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The Global Economics of Water: Is Water a Source of Comparative Advantage?†

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With newly available data, I investigate to what extent countries' international trade exploits the very uneven water resources on a global scale. I find that water is a source of comparative advantage and that relatively water abundant countries export more water-intensive products. Additionally, water contributes significantly less to the pattern of exports than the traditional production factors labor and physical capital. This suggests relatively moderate disruptions to overall trade on a global scale due to changing precipitation in the wake of climate change. (*JEL* F14, O13, O19, Q15, Q25, Q54)

The recent severe drought in key US farming states has focused attention on water issues. While some observers worry primarily about rising food prices in the wake of droughts, others see the drought as evidence that freshwater scarcity is bound to be a major challenge of the twenty-first century. Almost one-fifth of the world's population currently suffers the consequences of water scarcity, and this number is expected to increase (World Water Assessment Programme 2009). Population growth, rising standards of living, and the diet and lifestyle changes they imply will continue to increase the demand for water and strain available water resources. Pollution may also challenge the fresh water that can be used. In addition, discussions of climate change and the implied disruptions of the hydrologic cycle have only heightened concerns about water scarcity. In spite of the reports about an impending water crisis, it is important to realize that major concerns about water availability stem especially from the very uneven global distribution of water. The world as a whole is not running out of water. For one, the hydrologic cycle of evaporation, condensation, and precipitation makes fresh water a finite, but renewable, global resource. In addition, there are enormous quantities of water available, on the order of trillions of gallons of water per capita.[1] However, while many countries

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[1] See Young and Haveman (1985). Even though only a very small fraction of this amount is not salty and accessible, there is more than enough fresh water on earth to satisfy the growing demand, especially since water desalination is always an option, See Gleick (2009) and Richter (2012).

have more than enough water to satisfy their populations' increasing needs, some countries clearly do not. Water scarcity is thus tied to particular regions, which begs the question whether world production and trade adequately reflect the relative scarcity of water. Increasingly, scientists realize that tackling water scarcity warrants an international analysis.[2]

Most of the things we produce require water, and often much more water than people are aware of. One cotton T-shirt, for example, has a water footprint of about 2,500 liters, and it takes about 17,000 liters before you can buy 1 kilogram of chocolate in the store.[3] Since water is too heavy to be profitably shipped internationally on a massive scale, direct water trade among countries is not a practical means of addressing water scarcity on a global scale. However, the international division of labor made possible by international trade, at least in theory, should be able to help alleviate water scarcity in a more indirect way. Countries with relatively scarce water resources could shift their production and exports away from more water-intensive goods (i.e., goods whose production requires, compared to other factors, more water) to less water-intensive goods. In addition, those water-scarce countries could buy water-intensive goods from countries that do not face any significant water constraints. The fundamental question I investigate in this paper is to what extent water induces such international specialization of production and, in particular, to what extent does the uneven distribution of water shape the worldwide pattern of goods that countries export? This question can best be summarized with the title of the paper: To what extent is water a source of comparative advantage?

There have been repeated calls in fields other than economics to study water form a global perspective. Especially since the pioneering work by Allan (1994), there is a growing literature in hydrology and environmental science that investigates "virtual" water trade or the water content of international trade.[4] These pioneering global water analyses outside economics provide a wealth of invaluable data and insights, but often lack the notion of opportunity cost of water and comparative advantage. Needless to say, a country's trade not only contains a lot of water, but it also contains capital, labor, and other factors of production. From an economic point of view, it is especially the relative cost difference between all those factors that determines international trade flows. My study may be the first to study the basic question of water as a source of comparative advantage in a manner consistent with the extensive international trade literature, while explicitly taking into account the role of other production factors beyond water. Moreover, the international perspective of my study that emphasizes international exchanges also complements much of the existing water literature in economics. Oftentimes, water studies address especially the local conditions of water scarcity and how to improve these (e.g., by strengthening the efficiency of delivery, by seeking additional resources, or by making sure the allocation process is as efficient as possible through appropriate pricing, water rights, etc.).[5]

[2] See, for example, Postel, Daily, and Ehrlich (1996); Vörösmarty et al. (2000); Chapagain and Hoekstra (2008).
[3] www.waterfootprint.org.
[4] The work especially by Hoekstra and coauthors is important in this context.
[5] Countries are the unit of analysis since regional international trade data are not available for many countries.

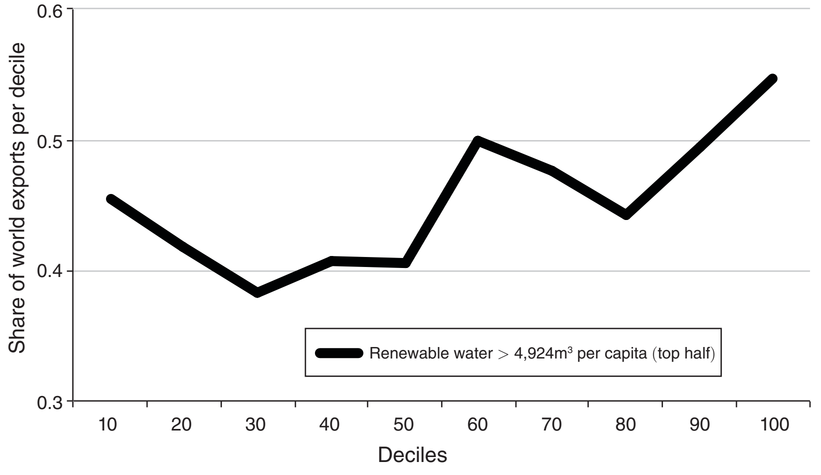

Figure 1. World Export Share by Decile of Water Intensity, Most Water-Abundant Countries

Notes: Products are split into deciles of green and blue water intensity. The share of world exports is calculated by dividing the exports of the most water-abundant countries (half the countries in the sample have more than 4,924m^3 per capita renewable water resources) by total world exports in each decile.

Source: Using BHV (2010) data

Exploiting the cross-sectional variation across 134 countries and 206 sectors, I find that water is indeed a source of comparative advantage and that countries that have more water available per capita tend to export more water-intensive goods. The raw data of Figure 1 visualizes this finding. Figure 1 shows how the share in world exports of water-abundant countries tends to increase with the water intensity of the goods that they export—the export goods are classified in deciles of increasing water intensity, see below. In addition, the econometric evidence reveals that water's impact on the pattern of exports is less critical than that of the other traditional factors of production such as capital or labor. From a global perspective, and in light of the discussion of climate change that should affect worldwide precipitation patterns, this result suggests that international trade patterns should not be subject to too much disruption by changing local water availability in the wake of climate change. Needless to say, this global assessment does not preclude nonnegligible impacts for individual countries, in particular for heavy exporters of water-intensive agricultural goods. Nor does it negate the significant role that international trade can play in addressing local water scarcity needs. For reference, virtual water contained in the world's total imports or exports is estimated to be around 20 percent of global water use.[6]

My study would not be possible without the recently available water data by Blackhurst, Hendrickson, and Sel i Vidal (BHV) (2010), the first sectoral water withdrawal study for the United States in 30 years, and Mekonnen and Hoekstra (2011), an invaluable resource for water use especially in agriculture. The paper is

[6] Hoekstra and Mekonnen (2012).

structured as follows. In Section I, I lay out the estimation framework. In Section II, key water data are discussed and descriptive statistics are presented. Section III focuses on the regression analysis and results. Section IV concludes.

I. Framework and Estimation Equation

My empirical specification draws on Romalis (2004), Nunn (2007), and Levchenko (2007).[7] To investigate whether water is a source of comparative advantage is to ask whether the international division of labor promotes the more efficient use of water on a global scale. In other words, is it the case that countries that are relatively abundant in water also export especially water-intensive goods? The following regression is the baseline specification that I use to study the role of water:

$$(1) \qquad x_{ic} = \alpha_i + \alpha_c + \beta_1 w_{i*} W_c + \beta_2 k_{i*} K_c + \beta_3 s_{i*} S_c + \varepsilon_{ic},$$

where x_{ic} measures the exports from country c in sector i to the rest of the world. α_i and α_c are country and sector fixed effects that should capture, among other things, sectors' factor intensities, their relative sizes and countries' resources, their GDP, their policies, geography, average technological differences, etc. The three interaction terms between sectors' factor intensities and countries' production resources—$w_{i*}W_c$, $k_{i*}K_c$, and $s_{i*}S_c$—are key for our analysis.[8] They measure, respectively, the water intensity (w_i) times a country's per capita water resources (W_c), a sector's capital intensity (k_i) times its capital-labor ratio (K_c), and the high-skilled worker intensity (s_i) times the skilled labor ratio (S_c). Note that because of the fixed effects, only the relative ranking of the factor intensities is assumed the same, not the absolute factor intensities.[9]

The interaction terms in the regression are meant to capture the extent to which water, capital, and skilled labor are sources of comparative advantage. In the case of water, all else equal, a positive coefficient on the interaction term should indicate that the amount of water available per worker in a country determines the international pattern of its exports. In particular, a positive coefficient would imply that comparatively more exports occur in the more water-intensive sectors of relatively water-abundant countries.[10] I focus primarily on the positive (nonzero) trade with variables in logs. In extensions I also include zero trade flows, since the extent of a country's water endowments arguably can preclude some countries from producing and exporting certain goods.

I will also estimate a variation of the above regression as in equation (2):

$$(2) \qquad x_{ic} = \alpha_i + \alpha_c + \beta_1 w_{i*} W_c + \beta_2 W_{c*} w_{i*} I_c + \sum_j \beta_{j*} f_{ji*} F_{jc} + \varepsilon_{ic}.$$

[7] Surprisingly enough, the empirical Heckscher-Ohlin literature does not study water at all. The absence of reliable data that go beyond water services mentioned in the Input-Output tables is the most likely reason. For a good survey of the Heckscher-Ohlin literature, see Baldwin (2008).

[8] They capture Costinot's (2009) notion of supermodularity that summarizes theories of comparative advantage.

[9] I use the US factor intensity to proxy for w_i, k_i, and s_i. When checking the robustness of my results I will use Mekonnen and Hoekstra (2011) data to let the water intensities for agriculture vary by country sector.

[10] Note that the estimated coefficient does not capture the overall effect of the water endowment on a country's total volume of trade, as in a gravity equation. This effect would be part of the country fixed effect in the estimation.

I interact the comparative advantage term for water, $W_{c*}w_i$, with an indicator variable I_c that is 1 if a country is relatively water scarce, and 0 otherwise. Note that $\sum_j \beta_j f_{ji*} F_{jc}$ summarizes the interactions term for the non-water resources j. This additional specification allows the study of two alternative hypotheses that posit a differential impact of water on exports for more versus less water-abundant countries.

A first hypothesis predicts the β_2-coefficient should be positive, so that more water resources per capita will have a stronger impact on the pattern of trade in water-scarce compared to water-abundant countries. The hypothesis tests whether water is a free resource in water-abundant countries. Indeed, beyond a threshold of water abundance, when water is a free good (like air) with zero opportunity cost, more water resources per capita should not strengthen the ability of water abundant countries to export in the same way that it does for countries in which water is not a free good. This hypothesis is particularly relevant in light of the very uneven distribution of water resources and the presence of international differences in technology and transportation costs, which all suggest we live in a world in which water prices will vary internationally with the relative abundance of water per capita.[11]

A second, alternative hypothesis predicts less effective water resources in water-scarce compared to water-abundant countries, which amounts to a negative β_2-coefficient. Water-scarce countries often use water in unsustainable ways that lower water quality, which makes the available water less effective than the measured volumes may suggest. Therefore, compared to more water-abundant countries, similar increases in water resources will have a weaker impact on the pattern of trade for water-scarce countries.[12] This second hypothesis draws on water resources vulnerability indices from the water literature; see Brown and Matlock (2011). These indices relate water use to the available water resources of a particular location. High-use ratios pose a challenge to the environment. They increase the chance that local sources of water (e.g., aquifers that need time to replenish) may get depleted, that species live in stress in and around the water, and that it is harder for water to assimilate pollutants. Also, to the extent that used water is released into the environment after use, higher water-use ratios are likely to let pollution lower water quality.[13] To differentiate water-scarce countries from others, I initially follow the literature and its threshold level of 1,500m^3 or 1,700m^3, see Matlock (2011).

[11] International trade theory suggests that the prices of factors of production (including water) will not be equalized across borders when the international distribution of resources is very uneven, when there are transportation costs, or when international differences in technology, see Debaere and Demiroglu (2003).

[12] This hypothesis is not unlike Trefler (1995) who translates countries' endowments into effective units by adjusting them for productivity differences among countries. In terms regression (2), for a water scarce country c the comparative advantage term (with estimated coefficient $b_1 > 0$) and the interaction term (with negative coefficient $-b_2, b_2 > 0$) can be rewritten as $b_1 (1 - b_2/b_1) W_{c*}w_i$. The multiplicative term $(1 - b_2/b_1)$ rescales the scarce country's water resources in effective or quality adjusted units. Note that b_2 should also be smaller than b_1.

[13] Richter et al. (2011) and Hoekstra et al. (2012) argue that water-use ratios above 20 percent or 40 percent challenge the sustainable use of water. Water scarcity is a key determinant of water-use ratios beyond 20 percent or 40 percent.

II. A Role for Water: Data[14]

A. *Water Resources*

I take from Gleick (2009) the standard measure of a country's water resources—the volume of renewable fresh water per capita. This measure sums the average annual surface runoff (e.g., from rivers or lakes) and the groundwater recharge (see Johnson, Revenga, and Echeverria 2001). Renewable water captures the water that can be withdrawn annually without violating the concept of sustainability. It is an attractive measure if one were concerned about endogeneity of water resources, since it is not determined by actual water use. Renewable water per capita proxies in particular for a country's blue water resources, but not its green water. Blue water comprises surface and ground water that matters for households and industry. It is also important for agriculture through irrigation. Green water, on the other hand, is stored in the soil or temporarily stays on top of vegetation. It matters exclusively for agriculture in the absence of irrigation. Since precipitation is an important source of both blue and green water, I will confirm the results for renewable water per capita with precipitation per capita data. Since I have mainly annual and country-based international trade data, I cannot address the variation within a country or year.[15]

The world's water resources are spread unevenly. The lowest tercile of least water-abundant countries has 1,150m^3 of water per year per person, which is 6 times less than the second tercile and 75 times less than the most water-abundant tercile. Table 1 categorizes our 134 countries into three deciles, while providing the minimum and maximum water available. Note that my measure of a country's available renewable fresh water per capita should be a better proxy of the true (opportunity) cost of water than the actual water prices consumers and producers pay. It is widely accepted that water prices do not reflect water's scarcity value (see Hanemann 2006). Since water is a necessary good, it is often subsidized and regulated. In addition, due to complementary uses, such as irrigation and recreation, and due to economies of scale in storage and distribution, private markets for water are thin or lacking. Water scarcity can be felt through many other channels than just price, however. The low, set water price may not reveal water rationing, or any interruptions of water supply because of scarcity. My per capita water endowment measures should pick up such implicit costs of water scarcity much better since shortages or interruptions in supply are more likely with scarce water resources.

B. *Sectoral Water Use*

For sectoral water use, I use BHV, who disaggregate US withdrawal data from the US Geological Survey into withdrawals for 426 sectors. I use the relative ranking of US water intensities constructed from BHV in regression (1) and (2). I rely both

[14] For a description of the standard data for the other factors of production, see online Appendix.

[15] The data include surface inflows from other countries. However, outflows committed to other (downstream) countries are not subtracted. Note that the year for which the estimates are available varies to some extent.

Table 1—Renewable Water (*Cubic meters per capita*)

Tercile	Average	Min.	Max.	Countries included (* in restricted sample)
1	1,157	11	2,650	Algeria, Bahrain, Barbados*, Belgium*, Bulgaria, Burkina Faso, Burundi, China, Comoros, Cyprus, Czech Republic, Denmark*, Djibouti, Egypt*, Ethiopia*, Germany*, Haiti, India*, Iran, Israel*, Jordan, Kenya, Kuwait, Lebanon, Malawi*, Maldives, Malta*, Mauritius*, Morocco*, Nigeria*, Oman, Pakistan*, Poland, Qatar, Rwanda, Saint Kitts and Nevis, Saudi Arabia, Singapore*, Somalia, South Africa*, South Korea*, Sri Lanka*, Tunisia*, United Arab Emirates, Yemen, Zimbabwe*
2	6,397	2,746	13,705	Afghanistan, Albania, Austria*, Bangladesh*, Benin, Chad, Côte d'Ivoire, El Salvador*, France*, Gambia, Ghana*, Greece*, Guatemala*, Hungary, Iraq, Ireland*, Italy*, Jamaica*, Japan*, Mali, Mauritania, Mexico*, Mongolia, Mozambique, Nepal, Netherlands*, Niger, Philippines*, Portugal*, Senegal, Spain*, Sudan, Switzerland, Syria*, Taiwan, Tanzania*, Thailand*, Togo, Trinidad and Tobago, Turkey*, Uganda, United Kingdom*, United States*, Vietnam, Zambia*
3	85,938	13,887	626,867	Angola, Argentina*, Australia*, Belize, Bhutan, Bolivia*, Brazil*, Brunei Darussalam, Cambodia, Cameroon*, Canada*, Central African Republic, Chile*, Colombia*, Congo, Costa Rica*, Ecuador*, Equatorial Guinea, Fiji*, Finland*, Gabon, Guinea, Guinea-Bissau, Guyana, Honduras*, Iceland*, Indonesia*, Laos, Liberia, Madagascar*, Malaysia*, New Zealand*, Nicaragua, Norway*, Panama*, Papua New Guinea*, Paraguay, Peru*, Russian Federation, Sierra Leone, Solomon Islands, Suriname*, Sweden*, Uruguay*, Venezuela*

Notes: The Restricted Sample Countries (with*) are those countries for which we have a complete set of factor endowment data.This set of countries is used in the estimation from Table 4 onward.

on sectors' direct and indirect water withdrawals. The indirect water withdrawal is based on Input-Output Tables and consists of the water used in the intermediate inputs of a good. I reclassify the BHV data into 206 industries to be consistent with the Bureau of Economic Analysis 1997 IO classification, which is the data format for the other factors of production. As many sectors have their own water supply and are not solely dependent on utilities, the total water use in the BHV data is an order of magnitude larger than the water use typically inferred from public utility water bills in the IO tables.

Power generation is the largest direct water user, ahead of agriculture, manufacturing, and mining. Since international trade in power is relatively small, the direct water use in power generation is arguably not directly relevant for international trade. However, as power generation is most often a nontraded sector, the capacity to produce internationally traded goods will not only depend on water as a direct input, but also indirectly on the available water for power use. For this reason, I use both direct as well as indirect water use measures that relate to the input-output structure of production. Even though power is the most important, very water intensive factor that is indirectly used in production, the focus on exports provides another reason to consider, next to direct, total (direct plus indirect) water use measures. Indeed, exports may, to varying degrees, include inputs that are not produced domestically. A country's textile industry, for example, may import cotton, which is very water intensive, rather than grow cotton itself. By relating relatively disaggregate export data to direct as well as to indirect measures of water use, we can see whether our results are sensitive to supply chain considerations.[16]

The BHV data measure water use as water withdrawals, which unlike water consumption, does not subtract the water that is released into the environment after use. While water consumption is sometimes preferred, it is not available at the disaggregate level for manufacturing and mining.[17] On the other hand, more often than not, it is water withdrawal, not consumption that is priced. The BHV water data capture blue surface and ground water use from rivers, lakes, aquifers, and public utility companies. Since green water that is stored in the soil or that stays on top of the soil or vegetation is important for agriculture, I adjust the blue water use data for agricultural sectors by applying the US ratio of blue to green water use from Mekonnen and Hoekstra (2011).

To construct the water-intensity measures for regressions (1) and (2) and to compare water costs to the cost of other production factors, water prices are needed to value BHV's water quantities. I take average water utility prices for public water and average water trade prices from the Western US states for water that is not intermediated by utilities; see Brewer et al. (2007). I follow Romalis (2004) and construct sectoral water-intensity as the ratio of the cost of water use over value added plus the cost of water use. In doing so, I ensure the ratio does not exceed one.[18] For reference, the median intensity is 0.04 for direct blue and 0.06 for total (direct plus indirect) blue water intensity. The low numbers confirm water costs are relatively moderate in the United States (see Hanemann 2006). Water is respectively 3.5 percent and 1 percent of value added (proxying for total cost of labor, land and capital) for the average and the median water user. One should keep in mind that the relatively high value added in manufacturing compared to agriculture is responsible for the higher water intensity of agriculture. In addition, the United States as a whole is a relatively water-abundant country whose low water cost to users may well not always reflect the true price of water. Low-intensity measures thus mask heavy water use. Take aluminum, whose direct water-intensity measure is quite low at 0.0002. Based on Byers et al. (2003), however, we know that producing 1 ton of aluminum basically requires 87 tons of water.[19]

The low-intensity measures for the United States should not make us infer that water is a negligible factor in the global allocation of production and trade. Countries' comparative advantage hinges on *both* the variation of factor intensities among sectors *and* on the relative factor abundances across countries. In the empirical analysis, I use the interaction of countries' water abundance and sectors' water intensity to explain a country's exports, as I investigate whether water-abundant countries export especially in water-intensive sectors. With tremendous variation in relative water abundance across countries (and thus in the opportunity cost of water), relatively high-effective water prices in very water-scarce countries quickly

[16] Figures A1 and A2 provide information on the direct and indirect water use across sectors in the United States.

[17] Mekonnen and Hoekstra (2011) approximate water consumption. Their data is very detailed for agriculture, but not for manufacturing and mining, which is why I rely on BHV's withdrawal data.

[18] See online Appendix Table A1for the 15 most and the 15 least water intensive measures.

[19] Note that as a robustness check, I will allow water intensities to vary by country for agriculture, relying on Mekonnen and Hoekstra (2011) data, see empirical results section and see Appendix for data description.

make production and trade in water-intensive goods prohibitively expensive in spite of the low water-intensity measures for the United States.

C. *Water and International Trade*

To draw Figure 1, I ranked all 134 countries by per capita freshwater abundance and broke them 2 equally sized groups of more and less water-abundant countries. Similarly, I ranked the 206 industries by the direct water intensity as found in the US data and split the industries into 10 equal groups. For each industry decile, I calculated the share of world exports of the more water-abundant countries. As Figure 1 reveals, the group of more water-abundant countries tends to see its share of world trade increase with the water intensity of the decile of goods considered, which suggests that water is a source of comparative advantage. I also find a raw correlation of 0.12 across countries between the per capita water endowments of countries and a water-intensity weighted sum of their exports, as in $\text{Corr}(W_c, \sum_{w_i} \times \theta_{ic})$, where W_c is the per capita water endowment of country c, θ_{ic} is the share of sector i from country c in country c's total exports, and w_i the water intensity of sector i. Exports of agricultural goods as a fraction of total exports are also consistent with a role for water. It tends to increase with countries' water abundance. Dividing countries[20] up into terciles according to water abundance, the average agricultural share increases from 8 percent to 8.4 percent to 20 percent as countries' water resources per capita rise.

While the presented statistics are suggestive, it is clear that the analysis needs to be supplemented by more careful econometric analysis that controls for other production factors, such as capital, labor, and land. However, the presented graphs on the trade patterns are consistent with the general tenor of the obtained results.

III. Estimation Results

The estimates in Table 2 show our basic results, with the key variables of interest as far as comparative advantage goes. I include the interaction of sectoral water intensity and a country's water abundance, as well as the interaction terms for the production factors capital, human capital, land, and the interaction of sectoral contractability and a country's judicial quality, which Nunn (2007) introduced to investigate the extent to which countries' ability to enforce contracts matters for trade. All coefficients are standardized. The regression includes country and industry fixed effects. I first consider the nonzero trade patterns. The first four columns vary the definition of water intensity. I extend the direct water-intensity measure in column 1 to the total (direct plus indirect) water intensity in column 2. In columns 3 and 4, I have included green water that is used in agricultural sectors to adjust the water-intensity measures. The basic regression is run for 196 industries and 68 countries.[21] In all instances and in all regression to follow, there is two-way

[20] For additional evidence, see Figure A3 in online Appendix.

[21] In the online Appendix Table A2 I also provide the correlations between exports and the various water-intensity measures for the more extended dataset with 206 industries and 138 countries. Consistent data for the other factors

Table 2—Comparative Advantage

	Dependent variable: log of exports per country and industry							
Explanatory variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Water interaction, direct, blue	0.042** (0.021)				0.039** (0.019)			
Water interaction, direct and indirect, blue		0.051** (0.024)				0.047** (0.022)		
Water interaction, direct, green and blue			0.041** (0.021)				0.037* (0.019)	
Water interaction, direct and indirect, green and blue				0.047** (0.023)				0.043** (0.021)
Capital interaction	0.11* (0.062)	0.11* (0.062)	0.11* (0.062)	0.11* (0.062)	0.23*** (0.072)	0.23*** (0.072)	0.23*** (0.072)	0.23*** (0.072)
Skilled labor interaction	0.24*** (0.042)	0.24*** (0.041)	0.24*** (0.042)	0.24*** (0.042)	0.15*** (0.039)	0.15*** (0.039)	0.15*** (0.039)	0.15*** (0.039)
Land interaction	0.21 (0.144)	0.19 (0.142)	0.21 (0.144)	0.19 (0.144)	0.20 (0.137)	0.18 (0.136)	0.20 (0.138)	0.18 (0.138)
Contractability interaction					0.38*** (0.062)	0.38*** (0.061)	0.38*** (0.062)	0.38*** (0.061)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.72	0.72	0.72	0.72	0.73	0.73	0.73	0.73
Number of observations	11,465	11,465	11,465	11,465	11,465	11,465	11,465	11,465

Notes: Water interaction stands for the interaction between water abundance and water intensity. Direct and indirect refer to direct and indirect water use. Blue focuses only on blue water used. Blue and green refer to both blue and green water used. Standard errors clustered by country and industry.

***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

clustering of the errors, i.e., by country and by industry, and in a manner consistent with Cameron, Gelbach, and Miller (2011). I estimate a positive and significant coefficient, which is consistent with the hypothesis that water is a determining factor of a country's comparative advantage. Moreover, the positive coefficient for capital, skilled labor, and contractability that is significant at the 1 or 5 percent levels confirms that these factors are sources of comparative advantage, even when water is added. The coefficient on land, however, is not significant in all cases. These basic results suggest that the international division of labor, which international trade facilitates, to some extent addresses water scarcity, so that more water-intensive products tend to be exported by more water-abundant countries.

The estimated coefficients are standardized, which makes a comparison across different factors of production meaningful. The impact of a standard deviation increase of water is significantly lower than the impact of a standard deviation change of capital or skilled labor. As a matter of fact, a standard deviation increase of water per capita increases exports by about 0.05 standard deviations, which is about half

of production are not available for the extended dataset. As one can see, narrowing down the dataset to 68 countries and 196 industries does not make a qualitative difference.

the impact for capital and about one-fifth the impact of skilled labor. Since climate change is likely to change precipitation patterns and affect the local availability of water, the obtained estimates have an important message to tell. In light of the discussion of climate change, these relatively low-impact numbers for water may seem like an encouraging outcome at first. The estimates indicate that from a global perspective, and while holding all else constant, changes in water resources should not have a very disruptive impact on the pattern of international trade.

This conclusion needs to be qualified and explained. For one, a low impact is in line with the low cost of water. As noted, the median and average sectoral cost of water is low, respectively, a mere 1 and 3.5 percent of value added, which is why one would expect a contained impact of changes in the availability of water especially in nonagricultural sectors that do not comprise the bulk of international trade. In addition, while it is true that the distribution of water is very uneven on a global scale and that there may be plenty of water-abundant countries with very low opportunity costs for water, my estimates take as a given the current global economic policy environment. This policy environment is characterized by water prices that are oftentimes regulated, subsidized, and distorted, which tends to encourage wasteful use of water. In this light, the obtained estimates may well be lower-bound estimates of the impact of changing water availability. Because the true opportunity cost of water is likely to be factored in more accurately in the future, especially in countries that do not use their resources sustainably, one would expect the impact of water on the pattern of trade to increase barring any technological advances or efficiency gains in water use.

Finally, it is important to complement the global perspective, and to keep in mind that climate change and the change in local water availability may have nonnegligible impacts on individual countries. Consider, in particular, exporters of especially water-intensive products such as agricultural products. By way of example, take a country such as Australia, which in terms of the average water intensity of its exports is ranked twenty-first. In response to the fourth assessment report of the 2007 Intergovernmental Panel on Climate Change (IPCC), which provided little detail on Australia, the Australian Greenhouse Office and the Australian Climate Change Program commissioned a study of climate change projections for Australia.[22] Since climate change depends on CO_2 emissions, the study distinguishes different scenarios for low, medium, and high levels of emissions. Taking the years 1980–1999 as baseline, the commissioned study's most likely fiftieth percentile projection shows, for most of Australia, a drop in precipitation on the order of 10 percent by the year 2030.[23] Just by way of example, I consider a 10 percent drop in the water resources due to climate change. My estimates suggest that, Australia's overall exports would be reduced by about 5.2 percent, which is not negligible from Australia's perspective. While the prediction is valid only under restrictive assumptions (it is assumed

[22] See http://www.climatechangeinaustralia.com.au. See also Heberger (2012) for a discussion of climate change and water availability and Australia.

[23] To be sure, there is quite a bit of uncertainty. The tenth percentile estimate shows drops in rainfall of up to 10 percent to 20 percent, whereas its ninetieth percentile estimates features increases of 10 percent to 20 percent.

that the fixed effect is not affected by the 10 percent drop in precipitation), it does give a sense of the order of magnitude.[24]

The obtained results reported so far are quite robust. I have dropped various outliers and the results remain consistent.[25] I have excluded the five countries with the most and the least water resources, if one is worried that the interaction term of water intensity and water abundance picks up correlations that have nothing to do with relative water abundance. I also exclude the five largest economies in terms of GDP and in terms of water, as well as five countries that have the highest GDP per capita or the five least developed countries that are still in our sample. Note that dropping the poorest countries addresses the concern that the water resources that are directly relevant for international trade should exclude subsistence levels of water use that are not available for production and international trade.

In Table 3, I address different concerns. I present my preferred estimates for total green and blue water measures alongside those for total blue water. The results without indirect water use are similar. I substitute in precipitation data as a different measure for water abundance in columns 1 and 2. The fact that the precipitation values yield a similar result helps address a subtle inconsistency between countries' water resources and the water use data. As argued above, the usual blue renewable water resources data may not capture "green water" well enough because they include mainly recharge of groundwater and water runoff. Precipitation measures can be helpful in this context since precipitation affects both blue and green water, even though precipitation data are probably less precise than the renewable water resources that we have used so far.

Another concern relates to our water intensity measures. In the regression specification we rely on relative water intensity measures for the United States. As we allow for country and industry fixed effects, we do not literally impose the same absolute water US intensity measures on all countries. Still, especially for agriculture one may be concerned that differences in water availability will make farmers grow different types of produce with different levels of water intake. Recent work by Mekonnen and Hoekstra (2011), allows us to adjust the water intensity measures for our 14 agricultural sectors for the individual countries that are included in our sample. In particular, Mekonnen and Hoekstra provide data on the total (green and blue) water use for different crops and livestock for countries other than the United States. Based on these data, I scale up or down the US water intensity measures based on BHV, for details see online Appendix. The results are presented in columns 3 and 4. As before, the estimates are not significantly different from our standard results. In columns 5 and 6, I exclude the fairly water-intensive gas and oil industries, and then exclude major oil and gas exporters whose oil exports comprise 80 percent or more of total exports in columns 7 and 8. In doing so, I want to avoid that the

[24] To obtain this number, I follow Nunn (2007). For each export sector, the log of the new export value, $x_{ic'}$, is obtained as follows: $\ln(x_{ic'}) = \ln(x_{ic}) + 0.3806233 \times w_i \times \ln(21.6125 \times 0.1)$, where x_{ic} is the old export value, 21.6125 Australia's water endowment, 0.1 the 10 percent change in the water endowment, w_i is the water intensity, and 0.3806233 the non-normalized direct water use coefficient that is obtained from a regression (1) without any interaction terms for other factors, which is the lowest across all specifications. Next, solve for $x_{ic'}$ and add across sectors i. To obtain the percentage, divide by the initial total exports.

[25] See results in online Appendix in Table 3A. Note that for the various subgroups, I obtain positive coefficients that in most instances are significant at the 5 percent level, and in some instances at the 10 percent level.

Table 3—Robustness Checks

	Dependent variable: log of exports per country and industry Ordinary least squares							
Explanatory variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Water interaction, direct and indirect, blue	0.089*		0.044**		0.052**		0.050**	
	(0.046)		(0.019)		(0.024)		(0.024)	
Water interaction, direct and indirect, green and blue		0.086*		0.041**		0.049**		0.047**
		(0.044)		(0.018)		(0.019)		(0.019)
Capital interaction	0.11*	0.11*	0.11*	0.11*	0.11*	0.11*	0.11*	0.11*
	(0.019)	(0.019)	(0.062)	(0.062)	(0.019)	(0.019)	(0.019)	(0.019)
Skilled labor interaction	0.23***	0.23***	0.24***	0.24***	0.25***	0.25***	0.24***	0.24***
	(0.019)	(0.019)	(0.041)	(0.042)	(0.019)	(0.019)	(0.019)	(0.019)
Land interaction	0.34**	0.34**	0.21	0.21	0.19	0.19	0.19	0.2
	(0.019)	(0.019)	(0.144)	(0.144)	(0.019)	(0.019)	(0.019)	(0.019)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Number of observations	11,465	11,465	11,465	11,465	11,325	11,325	11,411	11,411

	Dependent variable: exports per country and industry Tobit	
Explanatory variables	(9)	(10)
Water interaction, direct and indirect, blue	0.015***	
	(0.006)	
Water interaction, direct and indirect, green and blue		0.014***
		(0.005)
Capital interaction	0.084**	0.084**
	(0.037)	(0.037)
Skilled labor interaction	0.064	0.064
	(0.046)	(0.046)
Land interaction	0.071	0.071
	(0.046)	(0.047)
Country fixed effects	Yes	Yes
Industry fixed effects	Yes	Yes
Pseudo R^2	0.13	0.13
Number of observations	13,464	13,464

Notes: Water interaction stands for the interaction between water abundance and water intensity. Direct and indirect refer to direct and indirect water use. Blue focuses only on blue water used. Blue and green refers to both blue and green water used. Standard errors clustered by country and industry.
(1)–(2) Per capita precipitation replaces per capita water endowment
(3)–(4) Water use technology adjustment
(5)–(6) Excludes countries with oil and gas exports exceeding 80 percent of total exports
(7)–(8) Excludes oil and gas industry
(9)–(10) Tobit regression, includes zeros
***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

estimation results are driven by the demand or supply for oil and gas. Excluding the oil exporters has the added benefit of taking out those countries that are most active

Table 4—Additional Results, with Log Exports Differentiated by Greater or Less than 1,500 or 6,808 Cubic Meters: Renewable Water Per Capita

	Dependent variable: log of exports per country and industry			
Explanatory variables	(1)	(2)	(3)	(4)
Water interaction, direct and indirect, blue	0.049*		0.05**	
	(0.029)		(0.023)	
Water interaction, direct and indirect, green and blue		0.044		0.047**
		(0.027)		(0.022)
Below 1,500 = 1 × water interaction, direct, and indirect, blue	0.004			
	(0.013)			
Below 1,500 = 1 × water interaction, direct, and indirect, green and blue		0.005		
		(0.013)		
Below 6,808 = 1 × water interaction, direct, and indirect, blue			−0.01	
			(0.014)	
Below 6,808 = 1 × water interaction, direct, and indirect, green and blue				−0.007
				(0.015)
Capital interaction	0.11*	0.11*	0.11*	0.11*
	(0.063)	(0.063)	(0.063)	(0.063)
Skilled labor interaction	0.24***	0.24***	0.24***	0.24***
	(0.043)	(0.043)	(0.042)	(0.042)
Land interaction	0.18	0.18	0.21	0.2
	(0.161)	(0.168)	(0.15)	(0.151)
Country fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
R^2	0.72	0.72	0.72	0.72
Number of observations	11,465	11,465	11,465	11,465

Notes: Water interaction stands for the interaction between water abundance and water intensity. Direct and indirect refer to direct and indirect water use. Blue focuses only on blue water used. Blue and green refers to both blue and green water used. Standard errors clustered by country and industry.

***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

in desalination of seawater, which is not captured by the freshwater resources measure. In all these instances, the estimation results do not significantly change.

In the last two columns of Table 3, I present the results of a Tobit regression for the level of exports that includes zero trade flows. So far, the analysis has been restricted to nonzero trade. As mentioned in the discussion of water intensity and the relatively low-cost share of water, the huge variation in the relative water availability (and hence the opportunity cost of water) can quickly make water costs prohibitively high for water-intensive goods in water-scarce countries. Also the Tobit results confirm that water is a significant factor of comparative advantage. Here, again, the contribution of water is smaller than that of the traditional production factors.

In Table 4, I finally investigate whether water affects exports in a uniform way or not. To do so, I run regression (2), which has an additional interaction term $W_{c^*}\, w_{i^*}\, I_c$, where I_c is 1 for water-scarce countries and 0 otherwise. The additional interaction term distinguishes the more versus the less water-abundant countries. As indicated before, a positive coefficient on the additional interaction term would be consistent with water being a free resource with zero opportunity cost in the more water-abundant countries. Indeed, beyond a threshold of water abundance where the opportunity cost of water is zero, additional water abundance should not strengthen countries' comparative advantage as much as it does for water-scarce countries. A negative coefficient, on the other hand, could point to less effective water resources in water-scarce countries, possibly due to unsustainable water use in those countries. As a starting point, I choose the 1,500m^3 and 1,700m^3 of water per person mark, which are customarily used in the literature to distinguish water-scarce versus water-abundant countries. I report the results for 1,500m^3 that are very similar to those for 1,700m^3. As one can see in columns 1 and 2, the coefficient on interaction between the indicator variable and the water interaction term is negative but not statistically significant. In columns 3 and 4, I raise the cutoff between water-scarce to water-abundant countries to 6,808m^3 per person, which is Thailand's per capita water endowment. There are two reasons why this mark is chosen. First, it is halfway through the sample of countries and significantly higher than the usual measure. Second, and more importantly, beyond Thailand there are no countries with water use ratios of 20 or 40 percent or more—below 6.808m^3 per person about 53 percent of the countries have a water use ratio over 20 percent. In other words, 6,808m^3 is a reasonable measure to investigate the hypothesis that water is less effective a resource among water scarce countries because of their unsustainable use of it. For reference, below 1,500m^3 per person, 65 percent of the countries are using water at unsustainable levels. Here also, I obtain a negative, but again not significant coefficient. Including the zero trade flows in a Tobit specification yields comparable results. We get a negative but insignificant coefficient for the added interaction term.

IV. Conclusion

The production of virtually every product requires water, and in many instances lots of water. Because of its very nature, water is an input unlike any other. The price that is paid for water often does not reflect its true opportunity cost. Because water is a necessity for life and because there are economies of scale in water distribution and storage, there is ample room for government intervention and regulation. In addition, water is in many instances an open access resource that is subject to the tragedy of the commons, which explains why water is often used freely and overused especially in agriculture.

In spite of the above concerns, I find that it is indeed the case that water systematically affects countries' trade patterns in a manner consistent with international trade theory. My analysis shows the international distribution of water resources is uneven enough and that the differences in sectoral water intensities are important enough to affect the international division of labor of global production and trade. More water-abundant countries tend to export more water-intensive products, and less water-abundant countries less water-intensive goods. The fact that water is a source of comparative advantage is important in light of the impending water crises in many countries due to population growth, rising living standards, and climate change. The evidence suggests that water-scarce countries, at least to some extent, protect their scarce water resources by exporting less water-intensive goods that would tax their scarce resources even more. My study should invite careful studies of how trade policies could actually be used to help alleviate water scarcity, especially since about 20 percent of the world's global water use is traded as virtual water. At the same time, I do not find consistent evidence that suggests that water is a weaker or stronger source of comparative advantage in water scarce countries because of their more unsustainable water use, or simply because water is hypothesized to be a free good in water abundant countries.

My findings are also relevant with respect to discussions about climate change. My study is an exercise in positive analysis, unable to say whether the degree of specialization obtained is enough, too much, or just right. However, the estimates suggest that water affects the international pattern of production and trade to a lesser extent than do the traditional production factors of capital or labor. From a global perspective and in light of the expected disruption of trade due to changing international patterns of precipitation, this finding suggests relatively contained challenges and disruptions. A few important caveats should be mentioned here, however. To the extent that there are important policy distortions and to the extent that water is mispriced across the globe, the estimates found here may well be a lower bound. In addition, my results should not minimize the serious challenges that individual countries, and in particular, exporters of water-intensive goods may face in the wake of changing precipitation patterns.

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