VIRTUAL WATER TRADE: A CROSS-COUNTRY EMPIRICAL INVESTIGATION WITH INSTITUTIONAL PERSPECTIVE

Elena Vallino (Politecnico di Torino)
with F. Laio, L. Ridolfi, M. Tuninetti

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Outline

- Virtual water trade and relevance with respect to food trade
- Research purpose
- The data
- Methods
- Results
- Discussion

What is virtual water trade?

Virtual Water (VW): the volume of freshwater (rainfall, surface water and groundwater) used for the production of agricultural goods, and no more available for other uses at the production site.

International trade of agricultural goods => water resources that are physically used in the country of production are ‘virtually’ transferred to the country of consumption. The transfer is called virtual water trade (Allan, 2003 ; Antonelli and Sartori, 2015; Tuninetti et al. 2017)

Although water is rarely traded over long distances by itself, the total weight of the water utilized to produce traded commodities exceeds the weight of any other commodity traded in the world (Oki et al. 2017)

Why the VW perspective on food trade is interesting?

1. VW volumes can be summed across all different commodities and represent an alternative quantity to money or calories to investigate different aspects of the international trade.

2. Agricultural commodities are by far, the most water-intensive traded products and they are in large part ultimately devoted to human consumption. => Virtual water provides a quantitative general framework for the investigation of the water-food-trade nexus, with focus on water resources and the environment (Tamea et. al 2016, Scientific Reports-Nature).

3. Relevant environmental and socio-economic implications: water-scarce countries can rely on water resources available abroad. In semi-arid countries, water scarcity limits the local agricultural production (food security challenge).

Importing food produced elsewhere enables such countries to overtake water resource limitations and to increase the food available to the population, while possibly saving global water resources (Tamea et. al 2016, Scientific Reports-Nature)

4. D’Odorico et al. (2012): the community structure of the virtual water network appears to not align well with any one factor (e.g., population, GDP, distance metrics or production).

5. Different temporal trends of crop yields, volumes of food traded, values of food traded, virtual water content of each crop in each country, volumes of virtual water traded, value of virtual water traded

=> ex. vw flow increased much more than crop yields; the volume of water associated with global food trade more than doubled in 22 years (Dalin et al. 2012)

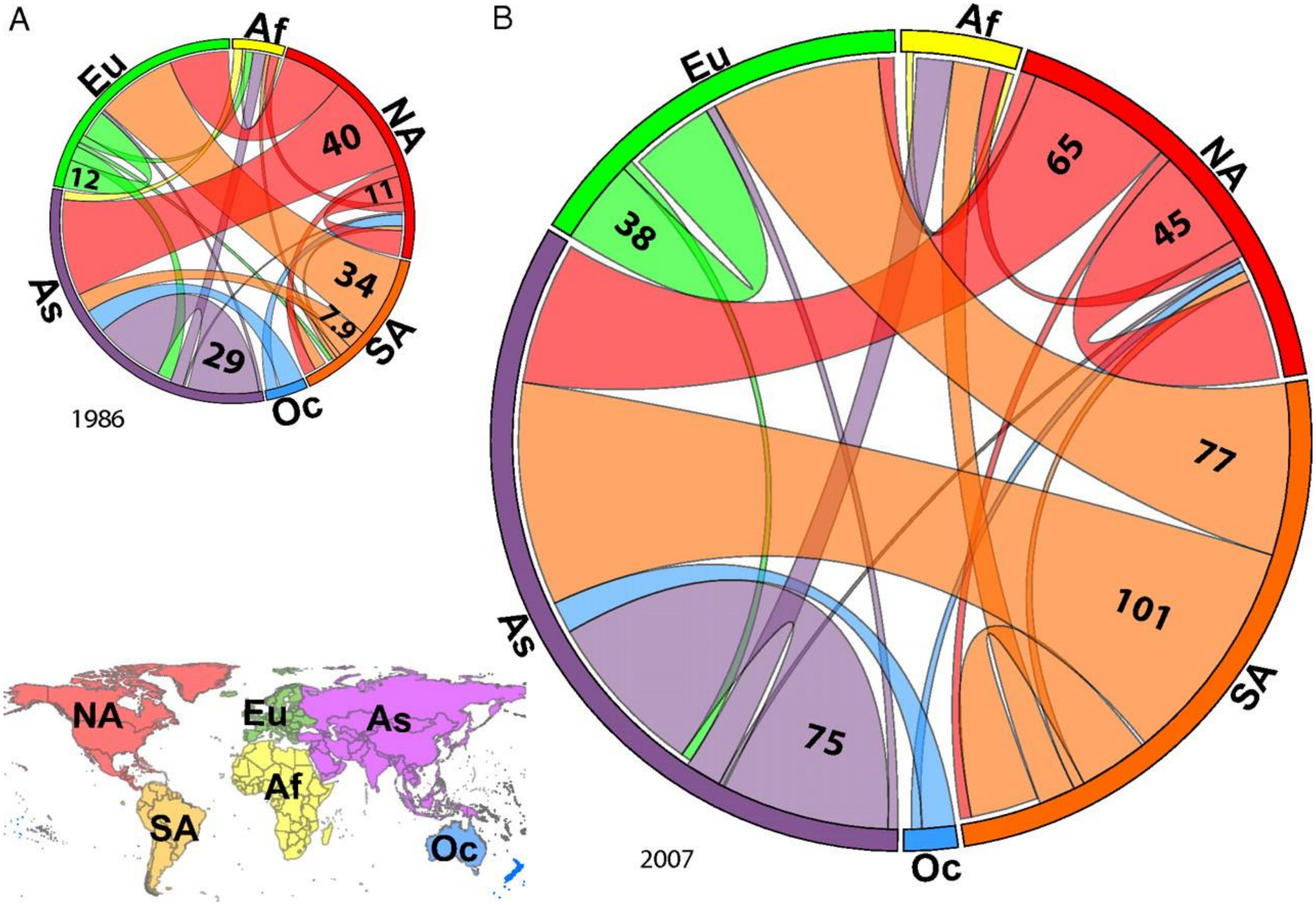
6.Global dimension of water consumption and pollution: several countries heavily rely on foreign water resources and that many countries have significant impacts on water consumption and pollution elsewhere.

7.It is possible to observe efficiency of each country in utilizing its water resources.

8. VW measure allows a cross-country comparison similar to the one in monetary values and more efficient than the one with volumes of traded food.

9. Water scarcity will be the major constraint to increase food production over the next decades (UNDP, 2006). => The understanding of structures and drivers of virtual water trade aims at contributing to the knowledge for building well-informed integrated policy options.

Virtual water flows between the six world regions: Africa (Af), North America (NA), South America (SA), Asia (As), Europe (Eu), and Oceania (Oc).



Carole Dalin et al. PNAS 2012;109:16:5989-5994

Research purpose

- The aim of this study is to assess whether, and to what extent, variables related to the domain of food security and of institutional dimension are relevant drivers of bilateral VWT.
- Exploratory empirical investigation
  - 74 countries
  - 2010

The data

Virtual Water Trade Network (Tuninetti et al. 2017; Tamea et al. 2014):

- Built on information on the trade of agricultural goods between all nations and the virtual water content of each good produced by the nations.
    - Bilateral trade flows: FAOSTAT database (http://faostat.fao.org/)
    - Country-specific virtual water contents for crops and animal products: Mekonnen and Hoekstra (2010; 2011). Green (precipitation) and blue (irrigation) component
- Trade data for each product are converted into virtual water data and summed up over 309 goods to obtain the total virtual water transfer between trade partners in a given year. => 2011: global flow of 2720 km^3 of virtual water
- Virtual water trade data of each year (from 1986 to 2011) create a matrix, **F** . $F_{i,j}$: virtual water flux from country *i* to country *j* .
- The matrix is non-symmetrical because of the network directionality, that is flux from *i* to *j* is different than flux from *j* to *i* .

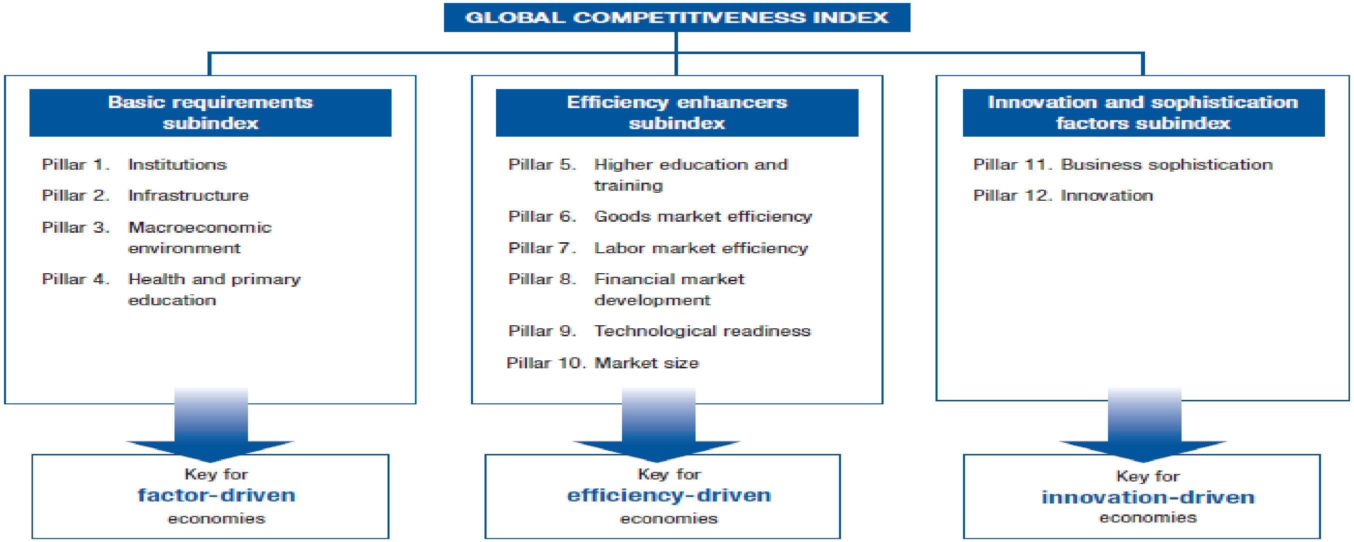
Food security resilience indexes (Seekell et al. 2017) Multidimensionalilty of food security.

- Resilience socio-economic: ability to make-up caloric deficits through food purchases (resilience to short term food price shocks)

- Capacity for production expansion: theoretical amount of people (%of total pop) that a country can feed with an adequate diet produced by redundant resources. Four subcomponents: water, land, yield gap on used land, and yield gap on available fertile land.

- Production quantity and variety: total food production and diversity of commodities in a country (long term). H-index

- Global Competitiveness Index: 7 pillars



(Global Competitiveness Report - World Economic Forum)

- Anderson, J. E., & Marcouiller, D. (2002) argue that the cross-country variation in the effectiveness of institutions and the consequent variation in the prices of traded goods offers a simple explanation for the stylized fact that high-income, capital-abundant countries trade disproportionately with each other.
- Other works on institutional dimension and trade: Levchenko 2011; Dollar and Kraay 2003. Countries with better institutions tend to trade more.

17 variables in Tuninetti et al. 2017

Table 1
Possible drivers of the gravity-law model, with their source and spatio-temporal availability.

	Label	Description	Source	No. of countries	Time interval
1	*P*	Population	FAOSTAT (http://faostat.fao.org/)	228	1961–2011
2	*wd*	Virtual water of national consumption in m^3/cap	Carr et al. (2012); 2013); Tamea et al. (2014)	175	1986–2011
3	*Pr*	Annual rainfall on cultivated area	Our computation on GAEZ dataset and New et al. (2002)	182	1960–2000
4	ET_0	Annual evapotranspiration on cultivated area	Our computation on GAEZ dataset and New et al. (2002)	182	1960–2000
5	*A*	Arable area in ha/cap	FAOSTAT	219	1960–2000
6	A_i	Area equipped for irrigation in ha/cap	FAOSTAT	184	1960–2000
7	*N*	Nitrogen fertilizers in tonnes of nutrients	FAOSTAT	160	1986–2012
8	*K*	Potash fertilizers in tonnes of nutrients	FAOSTAT	155	1986–2012
9	*Ph*	Phosphate fertilizers in tonnes of nutrients	FAOSTAT	154	1986–2012
10	*AP*	Agricultural population	FAOSTAT	154	1986–2012
11	*GDP*	Gross domestic product in $/cap	http://unstats.un.org/unsd/snaama/dnlList.asp	208	1970–2011
12	*AV*	Agricultural value of production	FAOSTAT	205	1986–2013
13	*wp*	Virtual water of agricultural production in m^3/cap	Carr et al. (2012; 2013); Tamea et al. (2014)	216	1986–2011
14	*vwv*	Virtual water value in $/$m^3$	This study	150	1986–2011
15	*rta*	Regional trade agreements	CEPII (http://www.cepii.fr)	208	–
16	*D*	Distance	CEPII	255	1986–2011
17	*b*	language, colony relation, contiguity, religion	Our computation on CEPII dataset	–	–

Methods

Gravity law model

- It is often used to study bilateral international trade flows (Fratianni 2007, Overman et al. 2001)

- These models are based on relationships which formally resemble the law of universal gravitation

$$F_{i,j} = \beta_0 \cdot \frac{v_i \cdot v_j}{d_{i,j}^2}$$

the total trade between any two countries is directly proportional to the product of country masses and inversely proportional to their geographic distance (Anderson 1979; Bergstrand 1985).

- Expanded to improve the fit by taking into account additional country or trade characteristics that may influence bilateral trade flows (Fagiolo, 2010; Overman et al., 2001).
- Here we apply the model to estimate bilateral virtual water flows associated to the trade of agricultural goods (previous applications: Tamea et al. 2014, Fracasso 2014; Tuninetti et al. 2017)
- A global relationship describing all the exchanged fluxes proved to be inadequate (Tamea et al., 2014).

⇒ Specific laws describing the virtual water import and export of each country

Import-law: trade flow from country *i* to country *j* as a function of characteristics of *i* (exporting country)

$$\hat{F}_{imp}(i,j) = \beta_{0,j} \cdot R_{i,1}^{\beta_{1,j}} \cdot R_{i,2}^{\beta_{2,j}} \cdot R_{i,3}^{\beta_{3,j}} \cdot R_{i,4}^{\beta_{4,j}} \dots,$$

Export-law: trade flow as a function of characteristics of *j* (importing country),

$$\hat{F}_{exp}(i,j) = \beta_{0,i} \cdot R_{j,1}^{\beta_{1,i}} \cdot R_{j,2}^{\beta_{2,i}} \cdot R_{j,3}^{\beta_{3,i}} \cdot R_{j,4}^{\beta_{4,i}} \dots,$$

where R**:** drivers

β= (β0 , β1 , β2 , . . .): matrix of the model parameters

- We fit bilateral-trade flows along all the links managing the gravity-law equations as linear multivariate regressions between the logarithm of fluxes and the logarithm of drivers.

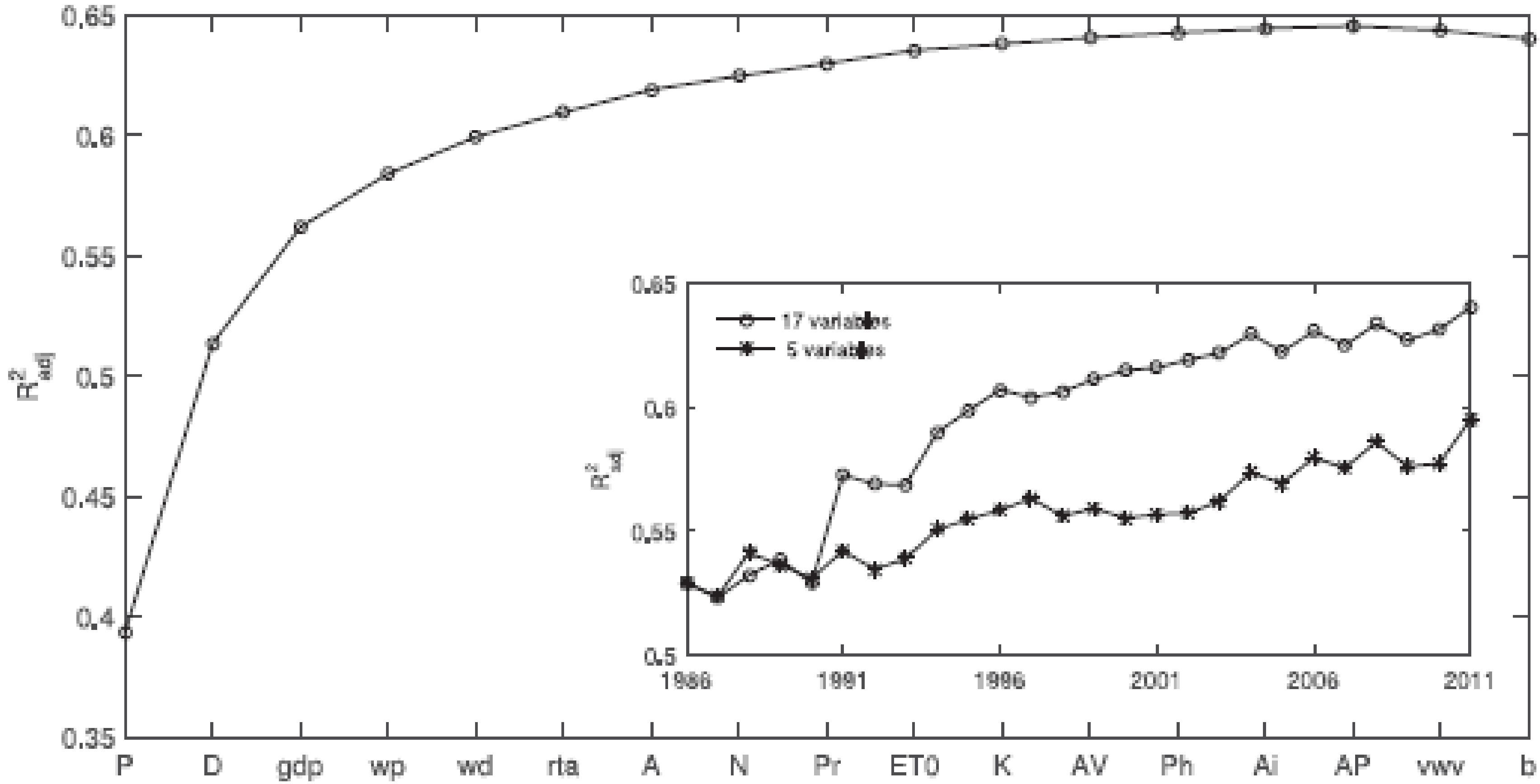
- Model parameters are interpreted as regression coefficients and estimated with the ordinary least square method.

- Significant variables are identified (Student's *t* –test at 5% significance level).

- New regression coefficients are evaluated using only the statistically significant variables ; in case that none of the variables were significant, the only coefficient remaining (b0) is taken as the mean flux.

- In Tuninetti et al. (2017) 17 potential drivers

- Stepwise regression: at each step, the variable that mostly improves the value of *R* 2 *adjusted* is added to the regression => drivers ordered => population, distance, and GDP per capita most important (in line with previous studies: Tamea et al. 2014).



Stepwise selection of the major drivers of the virtual water flows in year 2011 for a network of 117 countries. *R* 2 *adj* value as the comparison criterion. 17-variables regression

Considering three new variables: preliminary results

«ProdExpansion»: Food security resilience index - Biophysical capacity to expand food production (Seekell et al. 2017)

«ProdQuantity»: Food security resilience index - Quantity and variety of existing food production (Seekell et al. 2017)

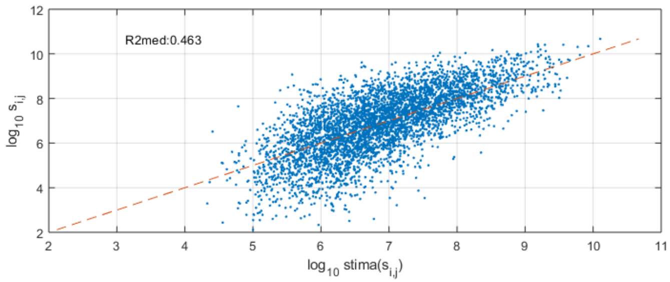
«Competitiveness»: Global Competitiveness Index (WEF)

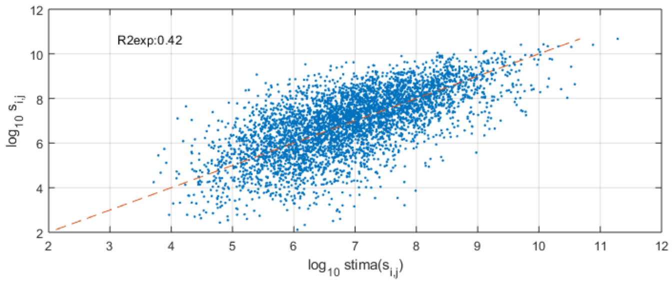
74 countries

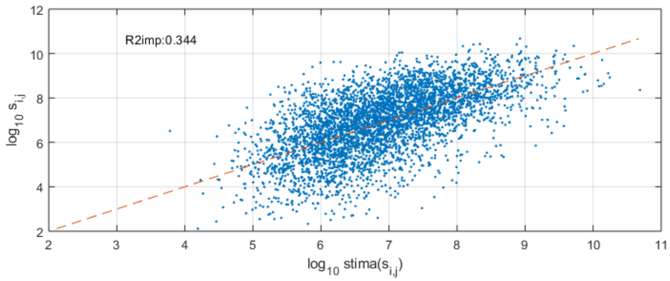
2010

ProdExpansion+ProdQuantity+Competitiveness

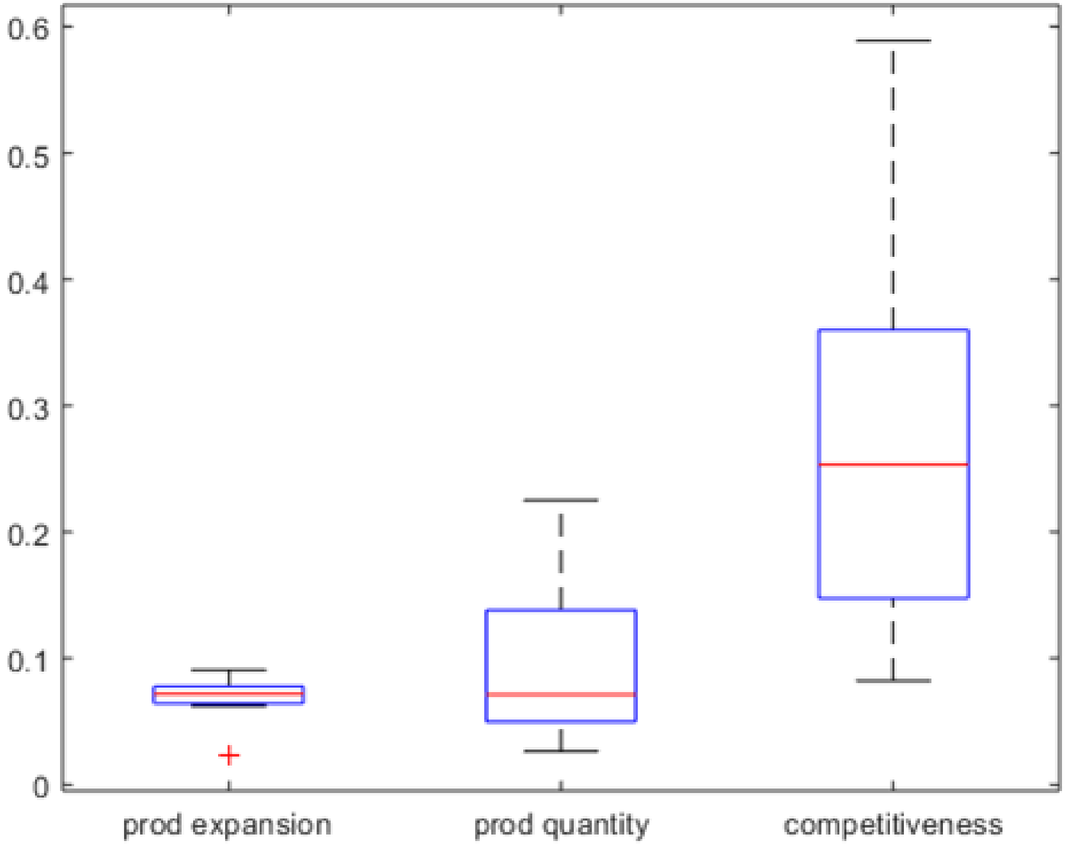
2010





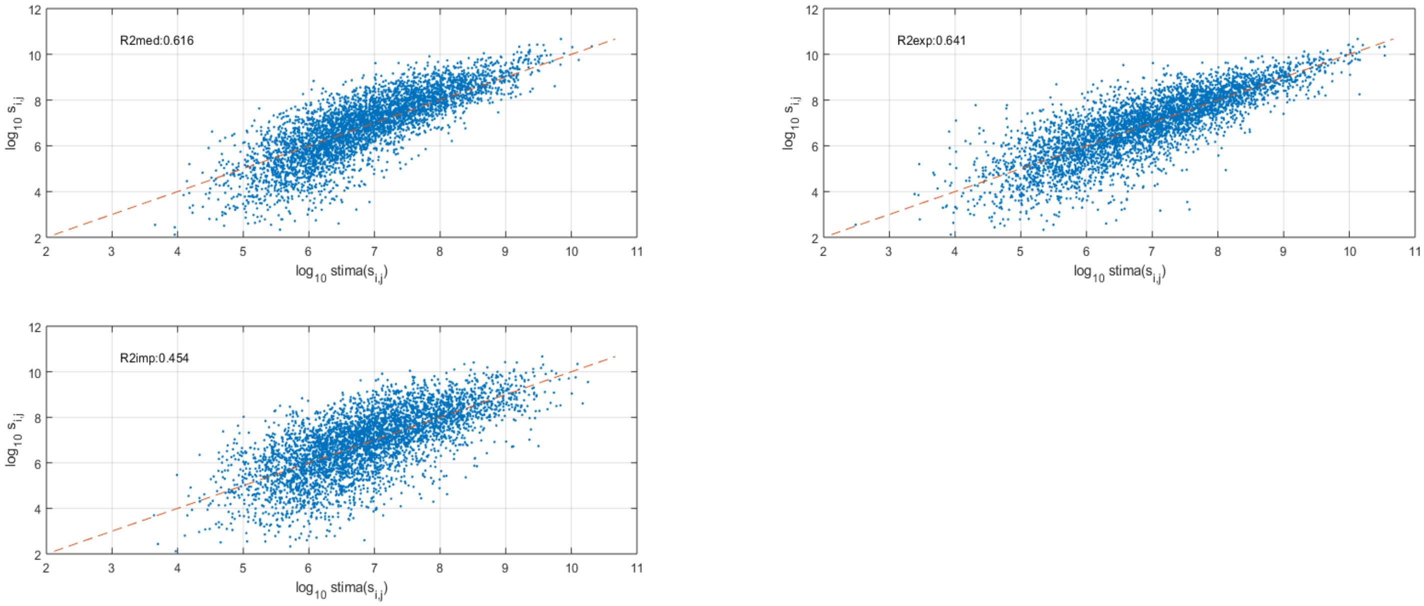


Commonality analysis

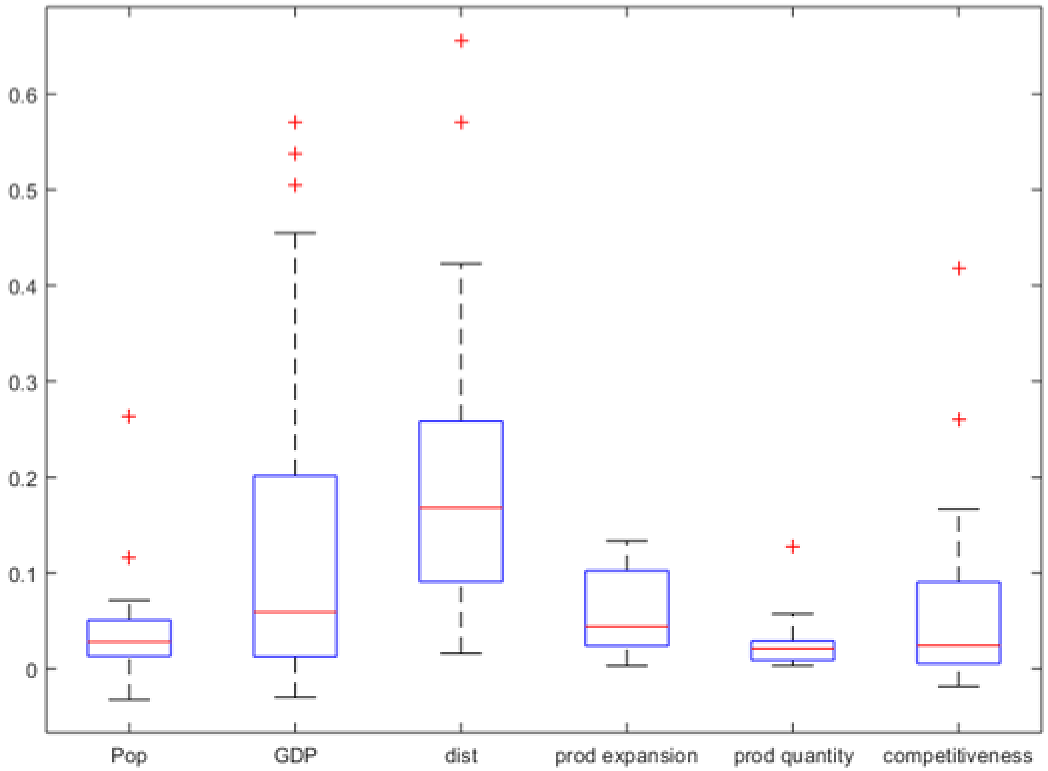


ProdExpansion+ProdQuantity+Competitiveness+GDP per capita+dist+Pop

2010

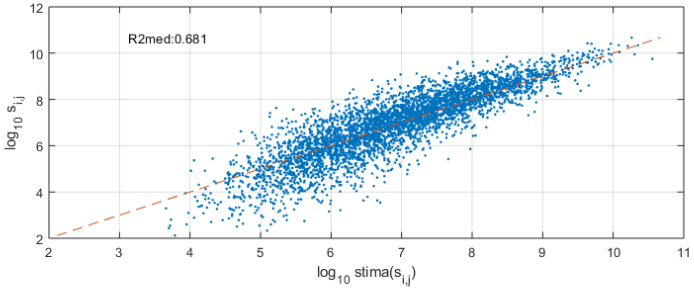


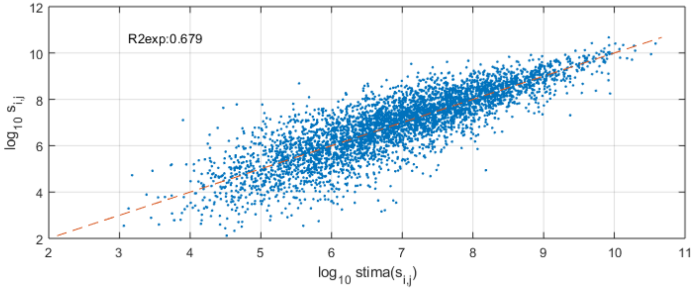
- Commonality analysis

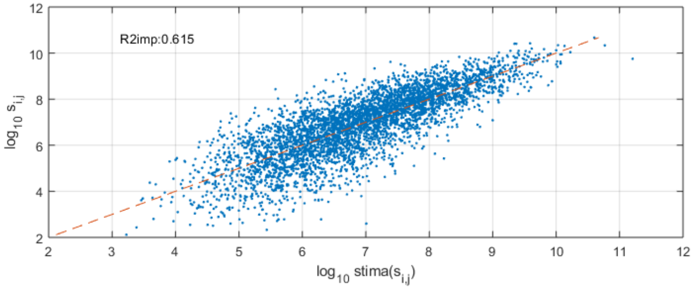


ProdExpansion+ProdQuantity+Competitiveness+GDP per capita+dist+Pop+wd+wp+A+ET0+vwv

2010







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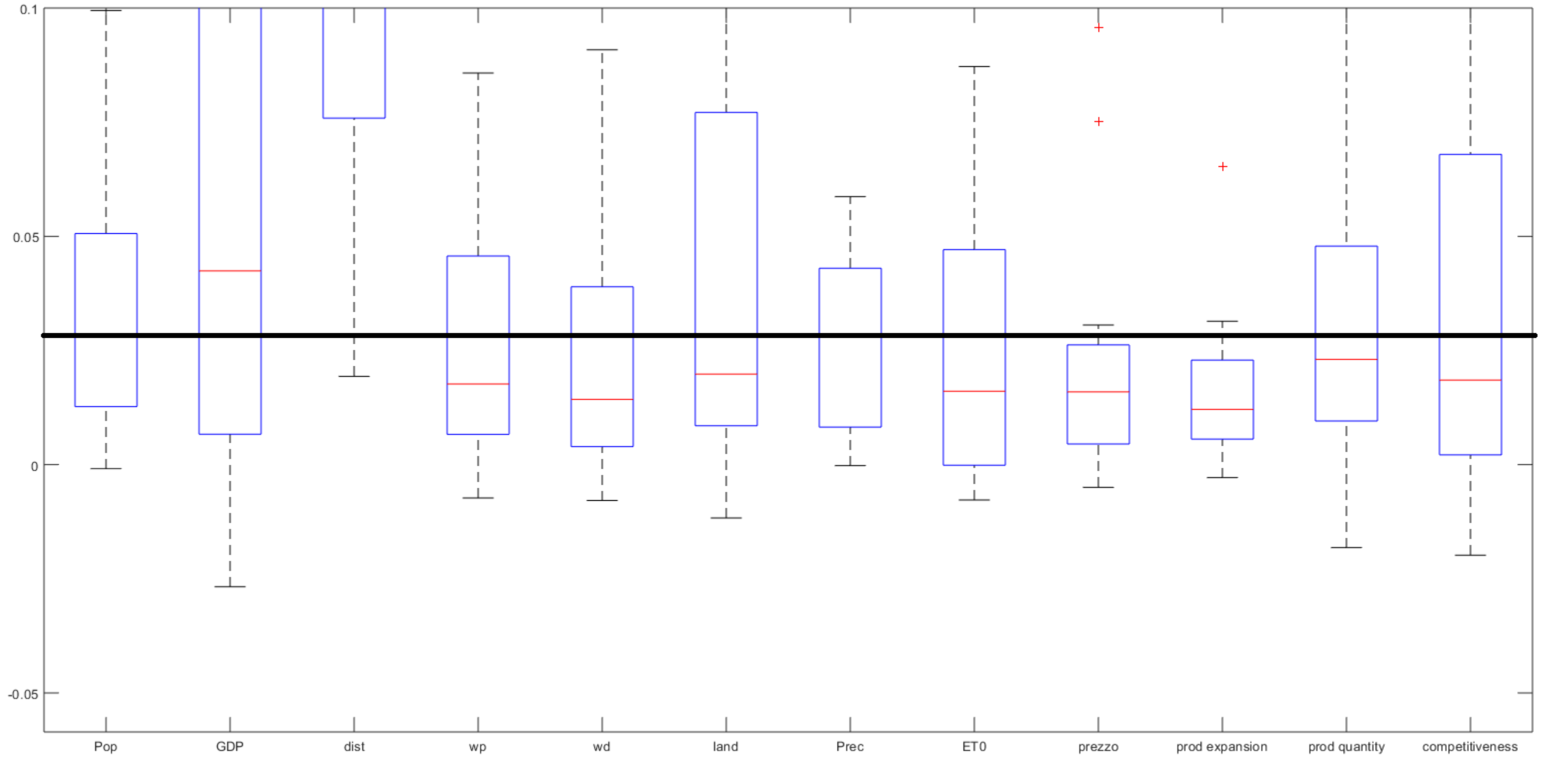

Discussion

- The three new variables alone perform well (R2 adj. 0.46)
- Both resilience indicators in the domain of food security are statistically significant in every model specification.
- In the 6 variables framework the food security indicators play a more important role, similar to the one of population and GDP per capita.
- In the 12 variables framework: R2 adj 0.68. Improvement w.r.t. the previous model specifications, but also higher than the result obtained in the previous work (0.65), where the “new” variables were not included.
- Global Competitiveness Index alone performs well, however more exploration is needed on contribution of single pillars in institutional domain.

Thank you for the attention!

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