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ECONOMETRICS | RESEARCH ARTICLE

A statistical analysis of the social and environmental risks of the international trade in virtual water

Y. Kopnova^{1*}

Abstract: This work develops a statistical methodology of analysis of the international trade in virtual water in the context of sustainable evolution. Using the example of agriculture, the impact of the flows of virtual water in the composition of products using indicators related to social and environmental risks was investigated. In the analysis data from websites of World Bank and the World trade organization for the period from 1996 to 2012 were used. The methodology was based on the toolkit of econometric modelling. The analysis showed the presence of stable groups of countries, including the groups of mainly exporting and mainly importing agricultural products. The share of the third group of countries with the varying sign of the balance of export and import amounted to only 30%. The factors influencing the formation of groups, in particular, were the role of water resources in terms of their scale and efficiency of use. The study of the impact of export and import of agricultural products on the indicators related to environmental and social risks identified significant problematic dependencies. The overall pattern for the three groups was that the countries with more intense trade flows had a lower rating of ecological sustainability.

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PUBLIC INTEREST STATEMENT

Virtual water trade is the trade of water-intensive products. The application of this concept in modern programs of social economic development of the countries of the world is primarily aimed at solving the global problem of water scarcity. The main risks of this are the deterioration of the environment and the growing problem of economic security. The first is considered for the countries that mainly are exporting water-intensive products. The second is the characteristic of countries that are mainly importing the products.

The article describes the technique of statistical analysis of trade flows of virtual water and the results of its application on the example of agricultural products for the period from 1994 to 2011. There was found that the intensification of the export of this product is consistent with a reduction in the rating of environmental sustainability of socio-economic development of countries. There were demonstrated relationships between trade flows and characteristics such as migration, unemployment, and social inequality.

Subjects: Environment & Agriculture; Environmental Studies & Management; Mathematics & Statistics

Keywords: virtual water; international trade; environmental risks; social risks; econometric model

JEL classifications: Q17; Q25; Q27

1. Introduction

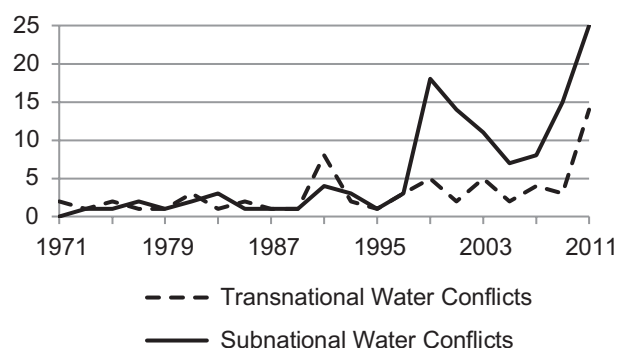
In the modern conditions of water scarcity in the international market, there is a noticeable trend of the increasing role of water-intensive products (Danilov-Danilyan & Khranovich, 2010). This corresponds to the concept of international trade in virtual water in the composition of these products. The concept was offered by Allan (1997) and developed by Hoekstra (2011). According to international statistics (UNESCO, 2009), the volume of virtual water currently accounts for 40% of the total world water consumption. It means that for water-scarce countries it is more profitable to import virtual water than to raise the efficiency of its own water resources. For water-rich countries, the increasing demand for water-intensive products opens up opportunities to improve the efficiency of such basic industries as metallurgy, chemical industry, and agriculture.

However the changes in the structure of international trade poses challenges related to the sustainable development of the world economy. In particular, improving the competitiveness of water-intensive industries can lead to the territorial restructuring of production. It can contribute to an imbalance of water resource distribution, and investment in national economics. Undue intensification of water use in water abundant countries threatens to violate of environmental standards, resulting in the degradation of water resources, aggravates the global problem of climate change. The dependence of consumption on the international market in water-scarce countries is connected with the problem of food safety and financial safety. It leads to negative changes in the labor market, reinforces migration flows, and enhances social tensions. The increasing role of water resources elevates the likelihood of violations of basin relations of neighboring countries and violent confrontations. Evidence of such negative consequences of the global trade in virtual water can be found, for example, in the works Horlemann and Neubert (2007), Gleick and Heberger (2014). The chart of the number of officially registered world water conflicts (Figure 1) shows the aggravating problem of water scarcity in the modern world. It also testifies to the prevalence of subnational conflicts compared with transnational conflicts.

The strategy of the global trade in virtual water is officially recognized by the Global Water Partnership (GWP). It is defined as a means of countering the global water crisis by a system of the Integrated Water Resources Management (IWRM) (<http://www.gwp.org/en/ToolBox/TOOLS/Management-Instruments/Water-Resources-Assessment/Water-footprint-and-virtual-water-concept/>). In 2004, the World Water Council (WWC) published statistics on the condition of the world trade in virtual water. They established the basic methodology for management and defined a system of indicators for monitoring (World Water Council, 2004). The practical application of this strategy involves developing specific methods of analysis and management for individual regions and on

Figure 1. The number of officially registered world water conflicts.

Source: Gleick and Heberger (2014).



a macroeconomic scale. The number of such developments increasing due to the improvement of statistical methods along with the accumulation of information and experience in research. The most illustrative examples of this are primarily the analysis of the flows of virtual water in Kenya (Mekonnen & Hoekstra, 2014) as well as (Dabrowski, Masekoameng, & Ashton, 2009) in the southern African region. Both studies are highly informative. They take into account the individual peculiarities of the countries. However, the methodology of the statistical analysis in these studies is restricted to methods of descriptive statistics. In later studies, modern econometric tools were used. In particular, in (Fracasso, 2014), the gravity model of international trade for the analysis of factors impacting on virtual water flows for countries of the world was applied. However, typically, researchers do not solve the problem of reliable statistical assessment of the consequences of the global trade in virtual water in the context of sustainable development.

This work develops a statistical methodology of analysis of the international trade in virtual water, which will be able to estimate the determinants of trade flows, and to identify the negative impact of these flows. The main task of the research was to determine the impact of the international trade in virtual water on social and environmental risks. This was done using a sample of the virtual water in agricultural products, at the macro level. The analysis used data from websites of the World Bank and the World Trade Organization for the period from 1996 to 2012. The methodology was based on an econometric model that represents a set of typological seemingly unrelated regressions (SUR) estimated on panel data for pre-selected groups of countries. Endogenous variables in the model are the indicators associated with the characteristics of social and environmental risks. The composition of the exogenous variables includes indicators of international trade in virtual water. To identify typological groups of countries their structure in relation to the balance of export-import of agricultural products was analyzed and indicators were selected according to the above recommendations of the WWC. Cluster and regression analyses were used.

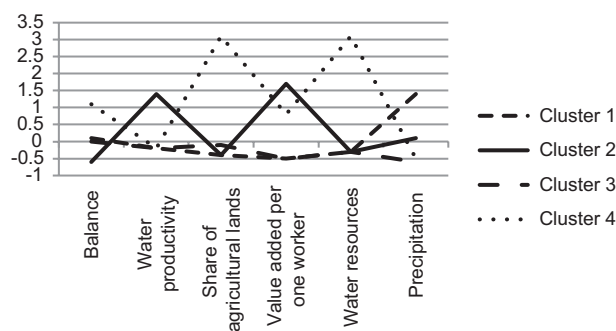
2. Formation of the typological clustering of countries

We determined the group of countries which were of mainly importing and another group of countries which were of mainly exporting agricultural products.

First a cluster analysis by the method of k-means ($k = 4$) (Aivazyan, 2001) on standardized data of 2011 was conducted. As grouping factors, the following indicators were used: the balance of export-import, water productivity, share of agricultural land, productivity in agriculture, volume of water resources, and precipitation. The result of the classification of countries is shown in Figure 2.

The chart determines the position of the average values of all indicators for each cluster. It is seen that the difference of the average values of the balance of export and import for the main clusters - fourth (mostly exporters of agricultural products) and second (mostly importers of agricultural products) is accompanied by a difference in the values of the indicators of the scale and efficient use of water resources. The exporters of agricultural products are mainly water-rich countries with large areas of agricultural lands, particularly countries such as Canada, Brazil, the USA. The importers are the country with limited water resources, arable land, and high productivity of the water resource, in particular, Japan, Germany, Denmark. The countries from first and third cluster differ mainly in terms of precipitation.

Figure 2. Result of the cluster analysis.



The model of Heckman (Verbeek, 2000) was used to justify the obtained groups, identify the significance of the factors of their formation, in particular, define the role of water resources.

$$G_i = \begin{cases} 1, & \text{if } G_i^* \geq 0 \\ 0, & \text{if } G_i^* < 0 \end{cases}$$

G_i^* is formed by the regression equation:

$$G_i^* = \mathbf{Z}^{(i)} \boldsymbol{\delta} + \zeta_i, \quad i = 1, 2, \dots, n, \quad (1)$$

$$\mathbf{Z}^{(i)} = (Z_1^{(i)}, Z_2^{(i)}, \dots, Z_k^{(i)}), \quad \boldsymbol{\delta} = (\delta_1, \delta_2, \dots, \delta_k)^T,$$

$\mathbf{Z}^{(i)}$ is the vector of observed independent variables (factors) in the i th observation, $\boldsymbol{\delta}$ is the vector of regression coefficients, and ζ_i is the regression error (1) in the i th observation.

It is assumed that ζ_i has a standard normal distribution and is not correlated with the components of the vector $\mathbf{Z}^{(i)}$:

$$\zeta_i \sim N(0, 1), \quad \text{cov}[\zeta_i, Z_j^{(i)}] = 0, \quad j = 1, 2, \dots, k.$$

$$Y_i = \begin{cases} Y_i^*, & \text{if } G_i = 1 \\ \text{not observed}, & \text{if } G_i = 0 \end{cases}$$

Y_i^* is formed by the regression equation:

$$Y_i^* = \mathbf{X}^{(i)} \boldsymbol{\beta} + \varepsilon_i, \quad i = 1, 2, \dots, n_1 \quad (2)$$

$$\mathbf{X}^{(i)} = (X_1^{(i)}, X_2^{(i)}, \dots, X_l^{(i)}), \quad \boldsymbol{\beta} = (\beta_1, \beta_2, \dots, \beta_l)^T,$$

ε_i is the regression error (2) in the i th observation.

It is assumed that ε_i has a standard normal distribution, and is not correlated with the components of the vector $\mathbf{X}^{(i)}$, and may correlate with ζ_i :

$$\varepsilon_i = \sigma_{\varepsilon\zeta} \zeta_i + \eta_i, \quad \eta_i \sim N(0, \sigma^2), \quad \text{cov}[\eta_i, \zeta_i] = 0, \quad \text{cov}[\varepsilon_i, X_j^{(i)}] = 0, \quad j = 1, 2, \dots, l.$$

The balance of export-import was considered as the dependent variable Y . The variable of selection G was defined as an indicator of the country's transition to predominantly export or predominantly import.

The factors described in Table 1 were taken in the composition of the vectors of independent variables \mathbf{Z} and \mathbf{X} : agriculture value added per worker, renewable internal freshwater resources per capita, GDP per person employed, agricultural land, average precipitation in depth, water productivity, charges for the use of intellectual property, air transport.

The model was estimated according to 2011, because observations in this year were most representative. We used Heckman's two-step procedure of taking into account the correction for heteroscedasticity. As an example, Table 1 shows the results of estimating the model for countries that are mainly exporters of agricultural products. The initial sample size n was equal to 83. The truncated sample comprised $n_1 = 39$ observations. As a result, the significance of the whole model (at the 0.01 level) confirmed the above classification of countries and confirmed the results of the evaluation.

Significant at 0.05, the results of the evaluation, first, testified to the importance of the role of water in the choice of orientation of the exporting countries, and, second, pointed out the different

Table 1. Estimation of the Heckman’s model

Dependent variable: Prob{G_i = 1}-the probability of positive balance		
<i>j</i>	Factors of choice (k = 7)	δ̂
1	Constant	-1.654956**
2	Agriculture value added per worker (constant 2005 US\$)	0.0000545**
3	Renewable internal freshwater resources per capita (cubic meters)	0.0000456**
4	GDP per person employed (constant 1990 PPP \$)	0.0000259
5	Agricultural land (% of land area)	0.021521**
6	Average precipitation in depth (mm per year)	0.000624**
7	Water productivity, total (constant 2005 US\$ GDP per cubic meter of total freshwater withdrawal)	-0.022271*
McFadden R ² = 0.322		
H ₀ : δ _j = 0 j = 2, 3, ..., 7 Prob(χ ²) = 0.000		
Dependent variable: Y - positive balance of export and import		n ₁ = 39
<i>j</i>	Factors of change Y (l = 9)	β̂
1	Constant	9697.1
2	Agriculture value added per worker (constant 2005 US\$)	-0.000483
3	Renewable internal freshwater resources per capita (cubic meters)	0.000039
4	Charges for the use of intellectual property, receipts	-0.0000221***
5	Air transport, freight (million t·km)	7.483773***
6	GDP per person employed (constant 1990 PPP \$)	0.035762
7	Agricultural land (% of land area)	0.041678
8	Average precipitation in depth (mm per year)	-0.000356
9	Water productivity, total (constant 2005 US\$ GDP per cubic meter of total freshwater withdrawal)	0.334328
σ _e = 11206 σ _{eε} = -6739*		
H ₀ : β _j = 0 j = 2, 3, ..., 9 Prob(χ ²) = 0.003		

*Significance level of the estimated parameters of the model at 0.1.

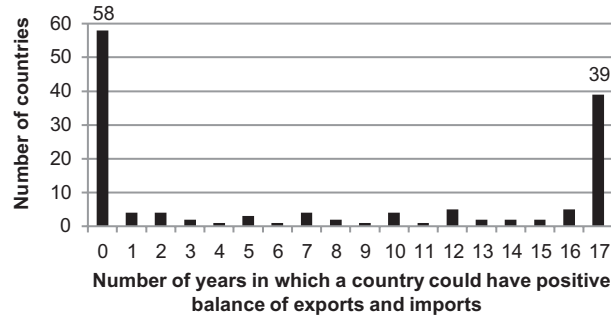
**Significance level of the estimated parameters of the model at 0.05.

***Significance level of the estimated parameters of the model at 0.01.

effects of its quantity and efficiency of use. The positive impact of the first factor and the negative impact of second factor correspond to the results obtained above, the classification which divided countries into water-exporting countries and economically developed water-scarce importing countries. The more water per capita, the more likely the prevailing agricultural exports. The more effective the water use in production, the less likely the domination of exports. Modelling also showed that a statistically significant (at 0.01) a change in the absolute value of the balance of exports and imports was exerted only by transport and innovative factors.

A typological grouping of countries was formed on the basis of the identification of the relative stability of the separation of countries according over 17 years. Figure 3 shows the distribution of 140 countries by the number of years during which the balance of export-import of agricultural

Figure 3. Distribution of countries by the number of years during which the balance of export-import of agricultural products was positive.



products was positive. Each histogram bar for the given number of years indicates the count of countries which had a positive balance of export-import of agricultural products for all these years. For example, the last column (17 years) shows that 39 countries were mainly exporting agricultural products for all 17 years (hereinafter referred to as group 1). The first column (0 years) shows that 58 countries had a negative balance of exports and imports for all 17 years (2nd group). The sign of the balance for the remaining 43 countries changed over these years (3rd group).

Further analysis of the impact of international trade on social and environmental risks was conducted for each of the three groups of countries.

3. Modelling the impact of exports and imports of agricultural products on the indicators of environmental and social risks

For each group of countries we studied the effect of exports and imports on indicators related to the social and environmental risks. The indicators were: indicators of emissions and discharges, country policy and institutions assessment to ensure environmental sustainability (CPIA), indicators of unemployment and migration, and the Gini index. We applied regression models which were estimated on panel data (Verbeek, 2000). For all equations, a specification with fixed effects in accordance with the result of Hausman test for the significance level 0.05 was selected:

$$Y_{it} = \alpha_i + \mathbf{X}^{(it)}\beta + \varepsilon_{it}, \quad i = 1, 2, \dots, n; \quad t = 1, 2, \dots, T;$$

$$\mathbf{X}^{(it)} = (X_1^{(it)}, X_2^{(it)}, \dots, X_l^{(it)}), \quad \beta = (\beta_1, \beta_2, \dots, \beta_l)^T,$$

$$\varepsilon_{it} \sim N(0, \sigma^2), \quad \text{cov}[\varepsilon_i, \varepsilon_j] = 0 \quad (i \neq j), \quad \text{cov}[\varepsilon_i, X_j^{(t)}] = 0, \quad j = 1, 2, \dots, l.$$

All regressions had high explanatory capability and were statistically significant (at the 0.01 level). Individual features of countries were taken into account correctly in accordance with the significance of fixed effects (at the 0.01 level). Analysis of residue patterns for the absence of heteroscedasticity and autocorrelation, testing for the normal probability distribution also confirmed the acceptable quality of the models and the possibility of interpreting the estimates of their parameters. It should be noted that parameter estimation was produced on unbalanced panels with the missing data. Therefore, the sample size for various regressions was different. The results of the identification are shown in Tables 2-4.

Table 2 shows the results of the estimates of regressions for the dependent variable Y, which was associated with environmental risks: Nit—emissions of nitrous oxide from agriculture (thousand tons of CO2 equivalent), Meth—methane emissions in agriculture (thousand tons of CO2 equivalent), Org—discharges of organic water pollutants (kg per day). The vector of independent variables X includes the exports and imports of agricultural products as well as the value added per worker and GDP per capita.

Table 2. Assessing the impact of international trade flows of virtual water in agricultural production on the environmental risk factors

Variable	Groups								
	1 group			2 group			3 group		
	Nit	Meth	Org	Nit	Meth	Org	Nit	Meth	Org
Export, 2005 US\$	0.63***	1.36***	3.91**	-0.06	-0.08	-1.44	-0.60***	-0.52***	-16.18***
Import, 2005 US\$	-0.81***	-1.88***	-4.79	-0.01	0.02	0.15	1.19***	1.20***	22.36***
Value added per worker, 2005 US\$	-0.01	0.33*	-2.28	-0.07	-0.01	0.09	-0.48*	-0.53*	-35.41**
GDP per person, 1990 PPP \$	-0.11	-0.49	3.22	0.03	0.04	-2.81**	0.09	-0.03	10.44**
<i>n</i>	121	126	173	136	138	157	57	61	48

*Significance level of the estimated parameters of the model at 0.1.

**Significance level of the estimated parameters of the model at 0.05.

***Significance level of the estimated parameters of the model at 0.01.

Table 3. Assessing the impact of international trade flows of virtual water in agricultural production on the rating of environmental sustainability

Variable	Groups		
	1 group	2 group	3 group
Export, 2005 US\$	-0.0000274	-0.000245***	0.000413**
Import, 2005 US\$	-0.0000062	-0.0000621**	-0.000108*
Value added per worker, 2005 US\$	-0.0000154	-0.000161**	0.000154
GDP per person, 1990 PPP \$	-0.000161***	-0.000154	0.0000692*
<i>n</i>	127	138	63

*Significance level of the estimated parameters of the model at 0.1.

**Significance level of the estimated parameters of the model at 0.05.

***Significance level of the estimated parameters of the model at 0.01.

Table 4. Assessing the impact of international trade flows of virtual water in agricultural production on indicators of social risk

Variable	1 group			2 group			3 group		
	Unemp	Migr	Gini	Unemp	Migr	Gini	Unemp	Migr	Gini
Export, 2005 US\$	-0.0001*	3.27	-0.00015**	0.0001*	-56.21**	0.0002	0.0001	93.78***	0.0000
Import, 2005 US\$	0.0001	-4.17	0.00042**	-0.0001*	70.69***	-0.0003	-0.0000	-51.75*	0.0001
Value added per worker, 2005 US\$	-	19.73	0.00004	-	-1.88	0.0002***	-	54.86*	0.0001
GDP per person, 1990 PPP \$	-0.0002**	11.52	0.00007	-0.0001*	-9.04	-0.0002**	-0.0002*	-12.51	-0.0002*
<i>n</i>	125	119	165	132	141	164	67	58	64

*Significance level of the estimated parameters of the model at 0.1.

**Significance level of the estimated parameters of the model at 0.05.

***Significance level of the estimated parameters of the model at 0.01.

Table 2 shows the positive impact of exports and productivity pollution in Group 1, which may indicate improper intensification of production. For the 3rd group, the multi-directional impact of import and export on emissions and discharges is visible. We can assume that for these countries the export of goods is accompanied by better control of the production and the import, a disregard for environmental risks.

Table 3 presents the results of the evaluation of the impact of these factors on the CPIA (1 = lowest, 6 = highest). From Table 3, it can be seen that trade flows of countries of the 2nd and 3rd groups have significant negative influence on the CPIA index

Table 4 shows the evaluation results of regressions for the dependent variables: Unemp—unemployment rate (% of total workforce), Migr—the number of foreign migrants, Gini is the Gini index. Significant (at 0.1) results of the evaluation show that exports have a negative impact on the unemployment rate for the countries of the 1st group and imports influence negatively the unemployment rate for countries of the 2nd group. The import and export of agricultural products are linked to migration flows of the 2nd and 3rd groups. A positive connection of migration with import in the 2nd group may be associated with a redistribution of the industry structure with a predominance of the service sector more attractive to migrants. The negative association of migration with imports of agricultural products for the 3rd group probably indicates a low level of development of these countries and the high proportion of migrant workers in agriculture. The relationship of trade flows with the stratification of society in terms of welfare was revealed only for the 1st group. The higher the level of the balance of exports and imports in these countries, the lower the Gini coefficient value.

4. Conclusion

Thus, it was shown the existence of a stable group of countries on the ratio of exports and imports of virtual water in the composition of agricultural products, determined a significant impact of water resources on the formation of such groups. It was shown the materiality of the impact of international trade flows of virtual water on the indicators related to environmental and social risks.

The flexibility and openness of the statistical techniques which we used can be used to solve similar problems with trade in virtual water for other water-intensive industries, as well as be applied at the regional level, taking into account basin relations.

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