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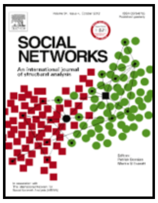

Flattening the curve? The structure of the natural resource exchange network and CO_2 emissions

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ABSTRACT

In this article, we advance literature on the political economy of climate change. First, we build upon ecologically unequal exchange perspectives to argue that the structure of the international natural resource exchange network moderates the impact of economic development on CO_2 emissions by inculcating resource dependency among less central countries. Thus, less central countries experience higher environmental costs to development than more central countries. Second, we conduct a network analysis of international trade in natural resources. This allows us to both describe the exchange relations that exist in this network and identify the unique structural locations that countries occupy within it. Our network analysis is unique in that it isolates the exchange of natural resources from an all-encompassing "world-system." Third, we assess the degree to which development has more deleterious effects on the environment among less central countries in this network using three operationalizations of CO_2 emissions and allowing for both linear and non-linear associations between development and CO_2 emissions. Fourth, we assess the degree to which resource dependency operates as a causal mechanism linking resource structure to higher environmental costs of development. The results of panel regression models suggest that the environmental costs to development are higher in less central countries across all three outcomes and specifications of the development-CO_2 association, and that resource dependency plays a significant but partial role in this process. We conclude by implicating these findings in ongoing debates about the political economy of climate change and suggesting avenues for future research.

Introduction

How does economic development impact the environment? An important perspective in the social sciences, Ecological Modernization Theory (EMT) and the related environmental Kuznets curve (EKC) hypothesis suggest that development first increases and then decreases environmental degradation. While the transition from an agrarian to an industrial society has real environmental costs, the subsequent transition to a post-industrial society brings with it more environmentally efficient technology and a more environmentally aware populace, polity and society. The less optimistic Treadmill of Production (ToP) theories suggest these purported increases in environmental efficiency with development are offset by increases in consumption and production. A third ecologically unequal exchange (EUE) perspective focuses upon the structure of the production and exchange of natural resources. This structure allows central countries to simultaneously extract raw materials from and export environmental degradation to countries in the periphery, and thereby conditions the developmental trajectory of peripheral countries.

While these literatures often play the role of adversary in much social-scientific research on climate change, there is room for integration (Fisher and Jorgenson, 2019), and each perspective provides ample empirical support. For example, EMT scholars point to a multitude of data points to illustrate the modernization process: there really is a worldwide trend toward more environmentalism in the world-polity and world-society, and technologies have become more environmentally efficient (York and Rosa, 2003). A related empirical literature examines the degree to which economic development has a concave association with greenhouse gas emissions and other environmental outcomes (e.g. Rosa and Dietz, 2012). Contrarily, ToP scholars show that the partial correlation between economic development is increasing over time rather than decreasing (Jorgenson and Clark, 2011, 2012), and that the

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association between economic development and the ecological footprint is convex rather than concave (Jorgenson and Clark, 2009, 2011). A number of EUE theorists highlight positive associations between the degree to which less developed countries export raw materials to more developed countries and various forms of environmental degradation (e.g. Shandra et al., 2008, 2009; Jorgenson et al., 2009).

We contribute to this literature in four distinct ways. First, in concert with the EUE literature, we argue the structure of the natural resource exchange networks inculcates sites of dependent extraction among less central[1] countries, which increases their environmental costs of development through both first and second-order effects. First-order effects emanate from the relatively large share of economic activity in extractive sectors. Second-order effects extend beyond extractive sectors to the entire economy and polity. Second, we conduct a network analysis of the international natural resource exchange network from 1970 to 2015. Our role/position analysis allows us to characterize the structure of the natural resource exchange network and identify structurally equivalent positions within these networks. It also allows us to compare the environmental costs of development across network positions. Third, we empirically examine the hypothesis that the environmental costs to development are higher in less central countries across three operationalizations of CO_2 emissions and allow for both linear and non-linear effects of development. Finally, we consider the degree to which dependency on natural resources mediates variation in the costs to development that we observe.

Our findings suggest that the international natural resource exchange networks are well characterized by a core/periphery interaction pattern. Less central positions have more dependent natural resource export ties and are more economically dependent on natural resource exports than central countries. Using panel regression models of three operationalizations of CO_2 emissions, we find that the environmental costs of economic development are significantly and substantively higher in less central countries. Finally, we also find that natural resource dependence explains between sixteen and thirty percent of these higher costs. We conclude by implicating these results into the bigger questions about economic development and climate change.

Economic development and CO_2 emissions

To the casual observer, rising economic output should naturally lead to rising CO_2 emissions given the current dependency of the world's economy on fossil fuels. Nevertheless, there remains a debate over (1) whether or not this is and will always be the case and (2) the mechanisms linking output to CO_2 emissions. Three distinct literatures exist: Ecological Modernization Theory (EMT) and the related environmental Kuznets curve (EKC) hypothesis, the treadmill of production (ToP), and ecologically unequal exchange (EUE). In what follows, we review these literatures in order to develop our own argument that the association between economic development and CO_2 emissions depends on a country's location in the global natural resource exchange network.

EMT and the related EKC literatures suggest that countries follow a natural path from low polluting to high polluting and back to low polluting as they develop (Spaargaren and Mol, 1992; Pellow and Nyseth Brehm, 2013). Nations at early stages of development have a small environmental impact. This impact increases as nations industrialize, but ultimately subsides as nations reach high industrialization. This curvilinear association between development and CO_2 emissions is premised upon two key mechanisms. First, economic development leads to more environmentally sustainable technologies (Jorgenson, 2016). Second, development leads to a more affluent consumer populace, which will demand sustainable goods. Thus, economic development becomes the solution to its own environmental problems insofar as the technologies it eventually produces mitigate its deleterious impact on the environment. That is, there is no necessary trade-off between continued economic expansion and environmental decline. Through deregulated, "free" market forces, capitalist production will innovate in an "eco-friendly" direction.

In contrast to the sanguine view of EMT, proponents of the ToP hypothesize a very different dynamic relationship between development and CO_2 emissions (Gould et al., 2004; Jorgenson, 2016). The perspective contends that innovation and market-based reforms to the ecological crisis create a paradox (Schnaiberg, 1980; Gould et al., 2004). While development does indeed lead to technological innovations beneficial to the environment, those very innovations only result in more production and consumption. Thus, development does not reduce the scale of CO_2 emissions. As a result of the growth imperative inherent in capitalist national development, then, this theory predicts a linear relationship between development and ecological outcomes rather than the curvilinear relationship predicted by EMT and EKC. That is, modernization through technological advancements actually poses a paradoxically higher threat to the environment.

A third EUE perspective suggests that cross-national differences in environmental degradation are at least in part a function of the structure of the organization of the world economy, which degrades any long-term beneficial effects of economic development. In particular, the perspective suggests there is a simultaneous "withdrawal of energy and other natural resource assets from [less developed countries] and the externalization of environmentally damaging production and disposal activities" to these countries (Jorgenson, 2016: 6). In effect, there is a "vertical flow" of exports from low-income to high-income countries, where the increasing level of carbon emissions in low-income countries are related to goods produced and then subsequently exported to high-income countries (Jorgenson, 2012, 2011), with this relationship remaining stable over time in non-recession periods and diminishing during recessions (Huang, 2018). Thus, differential ecological outcomes are found to depend on social relationships of structurally unequal exchange between nations, which in turn are fueled by economic development, debts, natural resource availability, et cetera (Rice, 2007). Here, CO_2 emissions are largely driven by the organization of the world economy, as position within the structure of the world economy, not volume of activity per se, predicts environmental outcomes. Integration into the world economy is shown to be worse for less developed countries in terms of CO_2 emissions (Thombs, 2018) and more beneficial for high-income countries in terms of the relationship between carbon emissions and well-being (Givens, 2018). As one influential author notes,

> "The stratified global social system shapes development and underdevelopment, which in turn contributes to various environmental and ecological problems at local, regional and global levels. These two global systems, the human and the natural, are deeply interconnected, and the premise of these interconnections is at the heart of coupled human and natural systems scholarship" (Jorgenson, 2016: 2).

In particular, the central premise of this research is that centralized "core" countries "export" some of their environmental burden to peripheral and semi-peripheral countries (Jorgenson, 2003, 2006, 2016).

The empirical track record of these perspectives is long but somewhat mixed. For example, there is evidence that many countries have become more environmentally conscientious over time, as evinced by the proliferation of environmental treaties and other outcomes and the moderating role of INGOs on the development—environment relationship (e.g. Frank et al., 2000; Longhofer and Jorgenson, 2017). Additionally, there are other case studies showing that particular firms or particular industries or particular countries engage in serious sounding envi-

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[1] The literature in social network analysis evokes many definitions of centrality (Bonacich, 1972; Freeman, 1978). We use the terms "central" and "less-central" throughout heuristically, but our concept corresponds closely to the concept of coreness. Central countries import/export with many other countries and with other central countries. Least central countries in the "periphery" of the network tend to trade only with a small subset of central countries. Middling countries in between these two extremes may have varying types of trade profiles that are neither purely "core like" nor purely "periphery like."

ronmental change. Nevertheless, there is little systematic evidence to support the idea that modernization leads to reductions in CO_2 emissions (York and Rosa, 2003). More developed countries emit much higher rates of CO_2 than less developed countries, for example. Moreover, countries with more environmental treaties and high rankings on other measures of environmentalism are also among the biggest polluters in the world (York et al., 2003). The EKC hypothesis produces mixed results (Rosa and Dietz, 2012). A number of ToP articles show that (1) development (GDP per capita) has a positive effect on CO_2 emissions and (2) these associations tend to increase over time (Jorgenson and Clark, 2011, 2012). Similarly, scholars in the ecologically unequal exchange tradition show that high levels of economic dependency and greater levels of debt increase deforestation (Shandra et al., 2008), and that exports of raw materials to developed countries increase a number of negative environmental outcomes including deforestation (Jorgenson et al., 2009), the number of threatened animal species (Shandra et al., 2009), and so on.

There are a number of questions raised by this body of work. For example, recent research on the ToP perspectives examines temporal dynamics in the association between linear specifications of development and CO_2 emissions, but does not consider non-linear associations (c.f. Jorgenson and Clark, 2009, 2012 for ecological footprints). If there is indeed a curvilinear association between development and CO_2 emissions, then specifying the relationship with an interaction between a linear term and time may overstate or understate the degree of decoupling (Jorgenson and Clark, 2011, 2012). Moreover, these findings vary with the operationalizations of CO_2. Sometimes the impact of development on CO_2 emissions is the same for developed and less developed countries and sometimes they are weaker in less developed countries (Jorgenson and Clark, 2011, 2012). Conversely, research on EUE contends explicitly that the theory requires both the extraction of resources from the periphery AND the exportation of environmental harm to the periphery. However, most analyses focus on the environmental impact of export measures on less developed countries and thus do not consider the implications of the structure of economic organization on both types of countries simultaneously (c.f. Prell and Feng, 2016).

Our approach

Our analytical approach advances the literature in two distinct ways. First, we argue that less central countries within the international natural resource exchange network experience higher environmental costs to development than more central countries (c.f. Van Rossem, 1996) and devote our attention to how network position conditions the link between development and environmental outcomes. Less central countries in the network become sites of dependent extraction, which leads to more environmentally costly developmental trajectories through first and second-order effects. First-order effects are certainly implied in the literature (e.g. Shandra et al., 2008, 2009; Jorgenson et al., 2009). The comparative historical literature suggests these sites are subject to volatile global commodity markets, which perpetuates their economic dependency on extractive activities. Because such activities are more carbon intensive than consumption and the service economy, increases in economic development are more carbon intensive on average (Bunker, 1984; Bunker and Ciccantell, 2005). Second-order effects extend beyond the extractive sector. Here, economic dependence on environmental extraction should stall many of the micro and meso-level mechanisms proposed by EMT. Workers in extractive industries will care less about environmental preservation out of fear of short-term economic loses. Governments who depend on natural resource rents for revenue will have less incentives to pass or enforce environmentally friendly legislation (Tester, 2020). Put differently, natural resource extraction increases environmental costs through higher pollution in large extractive sectors (first-order effects) and by stifling the demand for and supply of environmental protection (second-order effects). These second-order effects lead to higher pollution outside of extractive industries. Thus, less central countries should experience higher environmental costs to economic development. We summarize our argument with the following hypotheses:

H1. Development has more harmful environmental impacts in less central countries.

H2. Any beneficial curvilinear effects of development are weaker in less central countries.

Second, and following recent calls in the ecologically unequal exchange tradition to focus more explicitly on trade in natural resources, we measure systematically the structural location of nation-states within the international network of *natural resource* exchange. This allows us to both measure the relevant economic network with greater specificity than studies focusing on total trade or an all-encompassing "world-system" (e.g. Snyder and Kick, 1979; Smith and White, 1992; Mahutga, 2006; Nordlund, 2010; Mahutga and Smith, 2011; Prell and Feng, 2016) and examine the impact of development on differentially positioned countries simultaneously. The approach in this paper also differs from this previous research in the unequal exchange tradition because we begin with structural properties of the overall structure of the extractive exchange network rather than considering exports per se. In particular, we use role and position analysis to group nations into clusters based on structural equivalence of export ties in the global natural resource exchange network, applying a network methodology to revisit the concept of how social relations determine the environmental outcomes associated with extraction and production. By clustering nations into groupings based on their structural position in the global trade of natural resources more broadly, we empirically reconstruct these social relations, and show how environmental harms are differentially distributed in accordance with the social structures embedded within these networks.

Network analysis

Network data

The data informing this analysis come from the United Nations Commodity Trade Statistics (Comtrade) Database (2018). This was done for the years 1970 through 2015, at 5-year increments. The definition of natural resources used here is an adaptation from the World Trade Organization's preferred classification of natural resources, narrowly defined (2010). In this analysis, the definition of natural resources includes commodities from two broad categories of primary products from the first revision of the Standard International Trade Characterization: forestry, and fuels, and mining products. The full list of these commodities considered to be natural resources is included in Table 1. The countries included in these networks are reported in Table 2 below.

Network methods

For each year of the analysis, data on bilateral imports as well as exports were reported for the 138 nations in this sample. For each exporting nation *i* that trades with importing nation *j*, the volume of trade for

Table 1
SITC Revision 1 Natural Resource Commodities.

SITC1	Commodity
24	Wood, lumber and cork
25	Pulp and paper
27	Crude fertilizers and crude minerals
28	Metalliferous ores and metal scrap
3	Mineral fuels, lubricants and related materials
68	Non ferrous metals

Table 2
Country by Cluster Memberships in Each Year.

	1970	1995	2015
Belgium	3	3	3
Canada	3	3	3
France	3	3	3
Germany	3	3	3
Italy	3	3	3
Japan	3	3	3
Netherlands	3	3	3
Spain	3	3	3
Sweden	3	3	3
United Kingdom	3	3	3
United States	3	3	3
Australia	2	3	3
Austria	2	3	3
Brazil	2	3	3
China	2	3	3
Greece	2	3	3
Hong Kong SAR, Chi	2	3	3
India	2	3	3
Indonesia	2	3	3
Korea, Rep.	2	3	3
Malaysia	2	3	3
Saudi Arabia	2	3	3
Singapore	2	3	3
Switzerland	2	3	3
Turkey	2	3	3
Norway	2	3	2
Portugal	2	3	2
Egypt, Arab Rep.	2	2	3
Mexico	2	2	3
Poland	2	2	3
Thailand	2	2	3
Algeria	2	2	2
Argentina	2	2	2
Bulgaria	2	2	2
Chile	2	2	2
Cote d'Ivoire	2	2	2
Cyprus	2	2	2
Denmark	2	2	2
Finland	2	2	2
Ghana	2	2	2
Hungary	2	2	2
Iran, Islamic Rep.	2	2	2
Ireland	2	2	2
Israel	2	2	2
Kuwait	2	2	2
Lebanon	2	2	2
Morocco	2	2	2
Nigeria	2	2	2
Pakistan	2	2	2
Peru	2	2	2
Philippines	2	2	2
Romania	2	2	2
Tunisia	2	2	2
Venezuela, RB	2	2	2
Myanmar	2	1	2
Zambia	2	1	2
Congo, Dem. Rep.	2	1	1
Iraq	2	1	1
Liberia	2	1	1
Libya	2	1	1
United Arab Emirates	1	2	3
Bahrain	1	2	2
Cameroon	1	2	2
Colombia	1	2	2
Ecuador	1	2	2
Jordan	1	2	2
New Zealand	1	2	2
Oman	1	2	2
Qatar	1	2	2
Kenya	1	2	1
Syrian Arab Republic	1	2	1
Zimbabwe	1	2	1
Angola	1	1	2
Costa Rica	1	1	2
Dominican Republic	1	1	2
Iceland	1	1	2
Malta	1	1	2
Mozambique	1	1	2
Panama	1	1	2
Paraguay	1	1	2
Senegal	1	1	2
Sri Lanka	1	1	2
Tanzania	1	1	2
Uruguay	1	1	2
Afghanistan	1	1	1
Albania	1	1	1
Andorra	1	1	1
Bahamas, The	1	1	1
Barbados	1	1	1
Belize	1	1	1
Benin	1	1	1
Bermuda	1	1	1
Bolivia	1	1	1
Brunei Darussalam	1	1	1
Burundi	1	1	1
Central African Republic	1	1	1
Chad	1	1	1
Congo, Rep.	1	1	1
Cuba	1	1	1
Djibouti	1	1	1
Dominica	1	1	1
El Salvador	1	1	1
Equatorial Guinea	1	1	1
Ethiopia	1	1	1
Faroe Islands	1	1	1
Fiji	1	1	1
Gabon	1	1	1
Gambia, The	1	1	1
Gibraltar	1	1	1
Guatemala	1	1	1
Guinea	1	1	1
Guinea-Bissau	1	1	1
Guya	1	1	1
Haiti	1	1	1
Honduras	1	1	1
Jamaica	1	1	1
Lao PDR	1	1	1
Macao SAR, Chi	1	1	1
Madagascar	1	1	1
Malawi	1	1	1
Maldives	1	1	1
Mali	1	1	1
Mauritania	1	1	1
Mauritius	1	1	1
Nepal	1	1	1
Nicaragua	1	1	1
Niger	1	1	1
Papua New Guinea	1	1	1
Rwanda	1	1	1
Samoa	1	1	1
Sierra Leone	1	1	1
Solomon Islands	1	1	1
Somalia	1	1	1
St. Kitts and Nevis	1	1	1
Suriname	1	1	1
Togo	1	1	1
Uganda	1	1	1
Vanuatu	1	1	1

Notes: 3 = “Center”, 2 = “Middle”, 1 = “Least Central”.

each commodity reported by both *i* and *j* is reported in U.S. dollars (USD). Discrepancies may exist between reported exports and imports for a variety of reasons, though imports are thought to be a more reliable accounting of trade because governments use them to collect import taxes (Mahutga, 2013). For the purposes of this analysis, trade matrices were constructed using the maximum of the two values. The values were then dichotomized to 1 or 0 to indicate the presence or absence of a trade tie. A cutoff point of 100,000 USD was established as the minimum value for a tie to be established.

Following a rich tradition in the sociological literature on trade, we conduct a role and position analysis of this natural resource exchange network. Classical role and position analysis involve (1) measuring the degree to which each pair of nodes in a socio-matrix have equivalent relationships with the rest of the network using some equivalence criterion, (2) assigning nodes to relatively equivalent groups and (3) identifying the interaction patterns within and between relatively equivalent groups. Two common equivalence criteria are structural and regular equivalence, both of which have been implemented in analyses of international trade (see Smith and White, 1992; Snyder and Kick, 1979). Structural equivalence requires that nodes *i* and *j* interact in the same way with *identical* others, while regular equivalence requires that nodes *i* and *j* interact in the same way with *equivalent* others.

Some have argued that regular equivalence may be preferable to structural equivalence. For example, if the US and the UK both export manufactured goods and import raw materials from isolated others, but the US's partners are in Latin America while the UK's are in Africa, then perhaps the US/UK and Latin America/Africa occupy equivalent positions even though their geography differs. However, natural resources are not like manufactured goods insofar as that natural resource endowments are decidedly fixed in space; trading partners will have greater difficulty in substituting sources of supply. Thus, our implementation of structural equivalence is in keeping with the constraints of the spatial distribution of natural resources to the structure of the international natural resource exchange network.[2]

In our first step, we analyzed each year of the dichotomized matrix with a structural equivalence algorithm (see Snyder and Kick, 1979; Smith and White, 1992; Van Rossem, 1996; Mahutga, 2006; Mahutga and Smith, 2011). To calculate structural equivalence, we created a matrix of distances between nations *i* and *j* using the hamming distance. Hamming distance is calculated by summing the differences between the connections between nation *k* and nation *i,* and nation *k* and nation *j* as follows.

$$d_{ij} = \sum_{k=1}^{g}\left(\left|x_{ij} - x_{jk}\right| + \left|x_{ki} - x_{kj}\right|\right)$$

The hamming distance d_{ij} will equal 0 if nations *i* and *j* are perfectly structurally equivalent.

Our second step combines classical multidimensional scaling (MDS), otherwise known as principal coordinate analysis (Cox and Cox, 2000; Gower, 1966), with a *k*-means cluster algorithm to partition the structural equivalence network. MDS assigns coordinates in Euclidean space to each nation in the network so that the distances between the points are equal to the measures of dissimilarity. Nations that are more structurally equivalent will be closer together in this multidimensional space, and nations that are less structurally equivalent will be farther apart. We then clustered nations into three clusters using a *k*-means clustering algorithm. *K*-means clustering assigns nations into clusters such that the variance within each cluster is minimized. We opted for three clusters because scree plots show that a greater number of clusters produces a trivial increase in the explained variance of the principal coordinates (see Appendix 2). Our third step is described in the results section below.

Regression analysis

Dependent variables

Following the seminal work of Jorgenson and Clark (2012), we measure CO_2 emissions in three ways: total emissions, emissions per unit of GDP, and emissions per capita. As an indicator of the overall scale of emission, total emissions "has the most significance for sustainability issues in general and climate change in particular" (Jorgenson and Clark, 2012: 14). CO_2 emissions per GDP capture the "environmental efficiency" of national economies, which is important in scientific and policy settings. Finally, per capita emissions are most relevant to inequality insofar as they net out the scale effects of population size. Despite these substantive differences, we hypothesize that less central countries will experience greater environmental costs to development across all three measures. Thus, rejecting the relevant null hypotheses on all three outcomes is stronger evidence for our theory than rejecting the null for any one of them. These data come from the World Bank (2020), and were measured at five-year intervals from 1970 to 2015.

Independent variables

Our key independent variables are the network positions we identify in the network analysis described above. We employ two indicator variables representing groups of countries in the "least central" and "middling" network positions., Because our theoretical interests require a comparison of less-central to central countries, the most central countries are the reference category.

Control variables

In the models below, we include a parsimonious and theoretically relevant baseline model of CO_2 emissions. *Population Density* is the number of citizens per square kilometer of land area. Population density captures the "urbanness" of countries, as urban places produce as much as 70 % of CO_2 emissions worldwide (Johansson et al., 2012). These data come from the World Bank (2020). Some suggest that total population is a necessary control for total emissions (e.g. Jorgenson and Clark, 2012), and we consider that issue by way of a robustness check below. *Trade Openness* is the sum of imports and exports over GDP. It captures the share of the national economy that is traded. More open economies emit more CO_2. These data come from the World Bank (2020). *Natural Resource Exports* captures the total natural resource exports (in U.S. dollars). We control for natural resource exports to differentiate between a country's production and export of natural resources from its position in natural resource exchange networks. These data come from UN COMTRADE (2018). Finally, countries with high *infant mortality* typically lack the industrial infrastructure to emit high levels of CO_2. These data come from the World Bank (2020). These were measured at five-year intervals from 1970 to 2010.

Fixed-effects regression and interaction terms

In the regression models reported below, we report coefficients from a fixed-effects regression. These regressions eliminate all unobserved, time-invariant country-specific heterogeneity. Because some of the countries included in our network analysis are missing data on one or more of the dependent/independent variables in a given year, our panels are unbalanced. In total, we examine 997 country-years. The sample appears in Appendix Table A1.

For each operationalization of CO_2 emissions, we estimate three specifications detailed below in models 1–3.

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[2] There is also some skepticism about whether or not equivalencies are ever regular in any case (Boyd and Jonas, 2001).

$$y_{it} = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ \beta_4 x_1 x_2 + \ \beta_5 x_1 x_3 + \theta_{it} + z_i + \varepsilon_{it} \quad (1)$$

$$y_{it} = \beta_1 x_1 + \beta_6 {x_1}^2 + \ \theta_{it} + z_i + \varepsilon_{it}\text{h} \quad (2)$$

$$y_{it} = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ \beta_4 x_1 x_2 + \ \beta_5 x_1 x_3 + \beta_6 {x_1}^2 + \ \beta_7 x_2 {x_1}^2 + \ \beta_8 x_3 {x_1}^2 + \theta_{it} + z_i + \varepsilon_{it} \quad (3)$$

In Eqs. (1)–(3), y is one of three operationalizations of CO_2 emissions (total, per GDP and per capita), *i* indexes countries and *t* indexes years. All of the *x* covariates vary within and between cases, but we omit the subscripts for simplicity. x_1 is GDP per capita. x_2 is an indicator variable for middling countries, and x_3 is an indicator variable for the least central countries. θ is an *n* x *k* matrix of control variables. *z* is the fixed country intercepts and ε is the error term that is robust to heteroscedasticity and serial (AR1) correlation. Given our hypotheses above, the key null hypotheses we test are with respect to β_4-β_8. β_4 and β_5 test the null hypothesis that GDP per capita has the same effect on CO_2 emissions in the least central and middling countries as it does in the most central countries. β_6 tests the null hypothesis that the impact of development on CO_2 emissions attenuates at higher levels of development. Thus, β_7 and β_8 test the null hypothesis that any curvilinear effects of GDP per capita (β_6) in the most central countries are equal to those in less central countries.

Results

The structure of the natural resource exchange network

The results for three years of our role/position analysis are displayed graphically in Fig. 1. These are MDS results of the structural equivalence matrices in 1970, 1995 and 2015. The three-group solution in Fig. 1 is supported by the scree plot in Appendix 2, which shows that improvements in the explained variance of the MDS coordinates with our *k*-means clustering algorithm levels off after three clusters. Table 2 reports the country memberships of the three clusters depicted in Fig. 1. We omit intervening years for ease of presentation. To avoid confusing our clusters with the world-system construct, we label countries "center," "middle," and "least central." Provisionally, we interpret the horizontal dimension of these figures as a "coreness" dimension analogous to that observed in many similar analyses of different types of trade (e.g. Lloyd et al., 2009; Mahutga and Smith, 2011). Countries on the left-hand side of the graphs are least central. Casually, many of the countries in the central cluster are included among "core" countries in network analyses of the all-encompassing world-system. Conversely, many of the countries in the least central cluster are recognizably "peripheral" countries in these analyses. That said, some of the country placements depart from these constructs in significant ways. For example, the United Arab Emirates transitions from the least to most central cluster over the period, while Saudi Arabia transitions from the middling to central cluster. Given that we are measuring *natural resource exchange networks* rather than all-encompassing measures of trade, the "upward" mobility of the UAE and Saudi Arabia are rather intuitive, as are the more central locations of China, Brazil and Mexico vis-à-vis their placement in other network analyses.

To further buttress our interpretation, Table 3 reports density matrices (block models) for each of these years. Cells report a "1" if the block density is greater than the overall density of the network, and a "0" otherwise. These conform to the classic core/periphery structures, where the center block trades with all blocks, the middle block trades with itself and the center, and the least central countries trade only with the center (see Boyd et al., 2010). By 2015, the least central countries are fairly isolated.

Fig. 2 adds additional weight to our interpretation. The left-hand pane shows the average number of export ties per block. The right-hand pane reports the average proportion of export ties that are "dependent," defined as 10 or more percent of the focal exporter's total natural resource exports (Mahutga, 2014). In concert with the results in Table 3, we find that center countries have more export ties and fewer dependent export ties, on average, than both of the less central blocks. Finally, Fig. 2 also shows that natural resource dependency (natural resource rents over GDP) is lower among center nations. In short, the proportion of dependent export ties and natural resource dependency decrease with centrality while the number of export partners increases with centrality.

By way of summary, our network analysis yields several important findings consistent with our intervention. First, the structure of the natural resource exchange network is well-represented by a core/periphery interaction pattern (Fig. 1; Table 3). Second, less central countries are dependent extraction sites. Relative to the center, the middling and least central countries have fewer export ties, a greater proportion of dependent export ties and higher natural resource dependency (Fig. 2). Now that we've identified the structural position of these countries, we proceed to the fixed effects regression analysis of CO_2 emissions.

Network structure and the environmental costs of development

Table 4 reports the results of our fixed-effects regression models. Columns 1, 4 and 7 are estimates based on specification (1) above. Columns 2, 5 and 8 are estimates based on specification (2). Columns 3, 6 and 9 are estimates based on specification (3). The first three columns are total CO_2 emissions. The next three are CO_2 per GDP. The last three are CO_2 per capita. Consistent with our argument that network position moderates the impact of development on CO_2 emissions, we find that GDP per capita has a more deleterious impact on CO_2 emissions in middling and least central countries than the most central countries. In columns 1 (total) and 7 (per capita), the positive effect of development on CO_2 emissions is larger in less central countries. In column 4, the ef-

Fig. 1. K-Means Cluster Analysis of MDS 1970, 1995, 2015.

Table 3
Density Matrices 1970, 1995, and 2015.

1970			
	Center	Middle	Least Central
Center	1	1	1
Middle	1	1	0
Least Central	1	0	0
1995			
	Center	Middle	Least Central
Center	1	1	1
Middle	1	1	0
Least Central	1	0	0
2015			
	Center	Middle	Least Central
Center	1	1	0
Middle	1	0	0
Least Central	0	0	0

Notes: “1” indicates cell density was greater than network average. “0″ indicates otherwise.

ficiency increasing negative effect of development on CO_2 is weaker in less central countries.

Fig. 3 reports the marginal effects of GDP per capita for each network position. The left- and right-hand graphics display the coefficients for total (left) and per capita (right) CO_2 emissions. Here, the effect of GDP per capita is roughly 75 percent larger among the least central countries than the most central. It is roughly 45 percent larger among middling countries than the most central countries. The middle graphic displays the coefficients for per GDP emissions. The negative efficiency increasing effect of GDP per capita is approximately 46 percent smaller among the least central countries than the most central, and approximately 21 percent smaller among middling countries.

Columns 2, 5 and 8 report the quadratic effect of GDP per capita. Consistent with EMT and the EKC hypothesis, there is a curvilinear association between economic development and CO_2 emissions. In each operationalization of CO_2 emissions, GDP per capita appears to increase CO_2 at low levels of development, and then decrease it at higher levels. Fig. 4 reports the predicted levels of carbon emissions across the observed range of GDP per capita given the results of the quadratic equation in columns 2, 5 and 8. In each case, the predicted carbon emissions are positive across the full range of GDP per capita. This is not a new finding, but reinforces skepticism about EKC as it relates to climate change, particularly given insights from the treadmill of production perspective (Jorgenson and Clark, 2012). For development to have a net negative effect on carbon emissions, the environmental efficiency of development has to out-pace development (York and Rosa, 2003).

Does the structure of the natural resource exchange network moderate these curvilinear effects? To answer this question, columns 3, 6 and 9 report three-way interactions between GDP per capita, itself and each of the indicator variables for less central countries. The focal hypothesis tests are reported in rows five and six. For all three operationalizations of CO_2 emissions, we find that the attenuating effect of higher levels of development abates in less central countries. That is, the squared term on GDP per capita is significantly larger in middling and the least central countries *vis-à-vis* the most central countries. To better understand the substantive implications of these hypothesis tests, Fig. 5 graphs the best fitting quadratic term from models 3, 6 and 9 separately for each network position. In each case, we find that there is no curvilinear association between GDP per capita and CO_2 emissions in the least central countries, as the association is linear. Conversely, we do observe the curvilinear association among middling countries, but the attenuating effect of higher levels of GDP per capita is much smaller than in the center.[3] That is, the structure of the natural resource exchange network flattens the curvilinear association between development and CO_2 emissions in less central countries.

Robustness checks

The results thus far support both of our hypotheses: development is more environmentally costly in less central countries. This result holds across all three operationalizations of CO_2 emissions, and whether we specify the association in a linear or quadratic form. To assess the robustness of these results, we conducted four additional analyses. First, our control for infant mortality is somewhat novel vis-à-vis the literature. We control for it because countries with high infant mortality occupy the lowest developmental stratum and thus lack the industrial infrastructure to emit high levels of CO_2. But one could counter that this is therefore a post-treatment control that weakens the association between development and CO_2 emissions. Thus, we replicate our analyses after omitting infant mortality. The results are substantively identical. We observe *larger* partial associations between GDP per capita and CO_2 emissions in all clusters after omitting infant mortality suggesting that it is, indeed, a confounder (see Table C1, columns 1–6). Extending this logic, we omit all control variables and observe substantively identical results (columns 7–12) except that the interaction between middling countries and squared GDP pc is only marginally significant for total Co2 emissions (column 8). Many suggest that omitting population size in a model of total CO_2 emissions is a specification error because emissions scale linearly with size (Jorgenson and Clark, 2012). Thus, we replace population density with population size in Table C2. The results are substantively and numerically identical to two decimal places (also see Fig. C1). It is common in this literature to estimate two-way fixed effects regression models that net out country invariant time-specific shocks. Thus, Table C3 reports results of two-way fixed effects models. These results are also substantively identical. Finally, we consider the strength of ties in our trade data by measuring the structural equivalence of countries with the (logged) valued trade matrices rather than the dichotomous ones above. We replicated our analyses and report them in Table C4. The results are substantively identical.

Mechanisms

Having demonstrated our key finding that network structure increases the environmental cost of development for less central countries, we now turn to analyzing a key mechanism underpinning our argument. We argue that the structure of the network of international exchanges in natural resources produces sites of dependent extraction in less central countries. This dependency has first and second-order effects. In the first order, dependency increases environmental costs through higher pollution in extractive industries. In the second order, dependency stifles the demand for and supply of environmental protection throughout the entire economy. These second-order effects lead to higher pollution outside of extractive industries.

We use mediation analysis, and “mediated moderation” in particular, to identify the extent to which resource dependency is a mechanism of the observed interaction between network structure and economic development. Fig. 6 displays our mediated moderation analysis in conceptual terms. The path from network structure to the relationship between GDP per capita and CO_2 is what we modeled above. The mediated moderation is depicted in paths a (from network structure to dependency) and b (from dependency to the relationship between GDP

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[3] The 95% confidence interval on the conditional squared term (the base squared term plus the interaction between the least central cluster and the squared term) always contains zero. The conditional squared term for middling countries is about 58 percent smaller than that for the center.

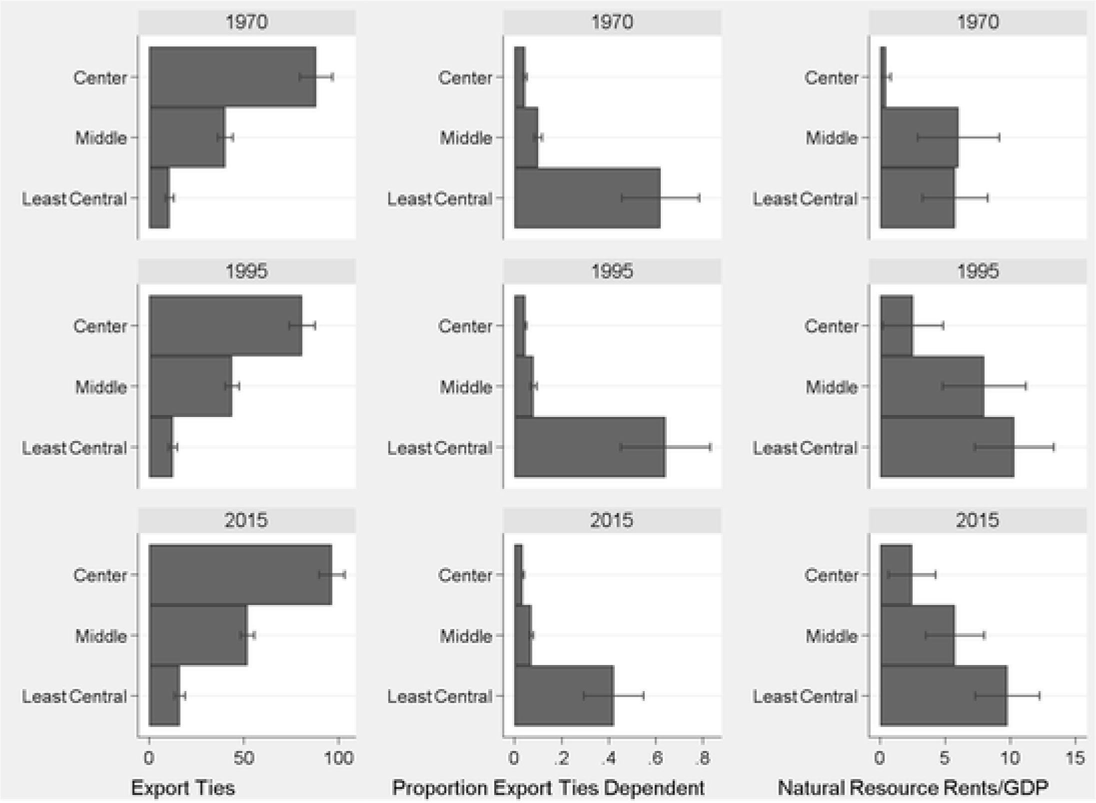

Fig. 2. Export Ties, Proportion Ties Dependent and Export Dependency by Position.
Notes: Export Ties is out degree after our dichotomization strategy. Proportion Export Ties Dependent is the proportion of export ties that are 10 % or more of the focal countries export volume. Middle and Least Central group means are significantly different from center at .05 or lower.

Table 4
Fixed Effects Regression Models of CO_2.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Total CO_2			CO_2 Per GDP			CO_2 Per Capita		
GDP per capita	0.437***	2.123***	3.355***	−0.569***	1.126***	2.399***	0.435***	2.127***	3.373***
	(0.051)	(0.221)	(0.376)	(0.051)	(0.220)	(0.379)	(0.051)	(0.220)	(0.377)
Least Central*GDP per capita	0.285***		−1.650***	0.290***		−1.724***	0.287***		−1.673***
	(0.051)		(0.477)	(0.052)		(0.479)	(0.052)		(0.478)
Middle*GDP per capita	0.120***		−1.580***	0.125***		−1.608***	0.121***		−1.592***
	(0.024)		(0.319)	(0.025)		(0.321)	(0.025)		(0.320)
GDP per capita squared		−0.207***	−0.369***		−0.208***	−0.375***		−0.208***	−0.372***
		(0.029)	(0.046)		(0.029)	(0.046)		(0.029)	(0.046)
Least Central*GDP per capita squared			0.230***			0.240***			0.233***
			(0.065)			(0.065)			(0.065)
Middle*GDP per capita squared			0.206***			0.209***			0.207***
			(0.039)			(0.040)			(0.040)
Least Central	−1.094***	−0.019	2.898**	−1.114***	−0.021	3.027***	−1.101***	−0.019	2.940**
	(0.183)	(0.025)	(0.893)	(0.185)	(0.025)	(0.896)	(0.184)	(0.025)	(0.895)
Middle	−0.496***	0.014	2.974***	−0.515***	0.013	3.024***	−0.500***	0.014	2.998***
	(0.101)	(0.014)	(0.642)	(0.102)	(0.014)	(0.647)	(0.101)	(0.014)	(0.645)
Population Density	0.862***	0.874***	0.884***	−0.138*	−0.126*	−0.118	−0.141*	−0.129*	−0.120
	(0.063)	(0.064)	(0.063)	(0.063)	(0.064)	(0.063)	(0.063)	(0.064)	(0.063)
Trade Openness	0.165***	0.141***	0.153***	0.170***	0.145***	0.158***	0.166***	0.142***	0.155***
	(0.035)	(0.034)	(0.034)	(0.035)	(0.034)	(0.034)	(0.035)	(0.034)	(0.034)
Natural Resource Exports	−0.001	0.001	0.003	−0.000	0.002	0.004	−0.001	0.001	0.003
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Infant Morality	−0.001***	−0.001***	−0.001***	−0.001***	−0.001***	−0.001***	−0.001***	−0.001***	−0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
N	1122	1122	1122	1122	1122	1122	1122	1122	1122
R-sq	0.980	0.981	0.981	0.755	0.762	0.775	0.954	0.956	0.959

Notes: Unstandardized Coefficients. Heteroscedasticity and serial correlation consistent standard errors in parentheses. †$p<.10$; *$p < .05$; **$p < .01$; ***$p<.001$.

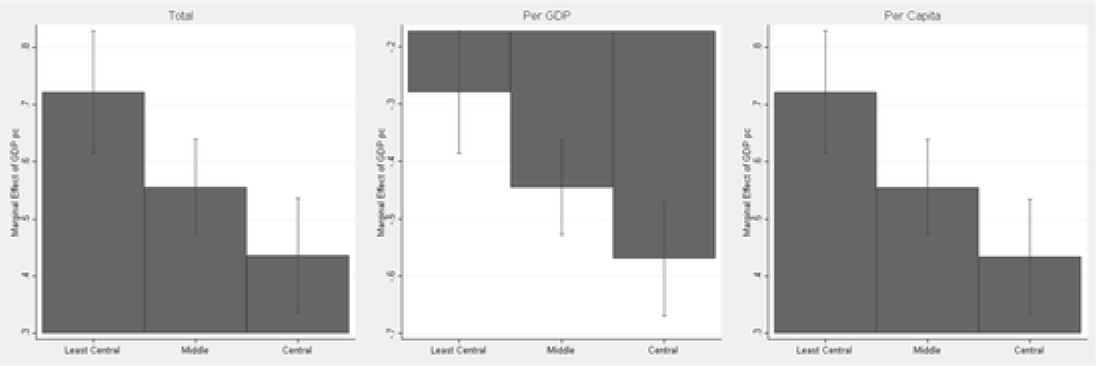

Fig. 3. Coefficients on GDP per capita by Network Position.
Notes: These coefficients are from models 1, 4 and 7 of Table 4. Cluster 1 is “least central” and cluster 3 is “center”.

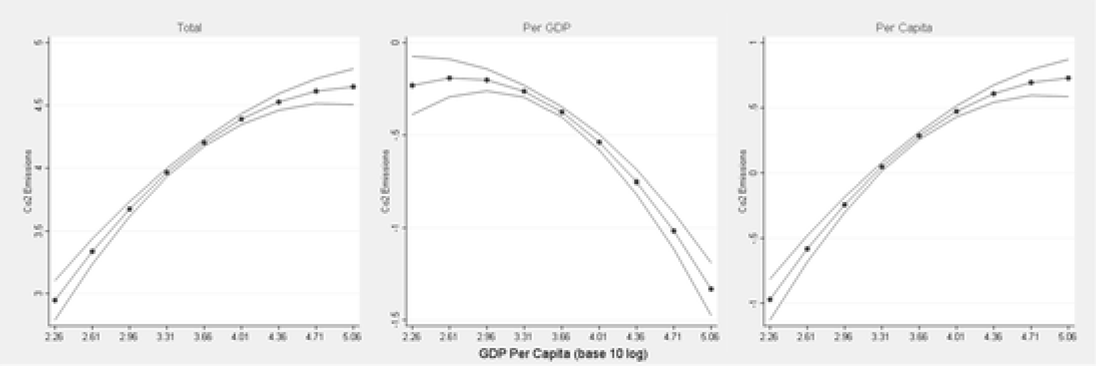

Fig. 4. Predicted Level of CO_2 Emissions across Observed Range of GDP per capita.
Notes: These graphs come from models 2, 5 and 8 of Table 4.

per capita and CO_2). Fig. 6 can also be depicted with three equations. The first is Eq. (1) (or 3) from above. The second and third are

$$m_{it} = \beta_6 x_1 + \beta_7 x_2 + \theta_{it} + z_i + \varepsilon_{it} \tag{4}$$

and

$$\begin{aligned} y_{it} = {} & \beta_8 x_1 + \beta_9 x_2 + \beta_{10} x_3 + \beta_{11} x_1 x_2 + \beta_{12} x_1 x_3 \\ & + \beta_{13} m + \beta_{14} m x_1 + \theta_{it} + z_i + \varepsilon_{it} \end{aligned} \tag{5}$$

In Eqs. (4) and (5), m is the proposed mediator (resource dependency) and β_6 and β_7 are path *a* in Fig. 6. In Eq. (5), β_{13} is the *b* path in Fig. 6—the coefficient on the interaction between GDP per capita and resource dependency. To conclude that the interaction between resource dependency and GDP per capita mediates the interaction between network structure and GDP per capita, we must observe that (1) β_6 and/or β_7 are significantly different from zero, (2) that β_{14} is significantly different from zero and (3) that β_{11} and β_{12} attenuate *vis-à-vis* β_4 and β_5 from model 1.[4] If the original path from network structure to the relationship between GDP per capita and CO_2 emissions attenuates to zero, then resource dependency completely mediates the moderation. If instead it attenuates but remains significant, then resource dependency partially mediates the moderation. Moreover, we can formally test the null hypothesis that there is an indirect effect of network structure that works through resource dependency with $H_0 : \beta_4 - \beta_{11} = 0$ and β_5 - $\beta_{12} = 0$.[5] If we reject any of these null hypotheses, we can also identify the proportion of the interaction between network structure and GDP per capita is mediated by the interaction between resource dependency and GDP per capita with the quantities $\frac{\beta_4 - \beta_{11}}{\beta_4}$ and $\frac{\beta_5 - \beta_{12}}{\beta_5}$.

The primary results of this mediated moderation analysis are displayed in Figs. 7 and 8. The regression results underlying these graphs are reported in Tables D1 and D2 in the appendix.[6] We measure resource dependency with the base 10 logarithm of the ratio of natural resource rents to GDP, which we obtain from the World Bank. In A4.1, we see that the first condition is met: both the least central and middling countries have significantly higher levels of resource dependency than the center countries. We also see that the second and third conditions are met: there is a significantly positive interaction between GDP per capita and resource dependency, and the interactions between network position and GDP per capita attenuate. Thus, in the top panel of Fig. 7, we see a significantly positive indirect effect in both the least central and middling countries. This indirect effect explains about 20 percent of the total network effect in the least central countries, and about 28 percent in middling countries.

Fig. 8 reports the same results for a quadratic version of model 5. Table D2 shows that the interaction between resource dependency and the squared term of GDP per capita is positive and significant, and that the interactions between this squared term and network position attenuate upon its inclusion. Indeed, the interaction between GDP per capita and the least central dummy is now only marginally significant. Thus,

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[4] Fig. 6 and Eq. (5) are general; GDP per capita also stands in for the squared term. Thus, Eq. (5) can be amended by adding an interaction between GDP per capita square and resource dependency to Eq. (3). In this case, the interaction between resource dependency and squared GDP per capita would have to be significantly different from zero and the interactions between GDP per capita squared and network position would have to attenuate.

[5] We use stata’s sureg (seemingly unrelated regression) procedure to test these null hypotheses, which is equivalent to structural equation modeling in this case.

[6] Note that the sample size differers in these tables and Table 4 because resource dependency reduced the available cases.

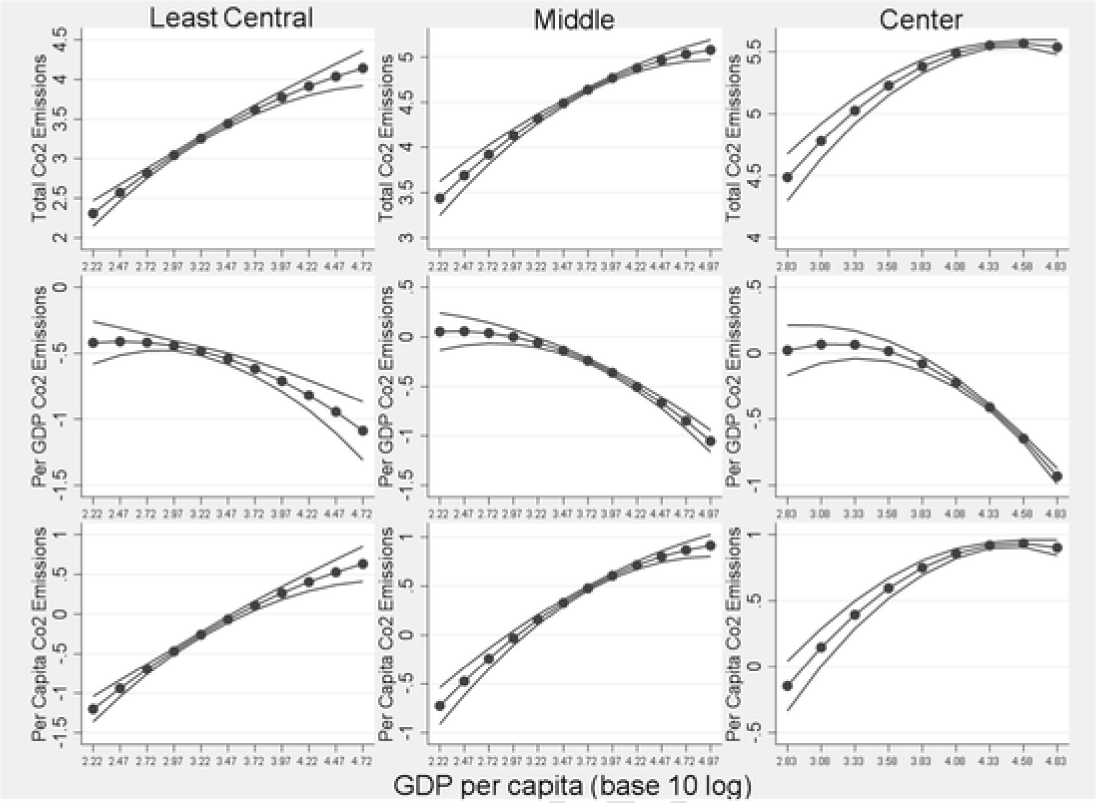

Fig. 5. Fit of Quadratic Term by Cluster.

Notes: These coefficients are from models 3, 6 and 9 of Table 4. Cluster 1 is “least central” and cluster 3 is “center”.

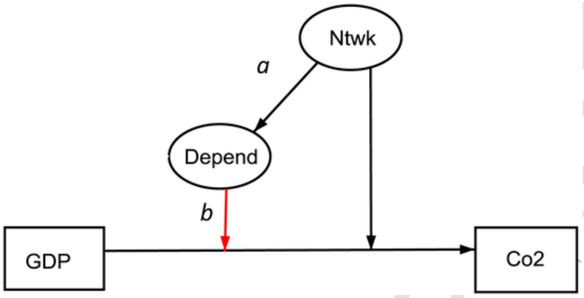

Fig. 6. Path Diagram of Mediated Moderation.

the top row of Fig. 8 shows that the indirect effect is significantly different from zero in both the least central and middling countries. Resource dependency now explains a greater share of the overall effect of network structure among the least central (~30 %) relative to middling countries (~16 %).

Conclusion

In this article, we argue that the structure of the natural resource exchange network increases the environmental costs of development among less central countries. Drawing from theories of Ecological Modernization Theory (EMT) and the related environmental Kuznets curve hypothesis (EKC), the treadmill of production (ToP), and ecologically unequal exchange (EUE), we suggest that the structural location of individual countries conditions the link from development to environmental degradation. In particular, we argue that less central countries in the natural resource exchange network become sites of dependent extraction, which increases the environmental costs to development through both first- and second-order effects. That is, natural resource extraction increases environmental costs through increasing pollution via the relative size of extractive sectors (first-order effects a la EUE) and by stifling the demand for and supply of environmental protection (second-order effects a la EMT). These second-order effects lead to higher pollution outside of extractive industries.

We conduct a novel network analysis of the entire natural resource exchange network and find that it exhibits a classic core/periphery interaction pattern even though the membership of the center departs in meaningful ways from membership in the core of the all-encompassing “world-system.” Less central countries have fewer export ties, more dependent natural resource export ties (dependent ties/total ties) and higher natural resource dependency (natural resource rents/GDP) on average. That is, our network analysis reveals structural characteristics in the natural resource-exchange network that are similar to those observed in network analyses of the broader “world-system,” but also a degree of decoupling of this structure from that of the world-system in terms of the membership of the center. While this decoupling likely arises because of the natural distribution of raw materials worldwide (see above), it also suggests that more circumscribed analyses of economic sectors could reveal additional decouplings of theoretical interest.

Using panel regression analysis, we find that less central countries experience more environmentally costly developmental trajectories. If we treat this trajectory in a linear fashion (a la ToP and EUE), the positive association between GDP per capita and total/per capita CO_2 emissions is stronger in less central countries, while the negative association between GDP per capita and per GDP emissions is weaker. Allowing for curvilinear effects of GDP per capita (a la EMT and EKC), we find that there is no curvilinear association in the least central countries, while middling countries experience a significantly weaker attenuation of the CO_2 increasing effect of GDP per capita. In short, the world-wide organization of natural resource extraction both inculcates natural resource dependency and increases the environmental cost of economic development in less central countries.

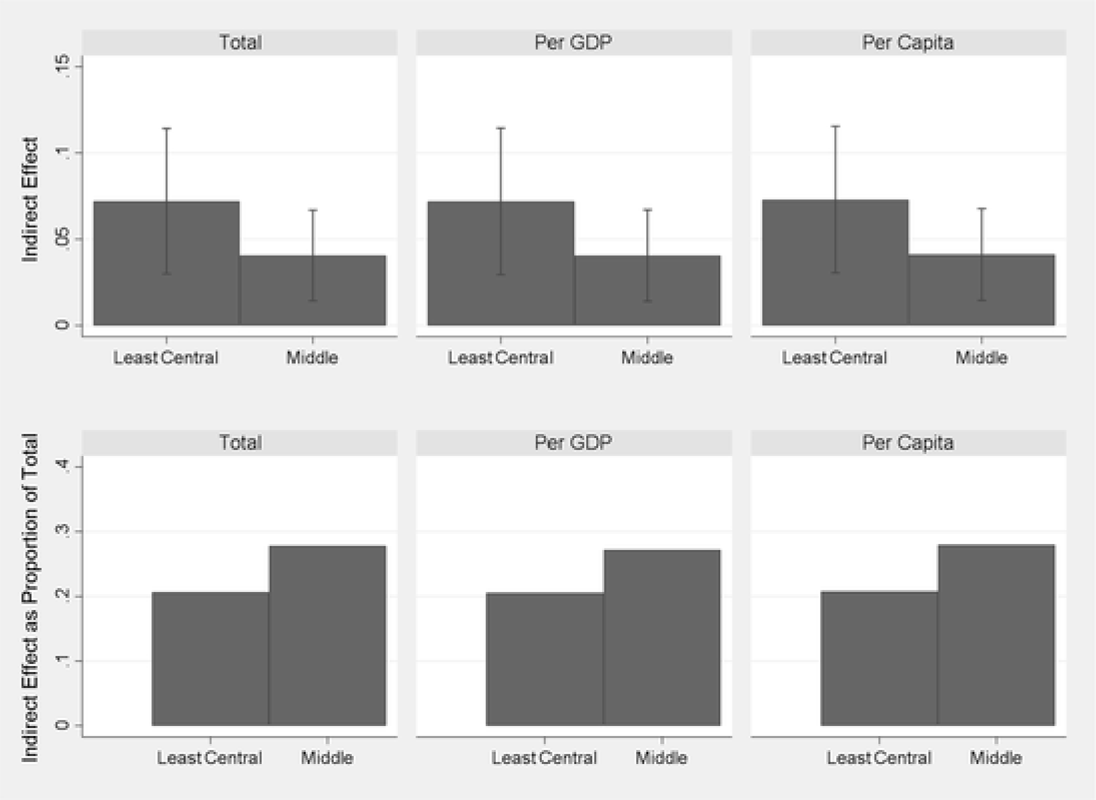

Fig. 7. Linear Indirect Effects of Network Structure through Resource Dependency.

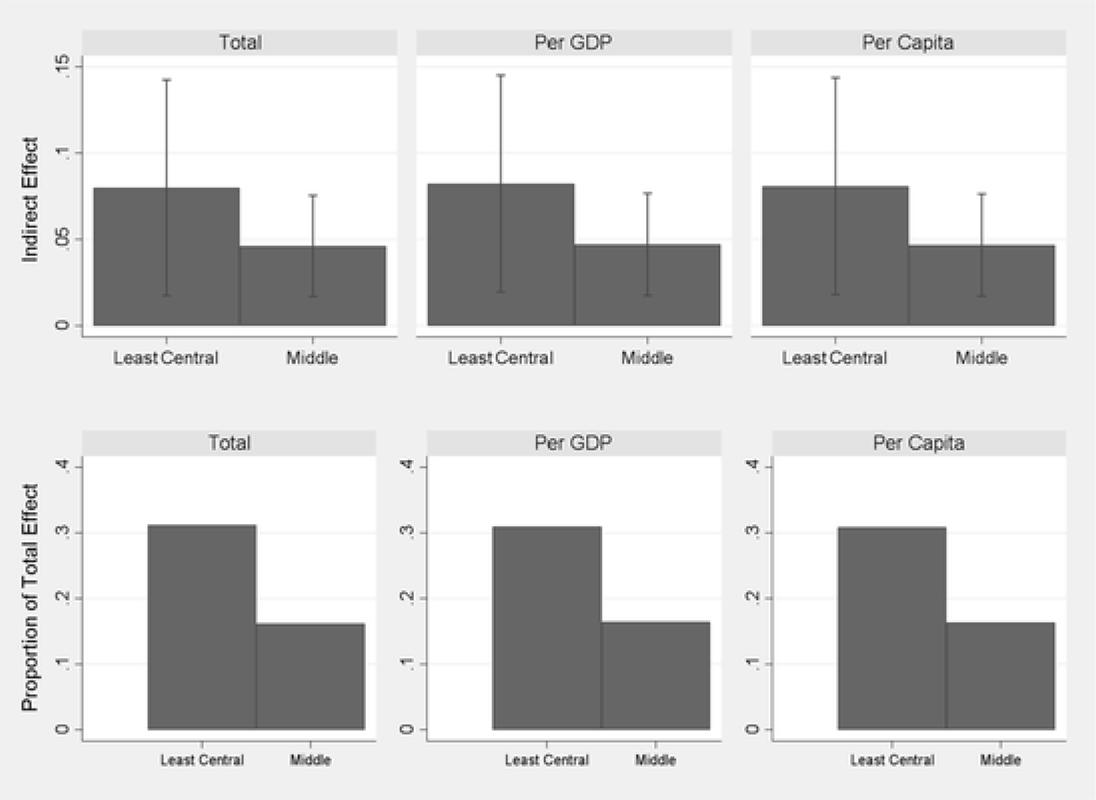

Fig. 8. Curvilinear Indirect Effects of Network Structure through Resource Dependency.

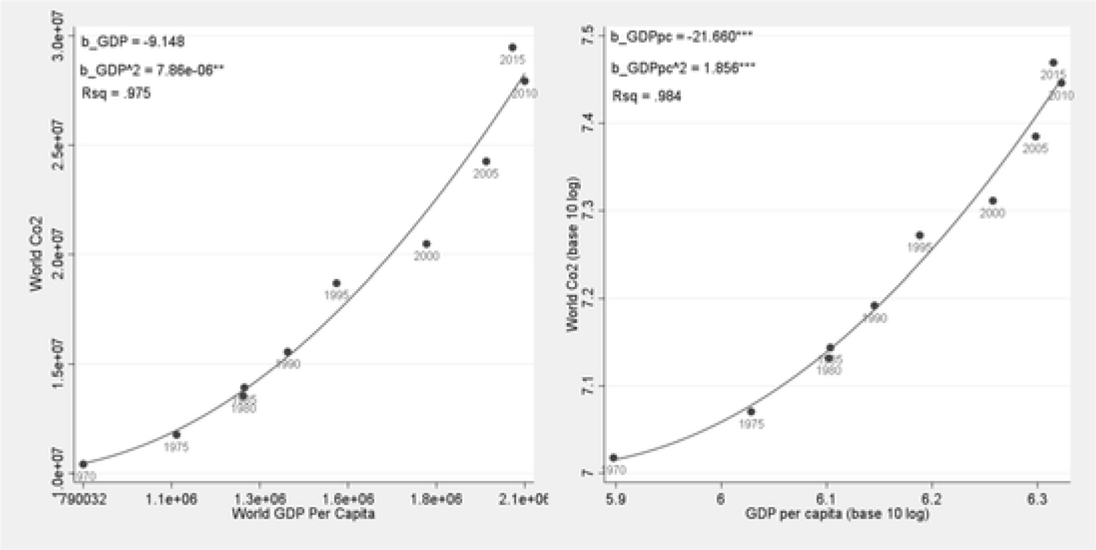

Fig. 9. World CO_2 Emissions by World GDP per capita.

Consistent with our theoretical intervention, we also find that resource dependency is an important mechanism linking network structure to higher environmental costs of development. Treating the association between GDP per capita and CO_2 emissions in a linear fashion, we find that network structure has a significant indirect effect on the association between GDP per capita and CO_2 emissions that works through the interaction between resource dependency and GDP per capita. The latter explains 20 (least central) to 28 (middling) percent of the former. Treating the association in a non-linear fashion, we also observe network structure has a significant indirect effect on the association between squared GDP per capita and CO_2 emissions that works through the interaction between resource dependency and squared GDP per capita. These indirect effects constitute a larger (~30 %) share of the total network effect among least central countries but a smaller share (~16 %) among middling countries. While these findings are consistent with our argument about how network structure matters, they also suggest additional mechanisms are at work. We return to this below.

These findings have important implications for the science of climate change. First, our finding that less central countries experience more harmful effects of development on CO_2 emissions matters because these are the countries with more room to grow. Since at least the late 1990s, economic growth has been faster, on average, in less developed countries (Alderson and Pandian, 2018). If these countries are growing faster and their growth trajectories are more environmentally costly than those in the center, then any gains in environmental efficiency in the center may be more than offset by the opposite process in the periphery. Climate change results from the scale of carbon emissions at the level of the world. Different environmental costs at the national level “add up” to climate change at the global level.

Our analysis is entirely consistent with the possibility that the organization of the natural resource exchange network more than offsets modernization dynamics in the center. Fig. 9 shows the association between world CO_2 emissions and world GDP per capita from 1970 to 2015. There is no evidence for an inverted-U shaped relationship as hypothesized by EMT/EKC. Rather, there appears to be a convex relationship: the carbon intensity of development appears to be increasing as the world gets richer. In both the raw and logged renditions, there is a significantly positive coefficient on the squared term when fitting CO_2 to a simple constant + GDP per capita quadratic. Our analysis contributes to an explanation for this strongly positive association between CO_2 emissions and development at the world level: gains in environmental efficiency development brings to center countries are more than offset by the high environmental cost of development in the periphery of the natural resource exchange network. While much attention has been rightfully paid to the environmental costs of the disproportionate (per capita) consumption patterns by rich countries in the center (Wiedmann et al., 2020), our results suggest strongly that efforts to reduce the environmental costs of development “in the periphery” are also important for our ecological future. Both concerns for economic justice and the natural reticence of less-developed countries to trade slower development for less carbon emissions (Dauvergne, 2016) suggest that these efforts must be international in scope and include meaningful commitments on the part of developed country governments vis-à-vis technology transfer and development aid.

Our analysis also suggests fruitful directions for future research. For example, the large and growing literature on the ToP showing varying associations between development and CO_2 emissions through time might consider the degree to which the shape of the association is changing over time from linear to curvilinear or vice versa. Moreover, we have specified two key mechanisms to explain the moderating role of the structure of the natural resource networks. The first is the first-order effects of natural resource dependency: economies more dependent on natural resource extraction may experience higher environmental costs to development because extractive industries are environmentally costly. There are second-order costs of resource dependency: workers laboring in extractive industries should be less likely to demand environmental protections from their governments for fear that such protections would erode their near-term economic gains. Governments that are revenue-dependent on extractive industries might be less likely to supply environmental protections if such protections undermine their short-term revenue needs. Our mediated moderation analysis shows that these mechanisms offer an important but incomplete accounting for exactly why the structure of the natural resource exchange network matters. Future research could seek to identify additional mechanisms.

Finally, our results should motivate new directions in the study of anthropogenic climate change for which the structural analyses of international relations are central. While our argument is premised upon both first and second-order effects of network structure, it is likely the case that more delimited analyses of particular extractive industries would shed more light on the relative importance of both types of mechanisms, as well as the degree to which different types of sectoral networks possess different types of structural properties or matter more or less for climate change. Such analyses are among many examples of what could be a network turn in macro-comparative environmental sociology, for which current and pre-existing social structures are the fundamental cause of anthropogenic environmental outcomes.

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgements

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Appendix A.

Appendix B.

See Fig. B1.

Appendix C. Robustness Checks

Appendix D. Regressions for Mediation Analysis

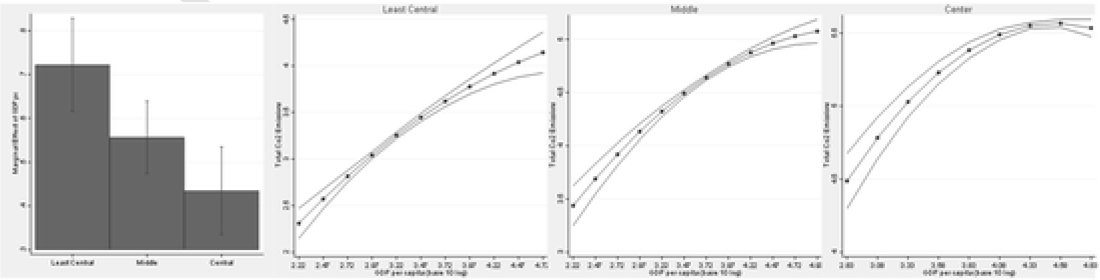

Fig. C1. Coefficients on GDP per capita by network position and Predicted level of CO2 Emissions across observed range of GDP per capita.

Table A1
Regression Sample.

	1970	1975	1980	1985	1990	1995	2000	2005	2010		1970	1975	1980	1985	1990	1995	2000	2005	2010
Afghanistan								X	X	Kenya	X	X	X	X	X	X	X	X	X
Albania					X	X	X	X	X	Korea, Rep.	X	X	X	X	X	X	X	X	X
Algeria	X	X	X	X	X	X	X	X	X	Kuwait						X	X	X	X
Angola			X	X	X	X	X	X	X	Lao PDR				X	X	X	X	X	X
Argentina	X	X	X	X	X	X	X	X	X	Lebanon					X	X	X	X	X
Australia	X	X	X	X	X	X	X	X	X	Liberia							X	X	X
Austria	X	X	X	X	X	X	X	X	X	Libya							X	X	X
Bahamas, The	X	X	X	X	X	X	X	X	X	Madagascar	X	X	X	X	X	X	X	X	X
Bahrain			X	X	X	X	X	X	X	Malawi	X				X	X	X	X	X
Barbados		X	X	X	X	X	X	X	X	Malaysia	X	X	X	X	X	X	X	X	X
Belgium							X	X	X	Maldives						X	X	X	X
Belize	X	X	X	X	X	X	X	X	X	Mali	X		X	X	X	X	X	X	X
Benin			X	X	X	X	X	X	X	Malta	X	X	X	X	X	X	X	X	X
Bolivia	X	X	X	X	X	X	X	X	X	Mauritania	X	X	X	X	X	X	X	X	X
Brazil	X	X	X	X	X	X	X	X	X	Mauritius				X	X	X	X	X	X
Brunei Darussalam				X	X	X	X	X	X	Mexico	X	X	X	X	X	X	X	X	X
Bulgaria			X	X	X	X	X	X	X	Morocco	X	X	X	X	X	X	X	X	X
Burundi	X	X	X	X	X	X	X	X	X	Mozambique						X	X	X	X
Canada	X	X	X	X	X	X	X	X	X	Myanmar							X	X	X
Cameroon	X	X	X	X	X	X	X	X	X	Nepal	X	X	X	X	X	X	X	X	X
Central African Republic	X	X	X	X	X	X	X	X	X	Netherlands	X	X	X	X	X	X	X	X	X
Chad		X		X		X	X	X	X	New Zealand	X	X	X	X	X	X	X	X	X
Chi	X	X	X	X	X	X	X	X	X	Nicaragua	X	X	X	X	X	X	X	X	X
Chile	X	X	X	X	X	X	X	X	X	Niger		X	X	X	X	X	X	X	X
Colombia	X	X	X	X	X	X	X	X	X	Nigeria	X	X	X	X	X	X	X	X	X
Congo, Dem. Rep.	X	X	X	X	X	X	X	X	X	Norway	X	X	X	X	X	X	X	X	X
Congo, Rep.	X	X	X	X	X	X	X	X	X	Oman	X	X	X	X	X	X	X	X	X
Costa Rica	X	X	X	X	X	X	X	X	X	Pakistan	X	X	X	X	X	X	X	X	X
Cote d'Ivoire	X	X	X	X	X	X	X	X	X	Panama	X	X	X	X	X	X	X	X	X
Cuba	X	X	X	X	X	X	X	X	X	Papua New Guinea	X	X	X	X	X	X	X	X	X
Cyprus			X	X	X	X	X	X	X	Paraguay	X	X	X	X	X	X	X	X	X
Denmark	X	X	X	X	X	X	X	X	X	Peru	X	X	X	X	X	X	X	X	X
Dominica					X	X	X	X	X	Philippines	X	X	X	X	X	X	X	X	X
Dominican Republic	X	X	X	X	X	X	X	X	X	Poland						X	X	X	X
Ecuador	X	X	X	X	X	X	X	X	X	Portugal	X	X	X	X	X	X	X	X	X
Egypt, Arab Rep.	X	X	X	X	X	X	X	X	X	Qatar							X	X	X
El Salvador	X	X	X	X	X	X	X	X	X	Romania					X	X	X	X	X
Equatorial Guinea				X	X	X	X	X	X	Rwanda	X	X	X	X	X	X	X	X	X
Ethiopia				X	X	X	X	X	X	Samoa				X		X			X
Fiji	X	X	X	X	X	X	X	X	X	Saudi Arabia		X	X	X	X	X	X	X	X
Finland	X	X	X	X	X	X	X	X	X	Senegal	X	X	X	X	X	X	X	X	X
France	X	X	X	X	X	X	X	X	X	Sierra Leone	X	X	X	X	X	X	X	X	X
Gabon			X	X	X	X	X	X	X	Singapore	X	X	X	X	X	X	X	X	X
Gambia, The			X	X	X	X	X	X	X	Solomon Islands					X	X	X	X	X
Germany						X	X	X	X	Spain		X	X	X	X	X	X	X	X
Ghana	X	X	X	X	X	X	X	X	X	Sri Lanka	X	X	X	X	X	X	X	X	X
Greece	X	X	X	X	X	X	X	X	X	St. Kitts and Nevis			X	X					X
Guatemala	X	X	X	X	X	X	X	X	X	Suriname				X	X	X	X	X	X
Guinea					X	X	X	X	X	Sweden	X	X	X	X	X	X	X	X	X
Guinea-Bissau				X	X	X	X	X	X	Switzerland	X	X	X	X	X	X	X	X	X
Guyana	X	X	X	X	X	X	X	X	X	Tanzania					X	X	X	X	X
Haiti	X	X	X	X	X	X	X	X	X	Thailand	X	X	X	X	X	X	X	X	X
Honduras	X	X	X	X	X	X	X	X	X	Togo	X	X	X	X	X	X	X	X	X
Hungary						X	X	X	X	Tunisia	X	X	X	X	X	X	X	X	X
Iceland	X	X	X	X	X	X	X	X	X	Turkey	X	X	X	X	X	X	X	X	X
India	X	X	X	X	X	X	X	X	X	Uganda				X	X	X	X	X	X
Indonesia	X	X	X	X	X	X	X	X	X	United Arab Emirates		X	X	X	X	X	X	X	X
Iran, Islamic Rep.		X	X	X	X	X	X	X	X	United Kingdom	X	X	X	X	X	X	X	X	X
Iraq	X	X	X	X	X			X	X	United States	X	X	X	X	X	X	X	X	X
Ireland	X	X	X	X	X	X	X	X	X	Uruguay	X	X	X	X	X	X	X	X	X
Israel		X	X	X	X	X	X	X	X	Vanuatu			X	X	X	X	X	X	X
Italy	X	X	X	X	X	X	X	X	X	Venezuela, RB	X	X	X	X	X	X	X	X	X
Jamaica	X	X	X	X	X	X	X	X	X	Zambia	X	X	X	X	X	X	X	X	X
Japan	X	X	X	X	X	X	X	X	X	Zimbabwe	X	X	X	X	X	X	X	X	X
Jordan		X	X	X	X	X	X	X	X										

Table C1
Relevant Regression Coefficients without Select Controls.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	No Infant Mortality						No Controls					
	Total		Per GDP		Per Capita		Total		Per GDP		Per Capita	
Lest Central	−1.271***	2.804**	−1.277***	2.925**	−1.276***	2.838**	−1.015***	2.553*	−1.263***	2.414**	−1.260***	2.343*
	(-6.773)	(3.055)	(-6.782)	(3.182)	(-6.793)	(3.086)	(-4.427)	(2.061)	(-6.682)	(2.615)	(-6.678)	(2.532)
Middle	−0.626***	3.105***	−0.636***	3.127***	−0.630***	3.119***	−0.467***	1.669	−0.651***	2.719***	−0.643***	2.698***
	(-5.793)	(4.592)	(-5.846)	(4.611)	(-5.809)	(4.598)	(-3.329)	(1.780)	(-6.001)	(4.071)	(-5.943)	(4.028)
GDP pc	0.425***	3.618***	−0.580***	2.635***	0.423***	3.633***	0.866***	4.284***	−0.485***	2.728***	0.522***	3.734***
	(8.063)	(9.271)	(-10.969)	(6.736)	(8.008)	(9.281)	(14.685)	(7.903)	(-10.721)	(7.088)	(11.519)	(9.669)
Least Central*GDP pc	0.332***	−1.604**	0.332***	−1.674***	0.333***	−1.623***	0.246***	−1.453*	0.323***	−1.378**	0.323***	−1.337**
	(6.306)	(-3.279)	(6.299)	(-3.417)	(6.329)	(-3.313)	(3.856)	(-2.229)	(6.071)	(-2.801)	(6.080)	(-2.712)
Middle*GDP pc	0.153***	−1.665***	0.155***	−1.678***	0.154***	−1.673***	0.104**	(0.877)	0.155***	−1.464***	0.153***	−1.451***
	(5.795)	(-4.950)	(5.845)	(-4.979)	(5.813)	(-4.958)	(3.041)	(-1.885)	(5.918)	(-4.429)	(5.863)	(-4.379)
GDP pc sq		−0.404***		−0.407***		−0.407***		−0.443***		−0.408***		−0.409***
		(-8.510)		(-8.550)		(-8.528)		(-6.713)		(-8.780)		(-8.753)
Least Central*GDP pc sq		0.224***		0.233***		0.226***		0.197*		0.190**		0.185**
		(3.386)		(3.529)		(3.423)		(2.280)		(2.863)		(2.773)
Middle*GDP pc sq		0.219***		0.220***		0.220***		0.111†		0.192***		0.190***
		(5.250)		(5.287)		(5.261)		(1.939)		(4.729)		(4.673)
N	1122	1122	1122	1122	1122	1122	1122	1122	1122	1122	1122	1122
R-sq	0.979	0.981	0.745	0.767	0.952	0.957	0.956	0.959	0.727	0.753	0.948	0.954

Notes: All controls from Table 4 included unless otherwise noted. Unstandardized Coefficients. Heteroscedasticity and serial correlation consistent standard errors in parentheses. †p<.10; *p < .05; **p < .01; ***p<.001.

Table C2
Relevant Regression Results for Total CO_2 Emissions replacing Population Density with Population Size.

	(1)	(2)
	Total	
Lest Central	−1.100***	2.930**
	(-5.992)	(3.278)
Middle	−0.500***	2.996***
	(-4.946)	(4.654)
GDP pc	0.435***	3.369***
	(8.501)	(8.939)
Least Central*GDP pc	0.287***	−1.668***
	(5.570)	(-3.492)
Middle*GDP pc	0.121***	−1.591***
	(4.945)	(-4.974)
Population Size	0.861***	0.882***
	(13.757)	(14.119)
GDP pc sq		−0.371***
		(-8.083)
Least Central*GDP pc sq		0.232***
		(3.591)
Middle*GDP pc sq		0.207***
		(5.243)
N	1122	1122
R-sq	0.980	0.981

Notes: Unstandardized Coefficients. All controls included. Heteroscedasticity and serial correlation consistent t-statistics in parentheses. *p < .05; **p < .01; ***p <.001.

Table C3
Relevant Regression Results in Two-Way Fixed Effects Regression.

	(1)	(2)	(3)	(4)	(5)	(6)
	Total		Per GDP		Per Capita	
Lest Central	−0.759***	2.568**	−0.772***	2.665**	−0.767***	2.614**
	(-3.879)	(3.056)	(-3.918)	(3.155)	(-3.913)	(3.102)
Middle	−0.340**	2.570***	−0.354***	2.637***	−0.345**	2.594***
	(-3.225)	(4.246)	(-3.314)	(4.323)	(-3.257)	(4.264)
GDP pc	0.618***	2.715***	−0.383***	1.777***	0.614***	2.739***
	(9.645)	(6.702)	(-5.944)	(4.350)	(9.570)	(6.735)
Least Central*GDP pc	0.197***	−1.476**	0.199***	−1.530***	0.199***	−1.502***
	(3.637)	(-3.261)	(3.653)	(-3.363)	(3.672)	(-3.309)
Middle*GDP pc	0.083**	−1.370***	0.086***	−1.407***	0.085***	−1.383***
	(3.282)	(-4.506)	(3.360)	(-4.597)	(3.317)	(-4.527)
GDP pc sq		−0.270***		−0.278***		−0.274***
		(-5.029)		(-5.140)		(-5.078)
Least Central*GDP pc sq		0.207***		0.214***		0.211***
		(3.354)		(3.453)		(3.406)
Middle*GDP pc sq		0.179***		0.184***		0.181***
		(4.722)		(4.824)		(4.747)
N	1122	1122	1122	1122	1122	1122
R-sq	0.982	0.982	0.776	0.787	0.958	0.961

Notes: Unstandardized Coefficients. All controls included. Heteroscedasticity and serial correlation consistent t-statistics in parentheses. *p < .05; **p < .01; ***p <.001.

Table C4
Relevant regression results with alternative network positions.

	(1)	(3)	(4)	(6)	(7)	(9)
	Total		Per GDP		Per Capita	
GDP pc	0.438***	3.187***	−0.569***	2.216***	0.436***	3.198***
	(0.053)	(0.361)	(0.053)	(0.363)	(0.053)	(0.362)
Least Central * GDP pc	0.269***	−1.576***	0.274***	−1.631***	0.271***	−1.587***
	(0.052)	(0.465)	(0.052)	(0.466)	(0.052)	(0.465)
Middle * GDP pc	0.109***	−1.364***	0.114***	−1.382***	0.110***	−1.374***
	(0.024)	(0.299)	(0.024)	(0.300)	(0.024)	(0.300)
GDP pc squared		−0.347***		−0.351***		−0.349***
		(0.044)		(0.044)		(0.044)
Least Central * GDP pc squared		0.220***		0.228***		0.221***
		(0.062)		(0.062)		(0.062)
Middle * GDP pc squared		0.176***		0.178***		0.177***
		(0.037)		(0.037)		(0.037)
Least Central	−1.056***	2.742**	−1.078***	2.835**	−1.063***	2.761**
	(0.185)	(0.873)	(0.186)	(0.875)	(0.185)	(0.875)
Middle	−0.483***	2.570***	−0.502***	2.600***	−0.486***	2.589***
	(0.100)	(0.600)	(0.101)	(0.604)	(0.100)	(0.602)
N	1122	1122	1122	1122	1122	1122
R-sq	0.980	0.981	0.750	0.770	0.952	0.957

Notes: Unstandardized Coefficients. All controls included. Heteroscedasticity and serial correlation consistent t-statistics in parentheses. *p < .05; **p < .01; ***p <.001.

Table D1
Regression of Natural Resource Dependency and CO_2 on GDP per capita in linear form.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Nat. Res. Dep.	Total		Per GDP		Per Capita	
GDP pc*Least Central		0.349***	0.277***	0.350***	0.278***	0.351***	0.278***
		(5.110)	(3.925)	(5.096)	(3.927)	(5.122)	(3.938)
GDP pc*Middle		0.146***	0.105**	0.149***	0.108**	0.147***	0.106**
		(4.339)	(3.104)	(4.395)	(3.188)	(4.349)	(3.123)
GDP pc*Natural Resource Dependency			0.086***		0.086***		0.087***
			(4.467)		(4.440)		(4.512)
Natural Resource Dependency			−0.349***		−0.347***		−0.352***
			(-4.429)		(-4.406)		(-4.470)
GDP pc	−0.760***	0.406***	0.403***	−0.597***	−0.600***	0.403***	0.401***
	(-7.740)	(6.554)	(6.511)	(-9.566)	(-9.659)	(6.483)	(6.473)
Least Central	0.225***	−1.347***	−1.070***	−1.353***	−1.077***	−1.353***	−1.073***
	(3.683)	(-5.467)	(-4.173)	(-5.472)	(-4.194)	(-5.479)	(-4.186)
Middle	0.181***	−0.609***	−0.446**	−0.622***	−0.460**	−0.613***	−0.448**
	(4.093)	(-4.311)	(-3.113)	(-4.370)	(-3.196)	(-4.318)	(-3.126)
N	1100	1100	1100	1100	1100	1100	1100
R-sq	0.925	0.988	0.988	0.844	0.849	0.975	0.976

Notes: All control variables from Table 4 included in each model. Unstandardized Coefficients. Heteroscedasticity and serial correlation consistent t-statistics in parentheses. $^*p < .05$; $^{**}p < .01$; $^{***}p < .001$.

Table D2
Regression of CO_2 on GDP per capita in curvilinear form.

	(1)	(2)	(3)	(4)	(5)	(6)
	Total		Per GDP		Per Capita	
GDP pc squared*Least Central	0.256**	0.176†	0.266**	0.183†	0.262**	0.181†
	(2.678)	(1.748)	(2.777)	(1.820)	(2.733)	(1.794)
GDP pc squared*Middle	0.285***	0.239***	0.286***	0.239***	0.286***	0.239***
	(5.402)	(4.598)	(5.412)	(4.601)	(5.405)	(4.598)
GDP pc squared*Natural Resource Dependency		0.055*		0.057*		0.056*
		(2.250)		(2.329)		(2.277)
GDP pc*Least Central	−1.914**	−1.342	−1.981**	−1.393	−1.953**	−1.376
	(-2.750)	(-1.835)	(-2.846)	(-1.905)	(-2.802)	(-1.879)
GDP pc*Middle	−2.206***	−1.868***	−2.213***	−1.868***	−2.214***	−1.872***
	(-5.135)	(-4.421)	(-5.142)	(-4.420)	(-5.138)	(-4.421)
GDP pc squared	−0.437***	−0.388***	−0.440***	−0.391***	−0.439***	−0.390***
	(-6.882)	(-6.057)	(-6.912)	(-6.096)	(-6.901)	(-6.077)
GDP pc*Natural Resource Dependency		−0.362†		−0.375†		−0.365†
		(-1.879)		(-1.955)		(-1.898)
GDP pc	3.894***	3.524***	2.916***	2.544***	3.913***	3.537***
	(7.452)	(6.755)	(5.565)	(4.872)	(7.463)	(6.766)
Natural Resource Dependency		0.526		0.551		0.529
		(1.412)		(1.482)		(1.423)
Least Central	3.492**	2.498	3.607**	2.583†	3.561**	2.557
	(2.719)	(1.864)	(2.806)	(1.927)	(2.766)	(1.904)
Middle	4.189***	3.583***	4.198***	3.580***	4.206***	3.593***
	(4.818)	(4.201)	(4.820)	(4.197)	(4.822)	(4.202)
N	1100	1100	1100	1100	1100	1100
R-sq	0.989	0.989	0.855	0.858	0.977	0.978

Notes: All control variables from Table 4 included in each model. Unstandardized Coefficients. Heteroscedasticity and serial correlation consistent t-statistics in parentheses. $^{\dagger}p < .10$; $^*p < .05$; $^{**}p < .01$; $^{***}p < .001$.

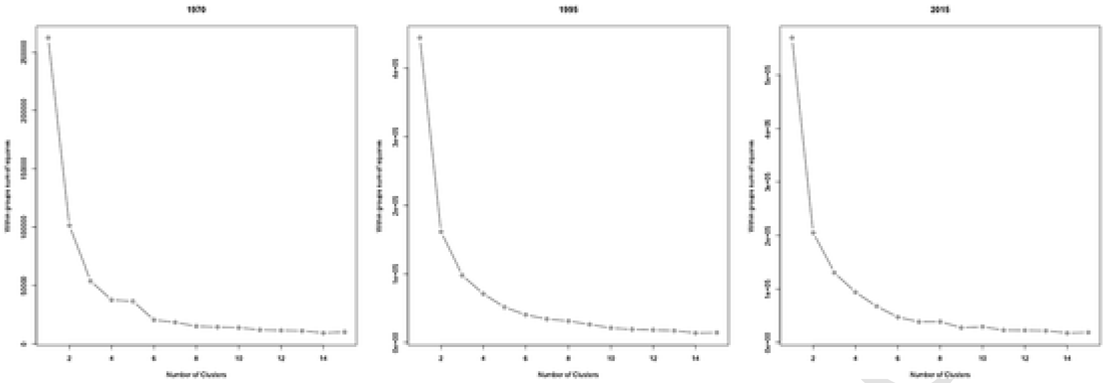

Fig. B1. Scree Plot.

References

Alderson, A.S., Pandian, R.K., 2018. What is really happening with global inequality? Sociol. Dev. Oakl. (Oakl) 4, 261–281. https://doi.org/10.1525/sod.2018.4.3.261.

Bonacich, P., 1972. Factoring and weighting approaches to status scores and clique identification. J. Math. Sociol. 2, 113–120. https://doi.org/10.1080/0022250X.1972.9989806.

Boyd, J.P., Jonas, K.J., 2001. Are social equivalences ever regular? Permutation and exact tests. Soc. Netw. 23, 87–123. https://doi.org/10.1016/S0378-8733(01)00032-6.

Boyd, J.P., Fitzgerald, W.J., Mahutga, M.C., Smith, D.A., 2010. Computing continuous core/periphery structures for social relations data with MINRES/SVD. Soc. Netw. 32, 125–137. https://doi.org/10.1016/j.socnet.2009.09.003.

Bunker, S.G., 1984. Modes of extraction, unequal exchange, and the progressive underdevelopment of an extreme periphery: the Brazilian Amazon, 1600–1980. Am. J. Sociol. 89, 1017–1064. https://doi.org/10.1086/227983.

Bunker, S.G., Ciccantell, P.S., 2005. Globalization and the Race for Resources. JHU Press.

Cox, T.F., Cox, M.A.A., 2000. Multidimensional Scaling. 2nd ed. Chapman and Hall/CRC.

Dauvergne, P., 2016. The political economy of the environment. In: Ravenhill, J. (Ed.), Global Political Economy. Oxford University Press.

Fisher, D.R., Jorgenson, A.K., 2019. Ending the stalemate: toward a theory of anthro-shift. J. Sociol. Theory Relig. 37, 342–362. https://doi.org/10.1177/0735275119888247.

Frank, D.J., Hironaka, A., Schofer, E., 2000. The nation-state and the natural environment over the twentieth century. Am. Sociol. Rev. 65, 96–116. https://doi.org/10.2307/2657291.

Freeman, L.C., 1978. Centrality in social networks conceptual clarification. Soc. Netw. 1, 215–239. https://doi.org/10.1016/0378-8733(78)90021-7.

Givens, J.E., 2018. Ecologically unequal exchange and the carbon intensity of well-being, 1990–2011. Environ. Sociol. 4, 311–324. https://doi.org/10.1080/23251042.2018.1436878.

Gould, K.A., Pellow, D.N., Schnaiberg, A., 2004. Interrogating the treadmill of production: everything you wanted to know about the treadmill but were afraid to ask. Organ. Environ. 17, 296–316. https://doi.org/10.1177/1086026604268747.

Gower, J.C., 1966. Some distance properties of latent root and vector methods used in multivariate analysis. Biometrika 53, 325–338. https://doi.org/10.2307/2333639.

Huang, X., 2018. Ecologically unequal exchange, recessions, and climate change: a longitudinal study. Soc. Sci. Res. 73, 1–12. https://doi.org/10.1016/j.ssresearch.2018.03.003.

Johansson, T.B., Patwardhan, A.P., Nakićenović, N., Gomez-Echeverri, L., 2012. Global Energy Assessment: Toward a Sustainable Future. Cambridge University Press.

Jorgenson, A.K., 2003. Consumption and environmental degradation: a cross-national analysis of the ecological footprint. Soc. Probl. 50, 374–394. https://doi.org/10.1525/sp.2003.50.3.374.

Jorgenson, A.K., 2006. Unequal ecological exchange and environmental degradation: a theoretical proposition and cross-national study of deforestation, 1990–2000*. Rural Sociol. 71, 685–712. https://doi.org/10.1526/003601106781262016.

Jorgenson, A.K., 2011. Carbon dioxide emissions in Central and Eastern European Nations, 1992–2005: a test of ecologically unequal exchange theory. Hum. Ecol. Rev. 18, 105–114.

Jorgenson, A.K., 2012. The sociology of ecologically unequal exchange and carbon dioxide emissions, 1960–2005. Soc. Sci. Res. 41, 242–252. https://doi.org/10.1016/j.ssresearch.2011.11.011.

Jorgenson, A.K., 2016. Environment, development, and ecologically unequal exchange. Sustainability 8, 227. https://doi.org/10.3390/su8030227.

Jorgenson, A.K., Clark, B., 2009. The economy, military, and ecologically unequal exchange relationships in comparative perspective: a panel study of the ecological footprints of nations, 1975—2000. Soc. Probl. 56, 621–646. https://doi.org/10.1525/sp.2009.56.4.621.

Jorgenson, A.K., Clark, B., 2011. Societies consuming nature: a panel study of the ecological footprints of nations, 1960–2003. Soc. Sci. Res. 40, 226–244. https://doi.org/10.1016/j.ssresearch.2010.09.004.

Jorgenson, A.K., Clark, B., 2012. Are the economy and the environment decoupling? A comparative international study, 1960–2005. Am. J. Sociol. 118, 1–44. https://doi.org/10.1086/665990.

Jorgenson, A.K., Austin, K., Dick, C., 2009. Ecologically unequal exchange and the resource Consumption/Environmental degradation paradox: a panel study of less-developed countries, 1970—2000. Int. J. Comp. Sociol. 50, 263–284. https://doi.org/10.1177/0020715209105142.

Lloyd, P., Mahutga, M.C., Leeuw, J.D., 2009. Looking back and forging ahead: thirty years of social network research on the world-system. J. World-Syst. Res. 48–85. https://doi.org/10.5195/jwsr.2009.335.

Longhofer, W., Jorgenson, A., 2017. Decoupling reconsidered: does world society integration influence the relationship between the environment and economic development?. Soc. Sci. Res. 65, 17–29. https://doi.org/10.1016/j.ssresearch.2017.02.002.

Mahutga, M.C., 2006. The persistence of structural inequality? A network analysis of international trade, 1965–2000. Soc. Forces 84, 1863–1889. https://doi.org/10.1353/sof.2006.0098.

Mahutga, M.C., 2013. Multi-relational international trade networks, 1965–2000. Connections 33, 46–49.

Mahutga, M.C., 2014. Global models of networked organization, the positional power of nations and economic development. Rev. Int. Polit. Econ. 21, 157–194. https://doi.org/10.1080/09692290.2013.779932.

Mahutga, M.C., Smith, D.A., 2011. Globalization, the structure of the world economy and economic development. Soc. Sci. Res. 40, 257–272. https://doi.org/10.1016/j.ssresearch.2010.08.012.

Nordlund, C., 2010. International trade in fuel commodities: a network approach. In: Hornborg, A., Jorgensen, A.K. (Eds.), International Trade and Environmental Justice: Toward a Global Political Ecology, Environmental Research Advances Series. Nova Science Publishers, New York.

Pellow, D.N., Nyseth Brehm, H., 2013. An environmental sociology for the twenty-first century. Annu. Rev. Sociol. 39, 229–250. https://doi.org/10.1146/annurev-soc-071312-145558.

Prell, C., Feng, K., 2016. The evolution of global trade and impacts on countries' carbon trade imbalances. Soc. Netw. 46, 87–100. https://doi.org/10.1016/j.socnet.2016.03.001.

Rice, J., 2007. Ecological unequal exchange: consumption, equity, and unsustainable structural relationships within the global economy. Int. J. Comp. Sociol. 48, 43–72. https://doi.org/10.1177/0020715207072159.

Rosa, E.A., Dietz, T., 2012. Human drivers of national greenhouse-gas emissions. Nat. Clim. Change 2, 581–586. https://doi.org/10.1038/nclimate1506.

Schnaiberg, A., 1980. The Environment: From Surplus to Scarcity. Oxford University Press, New York; Oxford.

Shandra, J.M., Shor, E., London, G., B.M., 2008. Debt, structural adjustment and deforestation: a cross-national study. J. World-Syst. Res. 1–21. https://doi.org/10.5195/jwsr.2008.345.

Shandra, J.M., Leckband, C., McKinney, L.A., London, B., 2009. Ecologically unequal exchange, world polity, and biodiversity loss: a cross-national analysis of threatened mammals. Int. J. Comp. Sociol. 50, 285–310. https://doi.org/10.1177/0020715209105143.

Smith, D.A., White, D.R., 1992. Structure and dynamics of the global economy: network analysis of international trade 1965–1980. Soc. Forces 70, 857–893. https://doi.org/10.1093/sf/70.4.857.

Snyder, D., Kick, E.L., 1979. Structural position in the world system and economic growth, 1955-1970: a multiple-network analysis of transnational interactions. Am. J. Sociol. 84, 1096–1126. https://doi.org/10.1086/226902.

Spaargaren, G., Mol, A.P.J., 1992. Sociology, environment, and modernity: ecological modernization as a theory of social change. Soc. Nat. Resour. 5, 323–344. https://doi.org/10.1080/08941929209380797.

Tester, A.W., 2020. Deforestation in the global south: assessing uneven environmental improvements 1993–2013. Sociol. Perspect. 0731121420908900 https://doi.org/10.1177/0731121420908900.

Thombs, R., 2018. The transnational tilt of the treadmill and the role of trade openness on carbon emissions: a comparative international study, 1965–2010. Sociol. Forum 33, 422–442. https://doi.org/10.1111/socf.12415.

UN Comtrade International Trade Statistics Database [WWW Document] URL https://comtrade.U.N.org/ 2018

Van Rossem, R., 1996. The world system paradigm as general theory of development: a cross-national test. Am. Sociol. Rev. 61, 508. https://doi.org/10.2307/2096362.

Wiedmann, T., Lenzen, M., Keyßer, L.T., Steinberger, J.K., 2020. Scientists' warning on affluence. Nat. Commun. 11, 3107. https://doi.org/10.1038/s41467-020-16941-y.

World Bank, 2020. World Development Indicators. World Bank, New York.

World Trade Organization, 2010. World Trade Report. World Trade Organization.

York, R., Rosa, E.A., 2003. Key challenges to ecological modernization theory: institutional efficacy, case study evidence, units of analysis, and the pace of eco-efficiency. Organ. Environ. 16, 273–288. https://doi.org/10.1177/1086026603256299.

York, R., Rosa, E.A., Dietz, T., 2003. A rift in modernity? Assessing the anthropogenic sources of global climate change with the STIRPAT model. Int. J. Sociol. Soc. Policy 23, 31–51. https://doi.org/10.1108/01443330310790291.