66549lnY_{it} + 92.64211$	✗
Sudan	2281.6	5	$lnC_{it}^1 = -1.63118(lnY_{it})^2 + 25.22656lnY_{it} - 83.65293$	√
Tunisia			$lnC_{it}^1 = 1.07726(lnY_{it})^2 - 16.13650lnY_{it} + 73.13318$	✗
Ukraine			$lnC_{it}^1 = 0.96248(lnY_{it})^2 - 14.87610lnY_{it} + 72.45788$	✗
Uzbekistan	909.2	−14	$lnC_{it}^1 = -0.97146(lnY_{it})^2 + 13.23627lnY_{it} - 31.20979$	√
Vietnam	2096.8	6	$lnC_{it}^1 = -1.04288(lnY_{it})^2 + 15.95227lnY_{it} - 45.78636$	√

(Continued)

Country	TP_{TC}	TY_{TC}	CKC model	Exists CKC or not
Zambia	9		$lnC_{it}^{1} = 1.83570(lnY_{it})^2 - 25.26594lnY_{it} + 98.26595$	✗
LI-level countries				
Benin			$lnC_{it}^{1} = 3.91170(lnY_{it})^2 - 43.20468lnY_{it} + 126.92596$	✗
Haiti	685.0	−2	$lnC_{it}^{1} = -52.61333(lnY_{it})^2 + 687.07386lnY_{it} - 2231.40680$	√
Mozambique			$lnC_{it}^{1} = 1.65127(lnY_{it})^2 - 17.31513lnY_{it} + 56.60250$	✗
Nepal			$lnC_{it}^{1} = 8.14936(lnY_{it})^2 - 98.62541lnY_{it} + 309.65201$	✗
Senegal			$lnC_{it}^{1} = 20.12690(lnY_{it})^2 - 269.83607lnY_{it} + 916.04448$	✗
Tajikistan			$lnC_{it}^{1} = 6.00474(lnY_{it})^2 - 73.48964lnY_{it} + 233.93109$	✗
Tanzania			$lnC_{it}^{1} = 0.54885(lnY_{it})^2 - 4.17618lnY_{it} + 16.77756$	✗
Togo	508.4	−1	$lnC_{it}^{1} = -53.16222(lnY_{it})^2 + 662.54001lnY_{it} - 2052.56667$	√
Zimbabwe	3257.3	13	$lnC_{it}^{1} = -1.22949(lnY_{it})^2 + 17.88989lnY_{it} - 52.74435$	√