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Scarce Water Resources and Cereal Import Dependency: The Role of Integrated Water Resources Management

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Received: 26 April 2020; Accepted: 17 June 2020; Published: 19 June 2020

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Abstract: This study globally analyzes the nonlinear relationship between cereal import dependency and total renewable water resources per capita by testing for potential thresholds in water resources. Data are from the Food and Agriculture Organization (FAO), and consider the years of 2002, 2007, and 2012. The results show evident ceiling effects with a threshold of 1588 m^3/(capita/year) in the multiple predictor model. Above this value, the total renewable water resources per capita no longer have a considerable effect on cereal import dependency. Importantly, we found that if integrated water resource management improves, cereal import dependency will increase for countries with total renewable water resources per capita between 1588 m^3/(capita/year) and 5000 m^3/(capita/year), but not for countries below or equal to the threshold of 1588 m^3/(capita/year). Water-scarce countries above the threshold use cereal imports as a coping strategy to save limited national water resources. This strategy might be suggested to extremely water-scarce countries below the threshold to increase their water use efficiency. Global solidarity of grain exporters with water-scarce countries is required to guarantee their food security, while water-scarce countries need to overcome their skepticism of foreign dominance through food imports.

Keywords: water scarcity; cereal-import dependency; food security; integrated water resources management; threshold analysis

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1. Introduction

As agriculture requires roughly 70% of a given region's water resources, a country's renewable water resources are closely linked to its food production potential. Water-scarce countries overcome water limitations by importing food or "virtual water" [1], which is water used for producing imported food [2]. For water-scarce countries, cereal imports are not only crucial to guarantee food security, but cereal imports are also the main user of virtual water [3]. In 2019, the United Nations (UN) announced that the world cereal balance is again negative, which puts vulnerable countries with high cereal import dependency and limited water endowment at increased risk of food insecurity. Furthermore, the global use of water resources in production, consumption, and trade grew by roughly 37% between 1995 and 2008. This has put additional pressure on scarce water resources [4]. The latest estimation in 2017 indicates that more than 124 million people suffer from severe food insecurity, which has increased by 16 million people in only one year [5]. In the beginning of 2017, a famine was proclaimed in South

Sudan and alarms went off to flag the high danger of famine-like conditions in northeast Nigeria, Somalia, and Yemen [6]. Verpoorten et al. [6] found that, in sub-Saharan Africa, agri-food importers have higher self-reported food insecurity than do agri-food exporters.

Today, the coronavirus pandemic has enormous potential to put pressure on global food security. If trade restrictions are put in place and global trade flows are disrupted, there is a substantial risk that prices of the main staple crops will shoot up, which can hurt a large share of the global population. For example, since the beginning of the year, the price of Canadian durum wheat has increased by 8.5 percent due to the stockpiling-driven pasta demand [7]. “There is a real fear that the number of hungry people could double in the next few months unless we take the right measures”, says Juergen Voegele, the Vice President of Sustainable Development at the World Bank in Washington [8]. He highlights the need for collective action and fears that the health crisis could easily initiate a food crisis with disruptions of not only food availability, but also food affordability due to many people losing their jobs and income sources.

Most research on virtual water focuses on analyzing virtual water trade among countries (see, for instance, [9–11] for their network analysis and literature review, as well as the study of Lenzen et al. [12]). Similarly, the water footprint concept that originates with Hoekstra and Hung [13] is used in many studies to calculate the water footprints of nations and products (e.g., [14–16]). While there is an increasing awareness about the link between water shortages and cereal imports, few studies have analyzed this relationship quantitatively using econometrics. Yang and Zehnder [3] found a negative relationship between cereal imports and domestic grain production for water-scarce southern Mediterranean countries, indicating that local grain shortages could be overcome with additional imports. Yang et al. [17] were the first to estimate water resource thresholds related to cereal imports for African and Asian countries. They found that cereal imports rise exponentially with declining water resources. These authors also discovered that the threshold declined from 2000 m^3/(capita/year) to 1500 m^3/(capita/year) between 1980 and 2000, respectively. Falkenmark and Widstrand [18] suggested a threshold of 1700 m^3/(capita/year) in the beginning of the 1990s. While mainly oil-rich countries, which are usually able to afford food imports, were below the threshold in the past, Yang et al. [17] have argued that in future poorer countries are increasingly affected, which increases food insecurity due to unaffordable cereal imports in these countries. Low-income countries are also far more vulnerable to world food price increases than are high-income countries [19].

We extend the literature on the interlinkage between low per capita water endowment and high cereal import dependency and the corresponding link to higher food insecurity with three major contributions. The first contribution of our article follows up on Yang et al.’s [17] threshold analysis. We use the latest data to analyze water-scarce countries focusing on the relationship between a country’s renewable water resources and its cereal import dependency ratio (CIDR) [20]. To do this, we use data for the years of 2002, 2007, and 2012 from the Food and Agriculture Organization (FAO)’s Aquastat database, thus extending previous knowledge on the 1990s [17,18] to the 2000s. Analyzing a more recent timeframe is important to understand to what extent previous results are still valid or not.

The second contribution is the consideration of oil exporting status as an additional determinant in the econometric analysis following Yang et al.’s [17] findings. The major oil exporting countries that are net cereal importers, such as Saudi Arabia, Iraq, United Arab Emirates, Kuwait, and Nigeria, have limited water resources but, except for Nigeria, are upper-middle- to high-income countries and have no monetary constraints for cereal imports. Whether the oil exporting status matters for determining the CIDR is crucial for better understanding the underlying water management practices linked to cereal imports and might provide important lessons for integrated water resources management (IWRM) to increase water use efficiency.

This leads us to the third contribution of this article, which is the consideration of IWRM, provided by the UN [21], in the analysis. We estimate the relationship between IWRM and the CIDR for water-scarce countries. IWRM implies a holistic management of water resources that combines concepts from engineering as well as from the environmental, economic, and social sciences using bottom-up approaches involving different stakeholders. The idea of IWRM, which dates back to the 1977 UN Mar del Plata conference, has been applied worldwide in different contexts, and with different goals (see [22] for an overview). IWRM scores are major determining factors to evaluate the achievement of the UN's sustainable development goal (SDG) 6 for 2030 [21]. Increasing cereal imports could be an integral component of IWRM for water-scarce countries to save national water resources [23] and could be a key element in the broader policy framework of a country considering the comparative advantage theory in international trade [24].

The remainder of the paper is organized as follows. Section 2 describes the empirical approach. Section 3 describes the dataset used for the empirical analysis. Section 4 provides results and discusses major empirical findings. In Section 5, we draw conclusions and provide policy recommendations.

2. Empirical Approach

2.1. Threshold Model

To extend the linear regression of the relationship between the total renewable water resources per capita and the CIDR, we allow coefficients to differ across regimes by using threshold models. The threshold model with two regimes is defined as follows:

$$cidr_i = \alpha + \beta_1 water_i + \gamma_1 x_i + \delta_t + \varepsilon_i \quad \text{if } -\infty < water_i \leq \tau \tag{1}$$

$$cidr_i = \alpha + \beta_2 water_i + \gamma_2 x_i + \delta_t + \varepsilon_i \quad \text{if } \tau < water_i < \infty \tag{2}$$

where $cidr_i$ is the dependent variable representing the CIDR for the ith country. $water_i$ represents the variable of total renewable water resources per capita and builds the threshold variable. τ is the estimated threshold and divides the equation into two regimes. Furthermore, similar to the study of Yang et al. [17], x_i controls for a country's population, the logarithm of gross domestic product (GDP), and the cultivated area. Additionally, we add regional specific controls, including a dummy variable for oil exporting countries (0/1) and dummy variables for the continents. δ_t is used to control for any time fixed effects by including year dummies. ε_i is an independent and identically distributed (IID) error with N (0,1). Regime 1 contains observations below or equal to the threshold value (τ), and Regime 2 contains observations above the threshold value (τ). To obtain the threshold, a grid search is used where the parameters are estimated with conditional least squares, and the threshold value is obtained by minimizing the sum of squared residuals (SSR) for all thresholds considered [25].

2.2. Inclusion of IWRM

We analyze whether cereal imports matter as a coping strategy in the water resource management of water-scarce countries. To do this, we include the IWRM score as an additional determinant into the model:

$$cidr_i = \alpha + \beta_3 water_i + \rho_1 IWRM_i + \gamma_5 x_i + \delta_t + \varepsilon_i \tag{3}$$

The sign of the coefficient is expected to be positive if a water-scarce country would increase its cereal import dependency to overcome scarce water resources (see, for example, [12]).

3. Data and Descriptive Statistics

Table 1 shows the variables used in this study, including definitions and descriptive statistics. The sample includes countries with a CIDR above zero and total renewable water resources per capita below 5000 m^3/(capita/year) for the years of 2002, 2007, and 2012. It includes 191 observations.

Table 1. Descriptive statistics.

Variables	Definition	Unit	Mean (Standard Deviation)
Dependent variable			
Cereal import dependency ratio (CIDR)	The cereal import dependency ratio indicates how much of the available domestic food supply of cereals has been imported and how much comes from the country's own production. It is computed as (cereal imports − cereal exports)/(cereal production + cereal imports − cereal exports) × 100. Given this formula, the indicator assumes only values <= 100. Negative values indicate that the country is a net exporter of cereals. This indicator provides a measure of the dependence of a country or region from cereal imports. The greater the indicator, the higher the dependence. The indicator is calculated in three-year averages, from 1990–1992 to 2011–2013, to reduce the impact of possible errors in estimated production and trade, due to the difficulties in properly accounting of stock variations in major food.	%	56.6 (34.5)
Control variables			
Total renewable water resources per capita	Total annual actual renewable water resources per capita. Total renewable water resources per capita = Total renewable water resources × 1,000,000/Total population.	m^3/capita/yr	1890.2 (1290.7)
Population	Usually refers to the present-in-area (de facto) population, which includes all persons physically present within the present geographical boundaries of countries at the mid-point of the reference period.	1000 inhabitants	36,383.8 (140,921.2)
Logarithm of gross domestic product (GDP)	GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in current United States dollars (US$). Dollar figures for GDP are converted from domestic currencies using single year official exchange rates. For a few countries where the official exchange rate does not reflect the rate effectively applied to actual foreign exchange transactions, an alternative conversion factor is used.	Current US$	23.8 (2.3)
Cultivated area	The sum of the arable land area and the area under permanent crops (Cultivated area (arable land + permanent crops)) = (Arable land area) + (Permanent crops area].	1000 ha	5816.8 (14,051.5)
Oil exporter	1 if the country is a major oil exporting country, 0 otherwise.		0.08 (0.3)
Integrated water resource management (IWRM)	Scores range from 0 to 100 and are based on 33 questions across four sections (enabling environment, institutions and participation, management instruments, and financing). Categories are 1 for scores from 0 to 10 (very low), 1 for scores from 11 to 30 (low), 2 for scores from 31 to 50 (medium-low), 3 for scores from 51 to 70 (medium-high), 4 for scores from 71 to 90 (high), and 5 for scores from 91 to 100 (very high).	Scores from 0–100	49.9 (19.5)
Continents		number of countries	
Africa	1 if the country is in Africa, 0 otherwise		26.9
Asia	1 if the country is in Asia, 0 otherwise		24.3
Americas	1 if the country is in the Americas, 0 otherwise		22.0
Europe	1 if the country is in Europe, 0 otherwise		23.2
Oceania	1 if the country is in Oceania, 0 otherwise		3.4
Observations			191

The CIDR is one indicator from the FAO Suite of Food Security Indicators (2017) in the dimension "stability" [20]. It informs about a country's dependence on cereal imports. The higher the CIDR is, the higher the dependence is. The calculation of the CIDR from FAO [20] is for three-year averages. In this article, we consider the period from 1999–2001 to 2011–2013. We use the middle years of each time range (2002, 2007, and 2012) to merge the CIDR via country and year with the explanatory variables. The FAO uses three-year averages to better account for stock variations in major foods [20]. The data sample used in this study is limited to countries with a CIDR above zero to focus on countries that are net importers. The average CIDR of our sample is 56.6%, with a standard deviation of 34.5%. Figure 1 shows the frequency distribution and kernel density of the CIDR for water-scarce countries with total per capita renewable water resources from zero to 5000 m^3/(capita/year).

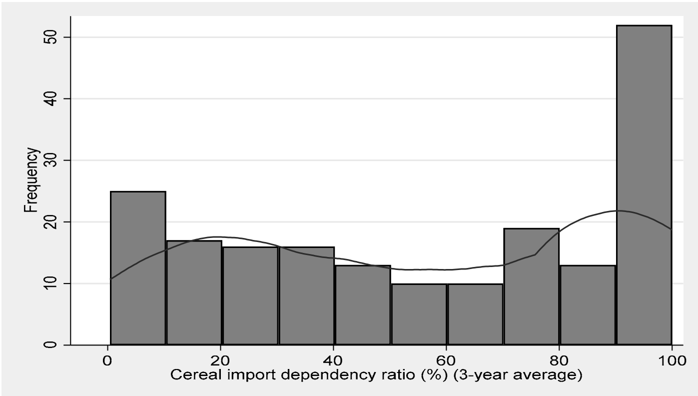

Figure 1. The figure shows the frequency distribution and kernel density of the cereal import dependency ratio (CIDR) for water-scarce countries for the full sample.

The most crucial explanatory variable in our study is the total per capita renewable water resources, and the other control variables are from FAO's Aquastat database [26]. The total per capita renewable water resources include a country's total renewable surface and groundwater resources per capita. It does not include non-conventional water resources, such as desalinated water or the reuse of treated wastewater [27]. Following Yang et al. [17], we restrict the sample to countries with total per capita renewable water resources from zero to 5000 m^3/(capita/year) to focus on water-scarce countries. Figure 2 shows the frequency distribution of the total renewable water resources per capita for water-scarce countries.

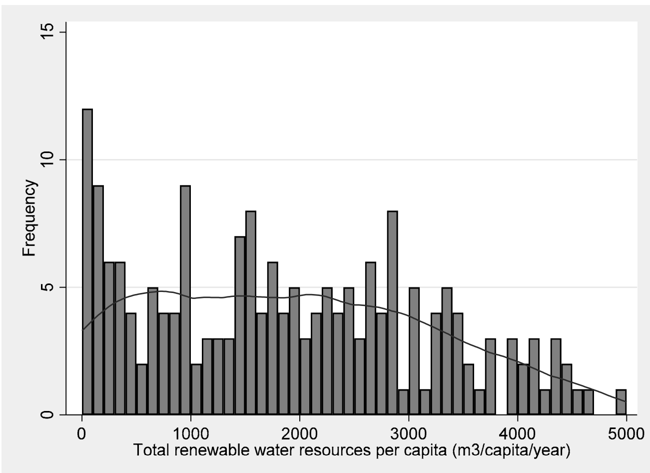

Figure 2. The figure shows the frequency distribution and kernel density of the total renewable water resources per capita for water-scarce countries for the full sample.

The sample's average renewable water resource per capita is 1890.22 m^3/(capita/year), with a standard deviation of 1290.71 m^3/(capita/year). It is available for the years 1992, 1997, 2002, 2007, 2012, and 2014 with the respective periods of 1988–1992, 1993–1997, 1998–2002, 2003–2007, 2008–2012, and 2013–2017. We use the final years in each time range to be able to merge the data with the dependent variable (CIDR) through the country and year identifiers. Therefore, we obtain a data sample for the years of 2002, 2007, and 2012.

A dummy variable is included for the major oil exporting countries. The mean of the dummy variable for oil exporting countries is 0.08, indicating that 8% of the net importers of cereals with total per capita renewable water resources from zero to 5000 m^3/(capita/year) are oil exporters. Oil exporting countries with scarce water resources are Saudi Arabia, Iraq, United Arab Emirates, Kuwait, and Nigeria.

To better understand the role of water resource management, the scores for IWRM at country level are included. The scores are taken from the UN's report on the evaluation of SDG 6 implementation, with special focus on the progress of IWRM implementation [21]. Scores range from 0 to 100 and are based on 33 questions across four sections (enabling environment, institutions and participation, management instruments, and financing) [21]. The scores are first measured in the 2017 survey and one wave of observations is available so far. Due to data limitations, we link the available scores to the year 2012 as an approximation of water management. The medium score is 49.87, with a standard deviation of 19.5. This presents a medium-low degree of IWRM implementation on average. The sample with IWRM includes 61 observations.

The other control variables used in the analysis are population, the logarithm of GDP, and the cultivated area (Table 1). Regional controls include dummies for continents, including Africa, Asia, the Americas, Europe, and Oceania. Yearly dummies are included to control for time fixed effects.

4. Results and Discussion

4.1. Estimation Results from Ordinary Least Squares (OLS) and Threshold Models

Table 2 shows the pooled ordinary least squares (OLS) results. We compare five different model specifications that differ in the explanatory variables considered. Model 1 is the single predictor model with total renewable water resources (water) and a constant as the only explanatory variables. Model 2 includes the control variables water, population, logarithm of GDP, cultivated area, and a constant. Model 3 includes the control variables of Model 2 and controls for a dummy variable of oil exporting countries. Model 4 includes the control variables of Model 3 and controls for the dummy variables of continents. Model 5 includes the control variables of Model 4 and controls for the time fixed effects.

We find a statistically significant and negative effect of the total renewable water resources per capita on the CIDR. The results from the different model specifications having similar signs with slightly different magnitudes. Model 4 provides the best model fit, and the following discussion focuses on its results. If the water resources increase by one m^3, then the CIDR will decrease by approximately 0.01 percentage points, holding all other control variables at mean values. The control variables, except for the logarithm of GDP, also show statistically significant effects. A population increase by a million people will increase the CIDR by approximately 0.178 percentage points. An increase in the cultivated area by 10,000 hectares will decrease the CIDR by approximately 0.024 percentage points. The strongest effect is observable for oil exporters. Oil exporting countries are much more dependent on cereal imports than are non-oil exporting countries. If a water-scarce country is an oil exporter, then the CIDR increases by approximately 23.6 percentage points compared to a non-oil exporter.

The results from the threshold models (Table 3) show non-linear effects in the total renewable water resources per capita. The thresholds crucially depend on the control variables considered. The single predictor model with the total renewable water resources per capita as a single determinant, Model 1, shows a threshold of 924 m^3/(capita/year). The multiple predictor models, Models 2 and 3, show thresholds of 1698 m^3/(capita/year) and 1588 m^3/(capita/year), respectively. The thresholds are in line with the literature. Falkenmark and Widstrand [18] suggest a water stress threshold of 1700 m^3/(capita/year) in the beginning of the 1990s, and Yang et al. [17] of 1500 m^3/(capita/year) at the end of the 1990s.

Table 2. Ordinary least squares (OLS) estimations of the relationship between a country's total renewable water resources per capita and the cereal import dependency ratio (CIDR).

Explanatory Variables	**Cereal Import Dependency Ratio (CIDR)**				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Water	−0.010 ***	−0.008 ***	−0.006 ***	−0.009 ***	−0.009 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Population		0.214 ***	0.240 ***	0.178 ***	0.178 ***
		(0.04)	(0.04)	(0.03)	(0.03)
Ln GDP		−0.436	−1.201	−0.777	−0.782
		(0.97)	(0.97)	(0.90)	(0.93)
Cultivated area		−0.029 ***	−0.032 ***	−0.024 ***	−0.024 ***
		(0.00)	(0.00)	(0.00)	(0.00)
Oil exporter			26.281 ***	23.551 ***	23.599 ***
			(7.70)	(6.68)	(6.72)
Continent controls				YES	YES
Year controls	NO	NO	NO	NO	YES
_cons	74.804 ***	90.552 ***	104.935 ***	98.332 ***	98.690 ***
	(4.15)	(23.02)	(22.78)	(21.86)	(22.19)
Observations	191	191	191	191	191
R-squared (R^2)	0.130	0.388	0.425	0.627	0.627
Akaike information criterion (AIC)	1871.205	1809.919	1800.248	1723.588	1727.399
Bayesian information criterion (BIC)	1877.709	1826.180	1819.762	1752.858	1763.174

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$.

Table 3. Threshold estimations of the relationship between a country's total renewable water resources per capita and the cereal import dependency ratio (CIDR).

	Cereal Import Dependency Ratio (CIDR)					
Explanatory Variables	**(1)**		**(2)**		**(3)**	
	Regime 1 ≤924	**Regime 2 >924**	**Regime 1 ≤ 1698**	**Regime 2 >1698**	**Regime 1 ≤1588**	**Regime 2 >1588**
Water	−0.035 ***	0.003	−0.027 ***	−0.005 *	−0.030 ***	−0.006 **
	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)
Population			−0.198	0.167 ***	−0.124	0.209 ***
			(0.19)	(0.04)	(0.16)	(0.03)
Ln GDP			1.924	−0.813	1.728	0.416
			(1.57)	(1.16)	(1.73)	(1.09)
Cultivated area			−0.045 ***	−0.023 ***	−0.031 ***	−0.027 ***
			(0.01)	(0.00)	(0.01)	(0.00)
Oil exporter					−13.123 *	37.417 ***
					(7.96)	(8.70)
Continent controls	NO	NO	NO	NO	YES	YES
Year controls	NO	NO	YES	YES	NO	NO
Constant	97.997 ***	37.209 ***	58.582	93.693 ***	64.661	52.382 *
	(6.41)	(6.82)	(36.71)	(26.95)	(40.51)	(29.32)
Observations	56	135	91	100	87	104
	191		191		191	
R-squared (R^2)	0.22	0.01	0.73 0.32		0.78	0.68
Bayesian information criterion (BIC)	1304.36		1269.30		1173.95	
Hannan–Quinn information criterion (HQIC)	1296.62		1242.21		1139.12	

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$.

The results for one of the threshold models (Model 3) fit best (Table 3). The R^2s values are astonishingly 0.78 and 0.68 for Regime 1 (below the threshold) and Regime 2 (above the threshold), respectively, indicating high predictive power. An increase of 1 m^3 of the total renewable water resources per capita decreases the CIDR by approximately 0.03 percentage points for water-scarce countries below the threshold of 1588 m^3/(capita/year) and by 0.006 percentage points for water-scarce countries above the threshold of 1588 m^3/(capita/year). The effect is, thus, five times larger for countries below the threshold of 1588 m^3/(capita/year) compared to those above the threshold.

Table 4 shows the list of water-scarce countries, which are all countries with total renewable water resources per capita below 5000 m^3/(capita/year). The countries with total renewable water resources per capita below or equal to 1588 m^3/(capita/year) are highlighted in bold. It is a stable group of 28 countries over the period considered, including countries from Africa and Asia, but also from the Americas and Europe (Table 4). Ethiopia was above the 1588 m^3/(capita/year) threshold in 2002 but fell below the threshold in the years 2007 and 2012, making it 29 countries below the threshold. The number of water-scarce countries remains, thus, stable in the 2000s and is not yet increasing considerably, as suggested by Yang et al. [17]. Depending on the country considered, the risk of food insecurity is accelerated through low incomes and development, such as in Algeria, Djibouti, Jordan, and Yemen [28–31]. Social unrest and conflicts such as the "Arab Spring" protests [32] and climate change [30,33,34] are other factors that increase food insecurity for some of the countries considered. These factors are often interlinked and can reinforce each other.

The findings (Table 3) indicate that the effect for water-scarce oil exporters shows strong statistically significant and nonlinear U-shaped effects. The findings may indicate that, if a water-scarce country is an oil exporter with total renewable water resources per capita below the threshold of 1588 m^3/(capita/year) (namely, Kuwait, Saudi Arabia, and the United Arab Emirates), the CIDR will decrease by approximately 13.1 percentage points compared to a non-oil exporter. The findings indicate that oil exporting Arab nations have a distrust of increasing cereal import dependency. This behavior could be explained by political, economic, and cultural skepticism against food imports from mainly Western countries [23]. In contrast, if a water-scarce country is an oil exporter with total renewable water resources per capita between 1588 m^3/(capita/year) and 5000 m^3/(capita/year) (namely, Iraq and Nigeria), the CIDR will increase by approximately 37.4 percentage points. As regards Iraq, our results are in line with those of Ewaid et al. [35], who consider cereal imports an important water management strategy to safeguard scarce water resources in Iraq.

Regarding the other control variables, we find that the population effect is insignificant for water-scarce countries below the threshold, but highly statistically significant for water-scarce countries above the threshold. If the population increases by a million people in countries with total renewable water resources between 1588 m^3/(capita/year) and 5000 m^3/(capita/year), the CIDR will increase by 0.21 percentage points. The statistically significant and negative effect of the cultivated area is similar for both regions, with coefficients of −0.031 and −0.027 for Regime 1 (below the threshold) and Regime 2 (above the threshold), respectively (Table 3). The results for the logarithm of GDP are insignificant in all model specifications. These results are in contrast to Yang et al. [17] who found a strong correlation. A possible reason could be the different dependent variable considered (Yang et al. used the net cereal imports), the different period considered (Yang et al. used the period from the 1980s to the 1990s), and the different countries considered (Yang et al. focused on Asian and African countries only). Furthermore, we include oil exporters as an additional determinant and continent controls that were not considered by Yang et al. [17]. In particular, the results for oil exporting countries show a significant effect that should not be omitted as in previous studies.

Table 4. List of water-scarce countries with total renewable water resources per capita below 5000 m^3 for the years 2002, 2007, and 2012.

2002	2007	2012
Afghanistan	Afghanistan	Afghanistan
Algeria	**Algeria**	**Algeria**
Antigua and Barbuda	**Antigua and Barbuda**	**Antigua and Barbuda**
Armenia	Armenia	Armenia
Azerbaijan	Azerbaijan	Azerbaijan
Bahamas	Bahamas	Bahamas
Barbados	**Barbados**	**Barbados**
Belgium	Belgium	Belgium
Benin	Benin	Benin
Burkina Faso	**Burkina Faso**	**Burkina Faso**
	Chad	Chad
	China	China
Cuba	Cuba	Cuba
Cyprus	**Cyprus**	**Cyprus**
Djibouti	**Djibouti**	**Djibouti**
Dominica	Dominica	Dominica
Dominican Republic	Dominican Republic	Dominican Republic
Egypt	**Egypt**	**Egypt**
El Salvador	El Salvador	El Salvador
Ethiopia	**Ethiopia**	**Ethiopia**
		Gambia
Ghana	Ghana	Ghana
Grenada	Grenada	Grenada
Haiti	**Haiti**	**Haiti**
Iraq	Iraq	Iraq
Israel	**Israel**	**Israel**
Italy	Italy	Italy
Jamaica	Jamaica	Jamaica
Japan	Japan	Japan
Jordan	**Jordan**	**Jordan**
Kenya	**Kenya**	**Kenya**
Kuwait	**Kuwait**	**Kuwait**
Kyrgyzstan	Kyrgyzstan	Kyrgyzstan
Lebanon	**Lebanon**	**Lebanon**
Lesotho	Lesotho	Lesotho
Malawi	**Malawi**	**Malawi**
Maldives	**Maldives**	**Maldives**
Malta	**Malta**	**Malta**
Mauritania	Mauritania	Mauritania
Mauritius	Mauritius	Mauritius
Mexico	Mexico	Mexico
Morocco	**Morocco**	**Morocco**
Niger	Niger	Niger
Nigeria	Nigeria	Nigeria
Oman	Oman	Oman
Poland	**Poland**	
		Philippines
Republic of Korea	**Republic of Korea**	**Republic of Korea**
Rwanda	**Rwanda**	**Rwanda**
Saint Lucia	Saint Lucia	Saint Lucia
Saint Vincent and the Grenadines	**Saint Vincent and the Grenadines**	**Saint Vincent and the Grenadines**
Saudi Arabia	**Saudi Arabia**	**Saudi Arabia**
Senegal	Senegal	Senegal
South Africa	**South Africa**	**South Africa**
Spain	Spain	Spain
Sri Lanka	Sri Lanka	Sri Lanka
Tajikistan	Tajikistan	Tajikistan
Togo	Togo	Togo
Trinidad and Tobago	Trinidad and Tobago	Trinidad and Tobago
Tunisia	**Tunisia**	**Tunisia**
Turkey		Turkey
Uganda	Uganda	Uganda
United Arab Emirates	**United Arab Emirates**	**United Arab Emirates**
	United Kingdom	
Uzbekistan	Uzbekistan	Uzbekistan
Yemen	**Yemen**	**Yemen**
Zimbabwe	**Zimbabwe**	**Zimbabwe**

* Countries below or equal to the threshold of 1588 m^3 per capita are highlighted in bold.

4.2. Estimation Results with IWRM

To better understand the role of water management, we included the additional determinant of IWRM into the model (Table 5). The pooled OLS results (Model 1 in Table 5) show a statistically significant and positive relationship between the IWRM score and the CIDR. If the IWRM score increases by one level, the CIDR will increase by 6.7 percentage points. This indicates that water-scarce countries use cereal imports to cope with scarce water resources [2,36,37]. However, the threshold model (Model 2 in Table 5) indicates that this holds true for water-scarce countries with total renewable water resources per capita between 1588 m^3/(capita/year) and 5000 m^3/(capita/year) but not for water-scarce countries below or equal to the threshold of 1588 m^3/(capita/year). If the IWRM score increases by one level for water-scarce countries with total renewable water resources per capita above the threshold of 1588 m^3/(capita/year), the CIDR will increase by 9 percentage points. The findings of the threshold model also show that for water-scarce countries with total renewable water resources per capita above the threshold of 1588 m^3/(capita/year), the total renewable water resources are not significant and may have no impact. This confirms the importance of a better IWRM for water-scarce countries.

Table 5. Ordinary least squares (OLS) and threshold estimations for the additional determinant of IWRM for the year 2012.

	Cereal Import Dependency Ratio (CIDR)		
Explanatory Variables	**(1)**	**(2)**	
	Full Model	**Regime 1 ≤1588**	**Regime 2 >1588**
Water	−0.008 ***	−0.018 *	−0.004
	(0.00)	(0.01)	(0.00)
Population	0.175 ***	−0.200	0.197 ***
	(0.05)	(0.21)	(0.04)
Ln GDP	−2.509	3.290	−2.829
	(1.53)	(3.68)	(2.05)
Cultivated area	−0.024 ***	−0.025 *	−0.026 ***
	(0.01)	(0.01)	(0.01)
Oil exporter	22.446 **	−4.401	44.001 ***
	(9.62)	(9.68)	(12.08)
IWRM score	6.663 **	−4.902	9.018 **
	(3.15)	(6.65)	(4.25)
Continent controls	YES	YES	YES
Constant	115.989 ***	51.388	102.321 **
	(33.48)	(70.17)	(46.07)
Observations	61	27	34
R-squared (R^2)	0.687	0.803	0.738
Akaike information criterion (AIC)	552.09	241.56	306.67
Bayesian information criterion (BIC)	573.20	254.52	321.93

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$.

The other control variables in Regime 2 show the same significance levels and signs but with slightly different magnitudes as in the previous model specification (Table 3). For water-scarce countries with total renewable water resources per capita below or equal to the threshold of 1588 m^3/(capita/year), the most crucial determinants of the CIDR are still the water and land endowments. The findings suggest that water-scarce countries below or equal to the threshold of 1588 m^3/(capita/year) could improve their IWRM by increasing cereal imports as one policy option to overcome scarce water resources, such as in Jordan [38,39], Egypt [23,40], and Iraq [35]. The findings of this article also suggest that governments of countries with water resources below or equal to the threshold of 1588 m^3/(capita/year) can promote cereal imports so as not to use scarce water resources for cereal production. Governments can apply policy instruments, such as taxes, subsidies, benchmarking, or behavioral nudges, to receive the environmental benefits without overlooking the economic and social dimensions considering each country's specific context.

5. Conclusions

As the global cereal balance is again negative and the coronavirus pandemic hits the global economy, water-scarce countries are at high risk of severe food insecurity. A negative relationship between local water resources and cereal import dependency indicates that a decrease in local water resources is usually linked to an increase in cereal import dependency. This inverse relationship is nonlinear, with different magnitudes depending on the estimated threshold regions [17,18]. However, water-scarce countries can improve their IWRM to manage limited water resources more efficiently. Water-scarce countries can use cereal imports as a coping strategy so as not to strain limited national water resources [2,36,37].

While the virtual water and footprint concepts have been extensively employed to analyze virtual water trade, econometric analyses are still limited. We extend Yang et al.'s [17] threshold analysis by using the latest publicly available FAO data for the years 2002, 2007, and 2012, as well as additional determinants in the econometric specifications, including a dummy variable for oil exporters. In particular, we consider IWRM as an additional determinant in the analysis for better understanding the role of water management for water-scarce countries. The findings from our econometric analysis are summarized as follows.

The estimated thresholds from the multiple predictor models show thresholds of 1698 m^3/(capita/year) and 1588 m^3/(capita/year). The thresholds are in line with the literature. Falkenmark and Widstrand [18] suggested a water stress threshold of 1700 m^3/(capita/year) in the beginning of the 1990s, and Yang et al. [17] suggested one of 1500 m^3/(capita/year) at the end of the 1990s. The estimated thresholds indicate the points above which the total renewable water resources per capita no longer have a considerable effect on the CIDR.

The additional control variable of oil exporting status has been shown to be statistically significant. However, the effect is nonlinear and follows a U-shaped pattern, with negative effects below or equal to the threshold of 1588 m^3/(capita/year) and positive effects above the threshold of 1588 m^3/(capita/year). The findings indicate that specifically oil exporting Arab nations could increase their cereal import dependency to better manage scarce water resources.

The inclusion of IWRM as an additional determinant shows that there is no statistically significant effect for countries below or equal to the threshold of 1588 m^3/(capita/year), while the effect is statistically significant and positive for countries above the threshold. Our findings suggest that increasing cereal imports is an important strategy for water-scarce countries, so as not to strain their limited national water resources. In particular, water-scarce countries below the threshold of 1588 m^3/(capita/year) need to improve their IWRM through additional cereal imports. Other studies have shown that cooperative water management and ecosystem protection have proven fruitful in typical arid and semiarid basins [41]. The development of national food security strategies needs to be further enhanced and compared, and best policy success stories must be identified to overcome food insecurity [42].

This study also suggests that from 2002 to 2012, there was a stable group of 28 countries that fall below the threshold of 1588 m^3/(capita/year). No country below the threshold could escape the water scarcity trap over the considered time, which reinforces the importance of improving IWRM, with one option being higher cereal imports. Governments can encourage cereal imports through policy instruments, such as taxes, subsidies, benchmarking, or behavioral nudges, considering the specific local conditions. Water-scarce countries will have to depend even more on a few grain producers like Argentina, Brazil, and the US to guarantee food security [12], indicating the need for global solidarity and less skepticism about cereal imports. In times of the coronavirus pandemic, global solidarity is as important as ever to avoid a global food crisis [8]. Political stability is found to be crucial for effective water resource management [43] such as in Jordan [44]. However, in countries with a higher CIDR, the food price pass through rises significantly [19]. Food price spikes are linked to increased poverty, in particular in urban areas of food importing countries, and to periods of increased political and social unrest [45–48].

Author Contributions: Conceptualization, B.C.C.; methodology, B.C.C.; software, B.C.C.; validation, B.C.C., Y.R., and J.-P.L.; formal analysis, B.C.C.; investigation, B.C.C.; resources, B.C.C.; data curation, B.C.C.; writing—original draft preparation, B.C.C.; writing—review and editing, B.C.C., Y.R., and J.-P.L.; visualization, B.C.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: We gratefully acknowledge the Food and Agriculture Organization (FAO) and the United Nations (UN) for providing the data used in this research.

Conflicts of Interest: The authors declare that there is no conflict of interest.

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