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Perspective

Networks, stocks, and climate change: A new approach to the study of foreign investment and the environment

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ABSTRACT

This study offers a new approach to the study of foreign direct investment (FDI) and the environment. We argue that both the accumulation of inward FDI and a nation's position in the global network of FDI could facilitate either environmentally beneficial spillover effects and technology transfers or the outsourcing and distancing of environmentally harmful and ecologically unsustainable economic activities. In other words, the environmental impacts, good or bad, are potentially greater for nations that occupy more central positions in the world's FDI network and for nations with relatively larger amounts of inward FDI. To test these arguments, we estimate cross-national longitudinal models of total carbon dioxide emissions and carbon dioxide emissions per unit of GDP. The results suggest that both emissions outcomes are positively associated with inward FDI stocks and FDI network centrality for the overall sample of nations, but these positive associations are much more pronounced for Global South nations than for Global North nations. Overall, the findings are consistent with the arguments that foreign investment facilitates the outsourcing of energy inefficiency and environmentally harmful production processes, leading to growth in fossil-fuel consumption and concomitant carbon emissions for receiving nations, especially in the Global South. We conclude by summarizing the limitations of our analysis, and outline some next steps for this new approach to the study of FDI and the environment.

1. Introduction

Substantial bodies of comparative-international research focus on how characteristics of economic globalization impact the environment. A central consideration in this work is whether greater integration in the world economy is harmful or beneficial for various environmental conditions, and if such socioenvironmental relationships differ for Global South nations and Global North nations.

World economy integration takes interrelated forms, including international trade and foreign investment [1–5]. Cross-national analyses of the former examine both the levels of trade integration and the structure of the international trade network, with their distinct environmental impacts commonly ranging from relatively harmful to inconclusive for the environment in Global South nations, while ranging from relatively less harmful to beneficial for the environment in Global North nations [6–10]. Much prior research on the latter analyzes the environmental impacts of inward foreign direct investment (FDI) stocks for Global South nations, but fails to consider if a nation's position in the international network of FDI also impacts their environmental performance, or if the effects of inward FDI stocks or network position differ for nations in the Global South compared to the Global North [11–20]. Foreign direct investment refers to a long-term relationship between two enterprises residing in different economies, with the parent enterprise (or investor) owning 10% or more voting power in the affiliate enterprise. Foreign investment stock refers to the accumulation of investment over time.

The limitations of past research on FDI and the environment are both theoretically relevant and substantively nontrivial [21–23]. Optimistic perspectives argue that foreign investment enhances technology transfers and sustainability spillover effects, which leads to increased resource efficiencies and overall reductions in environmental harms from economic activity in recipient nations [24–26]. In contrast,

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approaches that are more critical suggest that foreign investment facilitates the outsourcing of inefficient and environmentally harmful extraction and production processes, leading to growth in energy consumption, pollution, and overall environmental load displacement for receiving nations, especially in the Global South [27–29].

Both inward FDI network position and inward FDI stocks have clear implications for these competing perspectives. Nations more central in the international network of inward FDI possess relatively larger numbers of network ties with sending nations, relatively stronger ties, and sending nation partners that are themselves in more central network positions. The breadth and depth of these structural relationships, as well as the overall levels of inward FDI stocks, are world-economic integration mechanisms and characteristics of economic globalization that could facilitate either environmentally beneficial spillover effects and technology transfers or outsourcing and distancing of environmentally harmful and ecologically unsustainable economic activities. In other words, the environmental effects, good or bad, are potentially greater for nations that occupy central positions in the world's inward FDI network and for nations with relatively larger levels of inward FDI. More network ties and more volume likely mean greater impacts, whichever the direction may be.

In an initial step to advance this area of research on globalization and the environment, we estimate cross-national longitudinal models of total carbon dioxide emissions and carbon dioxide emissions per unit of Gross Domestic Product (GDP). The two key independent variables are centrality in the international inward FDI network and accumulated stocks of inward FDI as a percent of total GDP. Analyzing the two dependent variables allows for a relatively far-reaching analysis of the impacts of FDI network centrality and FDI stocks since total emissions are analogous with the overall scale of emissions, emissions per unit of GDP is an established measure of carbon efficiency, and the global economy remains far too reliant on the burning of fossil fuels [9,10,30–37]. We estimate models of the direct associations between both emissions outcomes and the two FDI measures, and we also estimate models that test if their effects on carbon emissions are significantly different for Global North nations than for Global South nations.

2. Methods and data

We use Stata software to estimate Prais-Winsten regression models with panel-corrected standard errors [38,39], allowing for disturbances that are heteroskedastic (i.e., each panel has its own variance) and contemporaneously correlated across panels (i.e., each pair of panels has its own covariance). Our sample includes 616 annual observations across 77 countries (eight observations per country) between 2009 and 2016 (see Appendix A for a list of the countries in our sample). For each model, we either specify an AR(1) autocorrelation structure (treating the process as common to all panels),[1] or we include a lagged dependent variable (t-1) [40]. In all models, we include both unit and temporal fixed effects with a series of dummy variables representing each country and each year in our sample (i.e., two-way fixed effects), correcting for unobserved heterogeneity that is both time-invariant within countries, as well as cross-sectionally invariant within years [41]. Collinearity diagnostics suggest that we can estimate our predictors simultaneously (maximum VIF = 4.71; mean VIF = 2.83; see Appendix B for a correlation matrix).

Consistent with prior cross-national analyses of emissions [35,42,43], we transform all non-binary variables into logarithmic form, which means the models estimate elasticity coefficients where the coefficient for the independent variable is the estimated net percentage change in the dependent variable associated with a 1% increase in the independent variable (see Table 1 for descriptive statistics). The full dataset and Stata commands used to estimate the reported models are available from the authors upon reasonable request.

The two dependent variables are total carbon emissions (measured in kilotons) and carbon emissions per unit of GDP (kilograms per 2010 US dollars of GDP). We obtain these data from the World Bank's online World Development Indicators database (https://databank.worldbank.org/source/world-development-indicators). Carbon dioxide emissions are those stemming from the burning of solid, liquid, and gas fossil fuels and gas flaring, and from the manufacture of cement. Total emissions focus on overall volume, capturing the extent to which nations contribute to the accumulation of emissions in the atmosphere, while emissions per unit of GDP are a standard measure of carbon efficiency.

Our network FDI data come from the IMF's *Coordinated Direct Investment Survey* [44], which reports stock (or position) data only. We extracted data from 2009 to 2017, featuring 122 countries reporting inward stock (ranging from 92 to 112 countries per year) from 246 economies across the world (ranging from 236 to 243 countries per year). We constructed our network using valued inward stock data to capture each country's inward investment position where production activities occur.[2]

We use the continuous coreness procedure available in UCINET 6 [46] to calculate a nation's structural location in the global inward FDI network, our first of two primary independent variables.[3] Scores range from 0 to 1, with larger values indicating closer proximity to the center (scores are normalized so that the sum of their squares equals 1). Scores are generated using the MINRES (minimum residual) method. MINRES seeks a vector C (whose values indicate the coreness of each node) that minimizes the off-diagonal sums of squared differences between the observed matrix and the pattern matrix, the latter of which is approximated by the product of the vector and its transpose (i.e., $C_i\,C_j$). Overall, centrality scores are a positive function of (1) the number of associations one has, (2) the strength of each tie, and (3) the centrality of one's partners.

Our second primary independent variable is inward FDI stocks as a percent of GDP. Stock refers to the accumulation of investment over time and is calculated as the share of capital and reserves (including profits) attributable to the parent enterprise plus the net indebtedness of affiliates to the parent enterprise. This is the most widely studied FDI measure in past cross-national research on foreign investment and the environment [11–14,16–19].

To evaluate if their effects are different for Global North and Global South nations, we test for significant interactions between our two FDI predictors (stock and network centrality) and Global North status, which we operationalize as OECD nation members (dummy coded) with a GDP per capita of $20,000 or greater in 2016. The OECD dummy variable is perfectly correlated with the country-specific fixed effects and thus excluded from the estimated models that include the interactions [41].

All models control for gross domestic product per capita (GDP PC) in 2010 US dollars, non-dependent population (percent of the total population between ages 15–64), urban population as a percent of the total population, services as a percent of GDP, and trade as a percent of GDP. Total population, which counts all residents regardless of legal status or citizenship, is also included in the models of total emissions. Data for these variables are obtained from the World Bank's online World Development Indicators database.

In line with much research on inward FDI and various environmental and social outcomes, the estimated models also control for inward FDI rate, which refers to inward FDI flow/inward FDI stock [47]. Including

[1] Diagnostics (xtserial Stata command) suggest the presence of serial correlation.

[2] Following prior research [3,21,45], we logged these values to reduce skew and use a minimum cutoff of $1 million in US dollars.

[3] Theoretically, networks that resemble a core/periphery structure feature a set of integrated actors who share ties with all others, along with a set of peripheral actors who only share ties with the center and are isolated from one another.

Table 1
Descriptive statistics.

	Mean	SD	Min	Max
Untransformed				
CO_2 emissions	335,834.600	1,239,938.000	326.363	10,300,000.000
CO_2 emissions per unit of GDP	0.498	0.462	0.031	4.125
GDP PC	21,758.730	22,733.910	455.418	110,162.100
Non-dependent population	66.477	5.178	48.853	80.233
Urban population	66.245	19.032	16.434	100.000
Services (% of GDP)	59.039	10.668	27.713	96.465
Trade (% of GDP)	104.261	70.630	20.723	442.620
Total population	51,600,000.000	161,000,000.000	87,298.000	1,380,000,000.000
FDI rate	0.089	0.135	−0.255	1.816
FDI stock	91.823	209.324	1.200	1811.579
FDI centrality	0.095	0.045	0.002	0.254
Logged				
CO_2 emissions	10.697	1.963	5.788	16.147
CO_2 emissions per unit of GDP	0.369	0.250	0.030	1.634
GDP PC	9.308	1.315	6.121	11.610
Non-dependent population	4.194	0.082	3.889	4.385
Urban population	4.143	0.341	2.799	4.605
Services (% of GDP)	4.062	0.184	3.322	4.569
Trade (% of GDP)	4.497	0.542	3.078	6.095
Total population	16.227	1.748	11.377	21.044
FDI rate	3.000	0.007	2.983	3.083
FDI stock	3.815	1.023	0.788	7.503
FDI centrality	0.090	0.040	0.002	0.226

Note: N = 616 (77 nations).

FDI rate purges our models of "denominator effects," which refers to the idea that higher stock levels contribute to a lower investment rate because stock represents the denominator in the latter [48,49]. Flows refer to annual investments and consist of three components: equity capital, reinvested earnings, and intra-company loans. The flows data are reported on a net basis, with negative flows indicating that at least one of the three components is negative and not offset by positive amounts of the other components (i.e., "reverse investment" or "disinvestment").

3. Results

Tables 2 and 3 present the results from our main analysis, estimating the effect of inward FDI centrality and inward FDI stocks on carbon emissions. Each cell reports the elasticity coefficient, with the panel-corrected standard error in parentheses and the 95% confidence intervals in brackets. Model 1a reports the fully specified model, model 2a adds an interaction term between FDI stock and Global North status, and model 3a includes an interaction term between FDI centrality and Global North status. Models 1b, 2b, and 3b replicate these models with the lagged dependent variable instead of the AR(1) specification. Table 2 reports the findings for total carbon emissions, while Table 3 reports the findings for the second dependent variable, carbon emissions per unit of GDP.

The results of Model 1a and 1b in Table 2 indicate that total emissions are positively associated with both inward FDI centrality and inward FDI stocks. A 1% increase in FDI centrality is associated with a 1.244% increase in total emissions in Model 1a and a 1.016% increase in Model 1b (overlapping confidence intervals), while a 1% increase in FDI stocks is associated with a 0.079% increase in emissions in Model 1a and a 0.042% increase in Model 1b (overlapping confidence intervals). The results of Models 2a through 3b show that the positive effects of FDI stock and FDI centrality significantly decline among the Global North nations. That is, while growth in the volume of FDI stock and FDI network embeddedness are both significantly associated with greater carbon emissions among the Global South nations, this relationship vanishes among the Global North nations. Figs. 1 and 2 illustrate these differences for FDI stock and FDI centrality by presenting the predictive margins based on models 2a and 3a in Table 2. At low levels of FDI stock or FDI centrality, there is not much difference between the emissions of Global North and Global South nations. As FDI stock or FDI centrality grows, however, Global South nations increase their emissions moderately to substantially, while the impact within Global North nations is negligible.

Turning to the analysis of carbon emissions per unit of GDP in Table 3, for Models 1a and 1b, we also find that FDI centrality and FDI stocks both have positive and statistically significant effects. In particular, a 1% increase in FDI network centrality is associated with a 0.412% increase in emissions per unit of GDP in Model 1a, and a 0.325% increase in Model 1b (overlapping confidence intervals). For FDI stocks, a 1% increase leads to a 0.026% increase in emissions per unit of GDP in Model 1a and a 0.019% increase in Model 1b (also with overlapping confidence intervals). The inclusion of the interactions in Models 2a through 3b generally suggests that the effects of both key predictors on carbon emissions per unit of GDP differ for Global North nations than for Global South nations. Figs. 3 and 4 illustrate these differences for FDI stock and FDI centrality by presenting the predictive margins based on models 2a and 3a in Table 3. Similar to the findings for the total emissions analysis, at lower levels of FDI stock or FDI centrality, there is minimal difference between the emissions per unit of GDP of Global North and Global South nations. As FDI stock or FDI centrality grows, however, Global South nations increase their emissions per unit of GDP quite substantially, while the impact within Global North nations remains relatively flat.

3.1. Sensitivity analyses

When analyzing FDI network data, it is difficult to distinguish between substantive investment and financial engineering, the latter of which is primarily motivated by tax avoidance (e.g., offshore investing or channeling FDI through regional investment hubs). Multinational enterprises (MNEs) have become more responsive to taxation over time by shifting profits to a low-tax jurisdiction through debt allocation, transfer pricing, or corporate inversions [50]. Thus, many MNEs are attracted to "offshore financial centers" (OFCs), which refer to nation-state jurisdictions that attract MNEs through low taxation and lax regulation. OFCs not only provide tax avoidance for MNEs, but also an escape from public scrutiny over their operations [51]. Affiliates in OFCs

Table 2
Elasticity coefficients for regression of CO_2 emissions.

	Model 1a	Model 1b	Model 2a	Model 2b	Model 3a	Model 3b
GDP PC	0.642***	0.240	0.678***	0.264	0.633***	0.239
	(0.155)	(0.134)	(0.150)	(0.137)	(0.157)	(0.135)
	[0.338 to 0.946]	[−0.023 to 0.503]	[0.384 to 0.972]	[−0.005 to 0.532]	[0.326 to 0.940]	[−0.024 to 0.503]
Non-dependent population	1.607**	0.972*	1.399**	0.890*	1.547**	0.943**
	(0.510)	(0.396)	(0.494)	(0.389)	(0.463)	(0.363)
	[0.608 to 2.606]	[0.196 to 1.749]	[0.430 to 2.368]	[0.127 to 1.654]	[0.640 to 2.454]	[0.232 to 1.654]
Urban population	1.972***	1.001**	1.993***	1.042**	1.920***	0.988**
	(0.402)	(0.368)	(0.379)	(0.375)	(0.391)	(0.369)
	[1.184 to 2.761]	[0.280 to 1.723]	[1.250 to 2.736]	[0.308 to 1.777]	[1.152 to 2.687]	[0.265 to 1.712]
Services (% of GDP)	−0.205	−0.200	−0.300*	−0.255*	−0.216	−0.204
	(0.143)	(0.117)	(0.143)	(0.123)	(0.141)	(0.117)
	[−0.486 to 0.076]	[−0.429 to 0.028]	[−0.579 to −0.020]	[−0.497 to −0.013]	[−0.492 to 0.061]	[−0.434 to 0.025]
Trade (% of GDP)	0.123*	0.119*	0.119*	0.114*	0.126*	0.124*
	(0.060)	(0.051)	(0.060)	(0.051)	(0.056)	(0.050)
	[0.005 to 0.242]	[0.018 to 0.220]	[0.001 to 0.237]	[0.014 to 0.215]	[0.015 to 0.236]	[0.027 to 0.222]
Total population	1.262***	0.533	1.286***	0.555	1.223***	0.527
	(0.302)	(0.292)	(0.294)	(0.293)	(0.303)	(0.292)
	[0.670 to 1.855]	[−0.040 to 1.106]	[0.710 to 1.863]	[−0.019 to 1.129]	[0.628 to 1.817]	[−0.045 to 1.099]
FDI rate	−1.522	−0.622	−1.116	−0.253	−1.667	−0.826
	(1.085)	(0.985)	(1.184)	(1.090)	(1.109)	(0.967)
	[−3.649 to 0.605]	[−2.551 to 1.308]	[−3.435 to 1.204]	[−2.389 to 1.882]	[−3.840 to 0.506]	[−2.722 to 1.070]
FDI stock	0.079**	0.042*	0.110**	0.060*	0.068*	0.033
	(0.027)	(0.021)	(0.033)	(0.027)	(0.026)	(0.021)
	[0.027 to 0.131]	[0.000 to 0.084]	[0.046 to 0.174]	[0.007 to 0.113]	[0.017 to 0.120]	[−0.009 to 0.075]
FDI centrality	1.244**	1.016**	1.121**	0.921**	2.909***	2.125**
	(0.421)	(0.323)	(0.397)	(0.314)	(0.722)	(0.622)
	[0.420 to 2.069]	[0.383 to 1.649]	[0.343 to 1.899]	[0.306 to 1.535]	[1.493 to 4.324]	[0.905 to 3.345]
FDI stock x Global North			−0.182**	−0.091*		
			(0.053)	(0.045)		
			[−0.286 to −0.078]	[−0.181 to −0.003]		
FDI centrality x Global North					−3.148***	−2.225**
					(0.845)	(0.754)
					[−4.804 to −1.492]	[−3.704 to −0.747]
Lagged DV		0.522***		0.511***		0.512***
		(0.109)		(0.111)		(0.108)
		[0.308 to 0.735]		[0.293 to 0.728]		[0.300 to 0.725]
R^2	0.997	0.998	0.997	0.998	0.997	0.998

* $p < .05$, ** $p < .01$, *** $p < .001$ (two-tailed tests).

Notes: N = 616 (77 States). Each cell reports the elasticity coefficient, with the panel-corrected standard error in parentheses, and the 95% confidence intervals in brackets. Models 1a, 2a, and 3a correct for first-order autocorrelation within panels, with AR1 disturbances as common to all panels. All non-binary variables are logged. All models include nation-specific and year-specific intercepts.

Table 3
Elasticity coefficients for regression of CO_2 emissions per unit of GDP.

	Model 1a	Model 1b	Model 2a	Model 2b	Model 3a	Model 3b
GDP PC	0.001	−0.052	0.006	−0.049	−0.004	−0.053
	(0.049)	(0.029)	(0.049)	(0.029)	(0.049)	(0.030)
	[−0.095 to 0.097]	[−0.109 to 0.005]	[−0.091 to 0.103]	[−0.106 to 0.009]	[−0.101 to 0.093]	[−0.111 to 0.005]
Non-dependent population	0.473*	0.345*	0.439*	0.328*	0.451*	0.333*
	(0.211)	(0.144)	(0.215)	(0.146)	(0.199)	(0.135)
	[0.059 to 0.887]	[0.064 to 0.627]	[0.017 to 0.861]	[0.042 to 0.614]	[0.060 to 0.842]	[0.069 to 0.597]
Urban population	0.282**	0.155	0.288**	0.161	0.268*	0.148
	(0.106)	(0.099)	(0.103)	(0.100)	(0.110)	(0.100)
	[0.074 to 0.489]	[−0.039 to 0.349]	[0.086 to 0.489]	[−0.035 to 0.356]	[0.053 to 0.483]	[−0.047 to 0.344]
Services (% of GDP)	−0.022	−0.005	−0.038	−0.016	−0.026	−0.007
	(0.047)	(0.034)	(0.048)	(0.036)	(0.047)	(0.034)
	[−0.115 to 0.071]	[−0.072 to 0.062]	[−0.133 to 0.056]	[−0.086 to 0.054]	[−0.119 to 0.067]	[−0.074 to 0.061]
Trade (% of GDP)	0.032	0.028	0.031	0.027	0.034	0.030
	(0.026)	(0.020)	(0.026)	(0.020)	(0.025)	(0.019)
	[−0.019 to 0.083]	[−0.012 to 0.067]	[−0.020 to 0.083]	[−0.013 to 0.067]	[−0.015 to 0.083]	[−0.008 to 0.067]
FDI rate	−0.037	0.264	0.034	0.341	−0.080	0.208
	(0.444)	(0.427)	(0.468)	(0.457)	(0.444)	(0.427)
	[−0.908 to 0.834]	[−0.573 to 1.100]	[−0.883 to 0.950]	[−0.555 to 1.237]	[−0.951 to 0.790]	[−0.628 to 1.045]
FDI stock	0.026*	0.019*	0.031*	0.022*	0.022	0.016
	(0.012)	(0.009)	(0.014)	(0.010)	(0.012)	(0.008)
	[0.002 to 0.050]	[0.002 to 0.036]	[0.004 to 0.059]	[0.002 to 0.043]	[0.000 to 0.045]	[0.000 to 0.032]
FDI centrality	0.412*	0.325*	0.392*	0.305*	0.899*	0.631*
	(0.194)	(0.137)	(0.187)	(0.133)	(0.379)	(0.257)
	[0.033 to 0.792]	[0.057 to 0.592]	[0.025 to 0.759]	[0.044 to 0.565]	[0.157 to 1.642]	[0.128 to 1.134]
FDI stock x Global North			−0.032*	−0.018		
			(0.014)	(0.011)		
			[−0.058 to −0.005]	[−0.040 to 0.004]		
FDI centrality x Global North					−0.937*	−0.615*
					(0.372)	(0.259)
					[−1.667 to −0.207]	[−1.122 to −0.108]
Lagged DV		0.537***		0.534***		0.529***
		(0.139)		(0.140)		(0.140)
		[0.264 to 0.810]		[0.260 to 0.808]		[0.254 to 0.803]
R^2	0.967	0.987	0.968	0.987	0.967	0.987

* $p < .05$, ** $p < .01$, *** $p < .001$ (two-tailed tests).

Notes: N = 616 (77 Nations). Each cell reports the elasticity coefficient, with the panel-corrected standard error in parentheses, and the 95% confidence intervals in brackets. Models 1a, 2a, and 3a correct for first-order autocorrelation within panels, with AR1 disturbances as common to all panels. All non-binary variables are logged. All models include state-specific and year-specific intercepts.

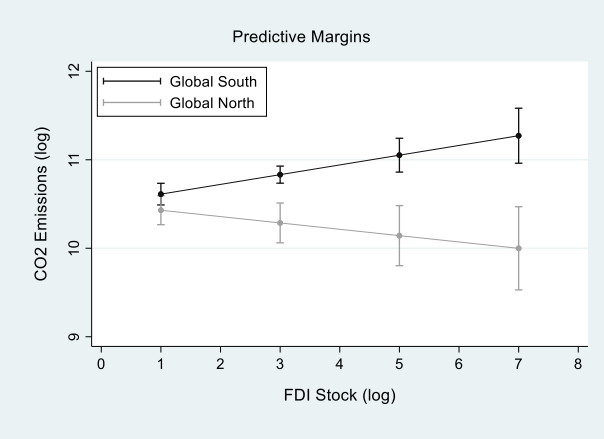

Fig. 1. The effect of FDI Stock on CO_2 emissions.
Note: Predictive margins based on model 2a, Table 2.

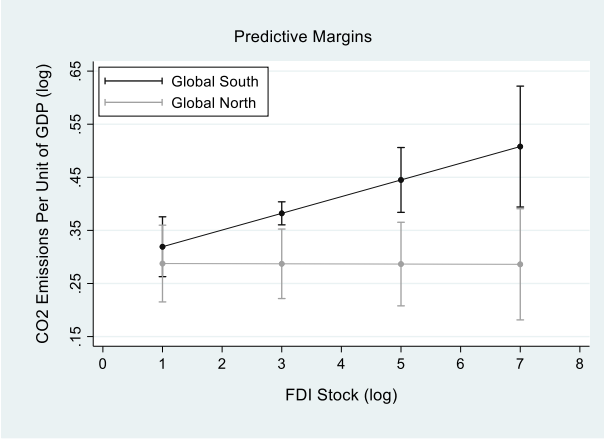

Fig. 3. The Effect of FDI stock on CO_2 emissions per unit of GDP.
Note: Predictive margins based on model 2a, Table 3.

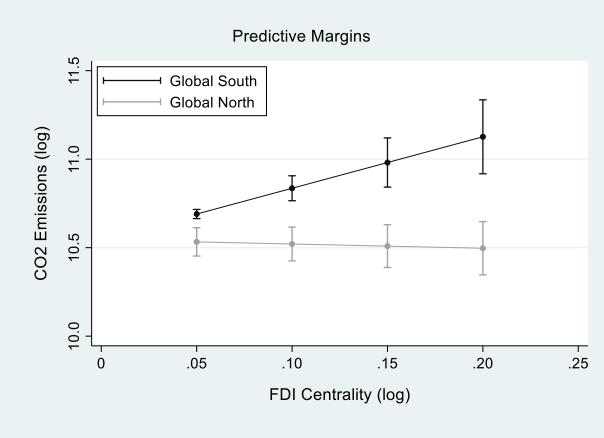

Fig. 2. The effect of FDI centrality on CO_2 emissions.
Note: Predictive margins based on model 3a, Table 2.

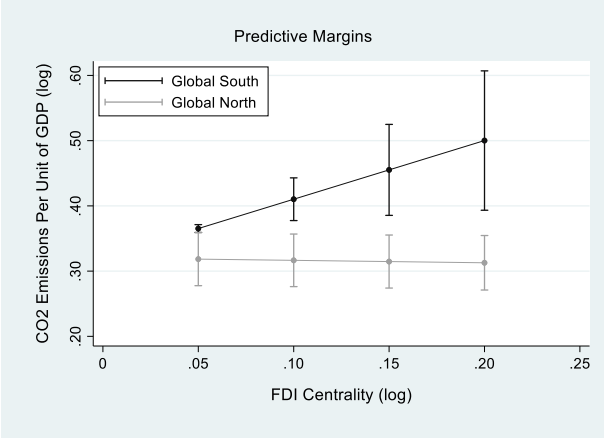

Fig. 4. The effect of FDI centrality on CO_2 emissions per unit of GDP.
Note: Predictive margins based on model 3a, Table 3.

are often referred to as Special Purpose Entities (SPEs). Very little real economic activity occurs in SPEs, and their presence significantly inflates FDI values. SPEs feature few or no employees, little or no physical presence, and little or no production in the host economy [50].

To account for this potential problem, we replicated our fully specified models while excluding nations that function as OFCs. Our list of OFCs comes from Garcia-Bernardo et al. [51], who identify 24 sink-OFCs (tax havens that attract and retain foreign capital) and 5 conduit-OFCs (intermediate jurisdictions used to route investments).[4] When excluding the 11 OFCs in our sample (Cyprus, Hong Kong, Ireland, Luxembourg, Malta, Mauritius, Netherlands, Seychelles, Singapore, Switzerland, and United Kingdom), the results remain substantively consistent with the reported findings in Tables 2 and 3. Taking matters one step further, we also replicated our procedure for calculating inward FDI network centrality by dropping the 29 OFCs from our original network data for the years 2009 and 2017. The correlations between our original scores and the OFC-purged scores are very high ($r = 0.991$ in 2009; $r = 0.991$ in 2017). We also examined whether each country's change in centrality between 2009 and 2017 was influenced by the establishment of OFCs during the sample period. Again, though, the removal of OFCs does not substantially alter the correlation in each country's change score ($r = 0.971$).

Finally, we re-estimated all models in Stata using the xtreg suite of commands with clustered robust standard errors, where the country fixed effects are estimated with the within estimator [41], and we include year intercepts for the time fixed effects. The results are substantively consistent with our reported findings in Tables 2 and 3.

4. Conclusion

By focusing on the extent to which FDI network centrality and FDI stocks are associated with carbon emissions in Global South nations compared to Global North nations, our preliminary analysis illustrates a new direction to the study of foreign investment and the environment in particular, and economic globalization and the environment in general. The results suggest that total carbon emissions and emissions per unit of GDP are both positively associated with inward FDI stocks and FDI network centrality for the overall global sample of nations, but these positive associations are much more pronounced for Global South nations than for Global North nations, and the results are robust to multiple model specifications and sensitivity analyses. Overall, the findings are consistent with the arguments that foreign investment facilitates the outsourcing of inefficient and environmentally harmful extraction and

[4] Twenty-four nations are classified as sink-OFCs: Anguilla, Bahamas, Belize, Bermuda, British Virgin Islands, Cayman Islands, Curacao, Cyprus, Gibraltar, Guyana, Hong Kong, Jersey, Liberia, Lichtenstein, Luxembourg, Malta, Marshall Islands, Mauritius, Monaco, Nauru, Saint Vincent and Grenadines, Samoa, Seychelles, and Taiwan. The following five are classified as conduit-OFCs: Ireland, Netherlands, Singapore, Switzerland, and United Kingdom.

production processes, leading to growth in energy consumption and concomitant carbon emissions for receiving nations, especially in the Global South.

Our analysis is preliminary and has limitations, which point to some next steps for this new approach to the study of FDI and the environment. Current data availability constrains the number of nations included as well as the time coverage and statistical modeling options. This also disallows for considering more fine-grained locational differences (e.g., regional variation) in the associations between our predictors and outcomes as well as sector-level differences in the FDI network and amount of FDI stocks. These limitations are addressable once additional and more nuanced data become available.

While we focus on multiple measures of carbon emissions resulting from the burning of fossil fuels, future research should consider how other environmental outcomes, such as deforestation, ambient air pollution, direct resource consumption, and industrial water pollution, are associated with levels of FDI stocks and FDI network centrality. This line of inquiry could also be expanded to include social and economic outcomes, such as income inequality and population health, as well as broader sustainability indicators, including the carbon intensity of human well-being. Finally, while additional research is warranted on these direct associations, future investigations should also consider how different political-economic and social factors might act as moderators that amplify or mitigate the relationships among environmental conditions, FDI network centrality, and FDI stocks.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Sample

	Global North		Global North		Global North
Australia	✓	Honduras		Nigeria	
Austria	✓	Hong Kong		Norway	✓
Azerbaijan		Hungary		Pakistan	
Bangladesh		Iceland	✓	Paraguay	
Belarus		Indonesia		Philippines	
Belgium	✓	Ireland	✓	Poland	
Bhutan		Israel	✓	Portugal	✓
Bolivia		Japan	✓	Romania	
Bosnia		Kazakhstan		Russia	
Botswana		Kyrgyzstan		Serbia	
Bulgaria		Latvia		Seychelles	
Canada	✓	Lithuania		Singapore	
Chile		Luxembourg	✓	Slovakia	
China		Macao		Slovenia	✓
Costa Rica		Macedonia		South Africa	
Croatia		Malaysia		South Korea	✓
Cyprus		Malta		Spain	✓
Czech Republic	✓	Mauritius		Sweden	✓
Denmark	✓	Mexico		Switzerland	✓
El Salvador		Moldova		Thailand	
Estonia		Mongolia		Turkey	
Finland	✓	Morocco		Uganda	
Georgia		Mozambique		Ukraine	
Germany	✓	Nepal		United Kingdom	✓
Greece	✓	Netherlands	✓	United States	✓
		New Zealand	✓	Zambia	

Note: "Global North" refers to OECD members with a GDP PC of $20,000 or greater in 2016.

Appendix B. Correlation matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) CO_2 emissions	–										
(2) CO_2 emissions per unit of GDP	0.213	–									
(3) GDP PC	0.239	−0.500	–								
(4) Non-dependent population	0.155	0.166	0.469	–							
(5) Urban population	0.278	−0.245	0.809	0.469	–						
(6) Services (% of GDP)	0.023	−0.470	0.678	0.295	0.589	–					
(7) Trade (% of GDP)	−0.425	−0.075	0.288	0.427	0.286	0.279	–				
(8) Total population	0.835	0.184	−0.225	−0.235	−0.156	−0.243	−0.644	–			
(9) FDI rate	−0.158	0.137	−0.239	−0.100	−0.229	−0.225	0.004	−0.057	–		
(10) FDI stock	−0.286	−0.124	0.348	0.249	0.391	0.446	0.690	−0.494	−0.199	–	
(11) FDI centrality	0.760	0.045	0.419	0.310	0.356	0.211	−0.073	0.512	−0.152	0.041	–

Note: $N = 616$ (77 nations).

References

[1] David Brady, Jason Beckfield, Wei Zhao, The consequences of economic globalization for affluent democracies, Annu. Rev. Sociol. 33 (2007) 313–334.

[2] Christopher Chase-Dunn, Yukio Kawano, Benjamin Brewer, Trade globalization since 1795: waves of integration in the world-system, Am. Sociol. Rev. 65 (1) (2000) 77–95.

[3] Rob Clark, Matthew Mahutga, Explaining the trade-growth link: assessing diffusion-based and structure-based models of exchange, Soc. Sci. Res. 42 (2) (2013) 401–417.
[4] Ino Rossi, Frontiers of Globalization Research: Theoretical and Methodological Approaches, Springer, New York, NY, 2007.
[5] Saskia Sassen, A Sociology of Globalization, W.W. Norton, New York, NY, 2007.
[6] Jennifer Givens, Ecologically unequal exchange and the carbon intensity of well-being, 1990–2011, Environ. Sociology 4 (3) (2018) 311–324.
[7] Xiaorui Huang, Ecologically unequal exchange, recessions, and climate change: a longitudinal study, Soc. Sci. Res. 73 (2018) 1–12.
[8] James Rice, Ecological unequal exchange: international trade and uneven utilization of environmental space in the world system, Social Forces 85 (3) (2007) 1369–1392.
[9] Ryan Thombs, The transnational tilt of the treadmill and the role of trade openness on carbon emissions: a comparative international study, 1965–2010, Sociol. Forum 33 (2) (2018) 422–442.
[10] Daniell Vesia, Matthew Mahutga, Bonnie Khanh Ha Bui, Flattening the curve? The structure of the natural resource exchange network and CO_2 emissions, Soc. Networks (2021), https://doi.org/10.1016/j.socnet.2021.07.004.
[11] Peter Grimes, Jeffrey Kentor, Exporting the greenhouse: foreign capital penetration and CO_2 emissions 1980–1996, J. World-Systems Res. 9 (2) (2003) 261–275.
[12] Andrew Jorgenson, Does foreign investment harm the air we breathe and the water we drink? A cross-national Study of carbon dioxide emissions and organic water pollution in less-developed countries, 1975–2000, Organ. Environ. 20 (2) (2007) 137–156.
[13] Andrew Jorgenson, The transnational organization of production, the scale of degradation, and ecoefficiency: a study of carbon dioxide emissions in less-developed countries, Hum. Ecol. Rev. 16 (1) (2009) 64–74.
[14] Andrew Jorgenson, Christopher Dick, Matthew Mahutga, Foreign investment dependence and the environment: an ecostructural approach, Soc. Probl. 54 (3) (2007) 371–394.
[15] Thai-Ha Le, Donghyun Park, What drives energy insecurity across the world? A panel data analysis, Energy Res. Soc. Sci. 77 (2021), 102093.
[16] Laura McKinney, Foreign direct investment, development, and overshoot, Soc. Sci. Res. 47 (2014) 121–133.
[17] Steven Mejia, Foreign direct investment dependence and the neglected greenhouse gas: a cross-national Analysis of nitrous oxide emissions in developing countries, 1990–2014, Sociol. Perspect. 64 (2) (2021) 223–237.
[18] Steven Mejia, Does foreign capital dependence affect carbon dioxide emissions in less-developed countries? A cross-national analysis, 1980–2014, Soc. Sci. Q. (2021), https://doi.org/10.1111/ssqu.13034.
[19] Annika Rieger, Doing business and increasing emissions? An exploratory analysis of the impact of business regulation on carbon dioxide emissions, Hum. Ecol. Rev. 25 (1) (2019) 69–85.
[20] Wei Zheng, Pei Chen, The political economy of air pollution: local development, sustainability, and political incentives in China, Energy Res. Soc. Sci. 69 (2020), 101707.
[21] Rob Clark, Jeffrey Kentor, Foreign capital and economic growth: a social network analysis, 2001–2017, Sociol. Perspect. (2021), https://doi.org/10.1177/07311214211035150.
[22] Jeffrey Kentor, Peter Grimes, Foreign investment dependence and the environment: a global perspective, in: Edward Kick, Andrew Jorgenson (Eds.), Globalization and the Environment, Brill, Leiden and Boston, 2006.
[23] Benjamin Sovacool, John Axsen, Steve Sorrell, Promoting novelty, rigor, and style in energy social science: towards codes of practice for appropriate methods and research design, Energy Res. Soc. Sci. 45 (2018) 12–42.
[24] Matthew Cole, Robert Elliott, Liyun Zhang, Foreign direct investment and the environment, Annu. Rev. Environ. Resour. 42 (2017) 465–487.
[25] Nagesh Kumar, Globalization, Foreign Direct Investment, and Technology Transfers, Routledge Press, London, 2003.
[26] Arthur Mol, Globalization and Environmental Reform: The Ecological Modernization of the Global Economy, MIT Press, Cambridge, MA, 2003.
[27] Stephen Bunker, Paul Ciccantell, Globalization and the Race for Resources, Johns Hopkins University Press, Baltimore, MD, 2005.
[28] Christopher Dick, Do environmental characteristics influence foreign direct investment growth? A cross-national study, 1990–2000, Int. J. Comp. Sociol. 51 (3) (2010) 192–210.
[29] William Robinson, A Theory of Global Capitalism, Johns Hopkins University Press, Baltimore, MD, 2004.
[30] Margarita Balmaceda, Differentiation, materiality, and power: towards a political economy of fossil fuels, Energy Res. Soc. Sci. 39 (2018) 130–140.
[31] Debra Davidson, Exnovating for a renewable energy transition, Nat. Energy 4 (4) (2019) 254–256.
[32] Intergovernmental Panel on Climate Change, Climate Change 2014: Synthesis Report. Contribution of Working Groups I, *II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, Geneva, 2014.
[33] Intergovernmental Panel on Climate Change, Climate Change 2021: The Physical Science Basis. *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, 2021.
[34] Georges Alexandre Lenferna, Can we equitably manage the end of the fossil fuel era? Energy Res. Soc. Sci. 35 (2018) 217–223.
[35] Eugene Rosa, Thomas Dietz, Human drivers of national greenhouse gas emissions, Nat. Clim. Chang. 2 (2012) 581–586.
[36] Ryan Thombs, When democracy meets energy transitions: a typology of social power and energy system scale, Energy Res. Soc. Sci. 52 (2019) 159–168.
[37] Richard York, Shannon Bell, Energy transitions or additions?: why a transition from fossil fuels requires more than the growth of renewable energy, Energy Res. Soc. Sci. 51 (2019) 40–43.
[38] Nathaniel Beck, Time-series–cross-section data: what have we learned in the past few years? Annu. Rev. Polit. Sci. 4 (2001) 271–293.
[39] Nathaniel Beck, Jonathan Katz, What to do (and not do) with time-series cross-section data, Am. Pol. Sci. Rev. 89 (3) (1995) 634–647.
[40] Mark Pickup, Introduction to Time Series Analysis, Sage, Thousand Oaks, CA, 2014.
[41] Paul Allison, Fixed Effects Regression Models, Sage, Thousand Oaks, CA, 2009.
[42] Thomas Dietz, Rachael Shwom, Cameron Whitley, Climate change and society, Annu. Rev. Sociol. 46 (2020) 135–158.
[43] Eugene Rosa, Thomas Rudel, Richard York, Andrew Jorgenson, Thomas Dietz, The human (anthropogenic) driving forces of global climate change, in: Riley Dunlap, Robert Brulle (Eds.), Climate Change and Society: Sociological Perspectives, Oxford University Press, New York, NY, 2015.
[44] IMF, Coordinated Direct Investment Survey, Retrieved February 2019, http://data.imf.org, 2019.
[45] Rob Clark, Jason Beckfield, A new trichotomous measure of world-system position using the international trade network, Int. J. Comp. Sociol. 50 (1) (2009) 5–38.
[46] Stephen Borgatti, Martin Everett, Linton Freeman, UCINET 6 for Windows: Software for Social Network Analysis, Analytic Technologies, Lexington, KY, 2002.
[47] UNCTAD, UNCTADstat, Retrieved June 2019, http://unctad.org, 2019.
[48] William Dixon, Terry Boswell, Dependency, disarticulation, and denominator effects: another look at foreign capital penetration, Am. J. Sociol. 102 (2) (1996) 543–562.
[49] Glenn Firebaugh, Growth effects of foreign and domestic investment, Am. J. Sociol. 98 (1) (1992) 105–130.
[50] Jannick Damgaard, Thomas Elkjaer, The global FDI network: searching for ultimate investors, IMF Working Paper No. 17/258 (2017).
[51] Javier Garcia-Bernardo, Jan Fichtner, Frank Takes, Eelke Heemskerk, Uncovering offshore financial centers: conduits and sinks in the global corporate ownership network, Sci. Rep. 7 (2017) 6246.