AIMS Energy, 4(4): 557-573.
DOI: 10.3934/energy.2016.4.557
Received: 23 December 2015
Accepted: 15 May 2016
Published: 19 May 2016

http://www.aimspress.com/journal/energy

Research article

Factors that affect the ecological footprint depending on the different income levels

Sheng-Tung Chen * and Hui-Ting Chang

Department of Public Finance, Feng Chia University, Taichung, 40724 Taiwan

* **Correspondence:** Email: stonchen@fcu.edu.tw; Tel: +886-4-2451-7250 Ext. 4310;
Fax: +886-4-2451-2749.

Abstract: The ecological footprint provides a method for measuring how much lands can support the consumption of the natural resources. Development and biocapacity debates revolve mainly around the factors that affect the ecological footprint and the approaches to improve the environmental quality. Therefore, we conducted the panel analysis of data for 99 countries from 1981 to 2006 to determine what factors affect the ecological footprint. The empirical results show that the effect of GDP per capita on the ecological footprint varies for different income levels. The effect of urbanization is significantly positive across income levels, which means that the higher the rate of urbanization in high or low income country, the higher the ecological footprint. As developing countries pursue economic development, there will be an impact on the environment. The developed countries may seek to develop their economies through activities that are more detrimental to the environment. Additionally, the export of goods and services divided by GDP is significant, which means that the higher the volume of exports, the greater the burden on the environment. However, this effect is not significant across different income level models. The income effect may explain the diverse effects of export on the environment. Therefore, panel data analysis and income classification are necessary to discuss the effect of export on the environment.

Keywords: Panel data; ecological footprint; income level

1. Introduction

In the process of achieving a high level of industrial development, we have depleted our environmental resources without considering the natural resource constraint. Researchers are therefore concerned that the consumption of natural resources will exceed the biocapacity. Thus, the problem of assessing environmental quality effectively and quantitatively has perplexed environmental scientists for decades [1,2]. To determine whether we have over consumed resources, Gary [3] states that "this has led to the development of various types of environmental indices, which, by definition, are tools for aggregating and simplifying information of a diverse nature into a useful and more advantageous form."

Additionally, environmentalists and economists have been involved in controversial debates about economic development and environmental conservation. According to Sheldon [4] and Ulph [5], environmentalists argue that any benefit from increased trade liberalization will be downplayed by the damage caused to the environment. On the contrary, economists argue that trade and economic growth may be good for ensuring environmental quality. While environmental quality is generally considered a normal good, the increase in per capita income will increase the demand for better environmental quality. Therefore, we are interested in determining the factors that affect environmental quality. We can then adjust our policies so as to reduce environmental degradation. Global environmental policies can be adjusted in order to assist the low-income countries in economic development through technology transfer and financial incentives, thereby ensuring that development is possible without causing environmental degradation.

The indicators of environmental quality are associated with different indicators. However, the most comprehensively developed and accepted indicator is the ecological footprint (EF), which was developed by Wackernagel and Rees [6]. The EF is measured as the total area of productive land and water required to continuously produce all resources consumed and to assimilate all wastes generated by a defined population in a specific location. It has become "the most widely-used measure of environmental sustainability" [7]. Grazi et al. [8] states that despite this indicator's structural weakness, which many researchers have attempted to address (e.g., [8-17]), it remains a widely used indicator for assessing environmental sustainability.

As environmental issues are a key concern, several studies have attempted to explain the optimal use of resources. The EF provides a method to measure how much lands can support the consumption of the natural resources. If the EF is larger than biocapacity, we can say that the waste of resources had exceeded the burden. Moreover, previous studies have pointed out that per capita ecological footprints are negatively correlated with various environmental outcomes, including deforestation and organic water pollution. These correlations are consistent with the findings reported above and by previous studies [18-24].

Therefore, researchers are now interested in the factors that affect the EF. Recently, Moran et al. analyzed the relationship between the UN Human Development Index (HDI) and the limited biocapacity of the planet that was measured by using the EF [25]. The limited biocapacity is a real constraint that is not often emphasized in other development assessments, and they found that a country's development is positively related to its EF. They indicated that the EF is affected by the following three factors: resource intensity in the production of goods and services, consumption of goods and services per person, and population size. Jorgenson applied OLS estimation to analyze the relationship between the EF and other variables, which include weighted export flows, the value of exported goods and services divided by GDP, income inequality, and other macroeconomic variables [26]. He found that weighted export flows and GDP have a significantly positive impact on the EF. The researchers have listed the other references to discuss the factors affecting the EF in Table 1.

Table 1. References used to analyze the factors affecting the EF.

References	Time	Country	Factor	Result	Notes
van Vuuren (2000)	1980–1994	4	GDP per capita	(+)	The EF for carbon dioxide emissions
			Population	(+)	
van Vuuren and Smeets (2000)	1980,1987, and 1994	4	GDP per capita	(+)	
York (2003)	1996	142	GDP per capita	(+)	Not stable in all models
			Population	(+)	
			Nondependent population	(+)	Positive trend showing a nation's population between the ages of 15 and 65 (the most productive ages) and a nation's ecological footprint.
			Land area per capita	(+)	
			Latitude	(+)	
			Capitalist nation	(+)	Not stable in all models
Jorgenson (2003)	1996	208	Income inequality	(−)	The inclusion of human capital indicators controls the domestic factors that affect the EF
			Urbanization	(+)	
			Human capital	(+)	
			Literacy	(+)	
			World-system position	(+)	
Mun˜izT (2004)	1986–1996	Barcelona	Average household income	(+)	
			Job ratio	(−)	
Jorgenson (2007)	1991–2001	138	GDP per capita	(+)	
			Population	Insignificant	
			Income inequality	Insignificant	
			Exports / GDP	(−)	
			Manufacturing /GDO	(−)	
			Services / GDP	(+)	
			Agriculture / GDP	Insignificant	
			State environmentalism	Insignificant	

References	Time	Country	Factor	Result	Notes
Moran et al. (2008)			Consumption of goods and services per person	Theoretical (+)	
			Population	Theoretical (+)	
Li (2009)	1988–2005	China	Total energy consumption	The greatest impact	Partial least squares (PLS) and five-fold cross-validation
			GDP	The second largest impact	
			Urbanization	<1	
			Total retail sales of consumer goods	<1	
			Expenditures by city residents	<1	
Mostafa (2010b)		140	GDP	(−)	OLS; Bayesian regression model: not support positive
			GDP^2	(+)	
			Income Inequality	(−)	
			Urbanization	(+)	
			Literacy	(+)	
			Exports / GDP	(+) Insignificant	
Jorgenson (2010)	1970–2000	37	Military expenditures per soldier	(+)	Fixed effects model estimates with AR(1)
			Military expenditures as % of GDP	(−) Insignificant	
			GDP per capita	(+) Insignificant in model B	
			Urbanization	(+) Insignificant	

Several studies have discussed the indirect evidence of countries' externalization of environmental and ecological costs associated with their higher levels of EF [23]. As shown in Table 1, GDP per capita has a positive impact on the EF, which implies that the developing economies will cause an increase in the EF. Income inequality is also an important indicator that affects the EF, but the results of its effect are not robust. The effect of urbanization (urban population divided by total population) on the EF is not found to be different in different studies [27,28]. While the effect of export of goods and services as a percentage of total GDP has a significantly negative effect on the EF in Jorgenson et al. [29], the effect is not significant in Mostafa [30]. However, we have found that few studies have employed panel data analysis, and most studies apply the cross-sectional analysis (for instance, York et al. [31], Jorgenson et al. [29]).

For the present study, we chose the factors that affect the EF in accordance with Jorgensen and Rice's [32] cross-sectional study involving 69 countries. The purpose of our research is to understand why developed countries consume more resources but have low EFs, whereas developing countries consume fewer resources but have high EFs. We wish to understand whether the import of goods and services by the developed countries from the developing countries is the factor responsible for high EFs of developing countries. From Table 1, we determine that the diverse results are due to the different data set or econometric methodologies and different countries' characteristics. Therefore, we used the limited available panel dataset to correct the above problem. Furthermore, the short time span of individual data sets weakens the significance of the results. Therefore, we selected the panel data set of 99 countries from 1981 to 2006. Jorgenson et al. [29] applied an ecostructural orientation to the theory of foreign investment dependence (see the World Bank's Global Development Finance). In the 1990s, FDI became the largest source of finance for developing countries, while official loans were also important in low-income countries. Several other cross-national studies suggest that foreign investment is a structural mechanism partly responsible for the emission of carbon dioxide gas [33-35], which affects the carbon footprint in the total national EF.

In our research, we provide evidence for the factors that affect the EF. Once we understand these factors, we can reduce the EF through effective policies. In addition, in order to determine the effect of FDI on the EF, we include the FDI that has been documented by the World Bank. We classify the countries into three income groups to discuss whether the effects of the different factors on the EF change for different income groups. The second section of this paper describes the data used in our study, and the third section illustrates the methodology. The empirical results are discussed in the fourth section, and the final section concludes the paper.

2. Data

We set our empirical model as follows:

$$\log(ef)_{it} = \alpha_i + \beta_1 \log(gdp)_{it} + \beta_2 \Delta gdp_{it} + \beta_3 (urb)_{it} + \beta_4 \log(\exp/GDP)_{it} + \beta_5 \log(fdi)_{it} + \varepsilon_{it} \quad (1)$$

where i refers to the countries and t is the time; i = 1,2,…,N, and t = 1,2,…,T. α is the interception. As mentioned earlier, our panel data set includes 99 countries from 1981 to 2006. The list of countries is in Table 2. We apply the linear interpolation to estimate missing data. Details of the missing data are presented in Table 3. The following is an explanation of the variables that affect the EF in our research:

ef: The ecological footprint is the dependent variable in our research. We obtain the data set from Ecological Footprint and Biocapacity [36]. Global Footprint Network provides data on cropland, grazing land, forestland, fish grounds, built-up land, and carbon footprint. In the summary worksheet of the Global Footprint Network Guidebook, cropland summarizes the Footprint of cropland embodied in both crop and livestock products; grazing land summarizes the Footprint of pasture grass embodied in livestock products; forestland summarizes the Footprint of forestland embodied in primary and processed forest products; fish grounds summarizes the Footprint of marine and inland water areas embodied in fish and other aquatic products; built-up land summarizes the Footprint associated with buildings, infrastructure, and hydroelectric reservoir area; and the carbon footprint summarizes the carbon Footprint of fossil fuel combustion (both domestically emitted and embodied in traded goods) and an additional bunker fuel carbon tax (Guidebook to the national footprint account [37]).

gdp: York et al. [31] indicated that further development and modernization may alleviate environmental problems. He also pointed out that economic development is usually measured as real GDP per capita, thus eliminating the effect of different scales because of different country sizes. Like Jorgenson and Rice [32], we also use the natural logarithm of the real GDP per capita, obtained from world development indicators [31].

Δgdp: Jorgenson and Rice [32] indicated that real GDP per capita change can control the extent of a country's average annual rate of economic development. Accordingly, we have included this variable in our empirical model.

urb_{resi}: The urbanization has been widely accepted in the research of environmental sustainability. For instance, Jorgenson [26] indicates that "A rather extensive body of literature addresses world-systemic factors and urbanization, which justifies the inclusion of urbanization as an intervening variable that is partly a function of world-system position." Mostafa [30] indicates that "several authors found a positive relationship between urbanization as measured by the percentage of total population living in urban areas and EF levels." The EF is measured as the total area of productive land and water required to continuously produce all resources consumed and to assimilate all wastes generated by a defined population in a specific location. It has become "the most widely-used measure of environmental sustainability." Therefore, the ecological modernization theorists use the urbanization as an indicator to explain EF because it is associated with many institutions of modernism. The urbanization of a country is an important indicator of modernization. Ecological modernization theorists use this indicator because it is associated with many institutions of modernism [31,39-41]. Jorgenson and Rice [32] suggest the use of the urban population percentage of the total as the urbanization variable; this data can be found in WDI [38]. In order to avoid the collinear problem of the urbanization variable and GDP, we use the residual of the regression between real GDP per capita and urban population percentage of the total as the urbanization variable. However, there might have some controversy in the literature regarding the causal mechanisms surrounding urbanization. For instance, Liddle and Messinis [42] apply heterogeneous panel causality tests to consider the relationship between urbanization change and economic growth and find the causality is different for different income levels. Therefore, we get the residuals through individually OLS regression. The purpose to do the regression is to keep the pure effect of the urbanization without GDP effect.

exp: In accordance with Jorgenson and Rice [32], to determine the extent of a country's integration into the world economy, we use the exports of goods and services as a percentage of total

GDP in order to measure the overall levels of exports and controls. Thus, we have the *exp* natural log. The *ex*p data can be found in WDI [38].

fdi[1]: We use FDI to capture the effect of FDI on the EF. The data can be found in WDI [38].

As mentioned earlier, we applied the linear interpolation to fill the missing data in Table 3. According to Meijering [43], the Linear Interpolation method had been widely applied in the problem of constructing a continuously defined function from given discrete data is unavoidable whenever one wishes to manipulate the data in a way that requires information not included explicitly in the data. Table 4 lists the descriptive statistics for all variables. Because the urb_{resi} is the residual of the regression between real GDP per capita and urban population percentage of the total, the average is almost 0. In addition, we have the variables in natural logarithm, except the *fdi* and GDP per capita change. Table 5 provides the correlation matrix between the variables. The correlations between the variables are all less than 1.

Table 2. List and classification of sample countries.

Country	High income	Country	Middle income	Country	Low income
Antigua and Barbuda	Non-OECD	Argentina	Upper	Bangladesh	
Australia	OECD	Botswana	Upper	Benin	
Austria	OECD	Brazil	Upper	Burundi	
Bahamas	Non-OECD	Chile	Upper	Congo, Democratic Republic of	
Bahrain	Non-OECD	Colombia	Upper	Ghana	
Barbados	Non-OECD	Costa Rica	Upper	Kenya	
Belgium	OECD	Dominica	Upper	Malawi	
Canada	OECD	Dominican Republic	Upper	Mali	
Cyprus	Non-OECD	Fiji	Upper	Mozambique	
Denmark	OECD	Gabon	Upper	Nepal	
Finland	OECD	Grenada	Upper	Niger	
France	OECD	Malaysia	Upper	Rwanda	
Germany	OECD	Mauritius	Upper	Senegal	
Greece	OECD	Mexico	Upper	Sierra Leone	
Iceland	OECD	Panama	Upper	Togo	
Ireland	OECD	Peru	Upper		
Israel	Non-OECD	Seychelles	Upper		
Italy	OECD	South Africa	Upper		
Japan	OECD	Suriname	Upper		
Korea, Republic of	OECD	Turkey	Upper		
Kuwait	Non-OECD	Uruguay	Upper		
Malta	Non-OECD	Venezuela, Bolivarian Republic of	Upper		

Country	High income	Country	Middle income	Country	Low income
Netherlands	OECD	Belize	Lower		
New Zealand	OECD	Bolivia	Lower		
Norway	OECD	Cameroon	Lower		
Oman	Non-OECD	China	Lower		
Portugal	OECD	Côte d'Ivoire	Lower		
Saudi Arabia	Non-OECD	Ecuador	Lower		
Spain	OECD	Egypt	Lower		
Sweden	OECD	El Salvador	Lower		
Switzerland	OECD	Guatemala	Lower		
Trinidad and Tobago	Non-OECD	India	Lower		
United Kingdom	OECD	Indonesia	Lower		
United States of America	OECD	Jordan	Lower		
		Lesotho	Lower		
		Morocco	Lower		
		Nicaragua	Lower		
		Nigeria	Lower		
		Pakistan	Lower		
		Papua New Guinea	Lower		
		Paraguay	Lower		
		Philippines	Lower		
		Solomon Islands	Lower		
		Sri Lanka	Lower		
		Sudan	Lower		
		Swaziland	Lower		
		Syrian Arab Republic	Lower		
		Thailand	Lower		
		Tunisia	Lower		
		Vanuatu	Lower		

Table 3. Details of missing data estimated by linear interpolation.

Variable	FDI	Variable	ex	Variable	ser
Nation	Years	Nation	Years	Nation	Years
Bangladesh	1981–1982;1985	Belize	1981–1983	Bahamas	1988
Belize	1982–1983	Burundi	1981–1984	Fiji	2006
Greece	1998	China	1981	Niger	2006
Grenada	1981	Gabon	2006	Oman	1989
Guinea-Bissau	1981–1983	Greece	1998	Suriname	2006
Lesotho	1985	Madagascar	2006		
Nepal	1992–1995	Malawi	2003–2006		
Nicaragua	1981–1982	Papua New Guinea	2006		
Switzerland	1981–1982	Vanuatu	1981		

Table 4. Descriptive statistics for variables included in the analysis.

	N	Mean	Std Dev	Skewness	Kurtosis	Max	Min
Ecological Footprint (log)	99	0.8653	0.7826	0.5857	4.3581	4.2449	−1.2378
GDP per capita (log)	99	7.8179	1.6036	0.0322	1.9031	11.1879	4.3925
GDP per capita change (log)	99	4.4546	13.1269	−0.1591	6.5100	81.8288	−62.3853
urb_{resi}	99	0*	9973.357	1.9062	7.0291	63200.55	−10870.3
Exports of goods and services % of the total GDP (log)	99	3.3741	0.6215	−0.4658	3.1797	4.8762	0.9261
Foreign direct investment(log)	99	16.3269	18.8351	−2.7431	9.4901	26.4956	−24.2956

* The average of urb_{resi} is $-6.02E^{-12}$ because it is the residual of the regression between real GDP per capita and the urban population percentage of the total.

Table 5. Correlations for variables included in the analysis.

	ef	gdp	Δgdp	urb_{resi}	ser	fdi
ef	1					
gdp	0.2236	1				
Δgdp	0.0686	0.0597	1			
urb_{resi}	0.0003	0.6875	0.0197	1		
ser	0.3066	0.0249	0.0544	−0.0702	1	
fdi	0.0790	0.0746	0.0833	0.0226	0.0021	1

3. Methodology

We employ the panel model to analyze the factors that affect the EF. The panel data model allows the individual difference between samples. It is set as follows:

$$ef_{it} = \alpha_i + \sum_{k=1}^{k} \beta_k X_{kit} + \varepsilon_{it} \quad (2)$$

where ef_{it} and X_{kit} refer to the data of the ith country during the t period and k is the kth explanation variable. α_i is the intercept. β_k is the coefficient of the kth explanation variable. ε_{it} is the error term and $\varepsilon_{it} \sim iid(0, \sigma_\varepsilon^2)$.

Owing to the different settings in the intercept, the panel data model is classified into the fixed effects model and random effects model. As the model allows for the difference between cross sections, the fixed effects model assumes that the intercepts can show the unobserved cross-sectional effect. The fixed effects can be classified into two categories: region-specific fixed effects and time-specific fixed effects. The former means that the regional characteristics have fixed effects on the explained variables because of the regional property. The latter means that the property of t has short-run fixed effects on the formerly explained variable in different regions, as we control other explained variables.

Equation (2) can be rewritten as follows:

$$ef_i = i\square\alpha_i + \sum_{k=1}^{k} \beta_k X_{ki} + \varepsilon_i \tag{3}$$

The model assumes that the difference between countries can be addressed through the interception and that the difference does not change with time. α_i is the unknown parameter that needs to be estimated, and i is the unit vector. ε_i is a T × 1 vector of error term. We express equation (3) in the matrix form:

$$\begin{bmatrix} ef_1 \\ ef_2 \\ \cdots \\ ef_n \end{bmatrix} = \begin{bmatrix} i & 0 & \ldots & 0 \\ 0 & i & \ldots & 0 \\ \ldots & & & \\ 0 & 0 & \ldots & i \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \cdots \\ \alpha_n \end{bmatrix} + \begin{bmatrix} X_{1k} \\ X_{2k} \\ \cdots \\ X_{nk} \end{bmatrix} \beta_k + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \cdots \\ \varepsilon_n \end{bmatrix}$$

Alternatively, it can be shown as follows:

$$ef = \left[d_1\, d_2 \cdots \quad d_n X_K \right] \begin{bmatrix} \alpha \\ \beta_k \end{bmatrix} + \varepsilon$$

where d_i is the dummy variable vector of observation i, and the N T × N matrix D = [d_1 d_2 … d_N], which contains the N × T vector and one-way fixed effects model that can be shown as follows:

$$ef_{it} = \sum_{j=1}^{n} \alpha_i D_{jt} + \sum_{k=1}^{k} \beta_k X_{kit} + \varepsilon_{it} \tag{4}$$

If i = j, D_{jt} = 1; Otherwise i ≠ j, D_{jt} = 0.

The random effects model allows for the difference between time series and cross-sectional data. The interception explains the difference and considers the individual observation data as random, which arise from a similar difference. Therefore, the model assumes the structural differences between nations and the time change difference as random with the randomness being formed in the error term.

We can rewrite equation (2) as a one-way random effect model:

$$ef_{it} = (\bar{\alpha} + \mu_i) + \sum_{k=1}^{k} \beta_k X_{kit} + \varepsilon_{it} \tag{5}$$

where $\bar{\alpha}$ refers to the unknown parameter of the average interception and μ_i is the unobservable random error term.

Owing to the different model settings between the region-specific fixed effects and random effects, we test which model is the optimal one by using the criteria in Hausman [44]. The basic assumption of Hausman's random model is that, as the random variables and dependent variables are uncorrelated, the OLS estimations of the fixed effects model and random effects model are consistent but the fixed effect model is inefficient. Otherwise, while the OLS estimation of the fixed effects model has consistency, the random effects model lacks consistency. The null hypothesis of Hausman [44] is $E(\mu_i, X_{it}) = 0$ and the alternative hypothesis is $E(\mu_i, X_{it}) \neq 0$. If the null is rejected, we should select the fixed effects model. Conversely, we should select the random effects model.

4. Empirical results

According to Liddle [45], for the purpose to examine the stationarity properties of panel data withcross-sectional dependence problem, we accept the advice to apply Pesaran [46] CD test to test the cross-sectional dependence among the variables and in residuals. As the Table 6 depicts, with the null hypothesis of CD test which means cross-sectional independence, all six variables significantly reject the null and have cross-sectional dependence problem. Thus, we should test the panel unit root test allows for cross-sectional dependence. Therefore, Pesaran [47] panel unit root test is applied to test the stationarity of all 6 variables. The results of Table 6 display that as the lag is one period without trend, only GDP per capita is nonstationary. But as we consider more lag and more conditions, Ecological Footprint (log), GDP per capita (log), Urban population % of the total (residual) might be the I(1) series. In our study, we first apply both the fixed effects model and the random effects model to analyze the effect and then apply the Hausman test to select the model. The data set is classified into the following three categories: high income, middle income, and low income. The classification is outlined in Table 2. The standard of income criterion is obtained from the World Bank. As Table 6 shows, model (1) includes the observations of all 99 countries from 1981 to 2006; Model (2), of 34 high-income countries from 1981 to 2006; Model (3), of 50 middle-income countries from 1981 to 2006; and model (4), of 15 low-income countries from 1981 to 2006.

Table 6. Cross-sectional dependence test ([46] CD test) and panel unit root test [47].

Variables		Ecological Footprint (log)	GDP per capita (log)	GDP per capita change (log)	Urban population % of the total (residual)	Exports of goods and services % of the total GDP (log)	Foreign direct investment (log)
CD teat		0.30(8.21**)	0.57(164.78**)	0.27(64.87**)	0.62(38.82**)	0.39(66.46**)	0.28(61.71**)
Panel unit root test (Level)	Lag 1	0.000 (0.000)	0.209 (1.000)	0.000 (0.000)	0.084 (1.000)	0.000 (0.009)	0.000 (0.000)
	Lag 2	0.266 (0.031)	0.695 (1.000)	0.000 (0.000)	0.944 (1.000)	0.089 (0.853)	0.010 (0.060)
	Lag 3	0.816 (0.117)	0.220 (0.999)	0.000 (0.000)	1.000 (1.000)	0.004 (0.760)	0.220 (1.000)
Panel unit root test (First difference)	Lag 1	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
	Lag 2	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
	Lag 3	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)

[1] The Null Hypothesis of CD test is cross-sectional independence. ** indicates significance at the 5% level that reject the Null Hypothesis. Absolute value mean correlation coefficient is shown and the CD-test statistic is in parentheses.

[2] The null of Pesaran [47] panel unit root test is nonstationarity. The result is the *p*-value with different lags and without trend. The value in parentheses is the *p*-value with trend.

As per the results of the Hausman test, the four model settings cannot reject the null hypothesis, which means that the random effects model should be accepted. To solve the panel data estimation with the nonstationary variables, we applied the panel linear estimator with AR(1) to correct the problem. As Table 7 displays the result, the residuals have been tested with the Pesaran [47] panel unit root test and the result tells that the residuals of model (1), (2), and (3) are stationary but the model (4) does not pass the test. Therefore, we conclude that the as the research with low income countries may suffer the spurious regression problem. And we had also corrected the research based on the result. Table 7 presents the empirical results of the random effects model for four sample selection model settings. We find that in all the models, GDP per capita has a significantly positive effect on the EF, except model (4). This effect is consistent with the findings of Jorgenson et al. [29], York et al. [31] and van Vuuren and Smeets [48]. Therefore, we can say that economic development will increase the EF, which means that the high economic performance will increase the burden on the environment. In addition, the GDP per capita change is significantly negative in low-income countries. However, it is not significant in model (1), high and middle countries, which is consistent with the findings of Jorgenson and Rice [32]. This suggests that the effect of GDP per capita change varies with data.

Table 7. Empirical results of the cross-section random effect.

		High income	Middle income	Low income
	Model(1)	Model(2)	Model(3)	Model(4)
n	99	34	50	15
GDP per capita (log)	0.0939***	0.1385***	0.1028***	0.0425
	(5.15)	(3.61)	(2.93)	(1.04)
	[0.0581,0.1296]	[0.0632,0.2140]	[0.0341,0.1716]	[−0.0376,0.1226]
GDP per capita change(log)	−0.0001	−0.0008	−0.0000	−0.0002
	(−0.23)	(−0.88)	(−0.06)	(−0.24)
	[−0.0008,0.0007]	[−0.0027,0.0010]	[−0.0010,0.0010]	[−0.0014,0.0011]
Urban population % of the total	−0.0000	0.0000	0.0000	0.0000*
(residual)	(−0.44)	(1.21)	(−1.44)	(1.87)
	[−3.46 E^{-06},2.19 E^{-06}]	[−1.60 E^{-06},6.79 E^{-06}]	[−8.64 E^{-06},1.33 E^{-06}]	[−3.29 E^{-07}, 1.33 E^{-05}]
Exports of goods and services %	0.0475*	−0.1520*	0.0705	−0.0062
of the total GDP (log)	(1.67)	(−1.71)	(1.57)	(−0.17)
	[−0.0083,0.1033]	[−0.3263,0.0223]	[−0.0175,0.1584]	[−0.0800,0.0675]
Foreign direct investment (log)	0.0003	0.0006	0.0000	−0.0004
	(0.59)	(0.58)	(0.04)	(−0.37)
	[−0.0008,0.0015]	[−0.0014,0.0026]	[−0.0017,0.0017]	[−0.0026,0.0017]
Residual Unit Root				
(Pesaran(2007))				
Lag 1 (*p*-value)	0.074	0.015	0.058	0.302

[1] Value of t-statistics is in parentheses. * indicates significance at the 10% level; ** indicates significance at the 5% level; *** indicates significance at the1% level. The 95% confidence intervals are in square brackets.

[2] The coefficients of average urban population as a percentage of the total are −6.37E^{-07}, 2.59 E^{-06}, −3.66 E^{-06}, 6.47 E^{-06}.

Furthermore, the effect of urbanization is not found to be significant. However, when we classify the observations into the three categories, we find that the effect of urbanization is significantly positive in low income categories, which means that the higher the rate of urbanization in a country, the higher the EF. This suggests that as countries develop and become more urbanized, the environmental burden increases. The insignificant effect of urbanization in model (1), (2) and (3) is because the urbanization variable is obtained by the residual of the regression between real GDP per capita and urban population percentage of the total, in order to avoid the collinear problem of urbanization variable and GDP. The residual of the regression between real GDP per capita and the urban population percentage of the total is negative in developed countries and is positive in developing countries; this effect is offset when we use all the samples. This finding suggests that, when discussing the factors that affect the EF, countries should be classified according to income level. This classification can show the exact evidence through the results.

The exports of goods and services divided by GDP is significant in model (1) and (2), which indicates that the higher the volume of export, the greater is the environmental burden. But as the country is in high income, the effect is significant negative. However, this effect is not significant in the middle and low income countries. Therefore, we find that the factors affecting the EF the most are GDP per capita and the export of goods and services divided by GDP. Additionally, the effect of GDP per capita is the largest in high-income countries, which implies that the high-income countries may exhibit the phenomenon described by Jorgenson and Rice [32]: less-developed countries often have lower ecological footprints because they largely focus on exporting produced goods and raw materials to higher consuming, more-developed countries.

5. Conclusion and policy implications

As environmental issues are a key concern, several studies have attempted to explain the optimal use of resources. The EF provides a method for measuring how much lands can support the consumption of the natural resources. However, development and biocapacity debates revolve mainly around the factors that affect the EF and the approaches to improve the environmental quality. Therefore, we conducted panel analysis of data for 99 countries from 1981 to 2006 to determine what factors affect the EF.

The factors affecting the environmental quality have been the topic of great interest since the 1990s, when concerns regarding climate change because of the deteriorating environmental quality, took center stage. In this study, we have considered the EF as an indicator of environmental quality. If the EF exceeds biocapacity, we can say that the consumption of resources has exceeded biocapacity. Our empirical results show that in all sample selection models, GDP per capita significantly affects the EF. This implies that the environmental quality will deteriorate with economic development irrespective of the income level. However, the empirical results also show that the effect of GDP per capita on the EF varies for different income levels. Thus, an increase in the GDP per capita of low-income countries will have a smaller effect on the EF than would an increase in the GDP per capita of middle and high-income countries.

As the countries are pre-industrial economies and the degradation is smaller than industrial economies. The effect of GDP per capita will not slow down as the economies become post-industrial economies. Thus, as mentioned earlier, an increase in the GDP per capita of these countries will have a larger effect on the EF than would an increase in the GDP per capita of middle-income and low-income countries. This result is consistent with the empirical result of Mostafa [30]. We also find that the effect of GDP per capita on the EF is insignificant in low-income countries; this means that as the GDP of countries with low-income economies increases, the impact on the environment decreases. We therefore conclude that global environmental policies should be adjusted such that high-income countries assist low-income countries in economic development through technology transfer and financial incentives.

Further, we find that the effect of urbanization is significantly positive in low income categories, which means that the rate of urbanization in a country is the key factors in the low income countries to affect the EF. This effect is larger in the low-income countries than in the high-income countries. This suggests that as the developing countries pursue economic development, there will be an impact on the environment, indicating that developing countries may seek to develop their economies through activities that are more detrimental to the environment.

Finally, while the export of goods and services as a percentage of total GDP has a significantly negative effect on the EF in Jorgenson et al. [29], but the effect is not significant in Mostafa [30]. However, few studies have employed panel data analysis, and most studies apply cross-sectional analysis (for instance, [29,31]). Our results show that the export of goods and services divided by GDP is positively significant in model (1), which means that the higher the volume of exports, the greater the burden on the environment. However, this effect is not significant in middle and low income level models. The income effect may explain the diverse effects of export on the environment. Therefore, panel data analysis and income classification are necessary to discuss the effect of export on the environment.

Conflict of interest

The authors declare there is no conflict of interest.

References

1. Ott WR (1978) Environmental Indices—theory and practice. Ann Arbor Science, Ann Arbor, MI, 371.
2. Patil GP, Rao CR (1993) Multivariate environmental statistics. North-Holland Series in Statistics and Probability, North-Holland, New York, 596.
3. Gary RS (2000) A generalized environmental sustainability index for agricultural systems. *Agr, Ecosyst Environ* 79: 29-41.
4. Sheldon I (2006) Trade and Environmental Policy: A Race to the Bottom? *J Agr Econ* 57: 365-392.
5. Ulph A (1997) International Trade and the Environment: A Survey of Recent Economic Analysis. in Folmer H and Tietenberg T (eds), *International Handbook of Environmental and Resource Economics*, Cheltenham: Edward Elgar, 205-242.
6. Wackernagel M, Rees W (1996) Our ecological footprint: reducing human impact on the Earth. New Society Publishers, Gabriola Island, Canada.
7. Binningsbo H, de Soya I, Gleditsch N (2007) Green giant or straw man? Environmental pressure and civil conflict, 1961–1999. *Popul Environ* 28: 337-353.
8. Grazi JC, van den Bergh JM, Reitveld P (2007) Spatial welfare economics versus ecological footprint: Modeling agglomeration, externalities and trade. *Environ Resource Econ* 38: 135-153.

9. Levett R (1998) Footprinting: a great step forward, but tread carefully—A response to Mathis Wackernagel. *Local Environ* 3: 67-74.
10. van den Bergh JCJM, Verbruggen H (1999) Spatial sustainability, trade and indicators: an evaluation of the ecological footprint. *Ecol Econ* 29: 61-72.
11. Ayres RU (2000) Commentary on the utility of the ecological footprint concept. *Ecol Econ* 32: 347-349.
12. Costanza R (2000) The dynamics of the ecological footprint concept. *Ecol Econ* 32: 341-345.
13. van Kooten GC, Bulte EH (2000) The ecological footprint: useful science or politics? *Ecol Econ* 32: 385-389.
14. Opschoor H (2000) The ecological footprint: measuring rod or metaphor? *Ecol Econ* 32: 363-367.
15. Lenzen M, Murray SA (2001) Amodified ecological footprint method and its application to Australia. *Ecol Econ* 37: 229-255.
16. Ferng JJ (2002) Toward a scenario analysis framework for energy footprints. *Ecol Econ* 40: 53-69.
17. Jorgensen AE, Vigsoe D, Krisoffersen A, et al., Assessing the ecological footprint. A look at the WWF's Living Planet Report 2002. Institute for Miljovurdering, Kobenhavn, Denmark, 2002.
18. Bergesen A, Bartley T (2000) World-System and Ecosystem. *J World Syst Res* 3: 364-368.
19. Bunker SG, Underdeveloping the Amazon: Extraction, Unequal Exchange, and the Failure of the Modern State. Chicago, IL: University of Illinois Press, 1985.
20. Burns TJ, Davis BL, Jorgenson AK, et al., Assessing the Short- and Long-Term Impacts of Environmental Degradation on Social and Economic Outcomes. Presented at the annual meetings of the American Sociological Association, August, Anaheim, CA, 2001.
21. Clapp J (2002) The Distancing of Waste: Overconsumption in a Global Economy. In Confronting Consumption, Princen T, Maniates MF and Conca K (Eds.) Cambridge, MA: MIT Press, 155-176.
22. Hornborg A, The Power of the Machine: Global Inequalities of Economy, Technology, and Environment. Alta Mira Press, Walnut Creek, California, USA, 2001.
23. Jorgensen AK, Burns TJ (2003) Globalization, the Environment, and Infant Mortality: A Cross-National Study. *Humboldt J Soc Rel* 28: 7-25.
24. Tucker R (2002) Environmentally Damaging Consumption: The Impact of American Markets on Tropical Ecosystems in the Twentieth Century. In Confronting Consumption, Princen T, Maniates MF and Conca, K (Eds.). Cambridge, MA: MIT Press, 177-196.
25. Moran DD, Wackernagel M, Kitzes JA, et al. (2008) Measuring sustainable development –nation by nation. *Ecol Econ* 64: 470-474.
26. Jorgensen AK (2003) Consumption and environmental degradation: a cross national analysis of the ecological footprint. *Soc Prob* 50: 374-394.
27. Li XM, Xiao RB, Yuan SH, et al. (2009) Urban total ecological footprint forecasting by using radial basis function neural network: A case study of Wuhan city, China. *Ecol Indic* 10: 241-248.
28. Jorgenson AK, Clark B, Kentor J (2010) Militarization and the environment: a panel study of carbon dioxide emissions and the ecological footprints of nations 1970-2000. *Global Environ Polit* 10: 7-29.
29. Jorgenson AK, Dick C, Mahutga MC (2007) Foreign investment dependence and the

environment: An ecostructural approach. *Soc Prob* 54: 371-394.
30. Mostafa MM (2010) A Bayesian approach to analyzing the ecological footprint of 140 nations. *Ecol Indic* 10: 808-817.
31. York R, Rosa EA, Dietz T (2003) Footprints on the earth: the environmental consequences of modernity. *Am Sociol Rev* 68: 279-300.
32. Jorgenson AK, Rice J (2005) Structural dynamics of international trade and material consumption: A cross-national study of the ecological footprints of less-developed countries. *J World Syst Res* 11: 57-77.
33. Grimes P, Kentor J (2003) Exporting the greenhouse: foreign capital penetration and CO2 emissions 1980–1996. *J World Syst Res* 9: 261-275.
34. Shandra JM, London B, Whooley O, et al. (2004) International Nongovernmental Organizations and Carbon Dioxide Emissions in the Developing World: A Quantitative, Cross-National Analysis. *Sociol Inquiry* 74: 520-545.
35. Roberts JT, Grimes P, Manale J (2003) Social roots of global environmental change: A world systems analysis of carbon dioxide emissions. *J World Syst Research* 9: 277-315.
36. Global Footprint Network, 2009. Available from: http://www.footprintnetwork.org/en/index.php/GFN/.
37. WDI, 2010. World Development Indicators. World Bank: Washington D.C., USA.
38. Kitzes J, Galli A, Rizk SM, et al. Guidebook to the National Footprint Accounts: 2008 Edition. Global Footprint Network, Oakland.
39. Ehrhardt-Martinez K (1998) Social determinants of deforestation in developing countries. *Soc Force* 77: 567-587.
40. Ehrhardt-Martinez K, Crenshaw EM, Jenkins GC (2002) Deforestation and the Environmental Kuznets Curve: a cross-national investigation of intervening mechanisms. *Soc Sci Q* 83: 226-243.
41. Kasarda J, Crenshaw EM (1991) Third world urbanization: dimensions, theories, and determinants. *Annu Rev Sociol* 17: 467-501.
42. Liddle B, Messinis G (2015) Which comes first urbanization or economic growth? Evidence from Heterogeneous Panel Causality Tests. *Appl Econ Lett* 22: 349-355.
43. Meijering E (2002) A chronology of interpolation from ancient astronomy to modern signal and image processing. *P IEEE* 90: 319-342.
44. Hausman JA (1978) Specification tests in econometrics. *Econometrica* 46: 1251-1271.
45. Liddle B (2015) What are the carbon emissions elasticities for income and population? Bridging STIRPAT and EKC via robust heterogeneous panel estimates. *Global Environ Chang* 31: 62-73.
46. Pesaran M, 2004. General Diagnostic Tests for Cross Section Dependence in Panels' IZA Discussion Paper No. 1240.
47. Pesaran M (2007) A simple panel unit root test in the presence of cross-section dependence. *J Appl Econometrics* 22: 265-312.
48. van Vuuren DP, Smeets EMW (2000) Ecological footprints of Benin, Bhutan, Costa Rica and the Netherlands. *Ecol Econ* 34:115-130.