Global Virtual Water Trade. Integrating Structural Decomposition Analysis with Network Theory.

A case study from 1995 to 2009.

T Distefano*, M Riccaboni* and G Marin**

*IMT Institute for Advanced Studies Lucca (Italy)

**Ceris-CNR, Milano (Italy)

Outline

1. Introduction
2. The Data
3. Water Footprint
4. Input Output Model
5. SDA
6. Community Detection
7. Conclusion

Main research questions

- *Which is the evolution in the use and distribution of Virtual Water due to International Trade (VWT)?*
- *Which is the impact of technological evolution and of final demand change?*
- *Which is the structure and the topology of VWT?*

Related literature

Two main research fields:

1 Input-Output and VWT

- Hoekstra, A.Y., Hung, P.Q., (2002);
- Antonelli et al. (2012);
- Mubako et al. (2013).

2 VWT NETWORK

- Konar M., Dalin C., Suweis S., Hanasaki N., Rinaldo A. (2011);
- D'Odorico P., Carr J., Laio F. and Ridolfi L. (2012);
- Dalin qt al. (2012).

DATA

Three main data-sets:

1 **WIOD:** World Input Output Database (trade of intermediate and final goods);

2 **FAOSTAT:** water estimation (Mekonnen and Hoekstra, 2011);

3 **WORLD BANK:** data on population.

Subject

- **Countries:** 40 (EU27, Usa, Japan, Brazil, China, India among others) + Rest of the World;
- **Sectors:** 35 (primary, secondary and tertiary);
- **Period:** from 1995 to 2009.

"Virtual"?

The **water footprint**, originally proposed by Hoekstra and Hung (2002), originates from the concept of virtual water proposed by Allan (1994).

Virtual water is a term that links water, goods and trade: it accounts the (direct and indirect) amount of water need to produce an unit of output.

- BLUE (**B**) water: it is an indicator of "consumptive" use of fresh surface or *groundwater* (possible alternative use);

- GREEN (**GN**) water: it is an indicator which refers to the precipitation on land stored in the soil or vegetation (*rainfall*);

- GREY (**GY**) **water:** it is the volume of freshwater that is required to assimilate the load of *pollutants* based on existing ambient water quality standards.

Global Distribution

Insights from direct water consumption (2009).

- **Skewed** and **stable** distribution: the top 3 (China, India and USA) consume the 41,37% of B, the 31,02% of GN and the 57,81% of GY. But at per capita level (1000 m3):

  USA (B = 0,62; GN = 2,62; GY = 0,72)

  China (B = 0,24; GN = 0,62; GY = 0,44)

  India (B = 0,26; GN = 0,72; GY = 0,19)

- The average growth rate (per year) of consumption at national level (B = 1,67%; GN = 2,03%; GY = 3,19%) has increased more than the world's population growth (Pop = 1,34%).

Why?

- Technological improvement;
- International trade;
- Final demand shift.

MODELS

GLOBAL Multi-Sectoral Multi-Regional Input-Output

$Z_{A1,A1}$	$Z_{A1,A2}$	$Z_{A1,B1}$	$Z_{A1,B2}$
$Z_{A2,A1}$	$Z_{A2,A2}$	$Z_{A2,B1}$	$Z_{A2,B2}$
$Z_{B1,A1}$	$Z_{B1,A1}$	$Z_{B1,B1}$	$Z_{B1,B2}$
$Z_{B2,A1}$	$Z_{B2,A2}$	$Z_{B2,B1}$	$Z_{B2,B2}$

+

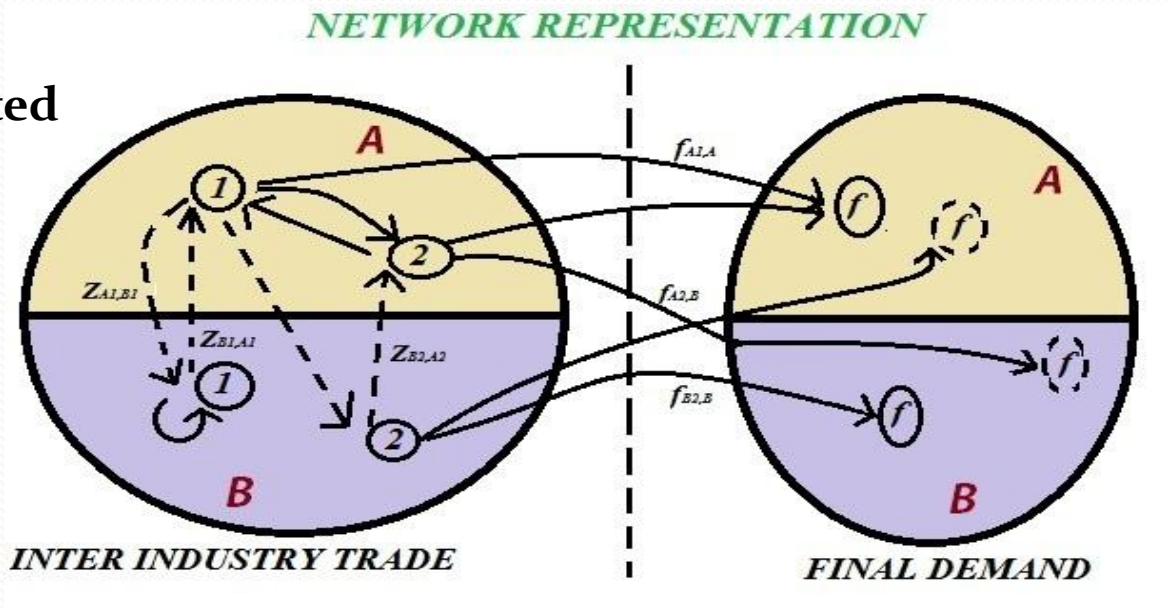
$F_{A1,A}$	$F_{A1,B}$
$F_{A2,A}$	$F_{A2,B}$
$F_{B1,A}$	$F_{B1,B}$
$F_{B2,A}$	$F_{B2,B}$

=

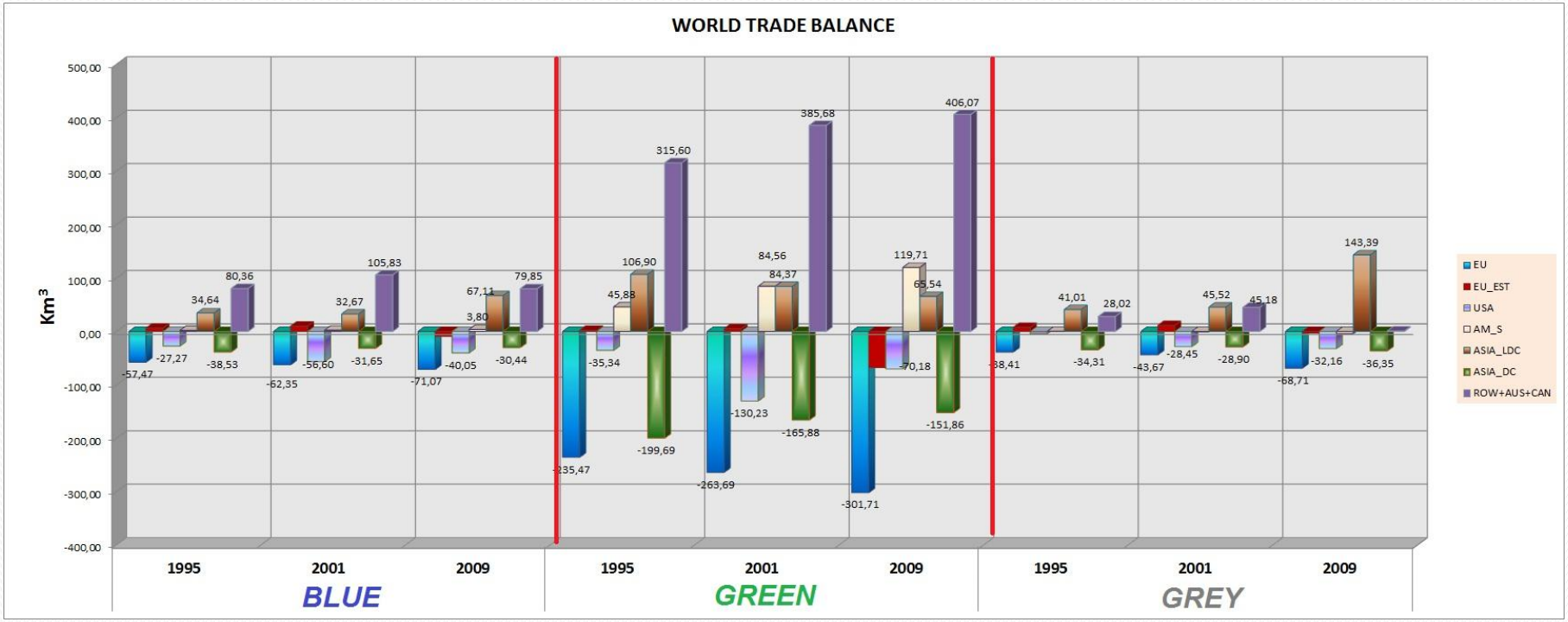
X_{A1}
X_{A2}
X_{B1}
X_{B2}

Z = intermediate goods (IO trade); F = final demand; x = total output.

Directed-Weighted Network with self-loops.



Water "*Debt*"



- main net IMPORTERS: USA, Japan, Germany and Great Britain
- (and Russia in 2009 of GN);
- main net EXPORTERS: China, India, ROW, Canada, Australia (GN), Brazil (GN);
- main sectors: AFF (B, GN, GY), EWG (B), DUS (GY);

Structural Decomposition Analysis

- Additive SDA, let the total variation from 1995 to 2009 be:

$$\Delta w = w_{2009} - w_{1995} = \Sigma_{\tau} (W_{IE,\tau} + W_{L,\tau} + W_{FD,\tau})$$

- **IE** represents the *intensity effect*, that is the variation of water use for any unit of output (v);
- **L** represents the variation of *Leontief* coefficients;
- **FD** represents the variation of virtual water due to changes in the volume of *final demand*, both at domestic and international level.

RESULT

WATER	IE	L	FD	ΔW%	ΔW
B	- 39,92 %	+ 10,17 %	+ 57,90 %	**+ 28,15 %**	**426 Km³**
GN	- 13,67 %	- 2,30 %	+ 51,25 %	**+ 35,27 %**	**2109 Km³**
GY	- 6,67 %	- 0,71 %	67,05 %	**+ 59,67 %**	**563 Km³**

- Each efficiency improvement, which saves resources per unit of output, is more than compensated by the increase in *consumption*;
- We should care about the great *heterogeneity* between countries, in fact previous percentages show a big range of variation.

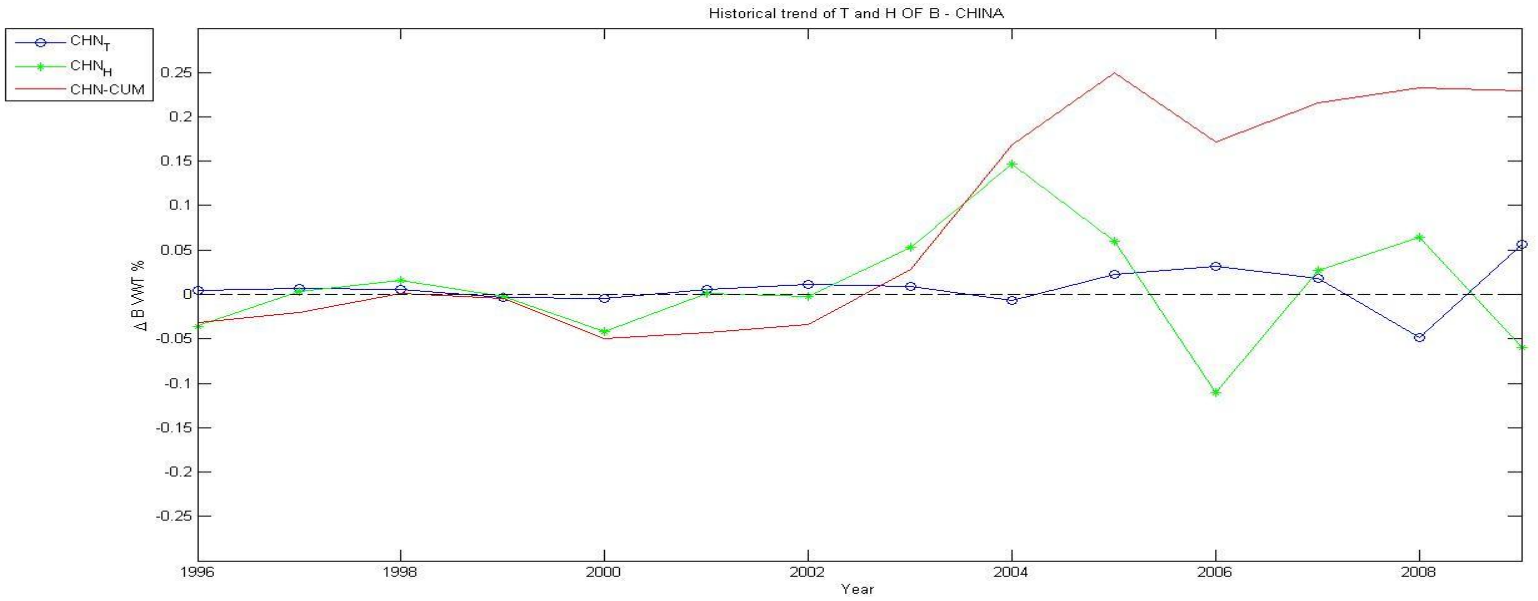
In order to trace the change due TRADE (T) from the TECHNOLOGICAL development (H), we rewrite W_L as a function of T and H:

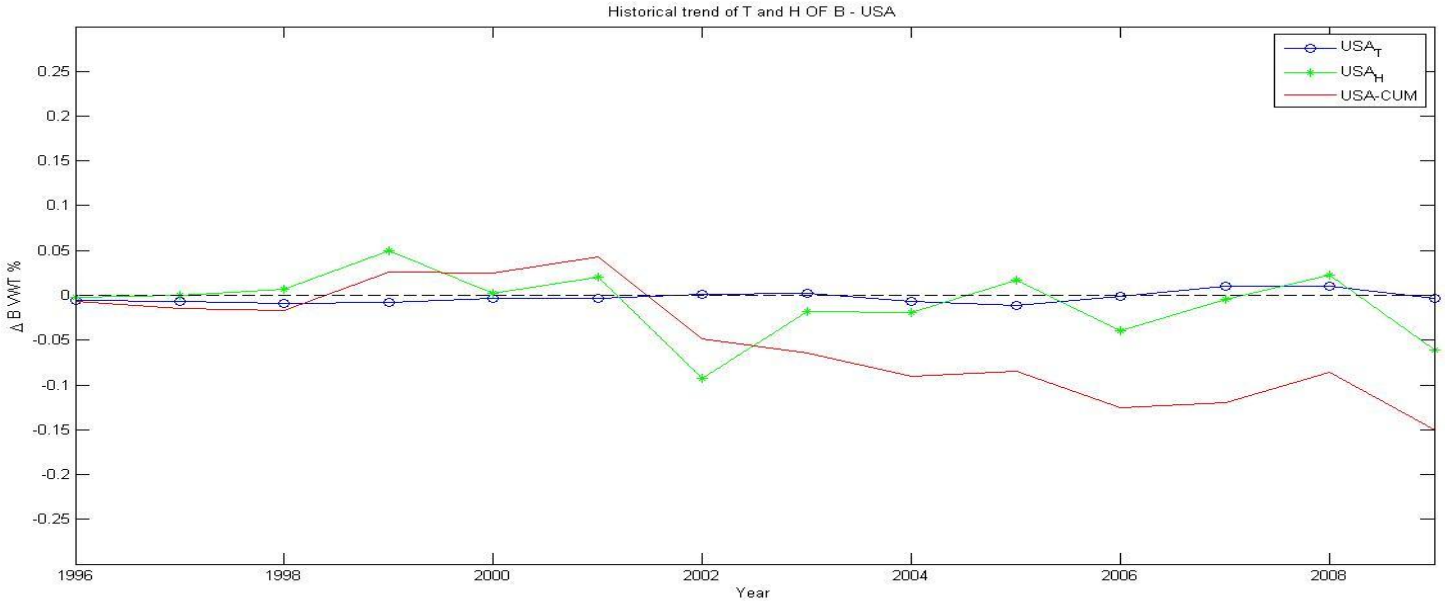
$$\mathbf{W_L = w(W_T , W_H)}$$

By the same reasoning we decomposed FD with the respect of POPULATION size (POP), consumption PER-CAPITA (CAP), consumption due to TRADE (D) and of consumption-bundle DISTRIBUTION (DIB):

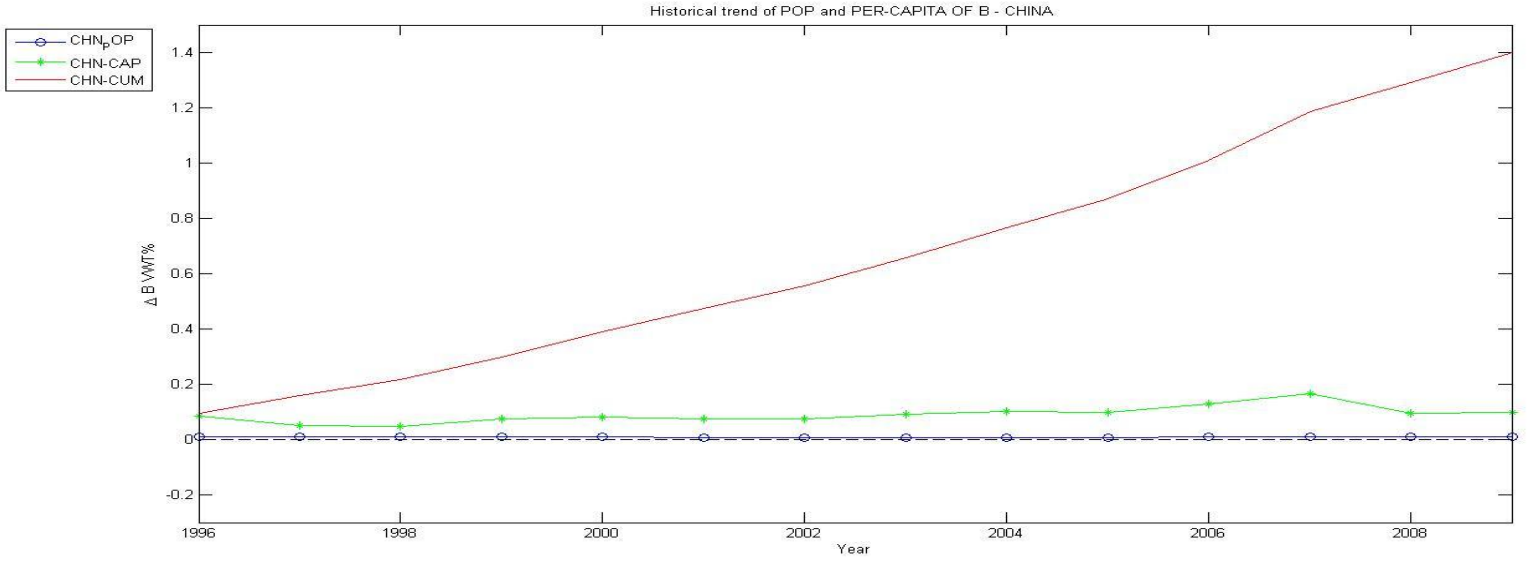
$$\mathbf{W_{FD} = w(W_D , W_{POP} , W_{DIB} , W_{CAP})}$$

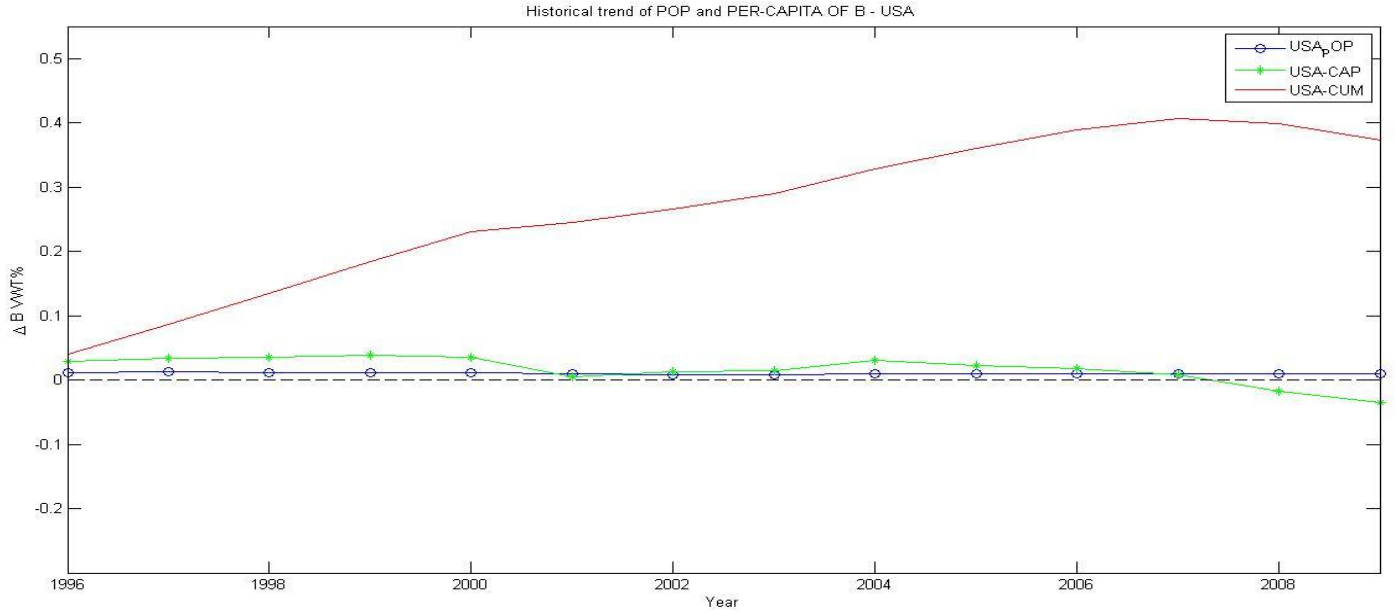
BLUE % T and H trend: China (top); USA (bottom).



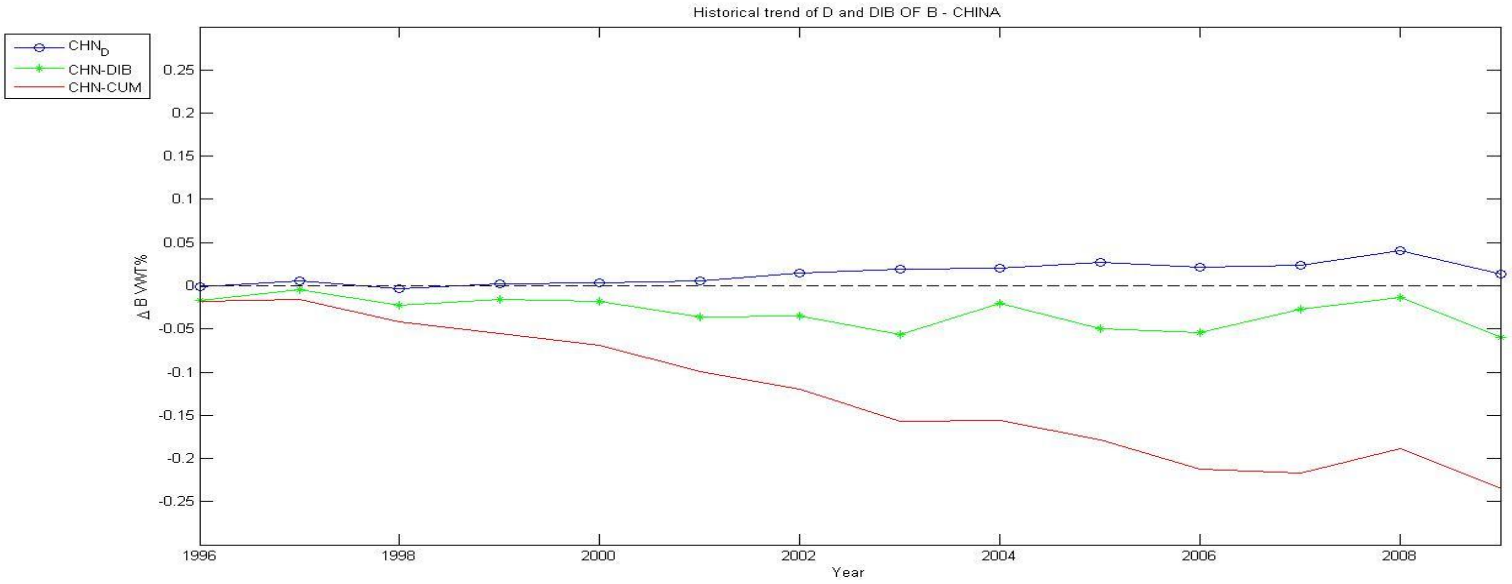


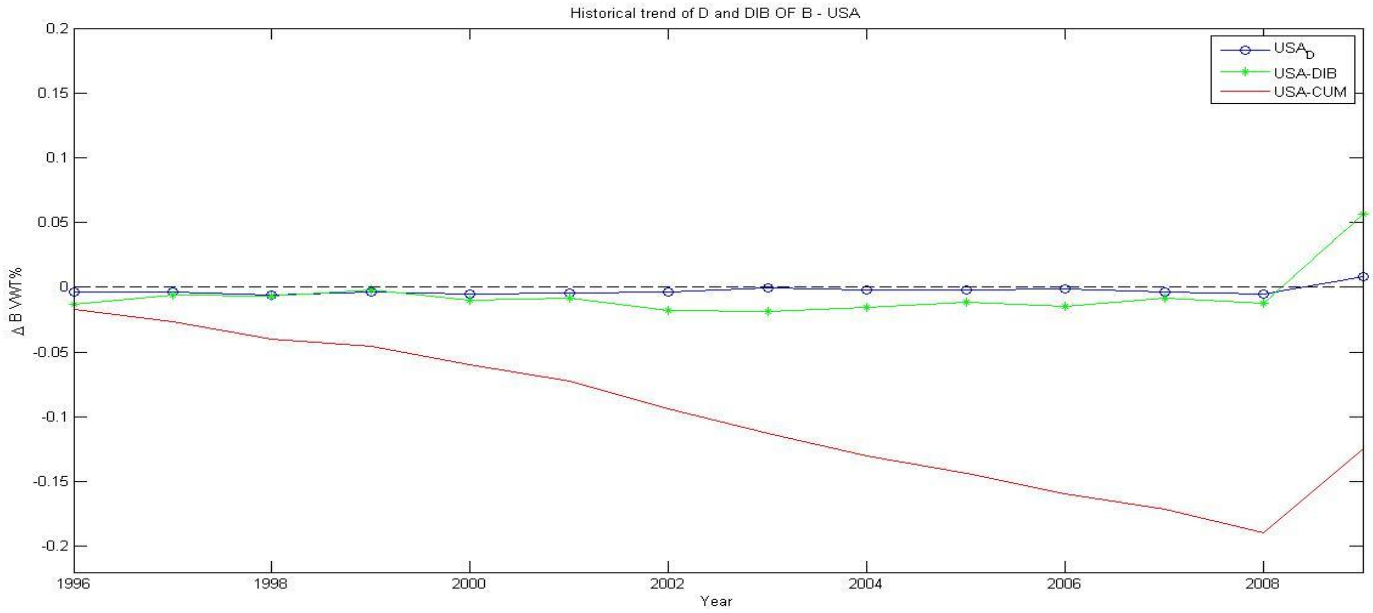
BLUE % POP and CAP trend: China (top); USA (bottom).





BLUE % D and DIB trend: China (top); USA (bottom).





SDA - SUMMARY

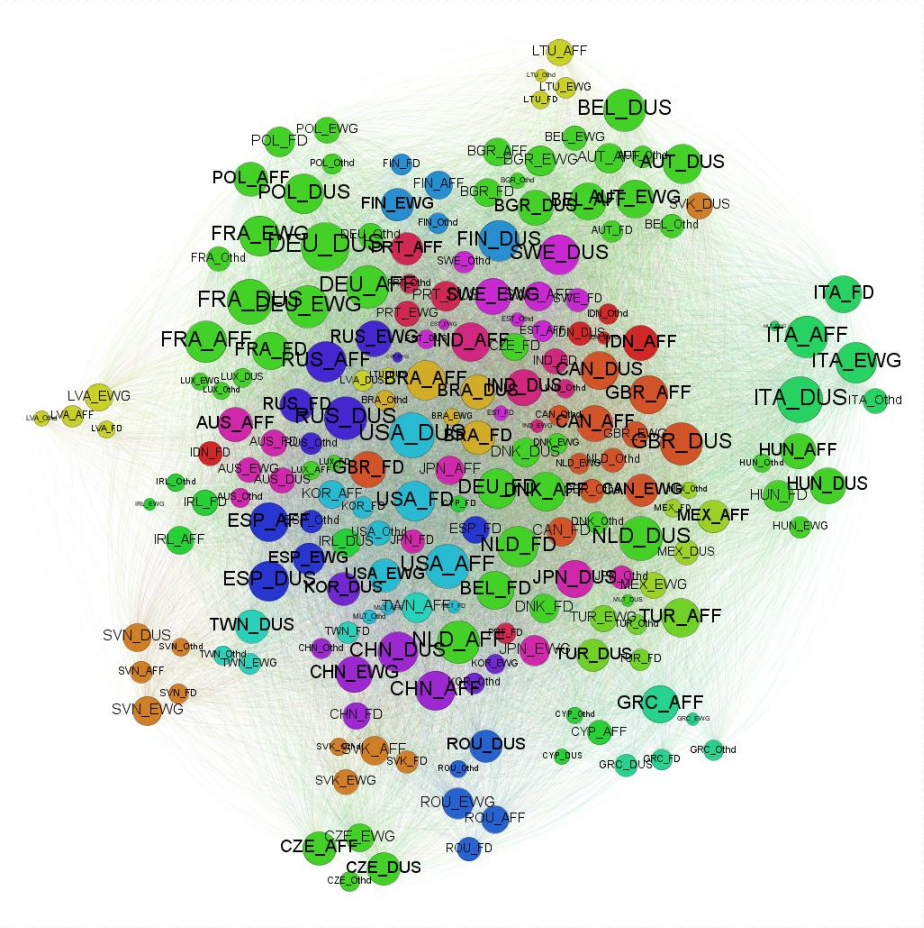
- B: in every case the effect of H overwhelms T, but China and India show higher variance. POP itself has a low impact, most of the variation is explained by the evolution of consumption per capita. Each country seems affected by the *economic crisis*.
- GN: as expected the change in T and H has almost no effect here since that the only important sector is *AFF*. Here again the changes in CAP overcome POP, but China and India seem not affected by the crisis which reduced the water consumption of USA and Italy.
- **GY**: here the crisis has a major impact. T and H are more balanced, fluctuating around zero. Only in the last years China shows higher *dynamics* with a positive impact of both T and H.

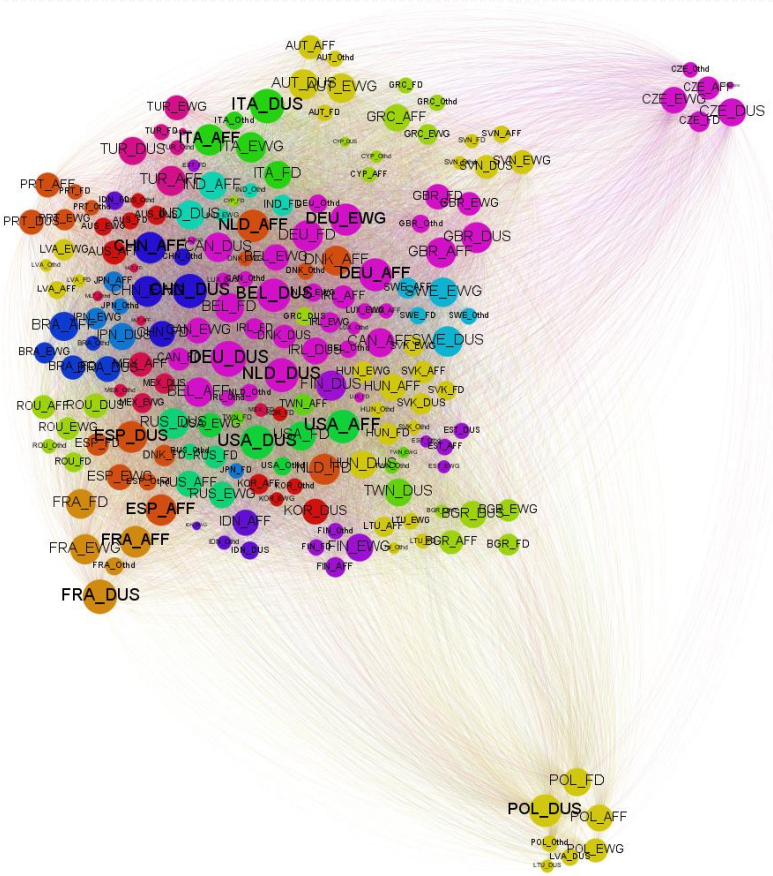
Q Modularity

- Newman and Girvan (2004): based on the idea that from a comparison between the *density* of the edges in a subgraph and that one would expect in a random graph, it is possible to detect cluster structures.

- Notice that by allowing intra-national trade, we can confirm that the **domestic** exchanges are the main important ones, nevertheless the emergence of international communities, whose are not always explained by geographical proximity, is confirmed.

BLUE Community: 1995(left), 2009 (right)



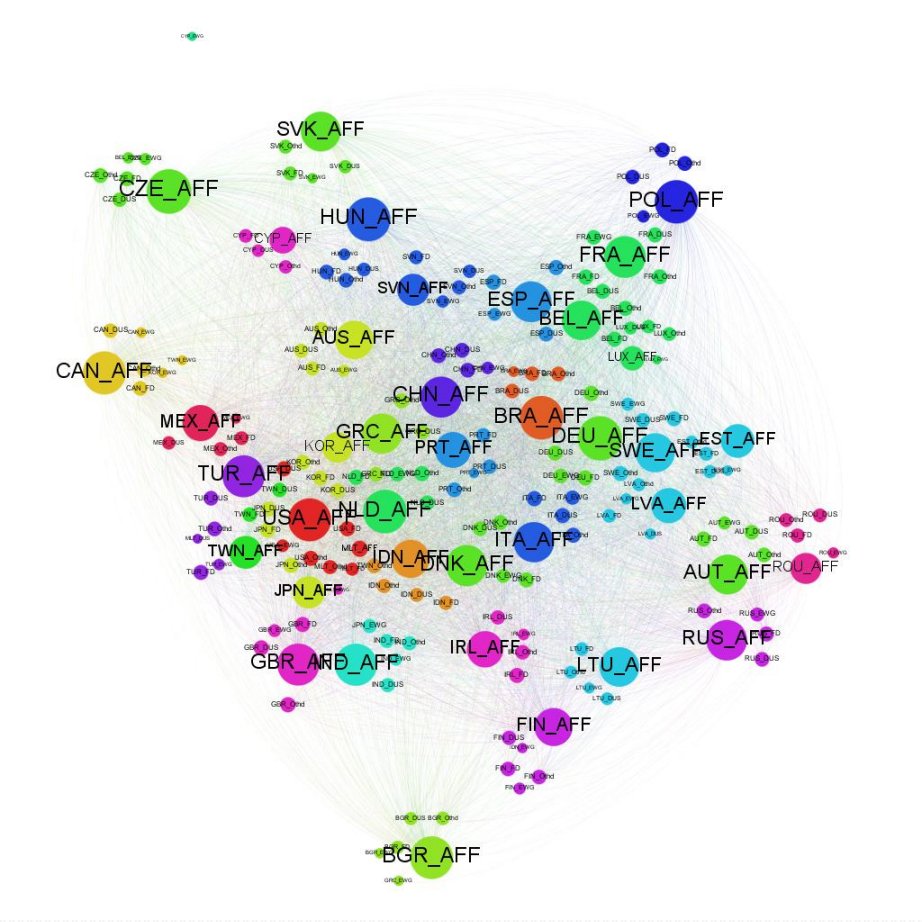


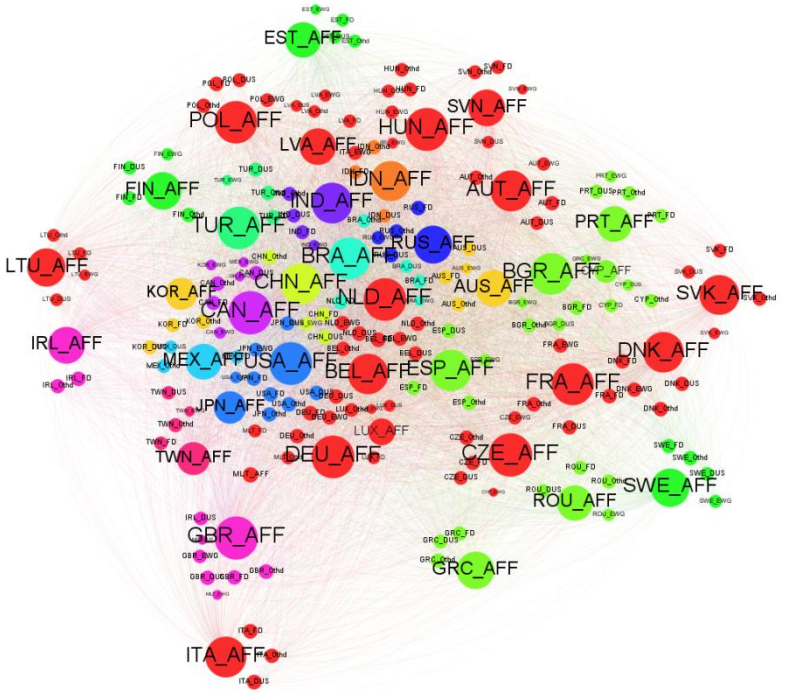
BLUE Community

- **Globalization**? most of the communities are based on a single economy (big countries) => *domestic* amount of virtual water traded is much higher than what they exchange at international level, moreover they are linked with many countries so they differentiate, without forming any significant cluster.

- **EU**: European countries tend to create more communities than that of other continents, secondly the emergence of communities is not always explained by *local proximity* as the presence of Canada in an EU community demonstrates.

GREEN Community: 1995(left), 2009 (right)





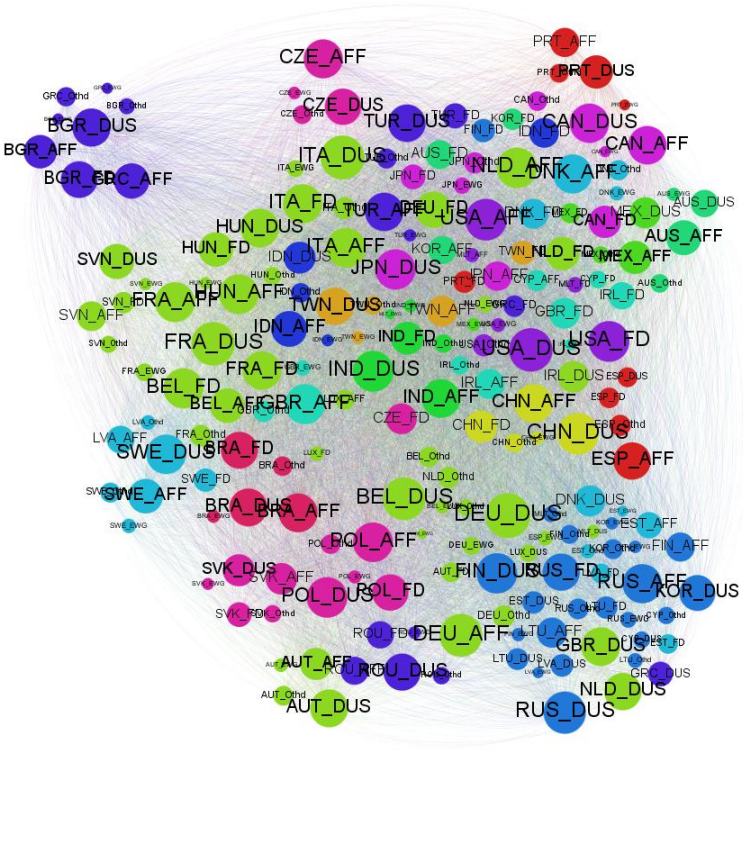
GREEN Community

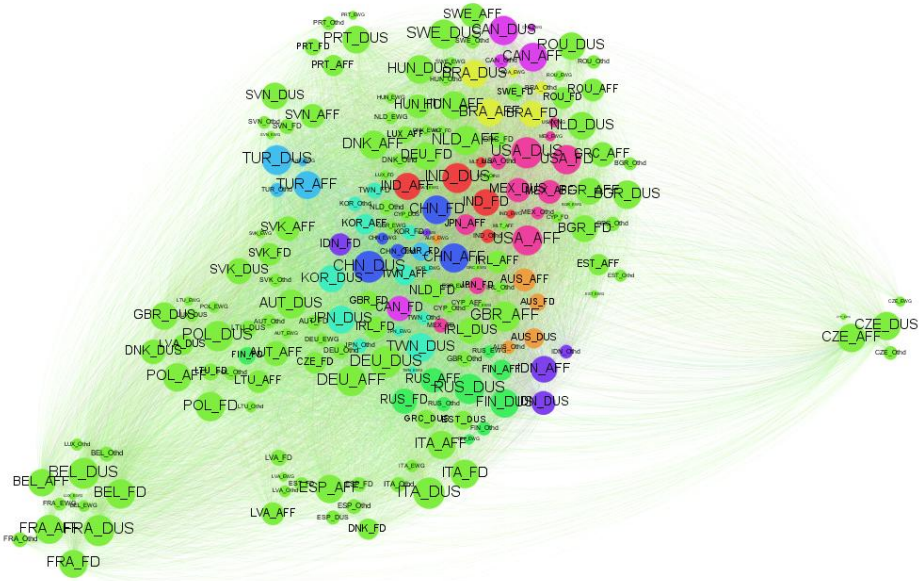
- Interesting is the behaviour of Russia which led a Community formed by many eastern European countries in 2001, but during the following years it lost its key role.

- Outside Europe we find and interesting evolution of Japan that until 2001 was mostly linked with Australia and Korea, while in 2009 formed a small community with USA.

- It seems that in case of green water the **geographical proximity** is more important in explain the emergence of community.

GREEN Community: 1995(left), 2009 (right)





GREY Community

- The European community has increased its size from 1995 to 2009 with Germany and Italy always among the most important in terms of VWT. Also here Russia lost the leading role, covered in 1995, within the eastern European community.

- Japan is very volatile: in 1995 it was strictly linked with Canada, in 2001 it created a community with Australia, Korea and Taiwan, while in 2009 it kept its relation with South Korea and Taiwan only through the following sectors: DUS, Fd and Othd.

CONCLUSIONS

- Care about sectoral level of *disaggregation* => shock diffusion and aggregate fluctuations.
- *Heterogeneity* within and across country;
- Care about *inequalities* since that income per capita is more important than population growth per se;
- Relative importance of *International* trade.

THANKS FOR THE ATTENTION.

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APPENDIX

COUNTRY	SECT	1995			2001			2009		
		B	GN	GY	B	GN	GY	B	GN	GY
AUS	AFF	3,75	32,09	1,45	5,94	43,50	2,35	0,65	15,58	-0,55
	EWG	-0,75	0,00	0,00	-0,88	0,00	0,00	-2,39	0,00	0,00
	DUS	-0,10	0,00	-1,19	-0,13	0,00	-1,59	-0,35	0,00	-4,35
	Other	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	0,00	0,00
BRA	AFF	-0,59	42,56	0,86	1,14	99,73	3,63	1,57	134,89	4,48
	EWG	2,20	0,00	0,00	4,56	0,00	0,00	5,67	0,00	0,00
	DUS	-0,05	0,00	-0,10	-0,06	0,00	-0,32	-0,25	0,00	-2,57
	Other	-0,01	0,00	0,00	0,02	0,00	0,00	0,02	0,00	0,00
CAN	AFF	-2,44	34,61	4,79	-3,51	20,10	4,25	-5,04	23,48	3,38
	EWG	20,77	0,00	0,00	24,77	0,00	0,00	17,55	0,00	0,00
	DUS	0,48	0,00	2,01	0,63	0,00	2,25	0,31	0,00	-0,98
	Other	-0,02	0,00	0,00	-0,01	0,00	0,00	-0,04	0,00	0,00
CHN	AFF	12,68	51,51	22,69	6,13	14,40	18,49	13,13	11,44	50,68
	EWG	7,48	0,00	0,00	8,46	0,00	0,00	36,14	0,00	0,00
	DUS	0,70	0,00	9,52	1,06	0,00	14,31	6,18	0,00	81,54
	Other	0,02	0,00	0,00	0,02	0,00	0,00	0,13	0,00	0,00
DEU	AFF	-10,90	-78,02	-6,90	-9,90	-73,42	-4,99	-10,91	-80,28	-6,71
	EWG	-8,43	0,00	0,00	-9,64	0,00	0,00	-10,50	0,00	0,00
	DUS	-0,03	0,00	-6,44	0,17	0,00	-7,30	-0,07	0,00	-11,83
	Other	-0,06	0,00	0,00	-0,06	0,00	0,00	-0,08	0,00	0,00
GBR	AFF	-5,80	-38,10	-3,52	-7,51	-54,55	-5,04	-8,95	-61,97	-7,06
	EWG	-4,57	0,00	0,00	-6,01	0,00	0,00	-5,87	0,00	0,00
	DUS	-0,29	0,00	-3,55	-0,51	0,00	-5,61	-0,58	0,00	-6,95
	Other	-0,02	0,00	0,00	-0,04	0,00	0,00	-0,06	0,00	0,00
IND	AFF	15,64	45,96	6,47	19,88	53,28	8,18	15,92	28,32	4,83
	EWG	1,30	0,00	0,00	0,54	0,00	0,00	-0,61	0,00	0,00
	DUS	0,16	0,00	3,69	0,22	0,00	5,13	0,16	0,00	6,26
	Other	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00
ITA	AFF	-4,11	-30,67	-2,84	-4,31	-35,47	-2,87	-4,50	-39,05	-4,26
	EWG	-3,60	0,00	0,00	-4,48	0,00	0,00	-3,84	0,00	0,00
	DUS	-0,11	0,00	-1,84	-0,22	0,00	-3,10	-0,38	0,00	-4,80
	Other	-0,01	0,00	0,00	-0,01	0,00	0,00	-0,02	0,00	0,00
JPN	AFF	-22,21	-169,54	-21,91	-16,77	-138,08	-16,24	-14,55	-121,32	-17,21
	EWG	-8,71	0,00	0,00	-7,73	0,00	0,00	-7,54	0,00	0,00
	DUS	-0,60	0,00	-6,74	-0,59	0,00	-7,26	-0,82	0,00	-10,84
	Other	-0,15	0,00	0,00	-0,12	0,00	0,00	-0,12	0,00	0,00
RUS	AFF	-2,48	-2,35	-1,68	-2,03	9,62	-0,74	-10,29	-55,32	-6,21
	EWG	9,09	0,00	0,00	14,96	0,00	0,00	8,86	0,00	0,00
	DUS	0,28	0,00	6,60	0,47	0,00	10,30	0,06	0,00	4,98
	Other	-0,03	0,00	0,00	-0,01	0,00	0,00	-0,01	0,00	0,00
USA	AFF	-4,80	-35,34	3,75	-15,81	-130,23	-6,30	-8,34	-70,18	0,13
	EWG	-22,61	0,00	0,00	-39,50	0,00	0,00	-29,95	0,00	0,00
	DUS	-0,05	0,00	-7,88	-1,39	0,00	-22,15	-1,89	0,00	-32,28
	Other	0,19	0,00	0,00	0,09	0,00	0,00	0,13	0,00	0,00