DETERMINANTS OF VIRTUAL WATER TRADE OF CEREAL CROPS IN SAUDI ARABIA

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ABSTRACT

In this research, we used a gravity model to investigate whether water scarcity variables influence agricultural trade of cereal crops for Saudi Arabia. We compare the OLS, Fixed effects, Random effects, and Poisson Pseudo-Maximum Likelihood (PPML) estimators to determine the best model. The AIC, and multicollinearity, heteroskedasticity, and autocorrelation tests assist in determining estimation procedures and the final model. We cluster the errors by distance to improve the specific country effect variables, such as economic mass. We find that water-related variables influence virtual water imports of cereals, millet, corn, barely, and sesame.

Keywords: imports, gravity model, panel data, PPML, FE, RE

محددات تجارة المياه الافتراضية لمحاصيل الحبوب في المملكة العربية السعودية

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المستخلص

في هذا البحث، استعملنا نموذج الجاذبية للتحقق مما إذا كانت متغيرات ندرة المياه تؤثر على التجارة الزراعية لمحاصيل الحبوب بالمملكة العربية السعودية. ولقد قارنا تقديرات OLS، والتأثيرات الثابتة، والتأثيرات العشوائية، وتقدير احتمال بواسون شبه الارجح (PPML) لتحديد أفضل النماذج. وقد اجريت اختبارات AIC والارتباط الخطي والتباين والارتباط الذاتي في تحديد إجراءات التقدير والنموذج النهائي. ولقد قمنا بتجميع الأخطاء بحسب المسافة لتحسين متغيرات تأثير الدولة المحددة، مثل الكتل الاقتصادية. ولقد ظهر أن المتغيرات المتعلقة بالمياه تؤثر على واردات المياه الافتراضية من الحبوب والدخن والذرة وبالكاد والسمسم.

الكلمات المفتاحية: الاستيراد، نموذج الجاذبية، البيانات القطاعية، PPML, FE, RE

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INTRODUCTION

The liberalization of world trade has led to the fluid movement of goods and services among countries. This more open trading environment has encouraged countries to seek gains from trade, which sometimes leads to difficulties when resources are priced inefficiently. The mispricing of water is a huge issue throughout the world, so open trade sometimes neglects the optimal use of water resources, especially for those countries that suffer from water scarcity Furthermore, Saudi government intervention in agricultural policies has supported many crop farmers, but this support has led to distorted agricultural prices where private prices are above social prices. The lack of control over the use of groundwater and the fact that water is essentially free (even groundwater resources) has helped lead to exhaustion of groundwater. Water management policies in Saudi Arabia have taken a back seat to supply-side policies that increase self-sufficiency in some crops, ignoring the importance of depleting water resources. All of this leads to the conclusion that Saudi Arabia has not benefited from foreign trade because it has squandered its meager groundwater supplies. Saudi Arabia's previous development plans ignored the indirect impacts of foreign trade in agricultural products on local water uses (sometimes called the closed water balance) (4). The authorities only looked at how to distribute local water for domestic uses. The agricultural sector relies heavily on non-renewable groundwater in Saudi Arabia, so it is using scarce water rapidly (2). Per hectare, water needs vary widely by crop in Saudi Arabia. The main concern is that most crops produced by Saudi Arabia, such as wheat, barley, and alfalfa, consume large amounts of water (16). Cucumbers need 8.39 thousand m3/ha of water (the lowest) while alfalfa needs 45.97 thousand m3/ha (the highest) on traditional farms (4). Hoekstra and Hung (12) show 3,000 to 5,000 kg of water is needed for every kilogram of grain produced. Therefore, it is very important for Saudi Arabia to follow policies that use its scarce water on water-efficient crops. This study aims to investigate whether water scarcity variables influence cereal crops trade between Saudi Arabia and its commercial partners. We first calculated virtual water trade for 20 crops and three groups, and then we estimate the gravity model using the concept of virtual water during the study period 2000-2016. We then examined the determinants of Saudi virtual water trade flows by applying the gravity model using the concept of virtual water. We compared the OLS, fixed effect, or random effect model to choose the preferred model. We also used the PPML model to solve the zero trade and heteroskedasticity issues.The design of the rest of the paper as follow: next section we present the methodology including the conceptual framework. Then discussion the results found. At the end, we gave the conclusion with recommendation for policy.

MATERIALS AND METHODS

In 1994 Allan described the concept of virtual water, referring to a situation in the Middle East where there is potential for water wars . He discussed the suffering of the water-scarce countries from shortage of freshwater as well as the depletion of their water resources to meet the needs of domestic and industrial uses. More water for such uses can become available through the concept of virtual water trade to avoid the consumption of rare domestic freshwater. Several studies have focused on estimating virtual water trade for the world using the methods developed by Allan (1, 4), but no study has focused on the virtual water trade for Saudi Arabia. There have been studies of virtual water trade using the gravity model recently. Fracasso (9), Duarte et al., (8), and Chen and Wilson, (6) used panel data to explain virtual water trade with OLS and PPML methods. Fracasso (9) used panel data in one analysis and cross-sectional data in another analysis. He found that water endowment (per capita water availability) and pressure on water resources (the ratio of freshwater withdrawn to total renewable water) had a definite impact on bilateral flows. To investigate the virtual water in agriculture trade between countries, Duarte et al., (8) amended the gravity model to include the availability of renewable water as measured by precipitation and total renewable water, and agricultural land by cultivated area. They found that the economic variables were significant factors on virtual water flows, but water variables were not. Following the model developed by Fracasso (9) and Chen and Wilson (6) investigate the impact of trade policy on virtual water trade across countries by adding ad valorem tariff equivalents to a model that included the water variables. They found a negative correlation between imports of crops and high water consumption and bilateral tariffs. Fracasso et al. (10) complemented the study of Fracasso (9) by using cross-section data to determinate the factors affecting the virtual water trade among Mediterranean basin countries. They conclude that countries with greater water endowments do not necessarily export more virtual water. Tamea et al. (21) estimated two gravity models (for imports and exports), to examine the factors, which affect the virtual water trade. They found that economic variables drive virtual water trade, rather than dietary demand. GDP, population, and virtual water production of exporting countries were the drivers of virtual water trade. Delbourg and Dinar (7) also examined the impact of water endowment on virtual water of bilateral trade and found a positive effect between virtual water imports and lower water endowment.

Model Specification

The emergence of the virtual water concept by Allan in 1994 helped people understand some of the water scarcity problems and how they can be overcome through international trade. It quantified ways of reducing water scarcity through production changes and international trade (11, 12). Allan's idea about virtual water is consistent with international trade theory. Countries with a comparative advantage in water (they are water abundant), could transfer their virtual water to water-scarce countries through the trade of water-using crops. This idea represents a rendition of the Ricardian and Heschker-Ohlin-Vanek (HOV) model. Taking into account Allan's ideas and following the HOV model about comparative advantage between two countries, we formulate a gravity model of virtual water trade. The gravity model results from production theory using endowments from an HOV trade model and consumption theory using a CES utility (6, 7, 9).====The main point here is whether crops, which are water-intensive in production, are exported from countries that have abundant water resources to water-scarce countries .Saudi Arabia is considered a water scarce country, and it is reasonable that it benefits by importing crops (importing virtual water) instead of using scarce local water on agricultural production . Therefore, we use a gravity model to test whether the volume of virtual water trade between Saudi (5, 9, 19, 23, 25) Arabia and the rest of the world is influenced by relative water scarcity. From the above explanation, we add importer and exporter fixed effects to solve the omitted variable bias in gravity models, which come from multilateral resistance trade and misspecification (5, 9, 19, 23, 25). However, Fracasso shows that including time-varying country fixed effects force all the country specifics to drop out of the model (GDP and population). Therefore, we build our related water variables, in the next section, as a ratio to keep these variables in the model (9). We ignore tariff variables due to data availability, and Saudi Arabia was not a colony of any country, so that variable is excluded too. We include five bloc dummies; each dummy represents the time in force for Regional Trade Agreements with Saudi Arabia. D98 identifies the agreement for the Pan-Arab Free Trade Area (PAFTA) (the number indicates the year the agreement began), D03 identifies the agreement with the Gulf Cooperation Council (GCC), D05 identifies the agreement with the WTO, D13 identifies the agreement with Singapore, and D14 identifies the agreement with the European Free Trade Association (EFTA). In addition to the above-mentioned explanatory variables, we include variables related to water. Other studies have used total renewable water, average annual precipitation and virtual water used in agricultural production for water endowment or availability, and arable land as a measure of land endowment 8 , 9 , 20 ,21). Among these variables, we introduce three variables describing Allan's idea of water-scarce countries (such as Saudi Arabia) importing crops from abundant countries. First, the Water Dependency Ratio (WDR) is a country's water dependency (WD) divided by Saudi Arabia's WD. If the ratio is greater than one, the country is more dependent on virtual water inflows than Saudi Arabia. We expect the coefficient on WDR to be negative in the import equation if Allan's hypothesis is correct. Second, the Water Footprint Ratio (WFR) for each product is the other country's water footprint divided by the water footprint of Saudi Arabia. A higher WFR means that the country consumes more water resources per ton produced than Saudi Arabia. If Allan's hypothesis holds, then the WFR should have a negative sign in the import equation. Third, the Relative Renewable Water to Arable Land Ratio (RRWALR) represents the m3 of renewable water per hectare for a country divided by the renewable water per hectare for Saudi Arabia. An RRWALR greater than one means the country has more abundant water resources relative to Saudi Arabia. Allan hypothesizes that the coefficient on RRWALR is positive for the import equation. We used panel data rather than purely cross-section data. Cross-sectional data could lead to bias in our results because the error terms reflect omitted variables that are correlated with trade and GDP. Also, cross-sectional data cannot estimate both GDP and country fixed effects due to multicollinearity. Panel data is preferred because it has observations over time that help control for an unobserved country-specific heterogeneity, control for time-invariant effects that lead to omitted variables bias, and provide more degrees of freedom (5, 23). Panel data accounts for the issues of varying multilateral resistance terms (MRT) over time by using importer/exporter time fixed effects (25). We also apply a PPML estimator (log-linearized) to solve the issue of zero trade flows, multilateral resistance terms (MRT), and inconsistency and bias (came from the log-log gravity model of heteroscedasticity) when estimating trade costs and policy. PPML leads to perfect compatibility between fixed effects and the unobserved multilateral resistance trade (8, 9) The dependent variables had a poisson distribution. PPML is in general generalized linear models. However, our estimations were different from previous studies. First, we applied our model to different cereals crops, rather than on aggregate data. Second, we calculated the VWT so that it more accurately reflected water scarcity. Third, we used a specific country (Saudi Arabia) in the analysis to gauge the influence of water-related variables on VWT. Fourth, we used different variables related to water scarcity relative to Saudi Arabia to capture ideas from Allan. Fifth, we include the effects of different trading blocs on virtual water trade. Finally, we conduct more diagnostic tests related to data and the model. Therefore, we used water availability and scarcity data with a gravity model to explain the virtual water trade flows between Saudi Arabia and trading blocs. Our final gravity model specification with PPML for import virtual water is:

$$\boldsymbol{VWT_{it} = \exp[\alpha_0 + \beta_1 lnY_{it} + \beta_1 lnY_{jt} + \beta_2 lnPOP_{it} + \beta_2 lnPOP_{jt} + \mu_{it} + D_{year} + D_{ij} + \pi_1 WDR + \pi_2 WFR + \pi_3 RRWALR + \epsilon_{ijt}]} \quad (\mathbf{1})$$

Where VWT - virtual water import, μ_{it} - exporter time fixed effects, D_{year} - dummies for the RTA member and non-member , D_{ij} - a set of Dummy Variables, which represent country pair fixed effects, WDR, WFR, and RRWALR - the related water variables, and ϵ_{ijt} - the error term.

Data

Data from 2000 through 2016 for virtual water trade of cereal crops came from different resources. Saudi Arabia production data were from the General Authority for Statistics. However, most of the trade data came from GATS: Global agricultural trade system from the United States Department of Agriculture (USDA). We used BICO codes for Wheat, Millet, Corn, and Sesame and Harmonized codes for Barley. The world water footprint provided by Mekonnen and Hoekstra (15) is more comprehensive, detailed, and accurate than other studies. Multsch et al., (17) has data on Saudi Arabia's water footprint that is newer based on an approach similar to Mekonnen and Hoekstra, (15). We rely on Multsch et al.,(17)for Saudi Arabia, but Mekonnen and Hoekstra for the rest of the world. If the data are not available for the country from Mekonnen and Hoekstra (15). We take the average global water footprint. For explanatory variables, country-specific characteristic data came from World Bank's (World Development Indicators) such as GDP and POP, except GDP for Korea, which came from the OECD (Organization for Economic

Co-operation and Development). Distance (Dist) came from the time and date website, which specializes in measuring the distance between cities. Total renewable water and arable land came from AQUASTAT. The water footprint variable came from Mekonnen and Hoekstra (15) while water dependency variables came from Hoekstra and Hung (13). RTA dummies variable came from Regional Trade Agreements Information System (RTA-IS) of The World Trade Organization (WTO) website.

RESULTS AND DISCUSSION

The panel data were balanced; all countries (cross-sectional units) had the same years (time series units). The use of panel data presents some problems such as heteroscedasticity and autocorrelation. In this study, we only concentrated on the import side, since Saudi Arabia is a water scarce country. In addition, the virtual water imports are much greater than virtual water exports. To account for unobservable trade costs, we include dummies variables such as whether the countries share a common religion, common border, and RTA membership, as well as geographical distance. These variables were invariant with time. The economic mass variables included country''s GDP, Saudi Arabia's GDP, GDPSA; and the population of both country i and Saudi Arabia, POP and POSA, respectively. There are three water-related variables included: WDR, which should be negatively related to imports, and RRWALR and WFR, which should be positively related to imports. For each crop, we compare the OLS, fixed effect, Random effect, and PPML estimators to obtain the best model. This final result is accomplished through tests designed to choose between models. The tests were the F-test (the data fit the model well if the F value is high to compared to least square dummy variable (LSDV) and fixed effect)), Variance Inflation Factor (which shows collinearity between explanatory variables), Breusch and Pagan LM test (which compares Pooled OLS and random effects), Hausman (which compares fixed and random effects)1, and Wald test (which compares the stability of the variance). We start by including all the variables in the model. We use a forward or backward stepwise procedure for final variable inclusion (14) which involves the Akaike Information Criteria (AIC). We pick the procedure that includes more water-related variables. We drop the common language dummy since it is perfectly correlated with the PAFTA member dummy. We also drop the culture dummy variable that is perfectly correlated with the GCC dummy variable. The D05 dummy (WTO member) was omitted because non-members had a tiny amount of virtual water trade with Saudi Arabia. Some of the variables were dropped from the model when using fixed effects because of their time-invariant nature. Because some of these time-invariant variables are interesting for our purposes, we tended not to include country fixed effects in our analysis. Heteroscedasticity is a common problem with panel data, so we used robust standard errors with OLS estimators to reduce bias (Woolridge, 2009). We also cluster the errors by the distance to improve the specific country effect variables such as the economic mass variables). Finally, we handle zero trade observations and the resulting heteroscedasticity issues by using a PPML estimator. Dropping zero trade flows leads to a loss of useful information. Cereals crops receive 97.8% of the total virtual water trade of Saudi Arabia compared to 1.9% with vegetables and 0.3% with fruit crops. Our general criteria for choosing the gravity model between OLS, fixed effect, and random effect, is shown in table 1. Only results for the selected model are shown. All models are fitted with the PPML estimators because of the zero trade observations, and the results from PPML are compared with the chosen model from Table 1. Zero trade observations are common; more than 55% of the observations in the Cereals groups are zero.

[1] **The null hypothesis states that using RE is better (efficient and consistent), while the alternative hypothesis states that FE is better.**

Table 1 .Selecting models of cereals crops

Crop	FE vs. OLS (F-test)	RE vs. OLS (Breusch & Pagan)	Preferred model
Cereals	Pooled OLS	*H_0: Rejected* RE	*RE*
Wheat	Pooled OLS	*H_0: Rejected* RE	*RE*
Millet	Pooled OLS	*H_0: Fail to reject* OLS	Pooled OLS
Corn	FE	*H_0: Rejected* RE	*Hausman test* *H_0: fail to reject* *RE*
Barley	Pooled OLS	*H_0: Rejected* RE	*RE*
Sesame	Pooled OLS	*H_0: Rejected* RE	*RE*

We found that water-related variables significantly influence the virtual water imports for cereals, millet, corn, barley, and sesame. All other crop models had all water-related coefficients that were not significantly different from zero.

Results of the Gravity model of virtual water import for cereals aggregate

Cereals crops are water-intensive compared to other crops. Earlier results show that these crops account for more than 90% of Saudi Arabia's total virtual water imports during 2000-2016. There were 1224 observations from 72 countries over the period 2000-2016 for cereals. Nine PAFTA member countries and four GCC countries exported cereals to Saudi Arabia accounting for 0.5% and 0.02%, respectively, of the total virtual water trade of Saudi Arabia. The water footprint ratio for cereals (WFRCE) was calculated by taking the average of wheat, barley, corn, millet, and sesame water footprint for each country as a ratio of Saudi Arabia We found that the AIC forward process is preferred for the cereals gravity model and the resulting model is random effects based on its high F-value and the result of the Breusch and Pagan LM test (Table 2). The religion dummy, GCC member dummy, and the population had unexpected sign while others were commonly expected. The results show diversion of trade to non-members of the GCC. The sign for the population of other countries was somewhat reasonable, as the population of other countries population rise, it will increase their consumption of cereals and reduce Saudi Arabian imports. The water coefficient for WDR was significant for cereals in the PPML estimation, which is consistent with Allan's idea. The negative sign on the coefficient for WDR suggests that Saudi Arabia imports more cereals from countries that have lower external water dependency (which makes sense). The positive sign on WFR was not consistent with Allan's hypotheses because it means that countries with a larger the water footprint ratio for cereals export more to Saudi Arabia. The RRWALR also had a negative sign (which was not expected) but it was not significantly different from zero. Fracasso (9) mentioned that there might be a relation between arable land and population after including arable land in his models.

Results of the Gravity model of virtual water import for Wheat

We chose backward AIC for the wheat models because the forward criteria only resulted in variables which were time-invariant (table 2). The VIF shows no problem with collinearity between the variables. OLS was preferred by the F-test, but the random effects model is efficient under the Breusch and Pagan LM. As the population in Saudi Arabia increases, there are more imports of wheat. Since 2008, the government established the policy to reduce support for wheat farmers, which lead to an increase in production and a gap to fill by imports (1). The random effects model provides little explain wheat imports since there is only one significant coefficient, a religion dummy variable, because Saudi Arabia gets the vast majority of its wheat from non-Muslim countries. This negative coefficient on religion is significant in both models.The results of the PPML model explain more variation in VWT for wheat, and there are more significant coefficients in this model. For instance, GDP, POP, POP of Saudi Arabia, and the religion dummy all have coefficients that are significantly different from zero. However, none of the coefficients on water variables were significantly different from zero. Thus, relative water scarcity does not seem to influence VWT for wheat.

Results of the Gravity model of virtual water import for Millet

For the VWT model for millet, GDP and POP of Saudi Arabia, distance, WDR, and PAFTA membership had coefficients that were significantly different from zero according to the forward AIC information (Table 2). The VIF test shows no problem with collinearity between these variables but the Wald test indicates a problem with heteroscedasticity. The Breusch and Pagan LM test points to pooled OLS as the preferred model. The coefficients for PAFTA had the expected sign, indicating that trade creation for millet occurred with PAFTA member. The coefficient for WDR was negative and significant suggesting that Allan's idea holds that a lower water dependency ratio leads to rising VWT trade with Saudi Arabia in millet. The PPML model had had more economic mass variables, such as GDP and POP of Saudi Arabia, as significantly different from zero but not much change in the other coefficients.

Results of the Gravity model of virtual water import for corn

The AIC forward procedure was used to pick to variables in the model for corn (Table 2). The fixed effects model was preferred according to F-test, while the Bresuch and Pagan LM and Hausman test show that the random effects model is preferred. The random effects model is reported. The coefficient for GCC membership and distance were both significantly different from zero and of an unexpected sign in the PPML estimation. Saudi Arabia imports little corn from GCC member countries. Most of Saudi Arabia's corn suppliers are a long way from the Kingdom (Argentina, Brazil, the US, and Ukraine), so this might be why the distance coefficient is positive. The random effects model had different significant coefficients than the PPML model. Saudi Arabia's GDP positively influenced corn imports while the relative water footprint ratio (WFR) had a positive effect. The WFR signs are not consistent with expectations, suggesting that Saudi Arabia imports more corn from countries with a larger footprint.

Results of the Gravity model of virtual water import for Barley

The backward AIC procedure resulted in the random effect model being selected for barley. Barley is the leading cereal imported by Saudi Arabia, and it accounts for more virtual water import than any other crop. Barley imports came from thirty-nine countries, but only one was a GCC member and only four members of the PAFTA. The F-test shows that OLS was preferred while the Breusch and Pagan LM test show that the random effects model was preferred. The coefficients for WDR were consistent with Allan's idea and the Hecksher-Ohlin-Vanke (HOV) theory, while the coefficients for WFR were not consistent with these ideas. The WDR variables show that Saudi Arabia, as a water-scarce country, imports barley from countries with more abundant water, but the WFR coefficient indicates that Saudi Arabia imports barley from water-scarce countries. The RRWALR coefficient was negative but not significantly different from zero. Overall, there is some evidence that barley imports are coming from water-abundant countries.The coefficients on the contiguous dummy had the opposite sign; countries that share a border with Saudi Arabia supply less barley. This is reasonable since almost the border countries have the same water problems. There is a high correlation between contiguous countries and GCC member too. The PAFTA trade agreement coefficient was negative and significant, meaning that virtual water barley imports were larger from non-members. PAFTA member countries export less than 1% of Saudi Arabia's barley imports. We conclude that countries who share a border with SA or are members of the PAFTA agreement are not important barley suppliers.

Table 2 .Gravity model of virtual water import of Cereals crops

Variables	Cereals		Wheat		Millet		Corn		Barley		Sesame	
	RE	PPML	RE	PPML	OLS	PPML	RE	PPML	RE	PPML	RE	PPML
GDPi	0.169 (-0.169)	1.442*** (-0.339)	0.594 (-0.717)	0.812*** (-0.263)					0.380*** (-0.135)	0.817*** (-0.195)	-0.86*** (-0.167)	-2.95*** (-0.808)
Saudi GDP					-0.687 (-1.19)	-0.729** (-0.33)	0.768** (-0.338)	0.65 (-0.412)			0.611 (-0.943)	2.801*** (-1.015)
POPi	-0.277 (-0.387)	-0.694* (-0.382)	-0.765 (-0.749)	-0.679** (-0.274)							1.060*** (-0.255)	3.945*** (-1.001)
Saudi POP			4.165 (-3.274)	6.492*** (-1.177)	3.365 (-4.174)	3.678*** (-1.309)					3.271 (-3.595)	-2.27 (-6.697)
Dis	-1.475 (-1.084)	-1.870** (-0.773)			-0.659 (-0.427)	-2.408 (-1.889)	0.475 (-0.835)	2.149*** (-0.537)			0.232 (-0.651)	1.7 (-1.274)
Drelg	-0.389 (-0.991)	-3.165*** (-0.894)	-3.738*** (-1.437)	-2.536*** (-0.947)							-0.616 (-0.745)	0.147 (-0.674)
Dcong			-2.384 (-1.836)	-1.618 (-1.356)			0.378 (-0.347)	4.503** (-2.086)	-6.437*** (-1.091)	-6.876*** (-1.306)		
D98	-0.306 (-1.682)	0.696 (-1.422)			1.893** (-0.838)	1.74 (-1.864)			-4.295*** (-0.645)	-5.448*** (-1.797)	1.916 (-1.417)	1.291 (-2.532)
D03	-3.435** (-1.574)	-6.567*** (-1.705)					-1.269 (-1.352)	-6.422*** (-1.452)	7.552*** (-0.961)	5.312** (-2.459)		
RRWALR	-0.129 (-0.343)	-0.33 (-0.276)							-0.462 (-0.34)	-0.231 (-0.257)	-0.09 (-0.288)	-3.360*** (-1.272)
WDR	-0.698 (-0.599)	-0.723** (-0.292)			-0.455* (-0.236)	0.177 (-1.144)			-0.563*** (-0.191)	0.199 (-0.376)		
WFR	0.577 (-1.547)	3.215** (-1.39)	3.785 (-2.307)	0.164 (-0.53)			2.192** (-1.01)	-0.373 (-1.049)	4.264*** (-0.703)	6.256*** (-2.078)	1.589*** (-0.435)	3.919*** (-1.289)
Constant	20.25*** (-6.879)	1.72 (-6.934)	-62.63 (-60.73)	-110.5*** (-18.5)	-29.17 (-42.92)	-21.19 (-16.93)	-15.2 (-10.87)	-25.23** (-9.946)	2.627 (-3.549)	-8.505* (-4.906)	-65.00* (-39.09)	-32.23 (-93.15)
Obs.	313	731	124	510	45	221	180	493	124	340	172	629
R-squared	0.219	0.584	0.307	0.142	0.543	0.539	0.057	0.086	0.576	0.686	0.596	0.623
AIC	Forward		Backward		Forward		Forward		Backward		Forward	
VIF	No		No		No		No		No		No	
Breusch & Pagan[a]	0.0000		0.0002		1.0000		0.0000		0.0019		0.0000	
Hausman[b]	--		--		--		0.72		--		--	

Standard errors in parentheses ***** p<0.01, ** p<0.05, * p<0.1**

[a](Prob > chibar^2) **[b](Prob > chi^2)**

Results of the Gravity model of virtual water import for Sesame

The forward AIC procedure was used to determine the reported model for sesame (the random effects model, table 2. The basic gravity variables were included in the final model, as well as PAFTA membership, WFR, RRWALR, and a dummy for religion. These variables did not have high multicollinearity according to the VIF test. Two GCC members and eight PAFTA members exported sesame to Saudi Arabia. The result for the relative water footprint of sesame does not support the Allan idea (it is positively related to virtual water imports in both models). The RRWALR coefficient was negative but not significant in the random effect models while it was negative and significant with the PPML model. Countries with less renewable water per hectare tended to export more sesame to Saudi Arabia. The religion dummy coefficients were negative but not significant. The GDP of other countries was negatively related to Saudi Arabia's virtual water imports of sesame. Saudi Arabia imports sesame from poorer countries; more than 90% of their total sesame imports come from countries with a lower GDP than Saudi Arabia.

CONCLUSIONS AND RECOMMEND-ATIONS

We used a Gravity model to investigate whether water scarcity variables influence trade. We fitted a gravity model and used either a forward or backward AIC to select the variables for each crop. We chose the OLS, fixed effect, or random effect model based on the F-test, Breusch and Pagan LM test, and Hausman test. We also check the models for heteroskedasticity. The PPML model was estimated to solve the issues of zero trade and heteroskedasticity. This was important because more than a third of the trade observations were zero. Our results indicate that all the water-related variables influence each crop model except wheat. Yet more than 60% of the significant coefficients for water-related variables had an adverse sign (not supporting Allan's ideas). Therefore, our results indicate that Saudi Arabia's crop imports often do not involve importing crops from water-abundant countries. Instead, the country is getting much of its imports from water-scarce countries, exacerbating world water problems. This is likely related to the mispricing of water in many countries and the lack of other policies that could overcome this mispricing.We found that Saudi Arabia's membership in various RTAs did not have a positive influence on its virtual water trade. Most of the coefficients for the RTA dummies were negative, and many were significantly different from zero. This likely reflects the fact that many RTAs are with similarly water-constrained countries surrounding Saudi Arabia, so their water issues likely had a more dominant impact than the free trade agreement. Future research should look at this question more closely for other countries. Water problems will persist in the future as water is mispriced and effective water policies are difficult for countries. Agricultural trade can be a means to redress policies that do not address water problems and can be used to reduce water shortages in many countries.

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