Quarterly Journal of Quantitative Economics, Summer 2017, 14(2): 215-232

Environmental Kuznets Curve: New Evidences Based on a Dynamic Panel Threshold Model

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Received: 2015/8/26 Accepted: 2016/7/11

Abstract:
This paper examines the non-linear relationship between CO_2 emissions and economic development using an innovative dynamic panel threshold technique. The sample consists of 35 developed countries over the period 2003-2010. The empirical results indicate that there is a threshold effect in the relationship between economic growth and pollutant emissions as suggested by the environmental Kuznets curve (EKC). In particular, at the early stage of economic development below the estimated threshold value, more growth deteriorates the environmental problems. However, after this threshold value further growth serves as a solution to the environmental problems. Accordingly, promoting economic growth and becoming rich in the long run, is necessary to solve the environmental problems arising from greenhouse gas (GHG) emissions. In the short run and in the early stage of economic growth, focus on investments in environmentally friendly technology and on the use of renewable energy is necessary for mitigating the pollution effects of economic progress.

JEL classification**:** Q53, O40, C33

Keywords: *CO_2 emissions; Economic growth; Environmental Kuznets curve; Threshold effects; Dynamic panel threshold*

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1. Introduction

The environmental effects of economic development have captured much attention of economists in recent years. One particular aspect, is the assertion that environmental problems arising from greenhouse gas (GHG) emissions deteriorate in the early stage of economic development and improve in later stages as economy develops. In other words, when economic development passes a threshold point it serves as a solution to environmental problems. This systematic relationship between economic development and environmental problems forms an inverse U-shaped relation and has been called the Environmental Kuznets Curve (EKC). The general idea is that at the early stage of economic development with the intensification of agriculture and other resource extraction, the rate of resource depletion begins to exceed the rate of resource regeneration, and waste generation increases in quantity and toxicity. At higher levels of development, structural change towards information-intensive industries and services, coupled with increased environmental awareness, enforcement of environmental regulations, better technology and higher environmental expenditures, results in levelling off and gradual decline of environmental degradation and therefore environmental quality will improve (Dinda, 2004; Stern, 2004; Ibrahim and Law, 2014).

The amount of literature on the EKC has grown in recent years to verify its presence and to estimate the income threshold point. To determine the income threshold point some scholars have adopted a standard quadratic relation between CO_2 emissions and income by incorporating the square term of the income level in their models. Extensive surveys on these studies were provided by Dinda (2004) and Ibrahim and Law (2014). The standard quadratic specification used by researchers to search for a non-linear relationship between CO_2 emissions and economic development has one important limitation. The square term of the economic development variable used to capture the threshold impact of economic development on CO_2 emissions imposes a prior restriction so that the impact of economic development on CO_2 emissions monotonically and symmetrically increases and decreases with the level of economic development. However, it may also be that a certain level of economic development has to be attained before development can have any impact on CO_2 emissions. Further, negative ranges of the relationship may differ in absolute impact compared to positive ranges. This can be accommodated in a threshold model but not a quadratic specification. Against this backdrop, this study uses a regression model based on the concept of threshold effects to shed light on how development affects CO_2 emissions.

In this study we use a dynamic panel threshold method developed by Kremer et al. (2013) that extends Hansen's (1999) original static setup to endogenous regressors and the cross-sectional threshold model of Caner and Hansen (2004). This method has not been used before in analyzing the non-linear relationship between CO_2 emission and economic development. The CO_2 emissions model is a dynamic process in nature due to the temporal dependence in CO_2 emissions, which can be justified by gradual changes in the production structure and technology. Thus using a dynamic panel method is more appropriate rather than a static threshold specification such as Hansen (1999). The Hansen (2000) and Caner and Hansen (2004) threshold techniques are able to deal with the dynamic issue, but both techniques are based on cross-section analysis. It is more useful to employ panel data, since it provides more information and reduces multicollinearity, as well as controls for cross-country heterogeneity. Therefore, the dynamic panel threshold proposed by Kremer et al. (2013) certainly fills this gap in econometrics literature. Moreover, in the analysis, we focus on CO_2 emissions, which are viewed to be the most important global pollutant contributing about 72% of the global warming effects (Yan and Yang, 2010). The rest of the paper is organized as follows: the next section reviews the theoretical and empirical literature. Section 3 lays out the empirical model, the econometric method, and the data. Section 4 contains a discussion of the empirical findings and Section 5 provides a summary and conclusions.

2. Literature review

The EKC hypothesis has been studied extensively in the previous literature from both theoretical and empirical perspectives.

2.1. Theoretical literature

Several factors are responsible to shape the EKC. Each factor is investigated in the following subsections considering other things remain constant.

2.1.1. Income elasticity of environmental quality demand

Most of the EKC models have emphasized the role of income elasticity of environmental quality demand and this elasticity is often assumed to be in excess of unity, i.e., clean environment and preservation are ‘luxury goods’. Poor people have little demand for environmental quality. However, as income grows, people achieve a higher standard of living and care more for the quality of environment they live in and demand for better environment (McConnell, 1997 and Shafik, 1994). This will be reflected through defensive expenditures, donations to environmental organizations or choice of less environmentally damaging products. In most cases where emissions have declined with rising income, the reductions have been due to local and national institutional reforms, such as environmental legislation and market-based incentives to reduce environmental degradation (Dinda, 2004).

2.1.2. Scale, technological and composition effects

As output increases, more input and thus more natural resources are used in production process. More output also contributes to more waste and emissions. Economic growth, thus, has a negative impact on environment through the scale effect. According to the composition effect, environmental degradation tends to decrease as the structure of economy changes from an energy- intensive industry to services and a knowledge-based, technology- intensive industry. As a wealthy nation can afford to spend more on R&D, dirty and obsolete technologies are replaced by cleaner ones, which improve the environmental quality through the technique effect of economic growth. Thus the negative impact on environment of the scale effect will eventually be compensated by the positive impact of the composition and technique effects (Grossman and Krueger, 1995 and Vukina et al., 1999).

2.1.3. International trade

Free trade has contradictory impacts on environment, both increasing pollution and motivating reductions in it. Trade leads to an increase in the size of the economy that increases pollution, thus trade is the cause of environmental degradation *ceteris paribus*. As trade volume increases (especially export), environmental quality could decline through the scale effect. On the other hand, trade can improve the environment through the composition effect and the technique effect as explained in the previous sub-section. As income rises through trade, environmental regulation is tightened that spurs pollution reducing innovation. Moreover, higher income levels of people in developing countries will create demands for a cleaner environment.

As trade relates one country with international communities, an underdeveloped economy may rely on technology transfer through foreign direct investment (FDI) that may reduce pollution. But lower trade barriers could hurt environment if heavy polluters move to countries with weaker regulations and environmental standards below their efficiency levels. Economists call this the Pollution Haven Hypothesis (PHH). The PHH refers to the possibility that multinational firms, particularly those engaged in highly polluting activities, relocate to countries with lower environmental standards. The PHH argues that low environmental standards become a source of comparative advantage, and thus lead to changes in trade patterns. The PHH is basically a theory that suggests that high regulation countries will lose all dirty industries and poor countries will get them all (Dinda, 2004).

2.1.4. Market mechanism

Economic development may strengthen the market mechanism such that a developing economy may gradually shift from nonmarket to market energy resources that are less polluting (Kadekodi and Agarwal, 1999). After a certain stage of development, markets for environmental resources develop and prices begin to reflect the value of natural resources. The consequent increase in the price of natural resources reduces their exploitation at later stages of growth as well as environmental degradation associated with it. Moreover, higher prices of natural resources also contribute to accelerating the shift toward less resource-intensive technologies (Torras and Boyce, 1998).

2.1.5. Regulation

Emission can be reduced through strengthened environmental regulations. Economic growth will result in advanced social institutions that are essential to enforce environmental regulation (Dasgupta et al., 2001). Developing countries are moving, now, from command-and-control policies to market-oriented forms of regulations (Dasgupta et al., 2002). Beside, treating resources as common goods in developing economies motivates most people to exploit common resources in their own interest that will result in the depletion of resources. By defining some aspects of commons as private goods, individuals have greater incentive to manage and to conserve the resources and pass them to future generations. Countries with a high degree of private ownership and proper allocation of property rights have more efficient resource allocation. This helps to increase income and decrease environmental problems (Cropper and Griffiths, 1994).

2.2. Empirical literature

The empirical evidence for the existence of an EKC has been found in various studies. These studies share some common characteristics with respect to the data and methods employed.

Most of the data used in these studies are cross-sectional panel data. A large number of econometric studies have used the following reduced form model to test the EKC:

$$y_{it} = \alpha_i + \beta_1 x_{it} + \beta_2 x_{it}^2 + \beta_3 Z_{it} + \varepsilon_{it} \quad (1)$$

Where y is environmental indicators, x is income and Z relates to other relevant control variables. Here, the subscript i is a country, t is time, α is constant, β is the coefficient of explanatory variables. From this mode an inverted-U-shaped relationship between x and y (the EKC) is present if we have $\beta_1 > 0, \beta_2 < 0$. The inverted-U relationship has been confirmed by Grossman and Krueger (1995), Selden and Song (1994), Stern and Common (2001), List and Gallet (1999), Shukla and Parikh (1992), Barbier (1997), Brandoford *et al.* (2000), Matyas *et al.* (1998), Jha and Murthy (2003), Tucker (1995) and Roca (2003). The extensive surveys of these studies were provided by Dinda (2004) and Stern (2001).

From model (1) the turning point of the EKC is obtained at $x^* = -\frac{\beta_1}{2\beta_2}$. The turning points of these inverted-U-shaped relationships vary for different pollutants or environmental indicators. Moreover, there are also large variations among studies for same indicators. As stated by Dinda (2004) for most pollution indicators, the estimated turning point lies within the income range of US$3000–10,000 (at a constant price, 1985 US dollar). Atici (2009) in his analysis of four central and eastern European countries (Bulgaria, Hungary, Romania, and Turkey) finds the income threshold point to be USD2077– USD3156. As he notes, this estimate is substantially lower than those by Schmalensee et al. (1998) for the US (USD10, 000) and by Cole et al. (1997) for OECD countries (USD25, 000). Ibrahim and Law (2014) based on model (1) and a panel of 69 developed and developing countries found the income threshold point between USD1431 (based on system GMM estimation method) and USD3431 (first difference GMM estimation method). These estimates are within those of Atici (2009), Schmalensee et al., (1998) and Cole et al., (1997). According to their findings they conclude that in their sample, it may be the relatively high awareness of environmental degradation problem that triggers the need for better environment during the recent periods.

The EKC's paradoxical outcome inspired a large amount of research. Some relevant factors are included in the EKC specification to explain the inconsistent results of the EKC. Among them, social, political and institutional factors are crucial for shaping the EKC. According to Panayatou (1997) improvement of the environment with income growth, however, is not automatic but depends on policies and institutions. Based on this argument, he analyses the EKC for SO2 concentrations in an unbalanced panel of 30 developed and developing countries by incorporating an indicator of institutional quality (the respect/enforcement of Contracts) in the analysis. He found supportive evidence that the quality of policies and institutions does flatten the EKC as with better institutional quality, the environmental costs of economic growth are lower at the early stage of development and the speed of environmental improvement is faster as income increases.

Bhattarai and Hammig (2001) Culas (2007) and Leitão (2010) also considered institutions in the EKC specification. In their analysis, Bhattarai and Hammig (2001) combined political rights and civil liberty indices as a measure of institution and evaluate whether it has a bearing on deforestation in Latin America, Africa and Asia. They found evidence that the institutional quality significantly shifts the EKC downwards in Latin America and Africa. Culas (2007) reassessed the EKC for deforestation for 14 tropical developing countries from Latin America, Africa and Asia for the period of 1972–1994. Applying the institutional measures suggested by Knack and Keefer (1995) and adopted by Panayotou (1997) in the analysis he confirmed the presence of the EKC for deforestation in Latin America and the downward shift in the EKC as the institutional quality increases.

Leitão (2010) assessed the impact of the corruption index provided by the International Country Risk Guide (ICRG) on the

EKC turning point for Sulphur in a panel of 94 countries and found a positive relation between a country's corruption level and the income threshold point beyond which Sulphur emissions decline. More recently, Ibrahim and Law (2014) emphasized the role played by social capital in emission–income patterns in a panel of 69 developed and developing countries. Their analysis relies on the generalized method of moments (GMM) estimation approach and adopting the recently constructed measure of social capital by Lee et al. (2011). They found that the pollution costs of economic development tend to be lower in countries with higher social capital reservoir. Surprisingly, there is also evidence to indicate that the income threshold point beyond which CO2 emissions decline is higher in countries with higher social capital.

3. Empirical model and data

3.1. Model specification

To test the EKC hypothesis outlined in the previous section, we use the dynamic panel threshold regression approach suggested by Kremer et al. (2013) to explore the nonlinear behavior of CO_2 emission in relation to the economic growth. Kremer et al. (2013) extended the Hansen (1999) original static panel threshold estimation and the Caner and Hansen (2004) cross-sectional instrumental variable (IV) threshold model, where generalized methods of moments (GMM) type estimators are used to deal with endogeneity problem. The model, based on threshold regression, takes the following form:

$$CO2G_{it} = \mu_i + \beta_1 GDPPG_{it} I(GDPPG_{it} \leq \lambda) + \delta_1 I(GDPPG_{it} \leq \lambda) + \beta_2 GDPPG_{it} I(GDPPG_{it} > \lambda) + \gamma X_{it} + \theta_t + \varepsilon_{it} \quad (2)$$

Where μ_i is the country-specific fixed effect, θ_t is the time effect, the growth rate of GDP per capita (GDPPG) is the threshold variable used to split the sample into two regimes and λ is the unknown threshold parameter. $I(.)$ Is the indicator function, which takes the value 1 if the argument in parenthesis is valid, and 0 otherwise? This type of modelling strategy allows the role of GDP growth to differ depending on whether GDP growth is below or above some unknown level of λ. X_{it} denotes the vector of explanatory repressor's which include lagged values of the dependent variable (initial CO_2 growth), as well as exogenous variable energy consumption per capita growth (ECG), for which the slope coefficients are all assumed to be regime independent. In our empirical application, the initial CO_2 growth is considered as an endogenous variable, i.e. $X_{2it} = GDP$ per capita growth from the previous period, while X_{1it} includes the remaining control variables. The impact of GDP growth on CO_2 emissions will be $\beta_1(\beta_2)$ for countries in low (high) levels of GDP growth regime. We also allow for differences in the regime intercepts(δ_1). Following Arellano and Bover (1995), lags of the dependent variable $(CO2G_{it-1}, CO2G_{it-2}, \dots, CO2G_{it-p})$ are used as instruments. Empirical results may depend on the number (p) of instruments. In particular, there is a bias/efficiency trade-off in finite samples. Therefore, we considered two empirical benchmark specifications. On the one hand, we use all the available lags of the instrument variable $(p = t)$ to increase efficiency (see Table 3). On the other hand, we reduced the instrument count to 1 $(p = 1)$ to avoid an over fit of instrumented variables that might lead to biased coefficient estimates. According to Table 3, the choice of instruments has no significant impact on our results.

3.2. Estimation procedure

Our model is an extension of the cross-sectional threshold model of Caner and Hansen (2004) where Generalized Methods of Moments (GMM) type estimators are used to allow for endogeneity. To estimate the model, in the first step one has to eliminate the country-specific fixed effects via a fixed-effects transformation. In the dynamic model (2), the standard within transformation applied by Hansen (1999) leads to inconsistent estimates because the lagged dependent variable will always be correlated with the means of the individual errors and thus all of the transformed individual errors. First-differencing of the dynamic equation (2), as usually done in the context of dynamic panels, implies negative serial correlation of the error terms such that the distribution theory developed by Hansen (1999) is not applicable anymore to panel data. Therefore, the forward orthogonal deviations transformation suggested by Arellano and Bover (1995) is used to eliminate the fixed effects. The distinguishing feature of this procedure is that serial correlation of the transformed error terms is avoided.

The estimation procedure of model (1) involves three steps. Following Caner and Hansen (2004), in the first step we estimate a reduced form regression for the endogenous variable, X_{2it} as a function of the instruments. The endogenous variable is then replaced in the structural equation by the predicted one. This step is repeated for a strict subset of the support of the threshold variable $GDPPG$. In step three, the estimator of the threshold value λ is selected as the one associated with the smallest sum of squared residuals. In accordance with Hansen (1999) and Caner and Hansen (2004), the critical values for determining the 95% confidence interval of the threshold value are given by:

$$\Gamma = \{\lambda : LR(\lambda) \leq C(\alpha)\} \qquad (3)$$

Where $C(\alpha)$ is the 95% percentile of the asymptotic distribution of the likelihood ratio statistic$LR(\lambda)$. Once $\hat{\lambda}$is determined, the slope coefficients can be estimated by the GMM for the previously used instruments.

3.3. Data and variables

Our empirical application of the dynamic panel threshold model to the CO_2 emissions and economic growth nexus is based on a balanced panel dataset of 35 advanced countries over the period 2003–2010. (The list of countries and some descriptive statistics have been presented in Table 1). The end year is dictated by the availability of data on CO_2 emissions. For each country, the annual growth rate of CO_2 emissions (CO2G) is represented by carbon dioxide emissions measured in metric tons per capita while real GDP per capita growth (GDPPG) is used as a measure of economic development. The GDP is in constant 2005 US dollar. As for the controlled variable, we utilize the growth rate of energy use (kg of oil equivalent per capita) as a measure of energy consumption growth (ECG). Data on CO_2 emissions, real GDP and energy use have been retrieved from World Development Indicators. Some statistical descriptive and of the variables used in the estimations have been provided in Table 1.

Table 1: Descriptive statistics

variables	Unit of measurement	Mean	Std. dev.	Min	Max
$CO2G$	metric tons per capita	-0.493	3.553	-27.058	9.571
$GDPPG$	US$ 2005 constant Price	0.675	1.672	-7.878	5.411
ECG	kg of oil equivalent per capita	0.131	2.331	-15.803	9.292

Notes: $CO2G$ = CO_2 emissions per capita growth, $GDPPG$ = real GDP per capita growth, ECG= energy consumption per capita growth. Countries: Australia, Austria, Belgium, Canada, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hong Kong, Iceland, Ireland, Israel, Italy, Japan, Latvia, Luxembourg, Malta, Netherlands, New Zealand, Norway, Portugal, Singapore, Slovak Republic, South Korea, Slovenia, Spain, Sweden, Switzerland, UK, USA. N = 35 cross-country. T = 2003–2010.

Table 2: Correlations

	$CO2G$	$GDPPG$	ECG	$Initial$
$CO2G$	1			
$GDPPG$	0.159 (0.008)	1		
ECG	0.373 (0.000)	0.374 (0.000)	1	
$Initial$	-0.188 (0.002)	0.142 (0.017)	-0.170 (0.004)	1

Note: Number in parentheses are p values. $Initial$= initial real GDP per capita growth.

3.4. Empirical results

Table 3 shows the results of estimating Equation (2) using the dynamic panel threshold model to the analysis of the impact of real GDP per capita growth on CO_2 emissions in advanced economies. The upper part of the table displays the estimated real GDP per capita growth threshold and the corresponding 95% confidence interval. The middle part shows the regime-dependent coefficients of real GDP per capita growth on CO_2 emissions. Specifically, $\widehat{\beta_1}$ ($\widehat{\beta_2}$) denotes the marginal effect of real GDP per capita growth on CO_2 emissions in the low (high) real GDP per capita growth regime, i.e., when real GDP per capita growth is below (above) the estimated threshold value. The coefficients of the control variables are presented in the lower part of the table.

The results in the first column of Table 3 with all the available lags of the instrument variable indicate that the point estimate of the threshold value is 6.48% with a corresponding 95% confidence interval [0.184 6.479]. In our dataset 50 out of 280 observations (or 17.86%) exceed this threshold value for real GDP per capita growth. Moreover, both regime-dependent coefficients of real GDP per capita growth are significant and plausibly signed. Real GDP per capita growth has a significantly positive impact on CO_2 emissions in low economic growth regime and a significantly negative impact on CO_2 emissions in high growth regime. More specifically, the impact of one percent increase in real GDP per capita growth on CO_2 emissions is 0.56% in low economic growth regime compared to the -2.40% in high growth regime. These findings provide empirical support for the presence of the EKC suggesting when economic growth passes a threshold point, it serves as a solution to the environmental problem as GHG emissions tend to decline. Therefore, the relationship between CO_2 emissions and economic growth in fact takes on a non-linear or inverse U-shaped relationship. The empirical support for the presence of the EKC is in line with Ibrahim and Law (2014), Atici [24], Schmalensee et al. [42] and Cole et al. [43], among others.

Table 3: Results of dynamic panel threshold estimations

Threshold estimates	Estimation with all the available lags of the instrument variable	estimation with reduced instrument count
$\hat{\lambda}$	6.479	6.479
95% Confidence interval	[0.184 6.479]	[2.835 6.479]
$GDPPG$		
$\hat{\beta}_1$	0.565 (0.268)**	0.549 (0.276)**
$\hat{\beta}_2$	-2.404 (1.302)*	-2.519 (1.782)*
Impact of covariates		
$Initial$	-0.245 (0.095)***	-0.172 (0.104)***
ECG	0.499 (0.285)*	0.522 (0.295)*
$\hat{\delta}_1$	-6.394 (3.651)*	-6.663 (4.540)*
Observations	280	280
N	35	35

Notes: The standard errors are reported in parentheses. Dependent variable: CO2 emissions per capita growth. Sample period: 2003–2010. ***, **, * indicate significance at 1%, 5% and 10% level, respectively.

The results from estimating model (2) as given in Table 3 also indicate that CO_2 emissions tend to negatively depend on the past emissions growth and to increase with energy consumption per capita growth. The estimated coefficients of the energy consumption per capita growth, in particular, suggest that one percent increase in energy consumption per capita growth is associated with the increase in expected carbon emissions per capita growth by roughly 0.5%. It is worth emphasizing that our results are robust with respect to the choice of instruments. According to the information provided in column 3 of Table 3, the results remain qualitatively unchanged if the instrument count is reduced to 1.

3.5. Conclusion

This study provided new evidence on the non-linear relationship between CO_2 emissions and economic growth using data from 35 developed countries covering 2001 through 2010. One major contribution of the paper was the adoption of the dynamic panel model based on the concept of threshold effect proposed by Kremer et al. (2013) to capture rich dynamics in the CO_2 emissions growth equation. This model extends Hansen's (1999) original static setup to endogenous regresses and the cross-sectional threshold model of Caner and Hansen (2004). Our results provide supportive evidence for the validity of EKC in the sample countries with an estimated threshold value equal to 6.48%. For economic growth below this estimated threshold value, growth will exert a positive effect on CO_2 emissions growth and thus deteriorate the environmental problems. On the other hand, if economic growth exceeds this threshold value, the impact of growth on CO_2 emissions growth will turn negative, suggesting that further growth serves as a solution to the environmental problems.

These results have several important implications. First, promoting economic growth and becoming rich in the long run is necessary to solve the environmental problems arising from greenhouse gas (GHG) emissions. In the short run and in the early stage of economic growth, focusing on investments in environmentally friendly technology and on the use of renewable energy is necessary for mitigating the pollution effects of economic progress. Second, as stressed by Nilsson (1993) and Vukina et al. (1999) transition to market economy is consistent with an overall improvement in environmental quality because of rising energy prices and penalizing of energy-intensive activities. Moreover, Bimonte (2002) argued that the degree of competition in the market, which depends on the information about the product quality and production process, may also help to determine environmental quality. Third, Strengthened environmental regulations, especially in developing countries that environmental regulations are lax, are important in alleviating the environmental problems caused by economic growth. Under certain circumstances, the pollution intensive industries are transferred from countries with stronger environmental regulations to those with weaker regulations and cause displacement of dirty industries to less developed economies (Copeland and Taylor, 1995). Fourth, advanced social institutions and moving from command-and-control policies to market-oriented forms of regulations are essential to enforce environmental regulation (Dasgupta et al., 2001; Dasgupta et al., 2002; Panayotou, 1999; Vukina et al., 1999). Last but not the least, by defining some aspects of common resources as private goods, individuals are motivated to manage and to conserve the resources and pass them to future generations. Countries with a high degree of private ownership and proper allocation of property rights have more efficient resource allocation, which help to increase income and decrease environmental problems (Cropper and Griffiths, 1994).

Acknowledgement
We would like to thank Islamic Azad University, Beyza branch for the financial support granted to this paper under a research project with the same title. We would also like to thank the two anonymous referees for the constructive comments made on the earlier draft of the paper. We would be responsible for the remaining errors.

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