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No. 9030

THE GLOBAL ECONOMICS OF WATER: IS WATER A SOURCE OF COMPARATIVE ADVANTAGE?

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INTERNATIONAL TRADE AND REGIONAL ECONOMICS

Centre for Economic Policy Research

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ISSN 0265-8003

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CEPR Discussion Paper No. 9030

ABSTRACT

The Global Economics of Water: Is Water A Source of Comparative Advantage?*

Freshwater scarcity is bound to be a major challenge of the 21st century. Drawing on newly available data, I investigate to what extent countries make efficient use of the very uneven water resources on a global scale. In particular, I find that countries that are relatively water abundant tend to export more water-intensive products. This evidence supports the hypothesis that water is a source of comparative advantage. My findings also indicate that water contributes significantly less to the pattern of exports than the traditional production factors such as labor and physical capital. In light of climate change, this suggests relatively moderate disruptions to trade on a global scale due to changing precipitation patterns. My results do not provide consistent evidence that there is a difference in the extent to which water determines the pattern of trade between water-scarce and water-abundant countries.

JEL Classification: F1
Keywords: comparative advantage, international trade and water

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*Nan Zhang and especially Amanda Kurzendoerfer provided excellent research assistance. This project benefitted from funding by the Darden Foundation. I thank Nathan Nunn for making his data available, as well as Arjen Hoekstra. This paper was written in part while visiting the Haas Business School at Berkeley. I received helpful suggestions from Gordon Hanson, James Harrigan, David Levine, John McLaren, Brian Richter, Andres Rodriguez-Clare, John Romalis, and Bob Stern and I benefitted from a presentation at UC San Diego. All remaining errors are mine.

Submitted 15 June 2012

THE GLOBAL ECONOMICS OF WATER: IS WATER A SOURCE OF COMPARATIVE ADVANTAGE?[1]

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Version, June 2012

Abstract

Freshwater scarcity is bound to be a major challenge of the 21st century. Drawing on newly available data, I investigate to what extent countries make efficient use of the very uneven water resources on a global scale. In particular, I find that countries that are relatively water abundant tend to export more water-intensive products. This evidence supports the hypothesis that water is a source of comparative advantage. My findings also indicate that water contributes significantly less to the pattern of exports than the traditional production factors such as labor and physical capital. In light of climate change, this suggests relatively moderate disruptions to trade on a global scale due to changing precipitation patterns. My results do not provide consistent evidence that there is a difference in the extent to which water determines the pattern of trade between water-scarce and water-abundant countries.

1. Introduction

Freshwater scarcity is bound to be a major challenge of the 21st century. Almost one-fifth of the world's population currently suffers the consequences of water scarcity, and this number is expected to increase (UNESCO, 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 water that can be used. But in spite of reports about an impending water crisis, the world 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.[2] Even though only a very small fraction of this

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[2] See Young and Haveman (1985)

amount is not salty and accessible, there is more than enough freshwater on earth to satisfy the growing demand, especially since water desalination is always an option.[3] The major concerns about water availability stem especially from the very uneven global distribution of water. While many countries clearly have more than enough water to satisfy their populations' increasing needs, some countries do not. Water scarcity is thus tied to particular regions, and the discussions of climate change and disruptions of the hydrologic cycle it entails have only heightened concern about water scarcity in those areas. Increasingly, scientists realize that tackling water scarcity warrants an international analysis.[4]

Since water is too heavy to be profitably traded internationally on a massive scale, direct water trade among countries is not a practical means of addressing water scarcity. 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. My study may be the first to study this very basic question in a manner consistent with the extensive international trade literature, while explicitly taking into account the role of other production factors beyond water.[5] Moreover, the international perspective of this study that emphasizes international exchanges also complements much of the existing water literature in economics.

[3] See Gleick (2009) and Richter (2012)

[4] See, for example, Postel et al. (1996) Vörösmarty et al (2000), Chapagain and Hoekstra (2008).

[5] Whether water is a source of comparative advantage is often brought up in the interdisciplinary environment in which water is studied. The pioneering global water analyses outside economics provide a wealth of invaluable data and insights. Since the work of Allan (1994), there is a growing literature of "virtual water," or of the water contained in the goods that are traded internationally. The work by especially Hoekstra and coauthors is important in this context. In that literature, references to the opportunity cost of water or to other factors of comparative advantage such as capital or labor are few; see Wichelns (2004). While a country's trade may contain a lot of water, it also contains capital,labor or other factors or production and it is, from an economic point of view, especially the relative cost difference between those factors that determines international trade flows.

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.).[6]

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. This finding is quite robust and suggests that international trade, at least to some extent, allows for a more efficient use of water on a global scale. 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.[7] 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 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 non-negligible impacts for individual countries, in particular heavy exporters of water-intensive goods. My estimation results, however, fail to deliver consistent evidence of a quantitative differential in the way water determines the pattern of trade between water-scarce and water-abundant countries. As such, the estimates are not consistent with water being a free good with zero opportunity cost in water abundant countries. I also do not find systematic and strong evidence that water is a less effective water resource in water scarce countries possibly due to unsustainable use.

To study water as a source of comparative advantage, I apply the framework of the factor proportions theory or the Heckscher-Ohlin (HO) theory. This key theory of international trade is the natural framework to use since it emphasizes the importance of countries' resources as important determinants of their trade patterns. While there is an extensive theoretical and empirical HO literature that goes back to Heckscher, Ohlin, and Leontief, the focus of the empirical literature has been on the resources capital, various types of labor and land as

[6] Countries are the unit of analysis since regional international trade data are not available for many countries.
[7] For full discussion of the data, see data section.

determinants of trade.[8] In other words, water is virtually absent in the literature and we do not know to what extent water abundance induces exports and imports of water-intensive products. This absence is somewhat surprising in the context of the current water crisis and the concerns about water scarcity. It is most likely to be attributed to the absence of reliable data so far. The recently available water data that are used in this study should take away the data obstacle. In particular, I especially take advantage of Blackhurst, Hendrickson and Vidal (BHV) (2010) and Mekonnen and Hoekstra (2011). BHV provides the first water withdrawal study at the sectoral level for the United States in 30 years. The study goes beyond sectors' water bills, which are customarily found in Input Output tables and are sometimes used. I will primarily use U.S. data to rank the water intensities for my global analysis. Mekonnen and Hoekstra (2011) proves to be an invaluable resource for water analysis especially where water use in agriculture is concerned: the study documents blue as well as green water use and makes it possible to differentiate the water intensities for agricultural products by country *and* subsector.

The paper is structured as follows. In Section 2, I lay out the conceptual framework and the estimation equation. In Section 3, key water data are discussed and some descriptive statistics are presented. In Section 4, the regression analysis and results are presented. Section 5 provides a discussion and conclusion.

2. Conceptual Framework and Estimation Equation

The framework used to analyze the role of water as a determinant of countries' pattern of trade draws on the HO theory. The HO theory has been formalized in many ways. Its basic insight is straightforward and most easily expressed in a two-country, two-sector, and two-factor model that assumes perfect competition, internationally immobile factors of production and constant returns to scale. It predicts that trading countries will shift their production and exports toward the good that uses its abundant factor intensively since such a country can produce those goods relatively cheaply. At the same time, countries will import goods that are intensive in their scarce factor, which can be produced abroad in a relatively more cost-effective way.

[8] In the wake of the Leontief paradox, natural resources have been included in empirical HO studies; see Baldwin (2008). In many instances, the factors considered were non-renewable resources. There are a few computable general equilibrium studies that include water, some of which have an HO component; see Berrittella et al. (2007). Recently, Nunn (2007) and others have extended the analysis of comparative advantage to institutions and contracts.

The empirical HO literature has evolved significantly since the work of Ohlin, Heckscher and Leontief.[9] It has moved beyond the two-sector, two-factor, two-country perfect competition models to models with multiple factors, countries and sectors that allow for transportation costs, different forms of competition, and different productivity levels across countries. My empirical specification draws on Romalis (2004) as well as Nunn (2007) and Levchenko (2007). 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.

$$x_{ic} = \alpha_i + \alpha_c + \beta_1 w_i{*}W_c + \beta_2 k_i{*}K_c + \beta_3 s_i{*}S_c + \varepsilon_{ic} \qquad (1)$$

, 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 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. 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.[10]

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-

[9] For a good survey of the literature, see Baldwin (2008).

[10] In the implementation I use the U.S. 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.

intensive sectors of relatively water-abundant countries.[11,12] I will focus primarily on the positive (non-zero) trade with variables in logs, but will include zero trade flows in the extensions, since the extent of a country's water endowments arguably will preclude some countries from producing and exporting certain goods.

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

$$x_{ic} = \alpha_i + \alpha_c + \beta_1 w_i * W_c + \beta_2 W_c * w_i * I_c + \Sigma_j \beta_j * f_{ji} * F_{jc} + \varepsilon_{ic} \qquad (2)$$

In this specification, 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 versus and 0 otherwise. Note that $\Sigma_j \beta_j f_{ji} * F_{jc}$ summarizes the interactions term for the non-water resources j. The rationale for including the additional specification is that it allows me to study two alternative hypotheses that tend to come up in discussions about water. They posit a differential impact of water on exports for more versus less water-abundant countries.

A first hypothesis posits that the β_2-coefficient of the added interaction term in regression (2) should be positive. A positive coefficient suggests 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 derives from the discussion as to 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 with zero opportunity cost. Note that the hypothesis of water as a free resource 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

[11] Note that Nunn (2007) focused on a country's trade in various sectors with the rest of the world. Romalis, on the other hand, investigated exports to the United States. Nunn investigated on non-zero trade; Romalis (2004) on the other hand included zero trade flows in his analysis. While Nunn included fixed effects, Romalis did not and directly inserts the country endowments and sectoral intensities as regressors. Note also that the interaction term is directly consistent with Costinot's (2009) notion of supermodularity that summarizes theories of comparative advantage.

[12] 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.

suggest we live in a world in which water prices will vary internationally with the relative abundance of water per capita.[13]

A second, alternative hypothesis posits the exact opposite. Water resources are expected to be less effective in water-scarce compared to water-abundant countries, which amounts to a negative β_2-coefficient in regression (2). Water-scarce countries often use water in unsustainable ways that lower the 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.[14] This second hypothesis draws on water resources vulnerability indices that have been increasingly prominent in the water literature; see 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. In an uncertain world with varying precipitation, higher water withdrawals ratios increase the chance that local sources of water (e.g., aquifers that need time to replenish) may get depleted. Higher water-use ratios also stress the environment in terms of the species that live in and around the water, and they challenge the ability of water to assimilate pollutants. In addition, to the extent that used water is released back into the environment after use, higher water-use ratios make pollution more likely and lower the overall quality of water. Richter et al. (2011) and Hoekstra et al. (2012) argue that water-use ratios above 20% or 40% challenge the sustainable use of water. While there are potentially many factors that determine water-use ratios beyond 20% or 40%, one key factor is the scarcity of water resources. The less water there is, the more likely more than 20% or 40% of water will be used. To differentiate between countries that are beyond water scarcity versus water-scarce countries, I initially follow

[13] 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. In particular, it is a standard results from the Heckscher-Ohlin theory that in a frictionless world with not-too-dissimilar water endowments and equal technology, there will be factor price equalization and the price of water should be the same across the globe. Debaere and Demiroglu (2003) shows that factor endowments are too different for factor price equalization to occur.

[14] This hypothesis is not unlike Trefler (1995) who translates countries' endowments into effective units by adjusting them for productivity differences among countries. In terms of algebra from regression (2), for a water scarce country c the comparative advantage term (with estimated coefficient $b1 > 0$) and the interaction term (with negative coefficient $-b2$, $b2 > 0$) can be rewritten as $b1\ (1 - b2/b1)\ Wc^*\ wi$. The multiplicative term $(1 - b2/b1)$ rescales the scarce country's water resources in effective or quality adjusted units. For this hypothesis to be plausible b2 should also be smaller than b1.

the literature and take the literature's threshold level of $1{,}500m^3$ or $1{,}700m^3$ as starting point, see Matlock (2011).

3. A Role for Water: Data

Deardorff (2006) provides a succinct definition of comparative advantage. It is the ability of a country to produce goods at lower cost, relative to other goods, compared to other countries. To determine whether water is a factor of comparative advantage, then, boils down to determining whether water is important enough as a cost factor relative to other factors such as capital and labor and whether this cost factor varies enough across goods and across countries to play a role in where goods are produced. Thus, for present purposes, comparative advantage is all about exploiting differences among countries and sectors in the use and availability of water compared to other factors. In what follows, I discuss some of the water data sources that I use and provide descriptive data on water availability across countries, water use across sectors, and how water use and water availability are reflected in international trade data. A discussion of the fairly standard data for the other factors of production that are used in the study is provided in Appendix I.

Water Resources

To explain the pattern of trade, I rely on the relatively standard measure of a country's water resources: the volume of renewable fresh water per capita. I take the data from Gleick (2009), who relies heavily on the UN FAO Aquastat database. The renewable freshwater resources are the sum of the average annual surface runoff (e.g., from rivers or lakes) and the groundwater recharge; see Johnson, Revenga and Echeverria (2001). As such, the water resources capture the amount of water that can be withdrawn annually without violating the concept of sustainability. I take the total amount of renewable water per capita as a proxy for the total availability of water in a country. Technically speaking, the total renewable water does not capture all water resources. It comprises blue water, but not green water, which is hard to measure.[15] Blue water comprises surface and ground water and is the only source of water for households and industry. Blue water is also important for agriculture through irrigation. Green water is stored in the soil or

[15] Hoekstra has measured green water *use*, which is different from the green water that is available.

temporarily stays on top of vegetation. It matters exclusively for agriculture especially 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 to work with, I will not be able to address the variation within a country or during the year.[16]

The world's water resources are spread very uneven way. Six countries, Brazil, Russia, the United States, Canada, Indonesia, and China—together account for almost 50% of the world's fresh water. Note also that the lowest tercile of the least water-abundant countries have about 1,150m^3 of water on average per year per person, which is 6 times less than the average amount of water available in the second tercile and 75 times less than the most water-abundant tercile has. Table 1 explicitly categorizes our 134 countries into three deciles, while providing the minimum and maximum water available per capita in each tercile.

Note that my measure of a country's available renewable fresh water per capita should capture the average opportunity cost of using water in a country. It is potentially a much better proxy of the true (opportunity) cost of water than the actual prices of water that consumers and producers face. It is widely accepted that the prices most users pay for water do not reflect water's scarcity value; see Hanemann (2006). There are multiple reasons for this. Since water is a necessary good, water is often subsidized and regulated. In addition, due to many complementary uses such as irrigation and recreation, and due to economies of scale in water storage and distribution, private markets for water tend to be thin or lacking However, water scarcity can be felt through many other channels than just price. The low or set water price may not reveal water rationing, for example, or any interruptions of the water supply because of water scarcity or shortage. However, my per-capita water endowment measures should pick up such implicit costs of water scarcity much better especially since shortages or interruptions in supply are more likely to take place with scarce water resources.

<u>Sectoral Water Use</u>

For this study, I heavily rely on BHV, which carefully disaggregates the aggregate water withdrawal data for the United States from the U.S. Geological Survey into the individual water

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

withdrawals of the 426 sectors. In particular, I use the relative ranking of U.S. water intensities constructed from BHV data in regression (1) and (2). To construct a detailed measure of sectoral water intensity, I draw both on sectors' direct as well as indirect water withdrawals that are inferred from Input Output Tables. I reclassify the BHV data into 206 industries that are consistent with the Bureau of Economic Analysis 1997 IO classification, which is the data format for the other factors of production. Because many sectors have their own water supply and are not solely dependent on utilities, the BHV data are a much better measure of water use than the sectors' water bills from IO tables, which are sometimes used. As a matter of fact, total water use for the United States, for example, is an order of magnitude larger than the water use inferred from the public utility water bills from the IO tables.

The pie charts in Figure 2 show the broad breakdown of the direct and total (direct plus indirect) sectoral water use in the United States. The upper chart shows that 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 very directly relevant for an analysis of international trade. It is important, however, not to ignore sectors' indirect use of water through their use of power. Indeed, because power generation is in many instances a non-traded sector, the capacity to produce internationally traded goods will not only depend on the availability of water as a direct input, but also on the extent to which water is available for power use. The second pie chart in Figure 2 illustrates the breakdown of both direct and indirect water use for the major traded good sectors. In terms of total water use, manufacturing surpasses agriculture. An important reason for this is the heavy water-intensive power use of manufacturing compared to agriculture combined with the stronger input-output links in manufacturing. Finally, the bar graphs in Figure 3 show, in the upper half, the distribution of direct, and, in the lower graph, the direct plus indirect water use within manufacturing. From the upper graph it can be inferred that textiles and chemicals are by far the most important direct water users, accounting together for about 75% of total water use in manufacturing. As is clear from the lower bar graph, the distribution of water use is much more even across sectors when indirect water use is included.

It is important to keep in mind that 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 data are preferred, they are not available at the disaggregate level for manufacturing and mining.[17] 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 will adjust the blue water use data for agricultural sectors by applying the ratio of blue to green water use for the United States found in Mekonnen and Hoekstra (2011), who provide both estimates of green and blue water use.

To understand the distribution of worldwide production and trade, it is not only important to have a sense of sectoral total water use, one wants to differentiate sectors by their water intensity. To construct the water-intensity measures that I need in regression (1) and (2) and to compare water costs to the cost of other production factors, water prices are needed in order to value the water quantities that BHV provides. Since I treat water use for the U.S. sectors as the benchmark, I take the average water utility price for the water provided by public utilities for public water and the average prices of water trades in the Western states of the United States for water that is not intermediated by the utilities; see Brewer et al. (2007) and the Appendix II for the details. I follow Romalis (2004) and construct the sectoral water-intensity measure as the ratio of the cost of water use over value added plus the cost of water use. In doing so, I relate the cost of water to the cost of other primary factors of production and ensure the ratio does not exceed one.

Table 2 reports the 15 most and the 15 least water-intensive sectors. Sectors related to agriculture and mining are the most water-intensive ones, at least as far as direct blue and green water use is concerned. By construction, the calculated water-intensity measures are between 0 and 1. The median intensity is 0.04 for direct blue and 0.06 for total (direct plus indirect) blue water intensity. The numbers are slightly higher when green water is included. Overall, the low numbers indicate that water costs are relatively moderate in the United States, a fact that has been known for quite some time; see Hanemann (2006). Indeed, compared to the total cost of labor, land, and capital combined (proxied for by value added), the cost of water is respectively 3.5% and 1% of value added for the average and the median water user, respectively. In assessing these numbers, it is important to keep in mind that the relatively high value added in

[17] Technically, the sum of the consumptive use of water plus the conveyance losses (the water losses in transit) and the return flows into the environment after use add up to the total amount of water withdrawal; see Young and Haveman (1985). Note that Mekonnen and Hoekstra (2011) approximate water consumption. Their data is very detailed for agricultural sectors, but much less so for manufacturing and mining sectors, which is why I rely on BHV's withdrawal data.

manufacturing compared to agriculture is in part 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.[18] 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), we know that producing one ton of aluminum basically requires 87 tons of water.[19]

The low intensity measures for the United States, should, however, not make us infer too quickly that water is a negligible factor in explaining the global allocation of production and trade. To explain international trade flows, we study countries' comparative advantage, which hinges on *both* the variation of factor intensities among sectors and on the relative factor abundances across countries. In the empirical analysis, I will use the interaction of countries' water abundance and sectors' water intensity to explain a country's exports, because I want to investigate whether indeed water-abundant countries export more in water-intensive sectors. As emphasized above, there is tremendous variation in relative water abundance across countries and thus in the opportunity cost of water, so that relatively high effective water prices in very water-scarce countries can quickly make production and trade in water-intensive goods prohibitively expensive in spite of the low water-intensity measures for the United States.[20]

Water and International Trade

In this section, I present some suggestive evidence based on analyzing the raw data that is consistent with water being a source of comparative advantage. Figure 1, which was referred to in the introduction, indicates there is a tendency for more water-abundant countries to export water-intensive products. To draw Figure 1, I ranked all 134 countries by per-capita freshwater abundance and broke them into two equally sized groups of respectively more and less water-

[18] As Byres et al (2003) note the perception that water is a 'free" resource is changing due to drought, stricter standards on water withdrawal and discharge, more rigorously enforced water rights and increasing demand by urban residents.

[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 III.

[20] To assess the potential impact of higher water costs, consider the price of desalinated water, an (expensive) alternative on which water-scarce and energy-rich oil-exporting countries rely. Zhou and Tol (2005) estimate the price of desalination at $1/m^3 for seawater and $0.6/m^3 for brackish water. For reference, to value the quantities of (non-utility) water in the United States, we used for agriculture an average price of $0.013/m^3 and an average price of $0.022/m3 for industries, which is 30 to 80 times cheaper than the reported price for desalinated water. Note also that this cost does not include the price of transporting the desalinated water, which can be prohibitively expensive in regions far from the ocean or situated at higher elevations.

abundant countries. Similarly, I ranked the 206 industries by the direct water intensity as found in the U.S. 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. Figure 4 is consistent with Figure 1 but provides evidence at the country level. For each individual country, I calculate the exports in each of the 10 deciles as a share of a country's total exports. For reference, the share of all deciles adds up to 1. Per decile, I calculate the average share across countries that are part of the more water-abundant group. I do the same for countries from the less water-abundant group. Figure 4 shows the average country shares across deciles for both groups. As one can see, the average share of more water-abundant countries tends to be higher than that of less water-abundant countries for more water-intensive goods. The reverse is true for less water-intensive goods. Finally, I 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 Corr (W_c, $\sum w_i * \Theta_{ic}$), 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 up into terciles according to water abundance, the average agricultural share increases from 8% to 8.4% to 20% 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, which is exactly what we do in the next section. However, the presented graphs on the trade patterns are consistent with the general tenor of the obtained results.

4. Estimation Results

The estimates in Table 3 show the basic correlations between countries' exports and the key variable of interest, the interaction of sectoral water intensity and a country's water abundance. All coefficients are standardized. The regression includes country and industry fixed effects but does not control for the other sources of comparative advantage. I first consider the non-zero 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. Including the total water-intensity measure is important. A significant fraction of water use comes through the use of power, which absorbs a huge part of a country's water use and in most instances is a locally produced and a non-traded service. In columns 3 and 4, I have included the green water that is used in agricultural sectors to adjust the water-intensity measures. The basic regression is run for 206 industries and 134 countries. In all instances and in all regression to follow, there is two-way clustering of the errors, i.e. by country and by industry and in a manner consistent with Cameron et al (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. Columns 5 through 8 then present the estimates of the corresponding coefficients for a smaller dataset of 68 countries and 196 industries that is used throughout the analysis.[21] This smaller set of countries and industries corresponds to the set of countries and industries for which I consistently have data for capital, labor, and land to measure countries' total factors of production and the factor intensity of the sectors. As one can see, the coefficient on the water interaction term is virtually identical for both sets of countries and industries, which indicates that the results are not driven by the particular subset of countries and industries that we investigate. In the smaller sample, not all factors are significant, however.

In Table 4, I include the more commonly studied sources of comparative advantage that are captured by the interaction terms for capital abundance and skilled labor abundance. Directly relevant especially for the agricultural sectors is also the per-capita availability of arable land in the four subsequent columns. The last four columns of Table 4 include 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. As one can see, water remains a significant source of comparative advantage and the size of the coefficient only decreases slightly. Moreover, the positive coefficient for capital, skilled labor, and contractability that is significant at the 1 or 5 % level 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

[21] In Table 1, the restricted set of countries for which we have a complete set of production factors are marked with an asterisk.

trade facilitates, to some extent addresses water scarcity, so that more water-intensive products tend to be exported by more water-abundant countries.

Since the estimated coefficients that are reported have been standardized, a comparison across different factors of production is meaningful. It is important to note, however, that 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 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, these 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 and in line with the relatively low measures of water intensity for many manufacturing industries. 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, however, in two important ways. While it is true that the distribution of water is 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.

At the same time, complementing the global perspective, it is important to keep in mind that climate change and the change in local water availability may have non-negligible 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 21st. 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 50th percentile projection shows, for most of Australia, a drop in precipitation on the order of 10% by the year 2030. To be sure, there is quite a bit of uncertainty. The 10th percentile estimate shows drops in rainfall of up to 10% to 20%, whereas its 90th percentile estimates features increases of 10% to 20%. Just by way of example, I consider a 10% drop in the water resources due to climate change. My estimates suggest that, overall, Australia's exports would be reduced by about 5.2%, which is not negligible from Australia's perspective.[23]

The obtained results reported so far are quite robust. In Table 5 and 6 I address various types of robustness concerns one may have. Each time, I present my preferred estimates for total green and blue water measures alongside those for total blue water. Note, however, that the results without indirect water use are similar. To make sure the results are not driven by outliers, I exclude the five countries with most water per capita resources in column 1 and 2. One may also be worried that the interaction term of water intensity and water abundance picks up correlations that have nothing to do with relative water abundance. I therefore exclude the five largest economies in terms of GDP and in terms of water. In the same Table 5, I also exclude five countries that have the highest GDP per capita as well as the 5 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. Note that in all those cases, I obtain positive coefficients that in most instances are significant at the 5 % level, and in some instances at the 10 % level.

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

[23] 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: $\ln(x_{ic}') = \ln(x_{ic}) + 0.3806233 \times w_i * \ln(21.6125 \times 0.1)$, where x_{ic} is the old export value, 21.6125 Australia's water endowment, 0.1 the 10 % change in the water endowment, *wi* 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.

In Table 6 I address different types of concerns. I substitute the per-capita precipitation data as a different measure for water abundance in column 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 U.S. intensity measures on all countries. Still, especially for agriculture one may be concerned that differences in water availability will make farmers use 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 lifestock for countries other than the U.S., which allows us to scale up our down the U.S. water intensity measures based on BHV, for details see Appendix III. The results are presented in Column 3 and 4. As before, the estimates are not significantly different from our standard results. In column 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% or more of total exports in columns 7 and 8. In doing so, I want to avoid that the 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 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 column of Table 6, 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 non-zero 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 7, 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 zero 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 for 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 % or more - below 6.808 m^3 per person about 53 % of the countries have a water use ratio over 20 %. In other words, 6,808 m^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 1500m^3 per person, 65 % 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.

Conclusion

In this paper, I have studied the fundamental question as to whether water is a source of comparative advantage. Building on growing body of work on water outside the economics field, I find that it is indeed the case that water systematically affects countries' trade patterns in a manner consistent with international trade theory. More water-abundant countries tend to export more water-intensive products, and less water-abundant countries less water-intensive goods. Because of the very nature of water, however, this positive result was not a foregone conclusion from the outset of the analysis. Indeed, because water is a necessary good that is essential for life and because there are economies of scale in water distribution and water storage, there is ample government intervention and regulation. Consequently, water prices are often distorted and may contribute to an inefficient domestic and international allocation of water. My analysis shows that in spite of those existing distortions, the international distribution of water resources is uneven enough and the differences in sectoral water intensities important enough to affect the international division of labor of global production and trade. Needless to say, my study is an exercise in positive analysis, unable to say whether the degree of specialization obtained is enough, too much, or just right. My study should invite careful studies of how economic policies and in particular trade policies affect the international trade pattern. Such analyses might also give us a sense about the extent to which trade policies could actually be used to help alleviate water scarcity.

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. My 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. Even though one might expect lesser effectiveness of water in water-scarce countries due to unsustainable water, I do not find strong and consistent evidence that the observed water resources are less strong source of comparative advantage than in water-abundant countries.

Finally, my 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 climate change and the expected disruption of trade due to changing international patterns of precipitation, this finding suggests contained challenges and disruptions. Two 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.

REFERENCES

Allan, J, 1994, "Overall Perspectives on Countries and Regions," in Rogers P. Lyon (eds), *Water in the Arab World: Perspectives and Prognoses*, Harvard University Press, Cambridge, p. 65–100.

Antweiler, W. and D. Trefler, 2002, "Increasing Returns and All That: A View from Trade," American Economic Review, XCII, pp. 93 – 119.

Baldwin, R., 2008, *The Development and Testing of the Heckscher-Ohlin Trade Models, A Review,* MIT Press, Cambridge, MA.

Bartelsman, E. and W. Gray, 1996, "The NBER Manufacturing Productivity Database," Technical Working paper 205, National Bureau of Economic Research.

Berrittella, M., A. Hoekstra, K. Rehdanz, R. Roson and R. Tol, 2007, "The Economic Impact of Restricted Water Supply: A Computable General Equilibrium Analysis," *Water Research*, 41, p. 1799–1813.

Blackhurst, B.M., Hendrickson, C., and J.S. Vidal, 2010, "Direct and Indirect Water Withdrawals for U.S. Industrial Sectors," *Environmental Science Technology* March 15, 44, t, 2126–30.

Brewer, J., R. Glennon, A. Ker and G. Lebcap, 2007, "Water Markets in the West: Trading, and Contractual Forms," Working Paper No 30.

Byers, W. G. Lindgren, C. Noling and D. Peters, 2003, *Industrial Water Management: A Systems Approach, Second Edition,* American Institute of Chemical Engineers.

Cameron, C., Gelbach, C. and D. Miller, 2011, Robust Inference with Multiway Clustering, Journal of Business and Economics Statistics, Vol. 29, 2, p. 238-249.

Chapagain, A.K. and A. Hoekstra, 2008, "The Global Component of Freshwater Demand and Supply: An Assessment of Virtual Water Flows Between Nations as a Result of Trade in Agricultural and Industrial Products," *Water International*, 33, 1, 19–32.

Costinot, A., 2009, "An Elementary Theory of Comparative Advantage," *Econometrica*, vol 77, Issue 4, pages 1165–1192.

Deardorff, A. 2006, *Terms of Trade: Glossary of International Economics*, Singapore, World Scientific Publishers.

Debaere, P. and U. Demiroglu, 2003, On the Similarity of Country Endowments, Journal of International Economics, vol. 59, 1, pp. 101-136.

FAO, 2003. Food and Agriculture Organization of the United Nations, Rome, Italy.

Feenstra, R., 2000, "World Trade Flows," Mimeograph, University of California Davis.

Gleick, P., 2009, *The World's Water, The Biennial Report on Freshwater Resources*, Islandpress, Washington.

Hanemann, W.H., 2006, "The Economic Conception of Water," in Eds. P.P. Rogers, M.R. Llamas, L. Martinez-Cortina, *Water Crisis: myth or reality?* Taylor & Francis, p. 61–91.

Heberger, M., 2012, Australia's Millennium Draught: Impacts and Responses, in Gleick, P. (ed.), *The World's Water, The Biennial Report on Freshwater Resources*, Islandpress, Washington, p. 97–126

Hoekstra, A. Y. and Chapagain, A.K., 2008, *Globalization of Water: Sharing the planet's freshwater resources*, Blackwell Publishing, Oxford, UK.

Hoekstra, A., M. Mekonnen, A. Chapagain, R. Mathews, B. Richter, 2012, "Global Monthly Water Scarcity: Blue Water Footprints vs. Blue Water Availability," PLosone. www.plos.one.org, February, vol. 7, issue 2.

Johnson, N., Revenga, C., & Echeverria, J., 2001, "Managing Water for People and Nature," *Science*, 292, May 11, pp. 1071–1072.

Levchenko, 2007, Institutional Quality and International Trade, Review of Economic Studies, vo. 74: 3, pp. 791-819.

Matlock, M. D, 2011, "Review of Water Scarcity Indices and Methodologies," Sustainability Consortium, White paper # 1061.

Mekonnen, M.N. and A.Y. Hoekstra, 2011, *National Water Footprint Accounts: The Green, Blue and Grey Water Footprint of Production and Consumption*, Vol. I & II, Value of Water Research Report Series No. 50, UNESCO-IHE, Delft, The Netherlands.

Nunn, N., 2007, "Relationship-Specificity, Incomplete Contracts and the Pattern of Trade," *Quarterly Journal of Economics*, 122, 2, pp. 569–600.

Postel, S.L., Daily, G.C., and Ehrlich, P.R., 1996, "Human Appropriation of Renewable Fresh Water," *Science* 271, p. 785–788.

Richter, B., "Are We Running Out of Water?" *National Geographic News Watch, Water Currents,* March 14, 2012, http://newswatch.nationalgeographic.com/blog/water-currents/

Richter, B., Davis, M, Apse, C. and C. Konrad, 2011, A presumptive Standard for environmental flow protections, River Research and Application, wileyonlinelibrary.

Romalis, J., 2004, "Factor Proportions and the Commodity Structure of Trade," *American Economic Review*, 94, p. 67–97.

Trefler, D., 1995, "The Case of Missing Trade and Other Mysteries," *American Economic Review* 85, p. 1029–1046.

UNESCO, 2009, *Water in a Changing World The United Nations World Water Development Report 3*, London, UK.

Vörösmarty, C.J., Green, P., Salisbury, J. and Lammers, R. B., 2000, "Global Water Resources; Vulnerability from Climate Change and Population Growth," *Science* 289: 284–288.

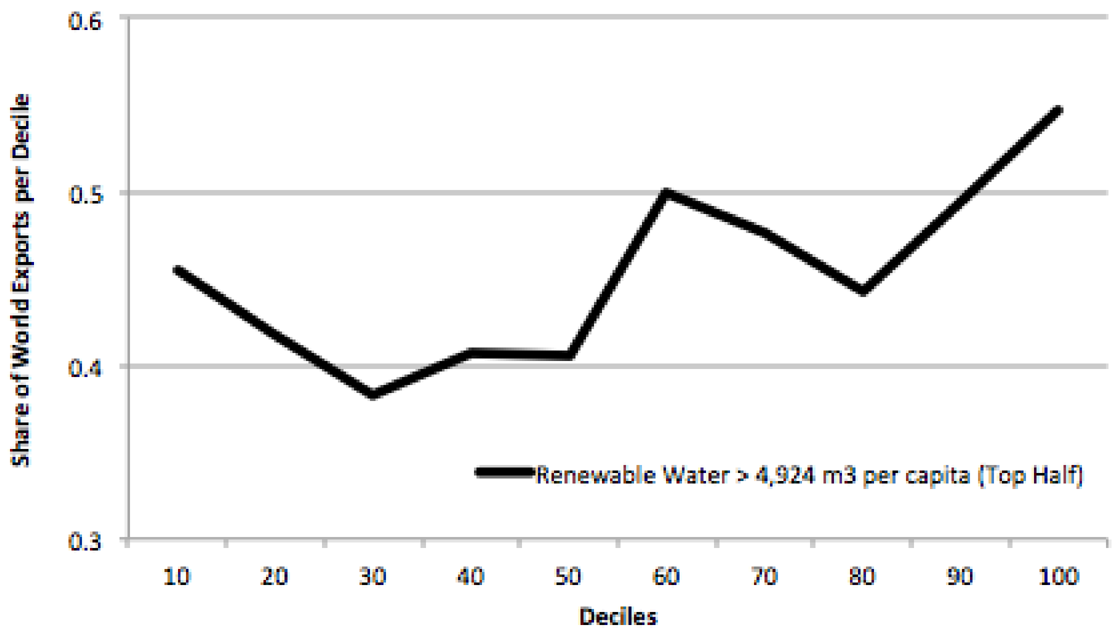
Wichelns, D., 2004, The Policy Relevance of Virtual Water Can Be Enhanced by Considering Comparative Advantage, *Agricultural Water Management*, 66, p. 49–63.

Yang, H., Reichert, P. Abbaspour, K.C. and Zehnder, A. J., 2003, A Water Resources Threshold and its Implications for Food Security, *Environmental Science and Technology*, 37, 14, p. 3048–3054.

Young, R. and R. Haveman, 1985, Economics of Water Resources: A Survey, in: Kneese, A.V. and J.L. Seeney, *Handbook of Natural Resource and Energy Economics*, vol. II, Elsevier Science Publishing.

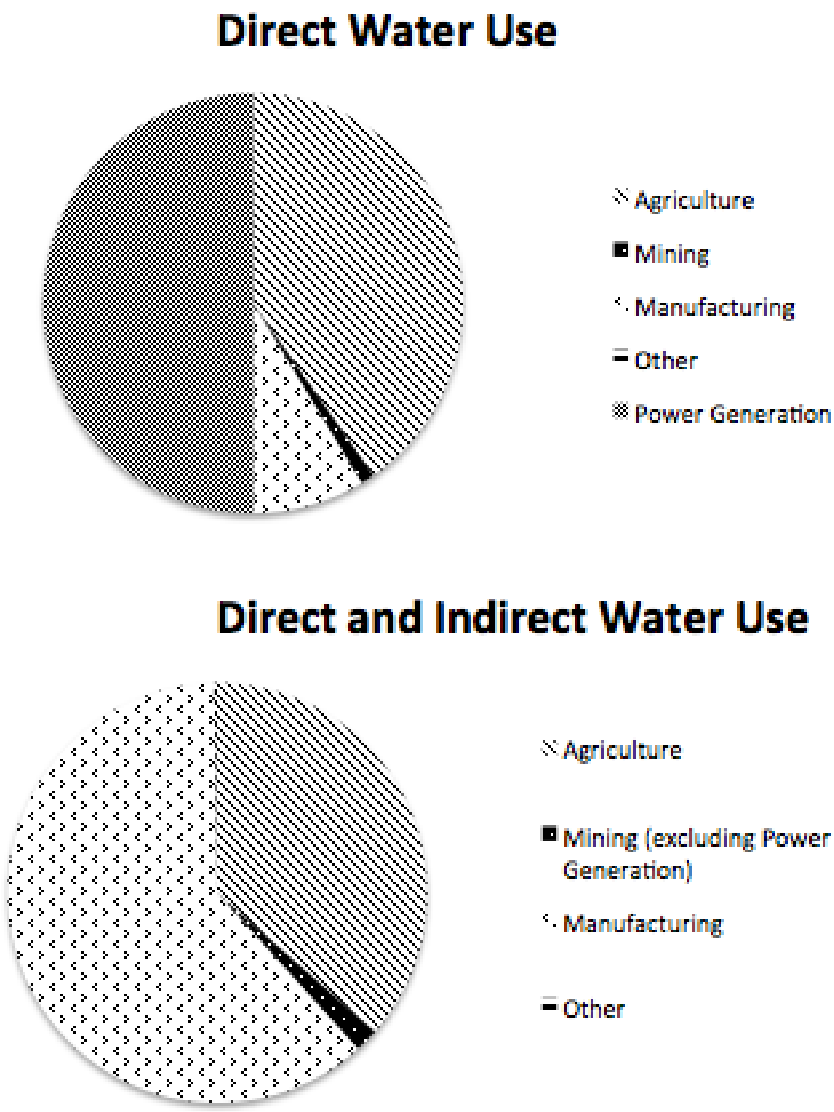
Zhou, and R. Toll, 2005, Evaluating the Costs of Desalination and Water Transport, *Water Resources Research*, Vol. 41, pp. 1–10.

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



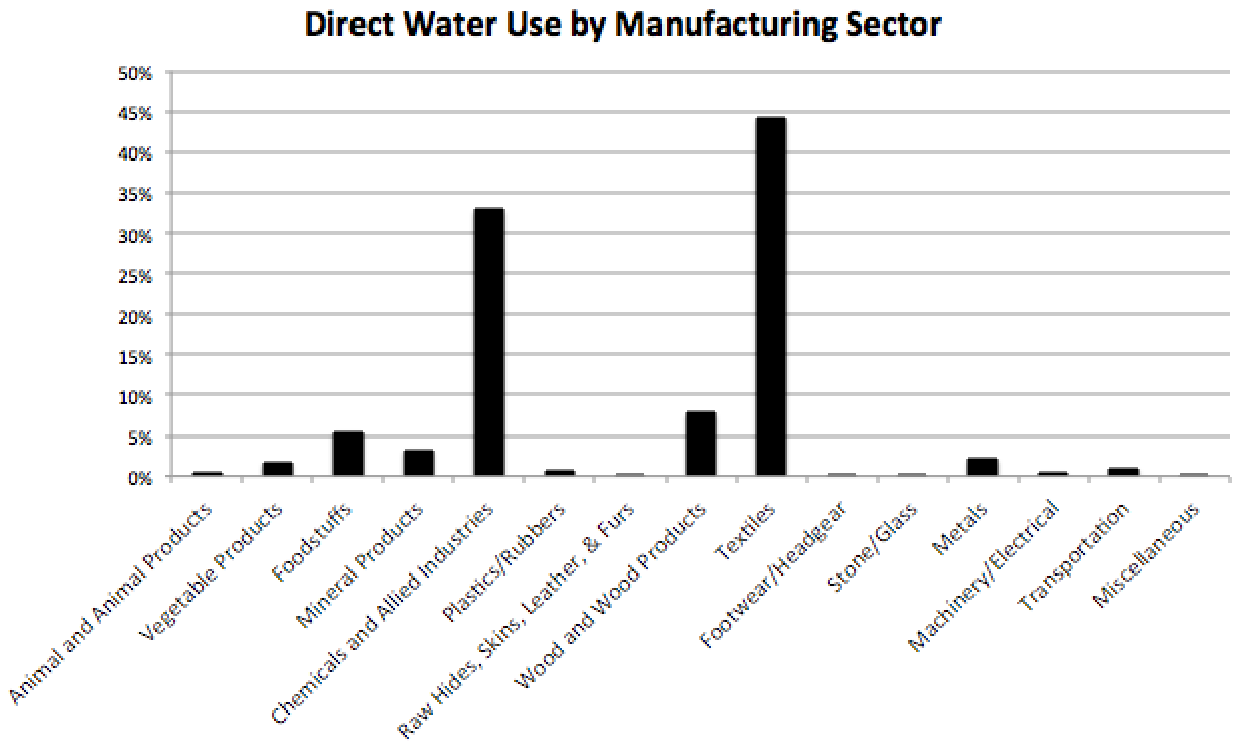
Notes: Products are split into deciles of green and blue water intensity. The share of world exports is calculated by dividing the exports of the most water-abundant countries (half the countries in the sample have more than 4,924m^3 per capita renewable water resources) by total world exports in each decile. *Source:* Using BHV (2010) data.

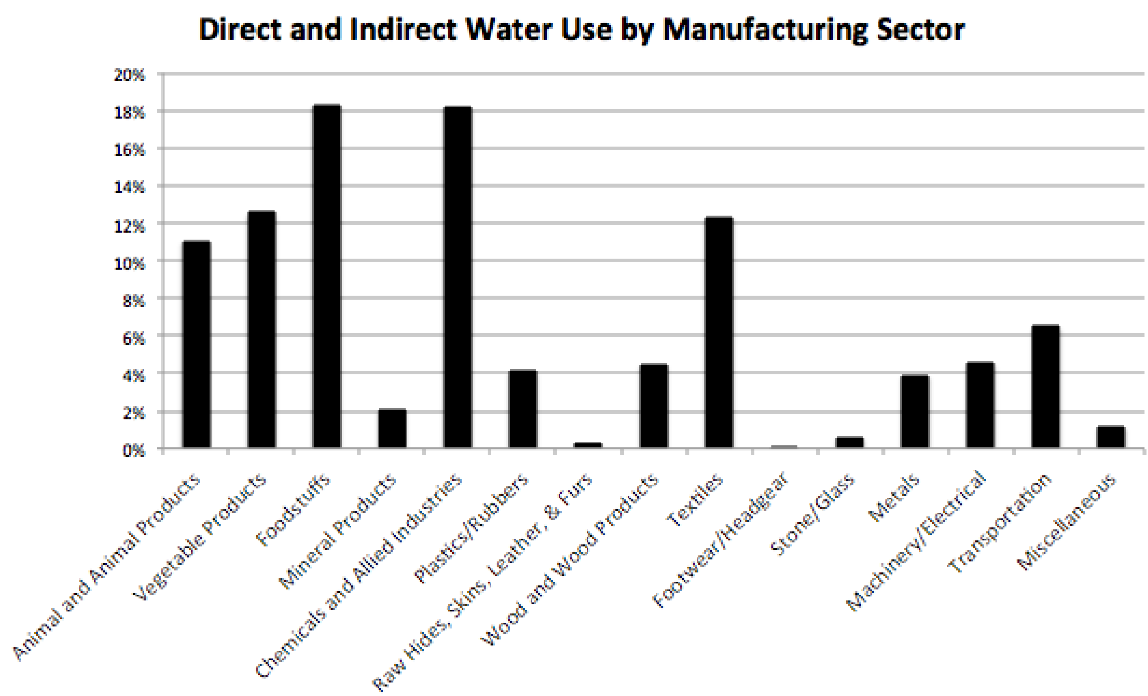
Figure 2: Direct and Total (Direct plus Indirect) Water Use by Sector



Notes: Direct water use consists of water withdrawals by the sector itself, and indirect water use takes place through the use of intermediates from other sectors. *Source:* Using BHV (2010) data.

Figure 3: Direct and Indirect Water Use within the Manufacturing Sector

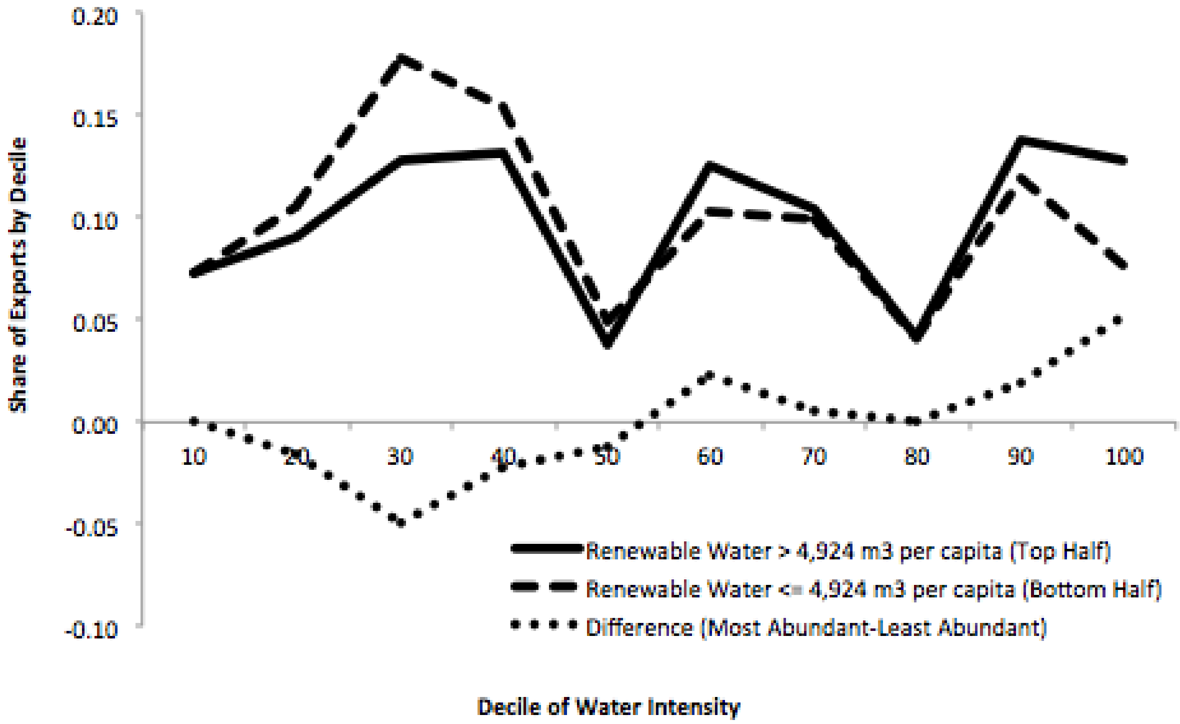




Notes: Direct water use consists of water withdrawals by the sector itself, and indirect water use takes place through the use of intermediates from other sectors. Each bar represents the percentage of total manufacturing water use by a sector. *Source:* Using BHV (2010) data.

Figure 4: Average Share of Individual Countries' Exports by Decile of Water Intensity

Most versus Least Water-Abundant Countries



Notes: Products are split into deciles of green and blue water intensity. The share of exports is calculated as the total amount of exports in each decile divided by the total amount of exports for the most and least water-abundant countries (half the countries in the sample have more than 4,924m^3 per capita renewable water resources). *Data source:* BHV (2010).

Table 1: Renewable Water (m3 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, Cote 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*

Note: 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.

Table 2: The fifteen most and least water intensive sectors

15 Most Water Intensive (Blue Water Only)			15 Most Water Intensive (Green and Blue Water)		
Industry Code	Industry Description	Water Intensity	Industry Code	Industry Description	Water Intensity
111920	Cotton farming	0.85351	1111B0	Grain farming	0.95606
1111B0	Grain farming	0.81751	111920	Cotton farming	0.93700
1119A0	Sugarcane & sugar beet farming	0.77959	1119A0	Sugarcane & sugar beet farming	0.92658
111335	Tree nut farming	0.65498	1113A0	Fruit farming	0.87206
1113A0	Fruit farming	0.65127	111335	Tree nut farming	0.74148
1119B0	Oth. crop farming	0.57134	111200	Vegetable & melon farming	0.73170
111200	Vegetable & melon farming	0.52943	111910	Tobacco farming	0.58083
1111A0	Oilseed farming	0.41767	1119B0	Oth. crop farming	0.55042
212320	S&, gravel, clay, & refractory mining	0.26816	1111A0	Oilseed farming	0.35753
212310	Stone mining & quarrying	0.23560	212320	S&, gravel, clay, & refractory mining	0.26816
2122A0	Gold, silver, & oth. metal ore mining	0.22406	212310	Stone mining & quarrying	0.23560
212230	Copper, nickel, lead, & zinc mining	0.16955	2122A0	Gold, silver, & oth. metal ore mining	0.22406
111910	Tobacco farming	0.16346	111400	Greenhouse & nursery production	0.21876
111400	Greenhouse & nursery production	0.14920	212230	Copper, nickel, lead, & zinc mining	0.16955
212210	Iron ore mining	0.13997	212210	Iron ore mining	0.13997

15 Least Water Intensive (Blue Water Only)			15 Most Least Intensive (Green and Blue Water)		
Industry Code	Industry Description	Water Intensity	Industry Code	Industry Description	Water Intensity
114100	Fishing	0.00000	114100	Fishing	0.00000
312229	Oth. tobacco product man.	0.00000	312229	Oth. tobacco product man.	0.00000
334517	Irradiation apparatus man.	0.00000	334517	Irradiation apparatus man.	0.00000
334515	Electricity & signal testing instruments	0.00000	334515	Electricity & signal testing instruments	0.00000
312221	Cigarette man.	0.00000	312221	Cigarette man.	0.00000
334510	Electromedical apparatus man.	0.00001	334510	Electromedical apparatus man.	0.00001
334210	Telephone apparatus man.	0.00001	334210	Telephone apparatus man.	0.00001
339115	Ophthalmic goods man.	0.00001	339115	Ophthalmic goods man.	0.00001
333315	Photographic & photocopying equip. man.	0.00001	333315	Photographic & photocopying equip. man.	0.00001
33451A	Watch, clock, & oth. measuring & controlling	0.00001	33451A	Watch, clock, & oth. measuring & controlling	0.00001
339994	Broom, brush, & mop man.	0.00001	339994	Broom, brush, & mop man.	0.00001
333993	Packaging mach. man.	0.00001	333993	Packaging mach. man.	0.00001
316900	Oth. leather product man.	0.00001	316900	Oth. leather product man.	0.00001
334220	Broadcast & wireless comm. equip.	0.00001	334220	Broadcast & wireless comm. equip.	0.00001
339113	Surgical appliance & supplies man.	0.00001	339113	Surgical appliance & supplies man.	0.00001

Notes: Water intensity is the ratio of the cost of water use to value added plus cost of water for each industry. Blue water includes fresh surface and ground water, and green water is rainwater absorbed through the soil.

Table 3: Determinants of Comparative Advantage

Explanatory variables	Dependent variable: log of exports per country and industry							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Water interaction, direct, blue	0.033**				0.039*			
	(0.015)				(0.023)			
Water interaction, direct and indirect, blue		0.041**				0.047*		
		(0.017)				(0.027)		
Water interaction, direct, green and blue			0.031*				0.037	
			(0.016)				(0.024)	
Water interaction, direct and indirect, green and blue				0.044**				0.042
				(0.018)				(0.026)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.72	0.73	0.72	0.73	0.72	0.72	0.72	0.72
Number of observations	19,719	19,719	19,719	19,719	11,661	11,661	11,661	11,661

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. *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent levels.

Table 4: Comparative Advantage, More Results

Explanatory variables	Dependent variable: log of exports per country and industry							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Water interaction, direct, blue	0.050**				0.042**			
	(0.02)				(0.021)			
Water interaction, direct and indirect, blue		0.059**				0.051**		
		(0.024)				(0.024)		
Water interaction, direct, green and blue			0.048**				0.041**	
			(0.021)				(0.021)	
Water interaction, direct and indirect, green and blue				0.055**				0.047**
				(0.023)				(0.023)
Capital interaction	0.11*	0.11*	0.11*	0.11*	0.11*	0.11*	0.11*	0.11*
	(0.061)	(0.061)	(0.061)	(0.061)	(0.062)	(0.062)	(0.062)	(0.062)
Skilled labor interaction	0.24***	0.24***	0.24***	0.24***	0.24***	0.24***	0.24***	0.24***
	(0.041)	(0.041)	(0.041)	(0.041)	(0.042)	(0.041)	(0.042)	(0.042)
Land interaction					0.21	0.19	0.21	0.19
					(0.144)	(0.142)	(0.144)	(0.144)
Contractability interaction								
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.73	0.73	0.73	0.73	0.72	0.72	0.72	0.72
Number of observations	11,661	11,661	11,661	11,661	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. *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent levels.

Table 4 Continued: Comparative Advantage, More Results

Explanatory variables	pendent variable: log of exports per country and indus			
	(9)	(10)	(11)	(12)
Water interaction, direct, blue	0.039**			
	(0.019)			
Water interaction, direct and indirect, blue		0.047**		
		(0.022)		
Water interaction, direct, green and blue			0.037*	
			(0.019)	
Water interaction, direct and indirect, green and blue				0.043**
				(0.021)
Capital interaction	0.23***	0.23***	0.23***	0.23***
	(0.072)	(0.072)	(0.072)	(0.072)
Skilled labor interaction	0.15***	0.15***	0.15***	0.15***
	(0.039)	(0.039)	(0.039)	(0.039)
Land interaction	0.20	0.18	0.20	0.18
	(0.137)	(0.136)	(0.138)	(0.138)
Contractability interaction	0.38***	0.38***	0.38***	0.38***
	(0.062)	(0.061)	(0.062)	(0.061)
Country fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
R2	0.73	0.73	0.73	0.73
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. *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent levels.

Table 5: Robustness Checks

Explanatory variables	Dependent variable: log of exports per country and industry									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Water interaction, direct and indirect, blue	0.047**		0.057**		0.046*		0.058**		0.058**	
	(0.022)		(0.025)		(0.025)		(0.024)		(0.025)	
Water interaction, direct and indirect, green and blue		0.042*		0.053**		0.042*		0.054**		0.054**
		(0.022)		(0.024)		(0.024)		(0.023)		(0.024)
Capital interaction	0.11*	0.11*	0.11*	0.11*	0.11*	0.11*	0.11*	0.11*	0.13**	0.13**
	(0.064)	(0.064)	(0.064)	(0.064)	(0.067)	(0.067)	(0.063)	(0.063)	(0.066)	(0.066)
Skilled labor interaction	0.25***	0.25***	0.25***	0.25***	0.23***	0.23***	0.22***	0.22***	0.23***	0.23***
	(0.042)	(0.042)	(0.046)	(0.046)	(0.045)	(0.045)	(0.044)	(0.044)	(0.041)	(0.041)
Land interaction	0.27**	0.27**	0.24*	0.24*	0.17	0.17	0.04	0.04	0.16	0.16
	(0.136)	(0.138)	(0.134)	(0.134)	(0.14)	(0.141)	(0.24)	(0.24)	(0.145)	(0.147)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.72	0.72	0.71	0.71	0.69	0.69	0.71	0.71	0.71	0.71
Number of observations	10,792	10,792	10,492	10,492	10,483	10,483	10,491	10,491	10,957	10,957

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. *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent levels.

(1)-(2)	Excludes five most water abundant countries, per capita
(3)-(4)	Excludes five most water abundant countries
(5)-(6)	Excludes five largest countries
(7)-(8)	Excludes five richest countries
(9)-(10)	Excludes five poorest countries

Table 6: Additional Robustness Checks

Explanatory variables	Dependent variable:	log of exports per country and industry							exports per country and industry	
	OLS								Tobit	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Water interaction, direct and indirect, blue	0.089*		0.044**		0.052**		0.050**		0.015***	
	(0.046)		(0.019)		(0.024)		(0.024)		(0.006)	
Water interaction, direct and indirect, green and blue		0.086*		0.041**		0.049**		0.047**		0.014***
		(0.044)		(0.018)		(0.019)		(0.019)		(0.005)
Capital interaction	0.11*	0.11*	0.11*	0.11*	0.11*	0.11*	0.11*	0.11*	0.084**	0.084**
	(0.019)	(0.019)	(0.062)	(0.062)	(0.019)	(0.019)	(0.019)	(0.019)	(0.037)	(0.037)
Skilled labor interaction	0.23***	0.23***	0.24***	0.24***	0.25***	0.25***	0.24***	0.24***	0.064	0.064
	(0.019)	(0.019)	(0.041)	(0.042)	(0.019)	(0.019)	(0.019)	(0.019)	(0.046)	(0.046)
Land interaction	0.34**	0.34**	0.21	0.21	0.19	0.19	0.19	0.2	0.071	0.071
	(0.019)	(0.019)	(0.144)	(0.144)	(0.019)	(0.019)	(0.019)	(0.019)	(0.046)	(0.047)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2 (Pseudo R^2 for Tobit)	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.13	0.13
Number of observations	11,465	11,465	11,465	11,465	11,325	11,325	11,411	11,411	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. *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent levels.

(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% of total exports
(7)-(8) Excludes oil and gas industry
(9)-(10) Tobit regression, includes zeros

Table 7: Additional Results, with Log Exports Differentiated by > 1500 m3 and < 1500 m3, and > 6,808 m3 and < 6,808 m3 Renewable Water Per Capita

Explanatory variables	Dependent variable: log of exports per country and industry			
	(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 1500=1 x water interaction, direct and indirect, blue	0.004			
	(0.013)			
Below 1500=1 x water interaction, direct and indirect, green and blue		0.005		
		(0.013)		
Below 6808=1 x water interaction, direct and indirect, blue			-0.01	
			(0.014)	
Below 6808=1 x 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. *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent levels.

Appendix I Non-Water Data Sources

Industry-level trade flows, stocks of human and physical capital, and skill and capital intensities are from Nunn (2007), which come from the following sources. Trade flows are from Feenstra (2000), and are converted from the original 4-digit SITC codes to the BEA 1997 IO industry classification. Stocks of human capital and physical capital are from Antweiler and Trefler (2002) and are for the year 1992. Human capital stocks are measured as the natural log of the ratio of workers completing high school to those not completing high school, and physical capital stocks are the natural log of average capital stock per worker. I construct the land stock measure as the natural log of arable land in hectares per capita in 1997. Hectares of arable land by country are from the World Bank. Skill and capital intensities of production are from Bartelsman and Gray (1996). I supplement the number of agricultural industries for which the skill and capital intensity measures are available using skill and capital shares for agricultural sectors from the Global Trade Analysis Project (GTAP). Shares are constructed as the ratio of skill or capital requirements to total factor requirements for a sector. The GTAP sectors are matched to 6-digit HS categories using the concordance provided by GTAP, which are then matched to the 1997 IO classification using the BEA concordance. When an IO classification maps into more than one GTAP sector, I take the average skill and capital measures. To ensure that the GTAP and Nunn intensities are consistent in magnitude, I scale the GTAP agricultural factor intensity measures by their output-weighted average and apply it to the output-weighted intensity for agricultural industries provided by Nunn. Land intensity of production is measured as the ratio of land use to total factor use for a sector. These data are also from GTAP and are concorded to IO industry classifications using the procedure described above.

Appendix II

The price for water supplied by public utilities is from Global Water Intelligence. It is calculated as the average variable utility price of water across major cities in the United States in the year 2007 and is \$0.175/m^3. Prices of water not intermediated by utilities are from Brewer et al. (2007) and are measured as the average price of water trades for agricultural and industrial use in Western U.S. states over the years 1987 to 2005. Prices are adjusted to 2002 dollars. The average agricultural price is $0.013/m^3, and prices for manufacturing industries range from $0.019/m^3 to $0.026/m^3. Manufacturing prices are scaled by the amount of 2003 gross state product that occurs in Western relative to Eastern U.S. states in each sector, and uses the relationship between Western and Eastern utility prices to infer a non-utility price for water in the Eastern United States. Gross state product is from the BEA. The sectoral water-intensity measure is the ratio of the cost of water use over value added plus the cost of water use. The cost of water use is measured as the quantity of water not provided by utilities (direct water use quantity from BHV (2010) less publicly supplied water use from the BEA IO tables) times the non-utility water prices described above, plus the IO value of publicly supplied water use. Value added is from the BEA IO tables.

Appendix III

To adjust the water intensity measures by country for agriculture, I match the 14 agricultural sectors from the IO classification with 11 sectors from the Mekonnen and Hoekstra (2011) data via the HS6 to IO1997 concordance. Mekonnen and Hoekstra (2011) provide data on green and water use for individual country in the different agricultural sectors. I divide for each individual country the water use in its agricultural sectors by the US sector level green and blue water use. I multiply the ratios obtained from these divisions with the U.S. water intensity based on BHV (2010) that we used before for each of the agricultural sectors of the countries in the dataset.