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The Political Economy of the Water Footprint: A Cross-National Analysis of Ecologically Unequal Exchange

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Abstract: Water scarcity is an important social and ecological issue that is becoming increasingly problematic with the onset of climate change. This study explores the extent to which water resources in developing countries are affected by the vertical flow of exports to high-income countries. In examining this question, the authors engage the sociological theory of ecologically unequal exchange, which argues that high-income countries are able to partially externalize the environmental costs of their consumption to lower-income countries. The authors use a relatively new and underutilized measure of water usage, the water footprint, which quantifies the amount of water used in the entire production process. Ordinary least squares (OLS) and robust regression techniques are employed in the cross-national analysis of 138 countries. The results provide partial support of the propositions of ecologically unequal exchange theory. In particular, the results highlight the importance of structural position in the global economy for understanding the effects of trade on water resources.

Keywords: environment; ecologically unequal exchange; development; water; water footprint; globalization

1. Introduction

In recent years, a considerable amount of cross-national research in environmental social science has been dedicated to understanding how the structure of the global economy unevenly affects the natural environment. This research includes studies on anthropogenic carbon emissions, air pollution, deforestation, and overall environmental pressure as measured by the ecological footprint [1–5]. However, within cross-national and comparative research, there have been relatively few studies discussing the structural factors that influence water use and scarcity. That water has not been more extensively studied in cross-national and comparative research is surprising given that it is a critical resource for the existence of life and access to freshwater is becoming scarcer, which has numerous socioeconomic implications [6].

According to Peter Gleick [7] (p. 1), "At least 780 million people do not have access to clean drinking water, some 2.5 billion people lack access to safe sanitation systems, and 2–5 million people—mainly children—die as a result of preventable diseases every year." Beyond that, "water withdrawals for agriculture, industry, and domestic purposes exceed 75 percent of river flows" [7] (p. 2). A more recent analysis indicates that "about 71% of the global population ... lives under conditions of moderate to severe water scarcity ... at least 1 month of the year" [8] (p. 3). With climate change, these issues are expected to worsen with time, especially in regard to drought [9,10]. While it may be tempting to attribute water problems solely to population growth, the United Nations Development

Program [11] points out that since the Second World War, water use has been growing twice as fast as population. One possible explanation for increased intensity in water usage comes from political-economic processes. For instance, Longo and York [12] argue that economic development and different connections to the global economy are key factors to understanding changes in water use.

The limited cross-national sociological studies that have examined water have focused either on organic water pollution [13–16] or freshwater withdrawals [12]. However, these studies note that studying water issues at this level of analysis has proven difficult. One explanation for the dearth of research is that the data on water at the national level are hard to come by and often problematic due to missing information. Furthermore, while these data allow researchers to examine water cross-nationally, they are only able to examine specific water issues, namely water pollution or water scarcity. This study seeks to address these problems by using a relatively new indicator of water usage: the water footprint [17]. The water footprint allows researchers to examine water used in the entire production process by taking into account virtual water as well as the origin of water usage [18].

A recent Special Issue of *Sustainability* delved deeply into implications of water footprint analysis (see volume 8, issue number 1). The articles demonstrated that the water footprint is becoming an increasingly global phenomenon. As supply and commodity chains become more complex so too does water usage [19]. While previous research on the water footprint has investigated the virtual water trade, nations' consumption patterns, the economic efficiency of virtual water flows, etc., thus far, the water footprint has not been interrogated in relation to unequal trade relations [20–25]. Jorgenson [26] (p. 2) suggests that "international political economy perspectives [like ecologically unequal exchange]" has "much to offer for theoretically-engaged research on environment and development research."

This study engages ecologically unequal exchange, a core theoretical perspective within contemporary environment and development literature, in an attempt to further understand the implications of the structure of the global economic system on the water footprint of nations. In doing this, we hope to shed light on the importance of understanding water as a finite resource and how unequal trade relationships between high-income and lower-income countries potentially affect it. We begin by providing a brief overview on water resources and water use cross-nationally. Next, we outline key tenets of ecologically unequal exchange theory. Then we discuss the concept of the water footprint, followed by an overview of the data and methodologies used in this study. We then present our results which provide support for some of the propositions of ecologically unequal exchange theory. Specifically, our findings indicate that trade to high-income countries does not appear to increase the water footprint for lower-income countries. These results highlight that position in the global economy matters when examining the effect of trade on the water footprint and indicate that ecologically unequal exchange is not necessarily a zero-sum game. Specifically, water resources in high-income countries seem to benefit from trade with other high-income countries. This is not the case for lower-income countries. This finding supports previous ecologically unequal exchange claims that "structural relationships between nations partly shape their uneven environmental demands" [27] (p. 229). We conclude with a brief discussion of the results and their theoretical implications and offer some suggestions for future inquiry.

2. Overview of Water Resources and Water Use

Thinking about water as a limited resource may seem counter-intuitive at first. After all, approximately 71 percent of the surface of the Earth is water [28]. While this seems like a large amount, most of that water is not suitable for human consumption. Of the water on Earth, oceans make up 96.5 percent and glaciers and ice caps make up another 1.7 percent. Water that is suitable and accessible for human consumption, in the form of groundwater, lakes and rivers, makes up roughly 0.77 of one percent [28].

Most water withdrawals around the world are used in the agriculture sector. Crop production uses approximately 11 percent of the global land surface and around 70 percent of water withdrawn from freshwater sources [29]. Approximately 15 percent of global water resources are used for industrial production [30]. For industry, water is typically used in one of two ways. Either it is actually used within a product, such as the production of beverages, or it is also used as an aid in production in the form of heating or cooling, cleaning machinery, or waste disposal [12,31]. While agriculture uses more water worldwide in terms of withdrawals, industry has a very large impact on water resources due to pollution through the introduction of toxins, heavy metals, and petroleum products [12,13,16]. Domestic water use is accountable for roughly 10 percent of global water withdrawals. These uses typically include cooking, cleaning, bathing, and landscaping [31]. Because domestic water use is such a small percentage of overall water use globally, policies focusing solely on encouraging individuals to change their water use behaviors may be relatively ineffectual. These sorts of policies overlook larger structural dynamics, such as global trade and economic development, that drive water usage and point to the utility of sociological thought when exploring these issues.

Access to water is not evenly distributed across the planet. According to the United Nations Development Program [11], at least 43 nations face water stress or scarcity and this number is estimated to increase. More recent analyses suggest that around two-thirds of the global population experience severe water scarcity at least one month a year, mostly in the developing world [8]. More than one billion people, primarily in the developing world, do not have suitable access to drinking water and around 90 percent of infectious diseases in the developing world are due to polluted water [32].

There are a number of contributing factors to the increasing problem of water scarcity. According to Longo and York [12] freshwater sources such as rivers, streams, and groundwater, are being polluted and depleted at unsustainable rates as a result of political economic processes. For example, urbanization and development projects (e.g., massive dam projects) decimate wetlands and watersheds, destroying important ecosystem services and sources of usable water. While these problems have affected people and communities all across the world, they are particularly problematic for developing countries. In fact, it has been argued that a country's level of development may be more important for understanding their access to water than the actual amount of water available [7,12]. Partially, this is because developed countries, even though they may not have large amounts of water within their borders, are better able to provide access to water for the majority of their population. Developing countries, in particular in growing urban areas, often lack the resources and infrastructure to provide basic public services [33]. To fully understand this phenomenon, though, we must consider other factors driving water usage, including the structure of the global economy.

3. Ecologically Unequal Exchange

Ecologically unequal exchange theory is historically rooted in the dependency, world-systems, and unequal exchange theoretical traditions. A central tenet of each of these traditions is that the organization of the global economy influences the relational characteristics of the modern interstate system. World-systems approaches demonstrate that the global system of states is hierarchical [34]. Within this interstate system, economic value tends to be transferred in an unequal way. Traditional unequal exchange studies focus on the process through which an international division of labor is created in which some nations tend to benefit more than others [35,36]. Building off of these discussions, ecologically unequal exchange takes into account how ecological value is transferred in these unequal relationships.

Ecologically unequal exchange theory is influenced in large part by the work of sociologist Stephen Bunker. Bunker [35] studied the development of industries focused on extraction of raw materials in the Amazon. Bunker's research [37,38] demonstrates that power and unequal relationships in the international system of states has had ecological implications for developing countries. More developed countries are able to utilize their structurally advantageous position in order to reorganize the focus of economies in developing countries towards raw material extraction and export. Building on these insights, environmental sociologists have demonstrated that a feature of the hierarchical interstate system is not just the unequal exchange of labor, but the coterminous unequal exchange of labor and nature. For instance, Clark and Foster [39] demonstrate that the historical creation of the division of labor is intimately tied to an international division of nature where the natural wealth of one area is removed from a local ecosystem to be transported to another location to expand private riches.

Generally speaking, ecologically unequal exchange presents a structural theory highlighting the ability of high-income countries to partially externalize their environmental costs of consumption and production to lower-income countries [13,40,41]. This externalization of environmental costs, also called environmental load displacement [40], allows for consumption levels in high-income countries to increase without significantly affecting their intra-national environmental burdens. Instead, this problem is passed on to developing nations where much of the extraction and waste dumping occurs [42–45]. This is particularly problematic because the earth has a set of biophysical limits which are increasingly being disrupted throughout the world [46]. These processes disproportionately overburden the environmental space of developing countries and disrupt the biochemical processes of local ecosystems, impacting their ability to act as sinks or reducing biological productivity [47].

One of the mechanisms that allows for this to occur is the focus of developing countries, for a variety of reasons, to pursue economic development through more export-oriented production [48]. Some studies in the ecologically unequal exchange tradition examine how the structure of the economy in developing countries is shaped and taken advantage of by more powerful countries. Developing countries' economies are reorganized by both internal and external forces towards exporting various low-value commodities, such as raw materials [37]. Raw materials, by themselves, are not worth that much monetarily on the global market, which leaves developing countries in a position of vulnerability due to the inability to accumulate capital. Instead, value is added further up the commodity chain in more-developed regions of the world [42]. Because the mainstream development paradigm measures progress through monetary means, these countries need to increase their extraction and exportation to make up for the lack of surplus value generated by raw material extraction leading to the internationalization and speeding up of environmental degradation within their borders [38,45]. In their pursuit of economic growth, developing countries also turn towards the production of commodities for export. In doing so, these countries often pursue transnational corporations to locate within their country. This process is a part of what has been termed the "globalization project" [49]. Developing countries often relax their environmental and labor regulations in order to attract transnational corporations [14,43,50]. Furthermore, international finance institutions, such as the World Bank and the International Monetary Fund (IMF), through mechanisms like structural adjustment loans and trade liberalization, facilitate the reorganization of economies in lower-income countries towards the intensification of production for export, leading to a growth in environmental problems [51,52]. In all, these processes tend to result in the vertical flow of ecological value from lower-income countries to high-income countries and reinforce unequal power relationships between them [41]. Through these unequal power relationships, developed countries are allowed to "carry out an 'environmental overdraft' that draws on the natural resources" of developing countries [39] (p. 330). While previous work in ecologically unequal exchange sees this as a zero-sum relationship (in which one set of countries benefits, while others lose out), more recent work sees ecologically unequal exchange as a set of asymmetrical power relationships, where more-developed countries "gain disproportionate advantages at the expense of", less-developed countries, due to the hierarchical structure of the world economy [26] (p. 6).

The relative lack of labor and environmental regulations has particularly dire consequences for water resources in developing countries. For instance, Frey's [43] study of maquiladoras—assembly factories in Northern Mexico that take advantage of inexpensive labor and export the finished products back to high-income countries for consumption—demonstrate how these factories contribute greatly to water pollution in Mexico. Often the waste water from these factories is released into rivers and streams without being treated. Additionally, as part of this "globalization project", developing countries increasingly focus their agriculture industries toward large-scale production of export-oriented crops. This has a number of important effects on the environment, but importantly for water usage it often results in increased "fertilizer and pesticide run-off into freshwater sources caused by the excessive use of synthetic farm inputs" [12] (p. 77). The water footprint captures the amount of virtual water embedded into various products, along with their place of origin. As such, it is particularly well suited to study to overall effects of these larger political-economic changes that have resulted in increased industrial and agricultural commodity production.

Most sociological studies in the ecologically unequal exchange tradition have emphasized that the vertical flow of exports from lower-income nations to high-income nations is a key structural mechanism through which ecologically unequal exchange takes place. These studies focus on a variety of environmental indicators. For instance, a number of articles have examined how the vertical flow of exports from lower-income countries to higher-income countries affects deforestation in developing countries [1,41,53,54]. Other studies have demonstrated how the structure of trade compresses consumption in developing countries through the examination of the ecological footprint [41,55]. Jorgenson [48,56] has highlighted the way in which the vertical flow of exports affects carbon dioxide emissions in developing countries in an increasingly unequal way. Previous quantitative studies of ecologically unequal exchange have also shown how the vertical flow of exports affects water pollution. For instance, Shandra et al. [16] find that an increase in the percentage of exports to high-income countries increases industrial water pollution in lower-income countries.

While previous research on water within the ecologically unequal exchange tradition has been insightful, it has been somewhat limited. In particular, previous studies have only been able to get at specific, albeit important, water issues like organic water pollution or water scarcity. The production of agricultural and industrial commodities has larger effects on water systems than just pollution and increased freshwater withdrawal. Furthermore, previous studies have examined pollution and scarcity as distinct phenomena while, in reality, these processes are directly related to one another in the production process. As discussed more thoroughly below, the water footprint quantifies water usage through the entire production process and thus takes into account the water embedded within products that are meant for export for consumption in high-income countries. This account includes both water withdrawals and pollution of water resources. We argue that examining the water footprint allows us greater insight into how the structure of the global economy affects water resources overall, expanding our understanding of uneven environmental harms.

4. The Water Footprint

The concept of the water footprint has been developed over the course of the last decade and a half by the Water Footprint Network (WFN). It was introduced in the early 2000s by Arjen Hoekstra. Though there are some important differences, the water footprint is similar in name and function to the widely used ecological footprint [18]. While the ecological footprint quantifies the amount of land (measured in hectares) needed to reproduce a certain standard of living (or level of consumption), the water footprint quantifies the amount of freshwater (measured in cubic meters) needed to produce goods, including agricultural products, and services.

There have been a number of critiques of the ecological footprint. One of the biggest criticisms is that the ecological footprint is based on global averages of land requirements for different goods that are produced. This, however, does not indicate the exact origin of the products, the precise amount of land needed in certain locations, or whether certain places use land more effectively [57]. The water footprint, on the other hand, is based on actual water usage and thus allows for an understanding of water use at the actual place of production or consumption [18].

Beyond its loose association with the ecological footprint, the water footprint is intimately related to the concept of virtual water. Virtual water refers to the amount of water used in the production process of consumer products, whether they are agricultural, industrial, or domestic [18]. The important difference between the two is that the water footprint incorporates the elements of time, when something was produced, and space, where something is produced, for a fuller understanding of water usage. Virtual water only quantifies the amount of water embedded into products. The water footprint allows researchers to examine where the water comes from and the different types of water used to produce various products.

According Hoekstra et al. [58] (p. 2), "The water footprint is an indicator of freshwater use that looks not only at direct water use of a consumer or producer, but also at the indirect water use." This means that the water footprint captures water usage through the entire production chain, not just the water used in the final product. The water footprint can be studied across a variety of units of analysis. For example, it can be understood as the water footprint of an individual consumer, a product, a city, or a nation. There are three components of the water footprint (which allows for a more in-depth understanding of water usage): blue, green, and gray [58]. The blue water footprint is the volume of surface or groundwater that is evaporated or assimilated into the production of a product. The green water footprint refers to the volume of rainwater consumed. Usually, this is most important for agricultural production. Finally, the gray water footprint is a measure of water pollution. It can be defined as the volume of freshwater that is needed to distill the pollutants in order to be usable again [17,58,59].

Previous studies conducted by the WFN have tended to be descriptive by design. They have looked at which countries have the highest water footprint and which countries are more or less reliant on water resources beyond their borders [17,59]. The findings show that countries with the largest water footprints also have the largest populations. For instance, China, India, and the United States, respectively, have the highest national water footprints. However, when looking at the water footprint per capita, the largest consumers are all industrialized Western nations, led by the United States [17]. It has been suggested that the high water footprint per capita for the industrialized Western nations is mostly attributed to their diets that are meat-heavy and their generally high standard of living [59]. In terms of the water footprint of production, agricultural production accounts for 92% of the global water footprint. Industrial production accounts for about 4.4% and domestic usage accounts for 3.6% [17]. Previous research also indicates that some countries have very high external water footprints, meaning that they are heavily reliant on water resources beyond their borders. For instance, Italy, Germany, the United Kingdom and the Netherlands rely on external water sources for 50%–80% of their total water consumption [59].

While the descriptive research is important, it is not theoretically grounded nor has it explicitly examined the potential social-structural drivers of the water footprint described above. Thus, although there is a good account of the variation in the water footprint globally, there is not much understanding in *why* there are differences in water consumption. Given these gaps in the research on the water footprint, this study tests whether these inequities in water usage and consumption can be attributed to structural global economic factors. As water becomes increasingly scarce across the world and nations continue to develop, understanding the drivers of water use is increasingly important. The water footprint offers us an innovative and relatively more nuanced way to do these relationships.

5. Data and Methods

The data consists of observations for 138 countries. Of these 138 countries, 43 are considered high-income and 95 are considered lower-income (see Table 1 for a list of these countries). The modeling technique we use here, which includes high-income countries, is well established in this field (e.g., [48]). It is important to note, though, that research on ecologically unequal exchange relationships cross-nationally typically focuses just on lower-income countries. Examining only lower-income countries is one way to effectively test the propositions of ecologically unequal exchange theory, especially the core proposition that the vertical flow of exports to high-income countries negatively affects the environments of lower-income countries. However, examining lower-income countries exclusively means that researchers might miss out on the role that high-income countries have in these unequal relationships. The theory is about high-income countries externalizing their environmental burdens as much as it is about lower-income countries dealing with those burdens. As such, we argue that it is important to include them in the analysis. Furthermore, Jorgenson [26] argues that examinations of ecologically unequal exchange (and other theories in environmental sociology) need to move beyond zero-sum characterizations of these relationships. We argue that including high-income countries in the analysis is one way of achieving this.

Consistent with previous research in this area, we label a country as high-income if it falls within the top income quartile of the World Bank's [60] country classifications. These countries are often typically referred to as "developed" in the ecologically unequal exchange literature. All other countries are considered lower-income. These countries tend to be less powerful in the global economy and are often referred to as "developing" in the ecologically unequal exchange literature.

Table 1. List of Countries.

Albania *	Congo, Dem Republic *	India *	Nicaragua *	Tajikistan *
Algeria *	Congo, Republic *	Indonesia *	Niger *	Tanzania *
Antigua and Barbuda	Costa Rica *	Iran *	Nigeria *	Thailand *
Argentina	Côte d'Ivoire *	Ireland	Norway	Togo *
Armenia *	Croatia	Italy	Pakistan *	Trinidad and Tobago
Australia	Cuba *	Japan	Panama *	Tunisia *
Austria	Cyprus	Jordan *	Paraguay *	Turkey *
Azerbaijan *	Czech Republic	Kazakhstan *	Peru *	Turkmenistan *
Bahamas	Denmark	Kenya *	Philippines *	Uganda *
Bangladesh *	Dominica *	Kiribati *	Poland	Ukraine *
Barbados	Dominican Republic *	Korea, Republic	Portugal	United Kingdom
Belarus *	Ecuador *	Kyrgyzstan *	Romania *	United States
Belize *	Egypt *	Laos *	Russian Federation	Uruguay
Benin *	El Salvador *	Latvia	Rwanda *	Uzbekistan *
Bolivia *	Estonia	Lebanon *	Samoa *	Venezuela
Bosnia and Herzegovina *	Ethiopia *	Macedonia *	Saudi Arabia	Vietnam *
Brazil *	Fiji Islands *	Madagascar *	Senegal *	Yemen *
Brunei Darussalam *	Finland	Malaysia *	Seychelles *	Zambia *
Bulgaria *	France	Mali *	Sierra Leone	
Burkina Faso *	Gabon *	Malta	Slovak Republic	
Burundi *	Gambia *	Mauritania *	Slovenia	
Cambodia *	Georgia *	Mauritius *	Solomon Islands *	
Cameroon *	Germany	Mexico *	South Africa *	
Canada	Ghana *	Moldova *	Spain	
Central African Republic *	Grenada *	Mongolia *	Sri Lanka *	
Chad *	Guinea *	Morocco *	Sudan *	
Chile	Guyana *	Mozambique *	Suriname *	
China *	Honduras *	Nepal *	Sweden	
Colombia *	Hungary	The Netherlands	Switzerland	
Comoros *	Iceland	New Zealand	Syria *	

Note: * denotes lower-income country.

5.1. Dependent Variable

Our dependent variable is the water footprint of national production. The water footprint of production is defined as "the amount of local water resources that are used to produce goods and services within the country" [61]. The water footprint of production measures the water used within a country for production of goods and services, but those goods and services are not necessarily for consumption within that country. For developing countries, often times the goods produced there are primarily for export to richer countries as part and parcel of the globalization project [49].

Although the water footprint of production can be broken down into its blue, green and grey components, for the purposes of this study, we examine the total water footprint of production. We choose to examine the total water footprint for a number of reasons. First, the water footprint is a measure that has not been examined in this field of research. As such, it makes sense to examine the total water footprint rather than its subcomponents because it allows for a more direct discussion of the water footprint concept rather than getting lost in the nuance of the different subcomponents of the measure. Second, focusing on each subcomponent would require a more in-depth discussion on each part and its various drivers, necessitating different models for each one. Finally, as noted above, previous research has focused on specific aspects of water usage such as freshwater withdrawal (which is similar to the blue water footprint) or organic water pollution (which is similar to the grey water footprint). Examining the total water footprint of production allows us to examine both of these aspects of water usage along with the green water footprint (rainwater) in one measure. This is arguably more appropriate for the theory being tested because it allows us to examine how the vertical flow of exports to high-income countries might increase pressure on water resources overall in lower- and higher-income countries rather than just one specific aspect of water usage.

Even though we see the water footprint as a useful way to measure water consumption, there are certainly limitations to its use. One of the largest limitations of the variable is that it cannot be disaggregated into single year time points. Rather, the only data available is in aggregate form for the years 1996–2005. The reason that the data cannot be disaggregated is due to the way in which they are counted. As the formula utilizes climate data, which are multi-year averages themselves, the data must be analyzed in aggregate form. Furthermore, Hoekstra and Mekonnen [17] point out that even if the water footprints of nations could be disaggregated, it may very well be unreliable due to the differing rainfall and temperatures year to year. So, although it would be ideal to look at changes over time, the information is simply not available.

5.2. Independent Variables

The key independent variable used in this study is percent of exports to high-income countries. It is measured as merchandise exports sent to high-income countries, which is based on the World Bank classification system, and reported as a percentage of total merchandise exports. The variable is only computed if at least half of the recipients in the partner country group had non-missing data. This variable has been used as a measure of the vertical flow of exports in prior studies on ecologically unequal exchange [16,46,56]. Other quantitative studies in this tradition [1,62,63] have used a variable developed by Andrew Jorgenson [1] referred to as weighted export flows, which "quantifies the relative extent to which the exports of a nation are sent to more-developed nations" [47] (p. 246). However, we do not use this variable in the present study because those data are available for a more limited number of countries. Prior research has also shown that the two commonly employed measures of the vertical flow of exports are correlated with one another at a level above 0.9 [48]. For reasons discussed more thoroughly below, this variable is centered on its mean.

We also include a dummy variable specifying whether a country is considered lower-income or not, which is based on whether or not they fall within the top income quartile defined by the World Bank [60]. This allows for an interaction term to be created between percent of exports to high-income countries and the dummy variable, to assess how the vertical flow of exports to high-income countries impacts the water footprint for lower-income countries relative to high-income countries. In the regression models where the interaction term is included, the main effect of exports to high-income economies represents the effect for high-income countries and the interaction represents the effect for lower-income countries relative to high-income countries. In order to measure the actual effect of exports to high-income countries for lower-income countries, the coefficients for the interaction term and the main effect must be summed.

The following variables are included in the analysis to control for other factors that have been shown to influence resource consumption in prior research. We measure a country's level of development as GDP per capita. This is measured in 2005 constant US dollars. While there are competing theoretical propositions regarding the relationship between economic development and environmental sustainability, prior research has consistently shown that economic development is positively associated with increased consumption-based environmental pressure [1,63–65]. We also include total population as a control variable in all of the models. This variable counts all residents in a given country regardless of their legal status. Previous research has shown that population size is an important driver of various environmental outcomes [2,66,67]. Another measure that has been shown to be associated with increased environmental pressure or degradation is urbanization, which is measured as a percentage of total population living in urban areas. While urbanization is important for understanding consumption demands [68] it is particularly important for understanding water usage. As Longo and York [12] (p. 76) explain, "Demographic changes, particularly population shifts to urban areas, are often associated with shifts in water use patterns. This growth in urban population has contributed to stress on water resources."

We also control for merchandise trade as a percentage of GDP, a common measure of relative levels of exports and the extent to which a country is integrated into the global economy. More importantly, controlling for the relative level of trade allows for a more rigorous assessment of the environmental impacts of the vertical flow of exports [16,48]. We also control for both agriculture and industry as a percentage of GDP, as both sectors account for most of the global water footprint. All of the independent variables were obtained from the World Bank's [60] World Development Indicators database, and all of the variables represent the average for the time period 1996–2005 so that they match up with the water footprint of production. In analyses not reported here, but available upon request, we also include measures of freshwater availability and arable land, two potentially important drivers of the water footprint. However, these data are not available for all of the countries in the dataset and are only available for the year 1997. We do not include these measures here because they limit the sample size, which is already relatively small, and they do not match up with the timeframe of the other variables included in the study. The results of the analyses including these measures are substantively the same as the ones reported here.

5.3. Model Estimation Techniques

Given the unavailability of longitudinal data for the dependent variable, we conduct cross-sectional regression analysis. We use both ordinary least squares (OLS) regression and robust regression techniques.

OLS regression is the most commonly employed regression modeling technique in cross-sectional studies of society/nature relationships at the national level. However, researchers in this field suggest the use of robust regression as well for cross-sectional studies [13,69,70]. With cross-sectional analysis, relative to longitudinal studies where the researcher is able to incorporate more data points, there is the greater potential for outliers to affect the results. An outlier is an observation with a large residual, or an observation that has a large discrepancy between the observed and predicted values in the regression model. Generally speaking, robust regression provides more conservative results relative to OLS regression through down-weighting the influence of outliers in residuals. Thus, observations with smaller residuals are given a larger weight relative to those with larger residuals. The authors conducted sensitivity analyses to test for the presence of overly influential cases (outliers) in the sample. The analyses indicate that no cases appear to be overly influential. This is confirmed by the models that remain substantively similar when using either OLS or robust regression. Regardless, using robust regression in addition to OLS allows us to perform more thorough hypothesis testing given that robust regression provides more conservative results relative to OLS.

We run the analyses in Stata 13. The command for robust regression is *rreg*. In Stata, the default for robust regression is to use biweighting, which means that all cases with a non-zero residual get down-weighted somewhat. The default biweight tuning constant for Stata is 7. It should also be noted that it is not possible to calculate the R-squared statistic in robust regression because it down-weights influential cases.

Consistent with previous research, we convert log (ln) all variables to minimize skewness and to make the interpretations of the coefficients more straightforward. This method of analysis is referred to as an elasticity model and used widely in research on cross-national environmental research. It was popularized by York, Rosa and Dietz in their formulation of the STIRPAT approach (Stochastic Impacts by Regression on Population, Affluence and Technology) [70]. The interpretation of a coefficient in an elasticity model is slightly different than for regular regression models. The coefficients in an elasticity model are understood in terms of percentages rather than unit changes. For instance, a one percent increase in the independent variable is associated with a percentage increase in the dependent variable.

In terms of regression diagnostics, it appears that heteroskedasticity is not an issue in the models. This is indicated by both the Breusch–Pagan/Cook–Weisberg and White's tests for heteroskedasticity. In the models below there is potential for collinearity issues. The highest VIF values are GDP per capita (i.e., VIF of 11.72 in model 3), and agriculture as a percentage of GDP (i.e., VIF of 8.27 in model 3). These high values are not entirely unexpected as the correlation between GDP per capita and agriculture as a percentage of GDP is −0.925. All other VIF values are below 3.5. Even though these variables are clearly important drivers of water usage, their VIF values may be affecting the results. Given this, in models 7 and 8, we run models removing both GDP per capita and agriculture as a percentage of GDP from the analysis to ensure the stability of our findings. The results remain substantively the same. It should also be noted here that, in general, including interaction terms in regression models results in higher VIF values. This is not a statistical problem according to Paul Allison, however [71]. In any case, to alleviate potential concerns of collinearity in the models with an interaction term, we center the exports to high-income countries variable on its mean. The interaction term is between this centered variable and the dummy variable for lower-income countries. Centering variables is one technique to try and deal with high VIF values when interactions or quadratic terms are used in regression models.

Tables 2 and 3 report descriptive statistics and pairwise correlations for all of the variables included in the analyses.

Table 2. Descriptive Statistics.

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Water Footprint of Production	138	9.379261	2.040438	3.779012	14.00397
GDP Per Capita	138	7.877516	1.595003	4.946545	11.02899
Total Population	138	15.95789	1.891841	11.15934	20.95797
Urban Population Percentage	138	3.855148	0.520171	2.124738	4.526859
Agriculture, % of GDP	138	2.368179	1.036455	−0.0348202	3.990138
Industry, % of GDP	138	3.314232	0.3353979	2.300388	4.12052
Merchandise Exports, % of GDP	138	3.964843	0.4781696	2.908672	5.16942
Merchandise Exports to High-Income Countries	138	4.25657	0.2613688	3.084621	4.574476

Note: All variables are logged (ln).

Table 3. Correlation Matrix.

Variable	1	2	3	4	5	6	7
1. Water Footprint of Production							
2. GDP Per Capita	−0.172						
3. Total Population	0.947	−0.136					
4. Urban Population Percentage	0.010	0.714	0.001				
5. Agriculture, % of GDP	0.123	−0.925	0.034	−0.637			
6. Industry, % of GDP	0.225	0.325	0.276	0.421	−0.390		
7. Merchandise Exports, % of GDP	−0.347	0.173	−0.377	0.139	−0.149	0.393	
8. Merchandise Exports to High-Income Countries	−0.068	0.461	−0.038	0.301	−0.418	0.166	0.184

Note: All variables are logged (ln).

6. Results

We report the findings for 6 models. Table 4 reports models 1–4. In model 1, we estimate an OLS model regressing the water footprint of production on GDP per capita, total population, urban population percentage, agriculture as percentage of GDP, industry as a percentage of GDP, and merchandise trade as a percentage of GDP. We treat this as our baseline model. We find that the estimated effect of GDP per capita is significant and positive. More specifically, our findings indicate that every one percent increase in GDP per capita is associated with a 0.310 percent increase in the water footprint of production, net of other factors. This finding is interesting as the prevailing logic surrounding water usage is that economic development allows countries use their water resources more efficiently [7,12]. Thus, this increase in efficiency ought to result in a decrease in the water footprint of production. Our findings indicate the opposite. We also find the estimated effects of both total population and agriculture as a percentage of GDP to be significant and positive. These findings are consistent with previous research that a larger agricultural sector and a larger population are important drivers of water usage. Urban population is non-significant in model 1, though it is significant in model 2. Turning to model 2, which is identical to model 1 except that it uses robust regression, we find that our results are confirmed using the more conservative estimates. In this model, all of the variables are statistically significant at the 0.05 level except for industry as a percentage of GDP. In models 3 and 4 we introduce two new variables, merchandise exports to high-income economies and the dummy variable for whether a country is considered lower-income or not. These models do not substantially alter the results of the first two models and both of the added variables are non-significant in both models.

Table 4. Water Footprint of Production.

Variable	Model 1: OLS	Model 2: RReg	Model 3: OLS	Model 4: RReg
Total Population	1.074 *** (0.034)	1.059 *** (0.031)	1.078 *** (0.035)	1.059 *** (0.031)
Urban Population %	0.265 (0.147)	0.288 * (0.131)	0.252 (.151)	0.301 * (0.136)
Agriculture, % of GDP	0.685 *** (0.136)	0.665 *** (0.121)	0.683 *** (0.139)	0.681 *** (0.125)
Industry, % of GDP	−0.232 (0.213)	−0.349 (0.190)	−0.247 (0.216)	−0.342 (0.194)
Merchandise Trade, % of GDP	0.189 (.138)	0.367 ** (0.123)	0.206 (0.140)	0.370 ** (0.126)
Merchandise Exports to HIC (% of Total)			−0.187 (0.220)	−0.019 (0.198)
Lower-Income Country (LIC)			0.043 (0.197)	−0.054 (0.177)
Constant	−12.824 *** (1.351)	−12.917 *** (1.204)	−12.288 *** (1.523)	−12.891 *** (1.368)
N	138	138	138	138
R-sq	0.921		0.922	
Mean VIF	4.23		4.08	
Max VIF	9.66		11.72	

Note: Standard errors in parentheses. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Table 5 reports models 5 and 6, which are the main models of interest for this study. The models regress the water footprint of production on GDP per capita, total population, urban population percentage, agriculture as a percentage of GDP, industry as a percentage of GDP, merchandise trade as percent of GDP, merchandise exports to high-income countries, the dummy variable for lower-income, and the interaction between the last two variables, the latter of which is our main variable of interest. We again find that GDP per capita, total population, and agriculture have significant positive effects on the water footprint of production.

Table 5. Water Footprint of Production.

Variable	Model 5: OLS	Model 6: RReg	Model 7: OLS	Model 8: RReg
GDP Per Capita	0.357 ** (0.107)	0.334 ** (0.101)		
Total Population	1.085 *** (0.034)	1.081 *** (0.032)	1.067 *** (0.036)	1.069 *** (0.033)
Urban Population %	0.216 (0.150)	0.267 (0.141)	0.299 * (0.021)	0.401 ** (0.119)
Agriculture, % of GDP	0.667 *** (0.138)	0.660 *** (0.130)		
Industry, % of GDP	−0.329 (0.216)	−0.425 * (0.203)	−0.574 * (0.224)	−0.712 ** (0.208)
Merchandise Trade, % of GDP	0.292 * (0.143)	0.373 ** (0.135)	0.328 * (0.154)	0.424 ** (0.143)
Merchandise Exports to HIC (% of Total)	−1.392 * (0.581)	−1.491 ** (0.549)	−1.519 * (0.605)	−1.464 ** (0.560)
Lower-Income Country (LIC)	−0.052 (0.199)	−0.189 (0.187)	0.146 (0.154)	0.124 (0.143)
Merchandise Exports to HIC x LIC	1.361 * (0.609)	1.498 * (0.575)	1.525 * (0.647)	1.354 ** (0.599)
Constant	−13.122 *** (1.374)	−12.973 * (1.296)	−8.225 *** (0.903)	−8.546 *** (0.835)
N	138	138	138	138
R-sq	0.925		0.911	
Mean VIF	5.46		3.62	
Max VIF	11.8		8.76	

Note: Standard errors in parentheses. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Turning to the main variables of interest, we find that the main effect of merchandise exports to high-income countries is negative and significant. As noted above, because we have an interaction term in the model, the main effect of exports to high-income countries represents the effect for high-income countries. Thus, this shows that that, for high-income countries, trade to other high-income countries is beneficial for their water resources. More specifically, for high-income countries, a one percent increase in exports to high-income countries results in a 1.392 percent decrease in the water footprint of production. The other main variable of interest, the interaction term between merchandise exports to high-income countries and the lower-income countries dummy variable, is also significant. This tells us that the effect of exports to high-income countries is significantly different for high-income and lower-income countries. While understanding how the effect of trade differs between high-income and lower-income countries is important, it does not get at the core assertion of ecologically unequal exchange theory, that trade with high-income countries adversely affects the environments of lower-income countries. To answer this question, we must sum the coefficients for the interaction term and the main effect in order to find the actual coefficient of exports to high-income countries for lower-income countries. Thus, we find that effect of exports to high-income countries for lower-income countries is -0.031 in model 5 and 0.007 in model 6. These values are very small and additional analyses indicate that these coefficients are not significantly different than zero. Additional analyses involved running the models with a sample of only lower-income countries without an interaction term and using an interaction term where the main effect of exports to high-income countries represented the effect for lower-income countries. These analyses are available upon request. Models 7 and 8, which remove both GDP per capita and agriculture as a percentage of GDP due to potential collinearity issues, show that the exclusion of those two variables does not substantively alter the findings. All in all, our results indicate that exports to high-income countries do not appear to increase pressure on water resources for lower-income countries, but they don't reduce pressure on water resources either. Thus, we do not find support for the main proposition of ecologically unequal exchange theory that the vertical flow of exports directly harms water resources in lower-income countries. On the other hand, the results do provide support for other propositions of ecologically unequal exchange theory. In particular, the results show that relative positions in the global economy are important for understanding the drivers of resource consumption. In this case, water resources in high-income countries benefit from trade with other high-income countries, as signified by the significant and negative main effect of exports to high-income countries, while lower-income countries do not benefit from trade with high-income countries, at least in the context of reducing their production-based water footprints.

7. Discussion and Conclusion

Ecologically unequal exchange theory posits, in part, that high-income countries are able to partially externalize the costs of their high levels of consumption to lower-income countries of the world through the vertical flow of exports from the latter to the former [27]. However, this is not always a zero-sum game. Instead of just highlighting winners and losers, ecologically unequal exchange highlights disproportionate and uneven environmental outcomes of trade relationships within the world economy. Previous research finds ecologically unequal relationships between high-income and lower-income countries when examining indicators such as deforestation, carbon dioxide emissions and the ecological footprint [16,46,51]. Here, we further examine the empirical validity of the theory through the examination of the water footprint of production. The water footprint of production measures "the amount of local water resources that are used to produce goods and services within the country" [61].

To examine how ecologically unequal exchange relationships affect water usage, we estimated a series of cross-sectional OLS and robust regression models. While it is important to recognize that cross-sectional regression models can only provide snap-shots in time, the findings for the analyses provide partial support for ecologically unequal exchange theory. The core assertion of ecologically unequal exchange theory is that high-income countries are able to partially externalize their environmental impacts to lower-income countries through their advantageous position in the global economy. Our findings indicate that the vertical flow of exports does not appear to negatively affect water resources, measured as the water footprint of production, in developing countries. This could be due to the fact that our data are cross-sectional. It is possible that with longitudinal data our results would find support for this key proposition of the theory. As noted above, though, this is not possible for the water footprint.

In any case, we find support for another proposition of ecologically unequal exchange theory. In particular, we find that a country's position in the global economy matters. More specifically, for high-income countries, there is a statistically negative association between the water footprint of production and the vertical flow of exports to other high-income countries. This indicates that high-income countries are able to take advantage of their structural positions in the global economy to benefit their water resources. As indicated by the interaction term in models 5–8, the effect of exports to high-income countries for lower-income countries, while not significantly different than zero, is significantly higher than it is for high-income countries. This indicates that lower-income countries are not able to displace their water footprint to the same extent as high-income countries, likely due to their structurally disadvantageous positions in the global economy.

Previous studies have shown that high-income countries are able to directly take advantage of natural resources and environments in lower-income countries through the vertical flow of exports [1,16,53,55,56]. Our results do not show this relationship to be occurring directly with the water footprint. However, these results demonstrate that unequal exchange is not necessarily a "zero-sum" game. Rather, they seem to indicate a dynamic of ecologically unequal exchange relationships in which there are disproportionate impacts. Instead of direct exploitation, our results elucidate disparities within a world economy where there is inequality in trade relationships in that high-income countries are able to benefit their water resources through trade with other high-income countries. Lower-income countries, on the other hand, have disadvantageous positions in the global economy which do not allow them to displace the burdens on their water resources to the same extent. This demonstrates, we believe, a nuance to the ecologically unequal exchange literature. This nuance potentially opens up broader understandings of the ecological implications of international trade relationships beyond a "zero-sum" game understanding of ecologically unequal exchange. Furthermore, it provides another layer of global analysis within the burgeoning water footprint literature.

We also find that, generally speaking, GDP per capita and the water footprint of production are positively associated. Our models indicate that an increase in GDP per capita is associated with an increase in the total water footprint of production. This is an interesting finding that warrants further investigation in future studies as the common conception now is that economic development is beneficial for a country's water resources. The line of thought is that economic development allows countries to use their water more efficiently. Our findings challenge this assumption somewhat and the finding deserves further examination.

While we believe that the water footprint is an innovative way to measure water usage, it is certainly not beyond criticism. One of the biggest issues of the water footprint is that, because of the way it is measured, it is only available to examine in cross-sectional models. This is an issue because many of the theories engaged with in environmental sociology, including ecologically unequal exchange, argue that relationships vary over time. For instance, is the ecologically unequal exchange relationship stable over time? Is it intensifying? Because the water footprint cannot be disaggregated into different time points, we are not able to examine these questions here. Thus, this measure is not appropriate for researchers interested explicitly in examining how different factors affect water usage over time.

We have focused on the total water footprint of production here. Future research would benefit from examining of the different sub-components (blue, green and grey) of the water footprint. Additionally, future research in environmental sociology using the water footprint could also explore the water footprint of specific types of products. These sorts of analyses would provide researchers with information on more specific aspects of the water usage. For example, it is possible that certain types of products are disproportionately adding to the unequal exchange relationship.

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