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Ecological footprint, human capital, and urbanization

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Abstract

The rapid development of the world economy has been accompanied by a significant increase in ecological footprint. Represented by population agglomeration, urbanization has exacerbated environmental pressure, but the improvements in the levels of human capital may offset this negative impact. This research thus uses cross-country data from 110 economies over the period 1990–2016 to explore the correlations among human capital, urbanization, and ecological footprint. The findings show that first, from a global perspective, human capital initially increases and then reduces ecological footprint. The analysis based on sub-samples shows that human capital of the high-income group decreases ecological footprint, whereas human capital of the low-income group and that of countries with large populations raise ecological footprint. Second, urbanization plays a linear moderating role in human capital's impact on the ecological footprint. The higher the level of urbanization is, the higher is the turning point of human capital that is needed to improve environmental quality. Third, when the population size is larger or ecological footprint is greater, the turning point of human capital is higher under the same urbanization level. Therefore, countries should continue to enhance human capital to promote the upgrading of industrial structure, green technology innovation, and changes in energy-saving lifestyle. Moreover, it is beneficial for countries to pay close attention to the negative impact of population size or accelerated urbanization on environmental quality.

Keywords

Ecological footprint, human capital, urbanization, moderating effect

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Introduction

The global economy has developed rapidly after nearly two hundred years of industrialization. World Development Indicators (WDI) show that global gross domestic product (GDP) per capita has increased from US$3,476 in 1960 to US$11,441 in 2019. With the advancement of industrialization, a large number of people have migrated from rural areas to urban areas, pushing the global average level of urbanization rate to increase from 33% to 56%. As population agglomeration is the main factor of environmental degradation, policy makers in various countries have gradually found it more and more difficult to make trade-offs between the economy and the environment,[1–3] yet improvements in the levels of urban human capital or population quality can help offset the negative impact of population size on the environment.[4,5] The data of WDI present that secondary and tertiary education enrollment rates have risen from 30% and 9% to 76% and 39% in the past six decades. Human capital advancement could lead to people being more aware of environmental protection, developing better green behavior habits, foreign direct investment (FDI), and technological progress,[6–9] which all impact on environment.[10–12] This research thus explores human capital, urbanization, and environmental issues.

Environmental quality affects the sustainable development of countries, but academia commonly uses the indicator of carbon dioxide (CO_2) emissions to study this topic. Because CO_2 emissions are only part of the environmental degradation caused by large-scale energy consumption,[13] in recent years the literature has taken ecological footprints to be more comprehensive and reliable indicators of environmental pressure and it has gradually replaced CO_2 emissions as the focus of research attention.[14–16] Ecological footprint is generally defined as "a method of measuring the impact of human activities on the earth", showing how much land and water a country or region needs to produce materials needed by people and to absorb the waste generated.[17,18] Data from the Global Footprint Network (GFN) indicate that global ecological footprints have increased from 700 million in 1960 to 2 billion global hectares (gha) in 2016. The difference among countries is very obvious, as more than 40% of countries exceeded the global average in 2016. Among them, Qatar's per capita ecological footprint is as high as 14.413 gha, which is about 3 times that of New Zealand, 12 times that of India, and 150 times that of Iran. Studies have been conducted on the ecological footprint gap of various countries, but it is disputed whether the gap would expand or shrink.[19,20] Therefore, it is of great significance to explore ecological footprint and its influencing factors from a global perspective.

Many studies on ecological footprint are based on the assumption of the environmental Kuznets curve (EKC),[21–24] mainly discussing the relationship between ecological footprint and economic growth and whether there is an inverted U-shape relationship. While other studies have expanded to other influencing variables, such as natural resources, FDI, trade openness, urbanization, and financial development,[6,25–27] few scholars have studied how human capital affects the ecological footprint. Related research has investigated the relationships between human capital and the environment, urbanization and the environment, and human capital and urbanization.[28–30] Although relationships between any two factors have appeared in the literature, studies have not comprehensively considered interactions among three of them. This paper thus uses data from 110 countries over the period 1990–2016 as a sample to study how human capital affects ecological footprint and to examine the moderating role of urbanization in the relationship between those two variables.

The contributions of this research to the literature is as follows. First, we study the nonlinear impact of human capital on ecological footprint. Existing studies generally consider the linear relationship between human capital and ecological footprint,[27,31] but we are able to confirm an inverted U-shape relationship between the two based on the endogenous growth theory and EKC hypothesis. Second, we take panel data of 110 countries for research and group the samples to study the impacts of human capital on ecological footprint under different groups. Compared to studies on a single country or a few countries, our research is able to draw richer conclusions. Third, we examine the role of urbanization in the relationship between human capital and ecological footprint and gain a deeper understanding of the factors affecting ecological footprint. Relevant studies only consider the influence of human capital or urbanization on the environment and do not factor in the interaction between human capital and urbanization. Our research shows that urbanization does play a crucial role in the link between human capital and environment quality.

The rest of our study runs as follows. The second section is "literature review", introducing research related to human capital, urbanization, and ecological footprint. The third section is "model and data", describing the empirical model constructed herein and the data and samples used. The fourth section is "results and discussion", showing and discussing the results of the basic model, interaction model, and heterogeneity analysis. The fifth section is "conclusions and policy implications", summarizing the conclusions of this study and proposing countermeasures based on them.

Literature review

Technological innovation is the driving force of economic growth in the endogenous growth theory, and human capital is the most important factor that determines the level of such innovation.[32] The level of human capital also has a "spillover effect" – that is, it not only increases its own productivity, but also raises the productivity of labor and material capital, leading to higher output returns.[33] Empirical research continues to confirm the above points.[34–37]

Given the close relationship between the environment and the economy, some studies have begun to investigate how human capital affects the environment. Aytun and Akin[28] analyze the links among CO_2 emissions, education, and energy consumption in Turkey from 1971 to 2010 via the bootstrap causality approach, revealing that there is no causal link between primary or secondary school enrollment and CO_2 emissions, and that higher education closely relates to environmental quality. Nasir et al.[38] employ three-stage least square (3SLS) methods to investigate how Pakistan's CO_2 emissions are influenced by its economic growth, renewable energy, and human capital over the period 1980–2014, finding that human capital could effectively reduce CO_2 emissions. Ahmed and Wang[39] use the cointegration test and autoregressive distributive lag (ARDL) bound test to study the influence of India's human capital on its ecological footprint over the period 1971–2014, indicating that human capital is beneficial to the environment in both the short term and long term. Iorember et al.[40] employ a multi-breakpoint cointegration model to test the relationship between human capital and ecological footprint in South Africa, noting that human capital can increase renewable energy, reduce ecological footprint, and improve environmental quality. Pata and Caglar[41] study the relationship between China's income, energy consumption, human capital, globalization, etc. and its ecological footprint during the period 1980–2016 based on augmented ARDL approach, finding that human capital plays a key role in reducing China's environmental degradation. However, Danish et al.'s[16] study on Pakistan data over the period 1971–2014 via the ARDL approach finds that human capital influences ecological footprint in the short term, but that the effect in the long run is not statistically significant. Some studies use certain categories of countries as their samples to analyze the relationship between human capital and environmental quality. Hao et al.[42] investigates the effect of multi-factor productivity growth adjusted by environmental variables in the Group of Seven (G7) countries from 1991 to 2017 on their CO_2 emissions and finds that the use of human capital and renewable energy does help to reduce carbon emissions. Halliru et al.[43] employ quantile regression to study EKC in six West African countries from 1970 to 2017, finding that human capital has a significantly positive impact on countries in the low, medium, and high quantiles. Nathaniel[44] examines the dynamic links between natural resources, human capital, economic growth and ecological footprint of the Association of Southeast Asian Nations (ASEAN) countries from 1990 to 2016 with augmented mean group model, indicating that human capital and economic growth promotes each other, but human capital is not effective in reducing ecological footprint of ASEAN countries.

Studies present that the impact of human capital on the environment is controversial, and this impact may differ between the short term and long term, which means that there may be a non-linear relationship between the two variables. The endogenous growth model believes that human capital has a positive impact on economic growth, while the EKC hypothesis notes an inverted U-shape relationship between economic growth and environmental pollution – that is, environmental quality first declines and then rises with economic growth.[45] One can infer that human capital and environmental pollution may also exhibit a non-linear relationship, as environmental pollution first increases and then decreases with a rise in human capital. Some scholars have tried to study the issue noted above. Li and Ouyang[29] use the ARDL method to study the dynamic impact of China's human capital on its CO_2 emissions from 1978 to 2015, revealing a non-linear relationship between the two: CO_2 emissions dropped under the influence of human capital before 1992, then increased, and finally decreased again. Hanif et al.[46] study the non-linear relationship between human capital and renewable and non-renewable energies. The panel feasible generalized least squares model (FGLS) confirms that both Organisation for Economic Co-operation and Development (OECD) and non-OECD emerging countries have an energy-human capital Kuznets curve. Based on the above research, it is reasonable to further explore the non-linear impact of human capital on ecological footprint. In addition, as the level of global human capital varies greatly, the research on a larger sample and sub-samples may be able to study this issue more deeply.

Given the universality of urbanization and environmental issues, most studies utilize panel data as their samples. Martínez-Zarzoso and Maruotti[47] use data of 152 developing countries from 1975 to 2003 to study how urbanization affects CO_2 emissions, finding that the impact of an increasing population under different income groups on environmental pollution is consistent, while the effect of urbanization on CO_2 emissions is significantly different among income groups. Zhang and Yan[48] investigate how urbanization affects national and regional CO_2 emissions with provincial panel data in China from 1995 to 2010, indicating that the country's CO_2 emissions and energy consumption are impacted by urbanization, and that the impact has significant regional differences. Rauf et al.[49] study data of 47 "Belt and Road Initiative" economies over the period 1980–2016, finding that urbanization leads to an increase in CO_2 emissions and a deterioration of environmental quality through dynamic ordinary least square (DOLS) and fully modified ordinary least square (FMOLS) models. Wang et al.[50] explore the drivers of particulate matter 2.5 (PM2.5) concentration in G20 countries via the panel quantile regression model and believe that PM2.5 concentration first increases and then decreases with urbanization. Based on 135 countries from 1998 to 2014, Wang et al.[51] note that urbanization significantly affects PM2.5 concentrations, and the effect is significantly different in various groups. Therefore, urbanization usually leads to environmental degradation, but analysis of sub-samples reveals that this impact has significant regional differences.

Scant studies have analyzed how environmental variables are simultaneously affected by human capital and urbanization. Ahmed et al.[30] examine the influences of urbanization and human capital on ecological footprint based on panel data of G7 countries from 1971 to 2014. Their conclusions state that urbanization increases ecological footprint, while human capital reduces it. At the same time, there is a two-way relationship between human capital and urbanization. But their research actually does not consider the integration of human capital and urbanization. Nathaniel et al.[52] study the influencing factors of CO_2 emissions in Latin American and Caribbean countries from 1990 to 2017, finding that natural resources, globalization, and urbanization all contribute to environmental degradation, but that human capital could reduce it. It is worth noting that the value of the interaction term between human capital and urbanization is significantly negative, indicating that human capital can reduce the negative impact of urbanization on the environment. Their research confirms and extends Ahmed et al.'s[30] conclusion.

This present paper discusses the correlations among human capital, urbanization, and ecological footprint in order to help fill the gap in related research. Based on a review of existing research, we study the non-linear impact of human capital on ecological footprint and explore whether there is a turning point in human capital. Next, we introduce the interaction term between human capital and urbanization to study how the turning point of human capital changes with the level of urbanization. Lastly, we take large-scale cross-country data as a sample so as to draw richer research conclusions through the study of sub-samples and to gain a deeper understanding of global ecological footprint trends and the related influencing factors.

Models and data

Construction of models

Following the practice of relevant literature,[53,54] our study is based on the expansion of the EKC hypothesis – that is, there is an inverted U-shape relation between environmental and economic variables. First, GDP per capita and its square term are introduced as the influencing factors of ecological footprint. It is expected that a low level of GDP per capita will cause environmental degradation, and when GDP per capita rises to a certain level, it will promote the decline of ecological footprint. Second, referring to existing research,[29,30,55] we introduce urbanization, energy use, and FDI as other control variables. Finally, after combing the existing literature and basic data analysis, this paper introduces human capital and its square term as the key explanatory variables, focusing on the non-linear impact of human capital on ecological footprint.

The basic model of our study is

$$\begin{aligned} \ln ef_{it} = {} & \beta_0 + \beta_1 \ln hc_{it} + \beta_2 \ln hc_{it}^2 + \beta_3 \ln pgdp_{it} + \beta_4 \ln pgdp_{it}^2 \\ & + \beta_5 \ln urban_{it} + \beta_6 \ln eu_{it} + \beta_7 \ln fdi_{it} + \varepsilon_{it} \end{aligned} \tag{1}$$

Here, $i = 1, \ldots, N$ and $t = 1, \ldots, T$ are the individual country and time period, respectively; β_0 is a constant term; ε_{it} represents the error term; and β_1 to β_7 are the estimated coefficients. The dependent variable *ef* represents ecological footprint (gha per person), and the core independent variable *hc* represents the human capital index. As for control variables, *pgdp* is GDP per capita (constant 2010 US dollars), *urban* is urban population[a] (% of total population), *eu* denotes energy use (kg of oil equivalent per capita), *fdi* is net flow of FDI (% of GDP), and hc^2 and $pgdp^2$ are the square terms of human capital and GDP per capita, respectively. Furthermore, in the robustness test *fdi* is replaced by *trade*, which represents the sum of imports and exports of goods and services (% of GDP). The estimation of the basic model allows us to know the non-linear relationship between ecological footprint and human capital. If the coefficient parameters β_1 and β_2 are significant, then the relationship is verified to be U-shape or inverted U-shape.

We also want to know the effect of urbanization in the link between ecological footprint and human capital. Therefore, we introduce the interaction term of urbanization and human capital in the basic model. It should be noted that the moderating effect of urbanization may also be non-linear. We test whether it is non-linear following Hainmueller et al.[56] and prove that the interaction effect of urbanization in this model is linear. Therefore, the interaction model of urbanization is shown as

$$\begin{aligned} \ln ef_{it} = {} & \beta_0 + \beta_1 \ln hc_{it} + \beta_2 \ln hc_{it}^2 + \beta_3 \ln pgdp_{it} + \beta_4 \ln pgdp_{it}^2 \\ & + \beta_5 \ln urban_{it} + \beta_6 \ln eu_{it} + \beta_7 \ln fdi_{it} + \beta_8 \ln hc_{it} * \ln urban_{it} + \varepsilon_{it} \end{aligned} \tag{2}$$

Here, $\ln hc * \ln urban$ denotes the interaction term of human capital and urbanization, which has been decentralized. Other variables are the same as equation (1). By calculating the first-order partial derivative of equation (2), we are able to know the marginal effect of $\ln hc$ on $\ln ef$. The results are shown in equation (3).

$$\partial \ln ef_{it} / \partial \ln hc_{it} = \beta_1 + 2\beta_2 \ln hc_{it} + \beta_8 \ln urban_{it} \tag{3}$$

We see that the marginal effect is jointly influenced by human capital and urbanization if β_2 and β_8 are significant.

$$\partial^2 (\ln ef_{it}) / \partial (\ln hc_{it})^2 = 2\beta_2 \tag{4}$$

Equation (4) is the result of calculating the second-order partial derivative of equation (2). If β_2 is less than 0, then the effect of $\ln hc$ on $\ln ef$ is an inverted U-shape. Ecological footprint increases with the improvement of human capital before a turning point and decreases after the turning point. When equation (3) equals 0, we can calculate the turning point of human capital as

$$\ln hc_{it}^* = -\beta_1 / 2\beta_2 - \beta_8 / 2\beta_2 \ln urban_{it} \tag{5}$$

Here, $\ln hc^*$ is the turning point of human capital.

The relationship between this turning point and the level of urbanization mainly depends on the values of β_2 and β_8. Note that β_2 is less than 0 when ln*hc* and ln*ef* have an inverted U-shape relation, and β_8 is greater than 0 if the coefficient value of the interaction term $\ln hc * \ln urban$ is positive. In this case, the turning point of human capital and the urbanization level have a positive linear relationship – that is, the greater the urbanization level is, the higher the level that human capital needs to reach in order to promote the decline of ecological footprint.

In the heterogeneity analysis, we perform linear regression on those subsamples that do not meet the non-linear relationship of human capital and ecological footprint, as shown in equation (6). Subsequently, we introduce interaction term $\ln hc * \ln urban$ to form an interaction model as shown in equation (7). Calculating the first-order partial derivative of equation (7) shows the marginal effect of ln*hc* on ln*ef*, and the coefficient value of the interaction term (γ_7) is crucial to illustrate the role of urbanization (see equation (8)). When the value of γ_7 is greater than 0, it indicates that urbanization enhances the positive or weakens the negative influence of human capital on ecological footprint. If the value of γ_7 is less than 0, then urbanization strengthens the negative or mitigates the positive effect of human capital on ecological footprint. From a practical viewpoint, it is conducive to improve the environment of various countries when the value of γ_7 is negative.

$$\begin{aligned} \ln ef_{it} &= \gamma_0 + \gamma_1 \ln hc_{it} + \gamma_2 \ln pgdp_{it} + \gamma_3 \ln pgdp_{it}^2 \\ &\quad + \gamma_4 \ln urban_{it} + \gamma_5 \ln eu_{it} + \gamma_6 \ln fdi_{it} + \varepsilon_{it} \end{aligned} \tag{6}$$

$$\begin{aligned} \ln ef_{it} = \gamma_0 + \gamma_1 \ln hc_{it} + \gamma_2 \ln pgdp_{it} + \gamma_3 \ln pgdp_{it}^2 \\ + \gamma_4 \ln urban_{it} + \gamma_5 \ln eu_{it} + \gamma_6 \ln fdi_{it} + \gamma_7 \ln hc_{it} * \ln urban_{it} + \varepsilon_{it} \end{aligned} \tag{7}$$

$$\partial \ln ef_{it} / \partial \ln hc_{it} = \gamma_1 + \gamma_7 \ln urban_{it} \tag{8}$$

The models constructed in this paper offer the following advantages. First, the basic model is able to verify whether there is an inverted U-shape relationship between human capital and ecological footprint, as other studies rarely consider non-linear relationships. Second, the moderating effect model is able to examine how the turning point of human capital changes with the level of urbanization. Third, group analysis observes heterogeneity in the relationship between human capital and ecological footprint. However, we do not consider other forms in the setting of the models, and human capital and ecological footprint may have a more complex non-linear relationship.

Sample and data description

Since the data of the ecological footprint are only updated to 2016, and after taking account of the data availability of other variables, this paper utilizes 110 countries from 1990 to 2016 as the research sample, listing them in Appendix Table A1. This paper not only takes 110 countries as a whole sample, but also classifies the sample to study the difference of the results among sub-sample groups. Specifically, following the WDI grouping method, we first divide the 110 countries into three groups: high-, middle- and low-income, which include 40, 34, and 36 countries, respectively. Second, the sample is classified into three groups according to the 25th and 75th quantiles of population: large-, medium- and small-sized groups, which include 27, 55, and 28 countries, respectively. Third, we use the panel quantile regression model to explore how the influence of human capital on ecological footprint changes with the change in the level of ecological footprint.

The data of control variables (such as *pgdp*, *urban*, *eu*, *fdi*, and *trade*) come from WDI in the World Bank database. The data of *ef* are from GFN.[27,30] Ecological footprint shows how much land and water area a country needs in order to make all products needed for production and living and to absorb waste generated by human activities. The per capita ecological footprint used in this paper is composed of six parts: the areas of carbon, cropland, build-up land, forest products, grazing land, and fishing grounds. The data of *hc* are gathered from Penn World Table 9.1, provided by Groningen Growth and Development Center.[57] Here, *hc* is mainly calculated by data of the average years of schooling and the return to education calculated by Mincer Equation.[58–60] Most recent studies on cross-country data use this indicator to reflect the level of human capital.[30,60,61]

Table 1 shows the variables' descriptive statistics. Table 2 lists the differences in the median values of ecological footprint, human capital, and urbanization level of different groups. From the perspective of different income groups, the higher the income level is, the greater are the ecological footprint, human capital, and urbanization level, and the difference in human capital is lower than the other two indicators. As population size increases, ecological footprint increases first and then decreases, while human capital and urbanization level decrease first and then increase. High and low levels of human capital correspond to a

Table 1. Descriptive statistics of variables.

Variable	*M*	*SD*	Min	Max	Skewness	Kurtosis
ln*ef*	0.971	0.727	−0.779	2.875	0.108	2.246
ln*hc*	0.835	0.307	0.029	1.326	−0.534	2.414
lnhc^2	0.791	0.472	0.001	1.759	0.088	1.913
ln*pgdp*	8.600	1.451	5.102	11.626	−0.065	2.136
ln$pgdp^2$	76.059	24.918	26.030	135.163	0.216	2.121
ln*urban*	3.972	0.474	2.181	4.605	−0.995	3.275
ln*eu*	7.100	1.238	0.010	10.004	−0.860	6.514
ln*fdi*	4.152	0.140	0.517	6.238	−2.108	207.075
ln*trade*	4.244	0.721	−3.863	6.081	−3.262	29.355
ln*hc**ln*urban*	0.015	0.160	−0.546	0.959	0.460	7.740

Table 2. Median of core variables in different groups.

Group	Country number	lnef	lnhc	lnurban
High income	40	1.691	0.929	4.359
Middle income	34	0.907	0.920	4.145
Low income	36	0.244	0.814	3.583
Large-sized population	27	0.923	0.846	4.149
Medium-sized population	55	1.001	0.841	4.036
Small-sized population	28	0.928	0.947	4.147
Full sample	110	0.948	0.891	4.122

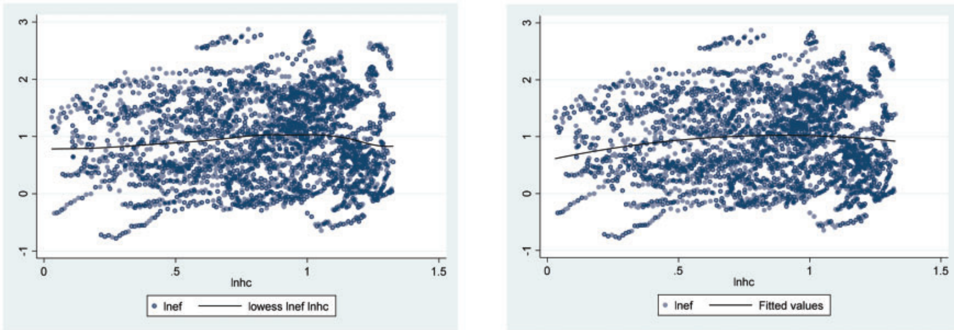

Figure 1. Scatter plots and fitted lines of *ln*ef and *ln*hc.

similar level of ecological footprint, meaning that there may be a non-linear link between ecological footprint and human capital. The above observations are only the differences in the median value among the sub-sample groups. When using global panel data to study the issue, it is reasonable to believe that the connection between ecological footprint and human capital could be interpreted by a non-linear model, and urbanization plays a moderating role in it.

Figure 1 shows the scatter plots and fitted lines of ln*ef* and ln*hc*. The fitted line of the left picture is drawn from the lowess process, while the right one is drawn based on quadratic regression. From Figure 1, ecological footprint first rises and then falls when the level of human capital increases, indicating an inverted U-shape relationship generally.

Results and discussion

Results of the basic model

Table 3 shows the estimated results of the basic model (equation (1)) – the relation between ecological footprint and human capital for 110 economies from 1990 to 2016. First, we employ the OLS method (OLS) and fixed effect panel data model (FE) to derive parameter values, and the value of the F test in which all $u_i=0$ (124.65, $P=0.0000$) rejects the null hypothesis, indicating that cross-sectional heterogeneity should be considered. Subsequently, we employ the random effect model (RE) to estimate the coefficient values, and the chi-square statistic (24.79, $P=0.0008$) of the Hausman test further determines that FE is more applicable. Finally, considering the time effect, we utilize a two-way fixed effect (TWFE) to estimate the basic model. The statistics of the dummy variables for years do not accept the null hypothesis of "no time effect" significantly, and so the results of TWFE is our main interest in this paper.

According to column (4) in Table 3, ln*ef* and ln*pgdp* show an inverted U-shape relationship at the 1% significance level, which is consistent with the EKC hypothesis. Many studies have also confirmed that as the economic development grows to a certain stage, the technological level could be sufficient to save energy and improve energy efficiency, which can reduce the ecological footprint.[41] In addition, consistent with most studies, we find that energy use increases the ecological footprint statistically significant. Some studies have also shown that non-renewable energy consumption is the main reason for the deterioration of

Table 3. Results of the basic model.

Variable	(1) OLS	(2) FE	(3) RE	(4) TWFE
lnhc	0.2410***	0.3246***	0.3093***	0.3166***
	(2.82)	(3.28)	(3.20)	(3.10)
$lnhc^2$	−0.1743***	−0.3138***	−0.3217***	−0.2526***
	(−3.27)	(−4.91)	(−5.15)	(−3.81)
lnpgdp	−0.0157	0.4420***	0.3637***	0.4679***
	(−0.35)	(6.38)	(5.56)	(6.71)
$lnpgdp^2$	0.0204***	−0.0135***	−0.0078**	−0.0148***
	(7.64)	(−3.19)	(−1.98)	(−3.42)
lnurban	0.0244	−0.0552	−0.0257	−0.0426
	(1.46)	(−1.39)	(−0.72)	(−1.04)
lneu	0.1446***	0.2506***	0.2426***	0.2448***
	(9.00)	(17.44)	(17.89)	(17.04)
lnfdi	0.2581***	0.0387*	0.0403*	0.0228
	(3.07)	(1.88)	(1.95)	(1.09)
year	No	No	No	Yes
_cons	−2.7075***	−3.5451***	−3.3573***	−3.6743***
	(−6.26)	(−12.52)	(−12.21)	(−12.80)
N	2970	2970	2970	2970
R^2	0.8080	0.3502		0.3663

Note: *z* statistics are in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

environmental quality, while the use of renewable energy can help reduce the ecological footprint.[62–65] The influence of ln*urban* and ln*fdi* on ln*ef* is not statistically significant, which may be due to the large size of our sample, but the sub-samples will be further studied in the following content. As for the core explanatory variable, the coefficient value of ln*hc* is positive and that of $\ln hc^2$ is negative, both at the 1% significance level, regardless of the regression method used. This confirms that there is indeed an inverted U-shape non-linear relationship between human capital and ecological footprint. When the level of human capital is low, an improvement of it increases ecological footprint, and when human capital exceeds a certain level, ecological footprint decreases as human capital continues to increase.

To check the robustness of the link between ecological footprint and human capital, we conduct the following four robustness tests (see Table 4). First, we replace the control variable ln*fdi* with ln*trade*. The result of column (1) shows that trade affects ecological footprint positively, while human capital still has an inverted U-shape relationship with ecological footprint. Second, we use the Winsor process to perform the 1% tail reduction for all variables and then perform a two-way fixed effect regression to derive more fitted values. The result of column (2) shows that ln*ef* and ln*hc* still have an inverted U-shape relationship at least at the 5% significance level. Third, considering that the effect of human capital on ecological footprint may be endogenous, we apply the generalized method of Moments (GMM) to further examine the relationship between them. The instrumental variables used here are the lagging second and third period values of ln*hc* and $\ln hc^2$. The result of column (3) shows that after considering the endogenous issue, ln*ef* still rises first and then falls with the increase of ln*hc* at the 1% significance level. Finally, in view of the fact that some studies believe that there is a linear relationship between ecological footprint

Table 4. Results of the robustness tests.

Variable	(1) trade	(2) Winsor	(3) GMM	(4) linear	(5) linear2
lnhc	0.4168***	0.2007**	0.4626***	0.0217	0.0359
	(4.12)	(1.97)	(4.02)	(0.33)	(0.54)
lnhc^2	−0.3292***	−0.2371***	−0.3017***		
	(−4.96)	(−3.56)	(−4.04)		
lnpgdp	0.5240***	0.5447***	0.5191***	0.4801***	0.5368***
	(7.60)	(7.49)	(6.92)	(6.87)	(7.76)
lnpgdp^2	−0.0185***	−0.0216***	−0.0153***	−0.0157***	−0.0195***
	(−4.34)	(−4.83)	(−3.33)	(−3.62)	(−4.57)
lnurban	−0.0451	−0.0535	−0.0459	−0.0306	−0.0248
	(−1.09)	(−1.32)	(−1.03)	(−0.75)	(−0.60)
lneu	0.2346***	0.3305***	0.2432***	0.2470***	0.2383***
	(16.15)	(20.45)	(15.79)	(17.17)	(16.36)
lnfdi		0.0532	0.0183	0.0222	
		(1.23)	(0.89)	(1.06)	
lntrade	0.0426***				0.0442***
	(3.99)				(4.13)
year	Yes	Yes	Yes	Yes	Yes
_cons	−3.8893***	−4.4435***		−3.7144***	−3.9621***
	(−14.19)	(−12.82)		(−12.92)	(−14.42)
N	2889	2970	2640	2970	2889
R^2	0.3569	0.3898	0.3709	0.3630	0.3511

Note: z statistics are in parentheses, *$p < 0.1$, **$p < 0.05$, and ***$p < 0.01$.

and human capital,[27,30] we observe whether the linear relationship exists by removing lnhc^2. The results in columns (4) and (5) show that the linear effect of human capital on ecological footprint is not statistically significant, which confirms our conclusion above. In addition, the impact of other control variables on ecological footprint is consistent with the results of column (4) in Table 3, thus proving the robustness of the conclusion of this paper again.

In summary, there is a turning point in human capital. When human capital is lower than a certain level, its improvement leads to an increase in ecological footprint; conversely, when the level of human capital continues to rise above the turning point, an increase in human capital is able to reduce ecological footprint. This is consistent with the conclusions of some existing studies. There is also an inverted U-shape relationship between human capital and energy use. The improvement of human capital level first increases non-renewable energy consumption, and then increases the use of renewable energy through energy-saving technologies and reduces the overall energy demand.[41] In addition, for a region that is too dependent on fossil fuel energy and natural resources, the corresponding human capital level is relatively low. The increase in human capital leads to the expansion of energy-intensive industries and hinders the improvement of environmental quality. And in an area with a high level of economic development, human capital can replace the energy input in the production process, thereby promoting the development of the industry in an environmentally friendly direction. Moreover, people with higher levels of human capital pay more attention to the trade-off between economic growth and environmental protection, and are more motivated to develop green behaviors.[39,66,67]

Results of the interaction model

Multiplicative interaction models are often used to study how a moderating variable affects the relationship between the independent and dependent variables. These models usually assume that the influence of the moderator is linear, which may be problematic. Following Hainmueller et al.,[56] we investigate the assumption of the linear interaction effect. After dividing the moderator ln*urban* into three groups, low, medium, and high levels, we draw the marginal effects of ln*hc* on ln*ef* in three groups, forming linear interaction diagnostic plots (see Figure 2). The figure demonstrates that the effects of human capital on ecological footprint are aptly fitted by the linear model when the moderator ln*urban* is at three different levels. The slope of the fitted line changes from negative to close to 0 and finally converts to positive, which means that as ln*urban* increases, the marginal effect also gradually increases, thus verifying the assumption of linear interaction effects.

This paper therefore introduces ln*hc**ln*urban* as shown in equation (2), mainly for examining the impact of urbanization on the connection between ecological footprint and human capital through the coefficient value of ln*hc**ln*urban* (see Table 5). Columns (1)–(4) are the estimated results of the TWFE, results of the model replacing ln*fdi* with ln*trade*, results of the model based on data after tailing reduction, and results of the GMM model considering the endogenous.. The coefficient value of ln*hc**ln*urban* is significantly positive at least at the 10% level. According to the interpretation of equation (5), when the coefficient value of ln*hc**ln*urban* is greater than 0 and that of $\ln hc^2$ is less than 0, the turning point of human capital rises with the increase of the urbanization level. In other words, when a country's urbanization level is relatively high, human capital must reach a higher level to improve environmental quality and reduce its ecological footprint. In an area with a high level of

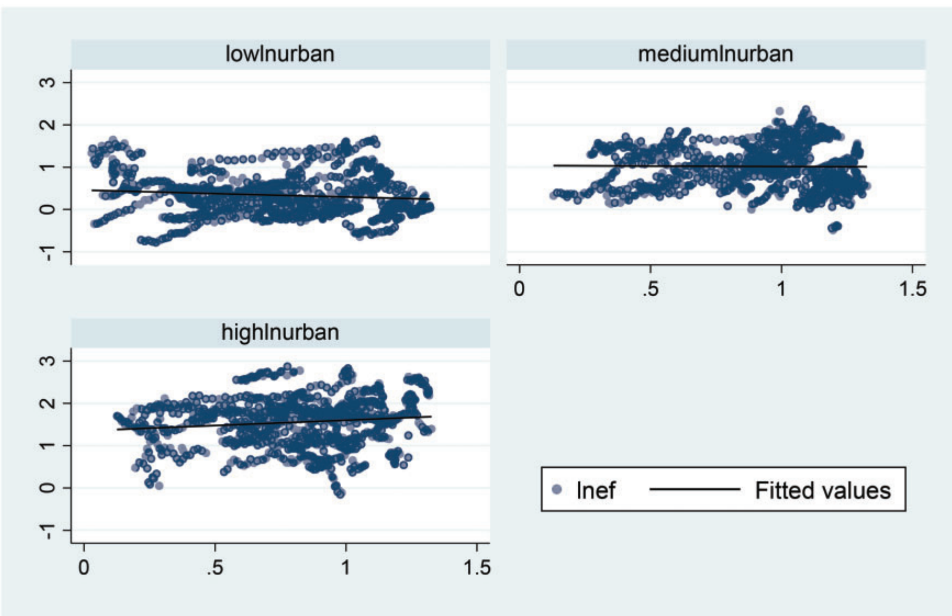

Figure 2. Linear interaction diagnostic plots.

Table 5. Results of the interaction model.

Variable	(1) interactTWFE	(2) interacttrade	(3) interactWinsor	(4) interactGMM
lnhc	0.4392***	0.5463***	−0.1539	0.5833***
	(4.01)	(5.03)	(−0.73)	(4.70)
$lnhc^2$	−0.3294***	−0.4129***	−0.2823***	−0.3779***
	(−4.65)	(−5.81)	(−4.00)	(−4.71)
lnpgdp	0.5468***	0.6113***	0.6017***	0.5960***
	(7.36)	(8.27)	(7.66)	(7.40)
$lnpgdp^2$	−0.0198***	−0.0240***	−0.0251***	−0.0201***
	(−4.28)	(−5.24)	(−5.19)	(−4.06)
lnurban	−0.0262	−0.0260	−0.1376**	−0.0380
	(−0.63)	(−0.62)	(−2.30)	(−0.85)
lneu	0.2482***	0.2365***	0.3306***	0.2481***
	(17.25)	(16.30)	(20.46)	(16.01)
lnfdi	0.0219		0.0503	0.0184
	(1.05)		(1.16)	(0.89)
lntrade		0.0400***		
		(3.74)		
lnhc*lnurban	0.1700***	0.1814***	0.1081*	0.1629***
	(3.05)	(3.24)	(1.92)	(2.59)
year	Yes	Yes	Yes	Yes
_cons	−4.1030***	−4.3468***	−4.3497***	
	(−12.85)	(−14.12)	(−12.43)	
N	2970	2889	2970	2640
R^2	0.3683	0.3593	0.3906	0.3729

Note: *z* statistics are in parentheses, *$p < 0.1$, **$p < 0.05$, and ***$p < 0.01$.

urbanization, the continuous increase in population density leads to higher energy consumption and pollutant emissions.[68] The expansion of urban areas also encroaches on more ecological resources and increases pollution from real estate-related industries and transportation.[69] And human capital plays an active role in improving the quality of the urban environment and promoting the sustainable development of the urban areas. Therefore, in order to improve environmental quality, when the level of urbanization is higher, people must receive a higher level of education to promote technological innovation, change lifestyles and reduce energy consumption.

Heterogeneity analysis

For the purpose of further investigating the link between ecological footprint and human capital, we group the samples and observe the differences in the relationships among the groups.

We first divide the sample into three groups based on income levels. The basic model (expressed by equation (1)) is applied to each group of data. From columns (1)–(3) in Table 6, the inverted U-shape relationship of each group is not obvious, indicating that the relationship between ecological footprint and human capital after grouping does not have a significant non-linear relationship. This may be due to the concentration of human

Table 6. Results of the basic model for different income groups.

Variable	(1) High	(2) Middle	(3) Low	(4) High	(5) Middle	(6) Low
lnhc	0.2145	0.2557	0.4878***	−0.5159***	0.1840	0.3917***
	(1.08)	(1.18)	(4.02)	(−3.92)	(1.57)	(4.36)
$lnhc^2$	−0.6160	−0.0539	−0.0995			
	(−1.85)	(−0.40)	(−1.18)			
lnpgdp	1.6610***	0.9139***	0.2765**	1.5246***	0.9273***	0.2727**
	(5.36)	(3.72)	(2.06)	(4.89)	(3.81)	(2.04)
$lnpgdp^2$	−0.0820***	−0.0454***	0.0005	−0.0753***	−0.0463***	0.0011
	(−5.03)	(−2.95)	(0.05)	(−4.58)	(−3.05)	(0.11)
lnurban	−0.5169***	0.0856	0.2616***	−0.5951***	0.0910	0.2726***
	(−3.72)	(1.34)	(4.82)	(−4.27)	(1.46)	(5.10)
lneu	0.4158***	0.3018***	0.0964***	0.4111***	0.3022***	0.0977***
	(11.72)	(12.41)	(5.48)	(11.47)	(12.44)	(5.56)
lnfdi	−0.0185	0.0557	0.1881**	−0.0200	0.0561	0.1818**
	(−0.73)	(0.73)	(2.51)	(−0.78)	(0.73)	(2.43)
year	Yes	Yes	Yes	Yes	Yes	Yes
_cons	−7.6165***	−6.4628***	−4.2060***	−6.4115***	−6.5153***	−4.2173***
	(−4.67)	(−6.40)	(−7.40)	(−3.93)	(−6.51)	(−7.42)
N	1080	918	972	1080	918	972
R^2	0.3060	0.5139	0.4804	0.2897	0.5138	0.4796

Note: *z* statistics are in parentheses, *$p < 0.1$, **$p < 0.05$, and ***$p < 0.01$.

capital in each group, which has not yet reached the level of a non-linear effect on ecological footprint. Therefore, we remove $\ln hc^2$ and examine whether there is a linear relationship between ecological footprint and human capital of each group, as shown in equation (6). It can be seen from columns (4)–(6) of Table 6 that ln*hc* of the high-income group significantly reduces ln*ef* at the 1% level, and the coefficient value of ln*hc* in the low-income group is positive at the 1% significance level, while the one in the middle-income group is not statistically significant.

Table 6 shows in different groups that the levels of ecological footprint, human capital and urbanization all increase with a rise in income level, and we analyze this conclusion from the following aspects. First, the industrial development in low-income countries usually consumes more non-renewable energy, which leads to an increase in the ecological footprint. And because they are more inclined to develop the economy at the expense of the environment, these countries have relatively loose environmental supervision policies and are more likely to become a "pollution haven" (the coefficient value of ln*fdi* is positive).[70] Moreover, human capital in low-income countries is not enough to promote green technological innovation, and so it is difficult to improve environmental quality through technological innovation. Research also shows that in areas with low levels of human capital, FDI is negatively correlated with environmental quality.[70,71] Second, the levels of human capital, industrial development and urbanization in middle-income countries are more diverse. With the improvement of human capital and the acceleration of industrialization, environmental pollution in middle-income countries has gradually become more prominent, and they have begun to improve environmental quality through active economic transformation. However, due to the widespread existence of differences and rapid

Table 7. Results of the interaction model for different income groups.

Variable	(1) High	(2) Middle	(3) Low
lnhc	−0.1895	0.1000	0.7474***
	(−1.18)	(0.83)	(6.63)
lnpgdp	1.4353***	1.0736***	0.4991***
	(4.61)	(4.33)	(3.58)
$lnpgdp^2$	−0.0704***	−0.0554***	−0.0153
	(−4.29)	(−3.58)	(−1.47)
lnurban	−0.2769*	0.0698	0.3559***
	(−1.67)	(1.11)	(6.45)
lneu	0.3955***	0.3115***	0.0999***
	(11.01)	(12.77)	(5.76)
lnfdi	−0.0169	0.0667	0.1325*
	(−0.66)	(0.88)	(1.78)
lnhc*lnurban	−1.0269***	0.3480***	0.3277***
	(−3.51)	(2.87)	(5.11)
year	Yes	Yes	Yes
_cons	−7.5150***	−7.0618***	−5.3650***
	(−4.55)	(−6.96)	(−8.88)
N	1080	918	972
R^2	0.2983	0.5185	0.4942

Note: z statistics are in parentheses, *$p < 0.1$, **$p < 0.05$, and ***$p < 0.01$.

economic and social changes, it is difficult to determine the level of human capital to reduce the ecological footprint. Third, the adoption of more renewable energy in high-income countries can effectively reduce the ecological footprint.[64] Moreover, the human capital of these countries is sufficient to promote technological innovation and industrial development in an environmentally friendly direction. In addition, high-income groups pay more attention to environmental quality and have stricter environmental supervision measures, which can help reduce the ecological footprint together with urbanization. On the whole, the conclusion here actually proves the inverted U-shape relationship between ecological footprint and human capital in the entire sample – that is, an increase in human capital (from low-income to high-income countries) has a positive impact first on ecological footprint and then a negative impact.

Countries have not only income gaps, but also ecological footprint gaps, studies have confirmed the existence of club convergence with ecological footprints among different income groups of countries.[19] Our research also found the heterogeneity of the ecological footprint of different income countries. But it should be noted that human capital in low-income countries is not enough to reduce ecological footprint, while the ecological footprint of high-income countries is expected to decline through the improvement of human capital, which means that the ecological footprint gaps of countries may further widen. With the development of globalization, if high-income countries can share their green technologies and support the improvement of human capital in low-income countries, then the gap in each country's ecological footprint could be reduced.

We now examine the role of urbanization in the connection between ecological footprint and human capital in three income groups. From Table 7, the coefficient value of

Table 8. Results of the basic model for different population groups.

Variable	(1) Large	(2) Medium	(3) Small	(4) Large	(5) Medium	(6) Small
lnhc	0.5518***	0.4923***	0.9007***	0.3231***	0.0016	0.1676
	(2.99)	(3.42)	(3.20)	(2.73)	(0.02)	(1.24)
$lnhc^2$	−0.2147	−0.4306***	−0.4962***			
	(−1.62)	(−4.89)	(−2.97)			
lnpgdp	0.7024***	−0.2285*	0.3566***	0.7105***	−0.1516	0.4008***
	(6.17)	(−1.78)	(3.06)	(6.24)	(−1.18)	(3.45)
$lnpgdp^2$	−0.0309***	0.0278***	−0.0028	−0.0310***	0.0231***	−0.0066
	(−4.58)	(3.51)	(−0.37)	(−4.59)	(2.91)	(−0.90)
lnurban	0.4850***	0.0974*	−0.5108***	0.4475***	0.1288**	−0.4629***
	(5.26)	(1.68)	(−6.85)	(5.01)	(2.22)	(−6.33)
lneu	0.1157***	0.4664***	0.1823***	0.1220***	0.4662***	0.1912***
	(3.36)	(16.94)	(8.84)	(3.56)	(16.79)	(9.32)
lnfdi	0.0519	0.0394	0.0068	0.0452	0.0293	0.0053
	(0.74)	(0.73)	(0.29)	(0.64)	(0.54)	(0.22)
year	Yes	Yes	Yes	Yes	Yes	Yes
_cons	−5.9432***	−3.0953***	−1.6014***	−5.8397***	−3.3986***	−1.6959***
	(−10.46)	(−5.95)	(−3.33)	(−10.33)	(−6.52)	(−3.51)
N	729	1485	756	729	1485	756
R^2	0.3681	0.3578	0.5581	0.3657	0.3468	0.5525

Note: z statistics are in parentheses, $^*p < 0.1$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

ln*hc**ln*urban* in the high-income group is negative, which is significant at the 1% level, while the values in the low- and middle-income groups are all significantly positive. Combined with the conclusions in Table 6, this means that urbanization of high-income countries can enhance the mitigation effect, while urbanization of low- and middle-income groups further exacerbates the promotion of human capital on ecological footprint. In other words, improving human capital and urbanization helps with the environmental enhancement of high-income countries, while other countries need to consider the negative effects of human capital and urbanization on the environment, and this may closely relate to industrial development and technological progress.

This research now divides the entire sample into three groups according to population size: large-, medium-, and small-sized population countries. We apply the basic model for each group and report the results without adding $\ln hc^2$. From Table 8, human capital in countries with small- and medium-sized population has a non-linear effect on ecological footprint, but humans in countries with a large population size will increase their ecological footprint. When the population size is not large, human capital can lessen the negative effect of population on environmental quality after increasing to a certain degree, thus showing an inverted U-shape relationship. However, when the population size is large, it is more difficult to increase human capital and offset the negative impact of the population, resulting in an increase in ecological footprint. Existing studies have also confirmed that population growth has greatly increased energy consumption, and that the increase in population density is an important reason for the expansion of ecological footprint.[64,68]

When considering the moderating effect of urbanization, we find that there are turning points in human capital in small- and medium-sized countries (see Table 9). According to

Table 9. Results of the interaction model for different population groups.

Variable	(1) Large	(2) Medium	(3) Small
lnhc	0.3309***	0.6470***	1.2938***
	(2.78)	(4.18)	(3.91)
$lnhc^2$		−0.5249***	−0.7037***
		(−5.55)	(−3.69)
lnpgdp	0.7367***	−0.1024	0.4643***
	(5.99)	(−0.75)	(3.69)
$lnpgdp^2$	−0.0324***	0.0198**	−0.0096
	(−4.50)	(2.34)	(−1.19)
lnurban	0.4481***	0.1140**	−0.4910***
	(5.02)	(1.96)	(−6.56)
lneu	0.1219***	0.4699***	0.1841***
	(3.56)	(17.08)	(8.95)
lnfdi	0.0456	0.0373	0.0055
	(0.65)	(0.69)	(0.23)
lnhc*lnurban	0.0666	0.2054***	0.2566**
	(0.57)	(2.67)	(2.24)
year	Yes	Yes	Yes
_cons	−5.9645***	−3.7117***	−2.2773***
	(−9.83)	(−6.53)	(−4.02)
N	729	1485	756
R^2	0.3660	0.3610	0.5613

Note: z statistics are in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

equation (5), the value of the term$-\beta_8/2\beta_2$ in medium- and small-sized countries are 0.196 and 0.182, respectively. This indicates that when the population size is larger, the turning point of human capital is more sensitive to the urbanization level. Under the same urbanization level, the larger the population size is, the higher is the level of required human capital to reduce ecological footprint. In addition, in countries with large population sizes, urbanization does not show a significant moderating effect. This may be due to the fact that these countries have a higher urban population density in which urbanization brings about more environmental problems, whereas a large population that has not entered urban areas adopts a lifestyle with high energy consumption. Many studies have shown that population agglomeration or an increase in population density leads to a decrease in arable land and an increase in energy demand, thereby putting greater pressure on the environment.[72]

We finally use a panel quantile regression model to examine how human capital plays a role when the level of ecological footprint changes. From the estimation results of the 25th, 50th, and 75th quantiles in Table 10, we see that human capital has an inverted U-shape influence on ecological footprint, making it an important measure for countries to enhance environmental quality by raising the level of human capital. Moreover, urbanization continues to be a moderator in the relationship between ecological footprint and human capital. According to equation (5), the value of the term $-\beta_8/2\beta_2$ at the 25th, 50th, and 75th quantiles are 0.191, 0.201, and 0.208, respectively. Therefore, when the level of ecological footprint is higher, under the same level of urbanization, human capital must reach a greater level to decrease ecological footprint. These conclusions confirm the inverted U-shape

Table 10. Results of the basic model and interaction model for different quantiles of lnef.

Variable	(1) 25th	(2) 50th	(3) 75th	(4) 25th	(5) 50th	(6) 75th
lnhc	0.2713*	0.3283***	0.3804***	0.3601**	0.4425***	0.5169***
	(1.93)	(3.17)	(2.82)	(2.20)	(3.72)	(3.35)
$lnhc^2$	−0.2796***	−0.3162***	−0.3497***	−0.3355***	−0.3873***	−0.4341***
	(−3.21)	(−4.94)	(−4.20)	(−3.37)	(−5.36)	(−4.64)
lnpgdp	0.3756***	0.4467***	0.5117***	0.4304***	0.5187***	0.5983***
	(4.25)	(6.87)	(6.05)	(4.33)	(7.20)	(6.41)0
$lnpgdp^2$	−0.0094*	−0.0138***	−0.0178***	−0.0129**	−0.0184***	−0.0233***
	(−1.67)	(−3.32)	(−3.29)	(−2.03)	(−3.99)	(−3.90)
lnurban	−0.0683	−0.0543	−0.0415	−0.0599	−0.0386	−0.0194
	(−1.29)	(−1.44)	(−0.82)	(−1.15)	(−1.02)	(−0.39)
lneu	0.2709***	0.2492***	0.2293***	0.2741***	0.2521***	0.2322***
	(8.36)	(10.44)	(7.39)	(8.52)	(10.8)	(7.68)
lnfdi	0.0659*	0.0368	0.0101	0.0660*	0.0361	0.0091
	(1.76)	(1.33)	(0.28)	(1.76)	(1.32)	(0.26)
lnhc*lnurban				0.1279*	0.1556***	0.1805**
				(1.56)	(2.62)	(2.34)

Note: z statistics are in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

relationship between ecological footprint and human capital and also show that countries with higher levels of ecological footprint need to pay more attention to the improvement of human capital and control the adverse effects of urbanization on the environment.

Conclusions and policy implications

Using data of 110 countries spanning 1990 to 2016 as the sample, this research studies how human capital affects ecological footprint as well as the moderating role of urbanization in their relationship. The findings show overall that ecological footprint first rises and then declines with the improvement of human capital. Moreover, urbanization has a linear moderating impact on the inverted U-shape relationship between ecological footprint and human capital, and under higher urbanization human capital must reach a higher level to reduce ecological footprint. In addition, the higher the level of energy use is, the greater is the ecological footprint of a country, but the relationship between FDI and ecological footprint from a global perspective is not statistically significant.

Analysis on the sub-samples shows the following conclusions. First, human capital in high-income countries could reduce ecological footprint, and urbanization is conducive to the improvement effect of human capital on environmental quality. However, human capital in low- and middle-income countries has no significant impact on the environment, and even increases ecological footprint, while urbanization exacerbates the adverse effect of human capital on the environment.

Second, when population size is not very large, ecological footprint and human capital of various countries also exhibit an inverted U-shape relationship. However, as the population size increases, human capital boosts ecological footprint as population quality cannot offset the destruction of the environment due to a large population size. In addition, the larger the population size is, the greater is the sensitivity of the turning point of human capital to urbanization – that is, improving human capital can reduce ecological footprint.

Third, no matter how the level of ecological footprint changes, human capital increases first and then decreases ecological footprint. At the same time, with an increase of ecological footprint, then under the same level of urbanization, a higher level of human capital must be reached to reduce ecological footprint.

Based on the conclusions above, this paper draws some policy implications.

For all countries, human capital improvement is conducive to environmental quality enhancement in the long run. It should be noted that when the accumulation of human capital rises, it is necessary to guide the transformation and upgrading of high energy-consuming industries as well as to manage the development of industrial production and social life in an environmentally friendly direction through technological innovation. More attention should also be paid to the negative effect of urbanization on environmental quality. When urbanization speeds up, investment in human capital should be accelerated accordingly.

Countries should also take relevant measures according to their own circumstances. First, high-income countries should insist on raising the level of human capital and promoting energy-saving technologies. There are obvious advantages in improving the level of human capital, because these countries not only have abundant educational resources, but also can attract foreign talents through high incomes. Environmental issues are related to the sustainable development of the whole world. During the process of political, economic, and social globalization, high-income countries can share their knowledge and skills with other countries to promote the control of the global ecological footprint.

Second, low- and middle-income countries should pay attention to the adjustment of their industrial structure. They can target to gradually shift energy-intensive industries such as high-energy-consuming steel, chemical, and cement to low-carbon industries such as new energy and new materials, health, and electronic information. In addition, these countries should pay attention to the matching of human capital and industrial development, which help promote local economic development and also prevent the outflow of human capital. At the same time, the level of FDI should be monitored in order to prevent becoming a "pollution haven".

Third, countries with large populations need to make more efforts to improve human capital, including health, knowledge, and skills, and to try and use population quality to offset the negative impact of population size on the environment. When population density is too high, attention should target the impact of real estate investment on ecological footprint, and energy-saving renovation of residential, commercial, and public buildings should be implemented. In addition, countries can guide residents to establish green habits, choose energy-saving appliances, and build low-energy, high-efficiency transportation modes.

Fourth, countries with high ecological footprints need to carefully investigate the root causes and reduce their ecological footprints in a targeted manner. They should thus focus on solving their current outstanding environmental problems. Examples can include saving more resources, promoting recycling and reusing, and actively developing new forms of energy.

The research in this paper illustrates the correlations among human capital, urbanization, and ecological footprint and specifically presents the turning point of human capital and how it changes along with urbanization. Our research helps to further understand the influencing factors of ecological footprint and the roles of human capital on the sustainable development of cities. In the future, it is possible to calculate the human capital gap in a specific country and provide suggestions for the education and introduction of talents in a country or region. Because ecological footprint contains six sub-categories, there are structural differences in different regions. Future studies can therefore analyze this topic in greater depth in order to realize the reasons for the increase in ecological footprint and to propose more targeted countermeasures.

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Note

a. Urban population refers to people living in urban areas as defined by national statistical offices. The data are collected and smoothed by the United Nations Population Division.

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Appendix

Table A1. List of countries.

Algeria	Costa Rica	Iran	Myanmar	Slovenia
Angola	Cyprus	Iraq	Namibia	South Africa
Argentina	Czech Republic	Israel	Nepal	Spain
Armenia	Denmark	Italy	Netherlands	Sri Lanka
Australia	Dominican Republic	Jamaica	New Zealand	Switzerland
Austria	Egypt	Japan	Nicaragua	Syrian Arab Republic
Bangladesh	Estonia	Jordan	Nigeria	Taiwan
Belgium	Ethiopia	Kazakhstan	Norway	Tajikistan
Belize	Fiji	Kenya	Pakistan	Thailand
Benin	Finland	Kyrgyzstan	Panama	Trinidad and Tobago
Bolivia	France	Lao People's DR	Paraguay	Tunisia
Brazil	Gabon	Latvia	Peru	Turkey
Brunei Darussalam	Gambia	Lesotho	Philippines	Uganda
Bulgaria	Ghana	Liberia	Poland	United Arab Emirates
Burkina Faso	Greece	Malawi	Portugal	United Kingdom
Burundi	Guatemala	Malaysia	Republic of Moldova	United States
Cambodia	Haiti	Maldives	Romania	Uruguay
Canada	Honduras	Mauritania	Russian Federation	Venezuela
Chile	Hungary	Mauritius	Rwanda	Viet Nam
China	Iceland	Mexico	Saudi Arabia	Yemen
Colombia	India	Mongolia	Sierra Leone	Zambia
Congo	Indonesia	Mozambique	Slovak Republic	Zimbabwe