

Supplementary Material

Evolution and Resilience of agri-food trade network

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ABSTRACT

In the complex global food system, the dynamics associated to international food trade became key determinants of food security. In this paper, we combine a community detection approach with a supervised learning technique in order to describe both the evolution and the resilience of agri-food trade network. Using a large amount of data, we detect similarities between countries and we identify the main drivers that affect trade dynamics over time. The analysis is completed also including the variability on food production and trading due to the climate conditions' evolution. Results emphasize how the topological structure of the network is evolving over time and how it is modifying the clusters composition. Interestingly, we identify sustainability, climate and food nutrition aspects between the emerging factors in the explanation of trade relationships.

List of Countries

Tables [1](#) and [2](#) report the list of countries and the related codes used in the analysis.

Country	Code	Country	Code
Afghanistan	AFG	Djibouti	DJI
Albania	ALB	Dominica	DMA
Algeria	DZA	Dominican Republic	DOM
Angola	AGO	Ecuador	ECU
Antigua and Barbuda	ATG	Egypt	EGY
Argentina	ARG	El Salvador	SLV
Armenia	ARM	Equatorial Guinea	GNQ
Australia	AUS	Eritrea	ERI
Austria	AUT	Estonia	EST
Azerbaijan	AZE	Eswatini	SWZ
Bahamas	BHS	Ethiopia	ETH
Bahrain	BHR	Faroe Islands	FRO
Bangladesh	BGD	Fiji	FJI
Barbados	BRB	Finland	FIN
Belarus	BLR	France	FRA
Belgium	BEL	French Polynesia	PYF
Belize	BLZ	Gabon	GAB
Benin	BEN	Gambia	GMB
Bhutan	BTN	Georgia	GEO
Bolivia (Plurinational State of)	BOL	Germany	DEU
Bosnia and Herzegovina	BIH	Ghana	GHA
Botswana	BWA	Greece	GRC
Brazil	BRA	Grenada	GRD
Brunei Darussalam	BRN	Guatemala	GTM
Bulgaria	BGR	Guinea	GIN
Burkina Faso	BFA	Guinea-Bissau	GNB
Burundi	BDI	Guyana	GUY
Cabo Verde	CPV	Haiti	HTI
Cambodia	KHM	Honduras	HND
Cameroon	CMR	Hungary	HUN
Canada	CAN	Iceland	ISL
Central African Republic	CAF	India	IND
Chad	TCD	Indonesia	IDN
Chile	CHL	Iran (Islamic Republic of)	IRN
China, Hong Kong SAR	HKG	Iraq	IRQ
China, Macao SAR	MAC	Ireland	IRL
China, mainland	CHN	Israel	ISR
China, Taiwan Province of	TWN	Italy	ITA
Colombia	COL	Jamaica	JAM
Comoros	COM	Japan	JPN
Congo	COG	Jordan	JOR
Cook Islands	COK	Kazakhstan	KAZ
Costa Rica	CRI	Kenya	KEN
Cote d'Ivoire	CIV	Kiribati	KIR
Croatia	HRV	Kuwait	KWT
Cuba	CUB	Kyrgyzstan	KGZ
Cyprus	CYP	Lao People's Democratic Republic	LAO
Czechia	CZE	Latvia	LVA
Democratic People's Republic of Korea	PRK	Lebanon	LBN
Democratic Republic of the Congo	COD	Lesotho	LSO
Denmark	DNK	Liberia	LBR

Table 1. List of countries and ISO codes - Part 1

Country	Code	Country	Code
Libya	LBY	Sao Tome and Principe	STP
Lithuania	LTU	Saudi Arabia	SAU
Luxembourg	LUX	Senegal	SEN
Madagascar	MDG	Serbia	SRB
Malawi	MWI	Seychelles	SYC
Malaysia	MYS	Sierra Leone	SLE
Maldives	MDV	Singapore	SGP
Mali	MLI	Slovakia	SVK
Malta	MLT	Slovenia	SVN
Marshall Islands	MHL	Solomon Islands	SLB
Mauritania	MRT	Somalia	SOM
Mauritius	MUS	South Africa	ZAF
Mexico	MEX	South Sudan	SSD
Micronesia (Federated States of)	FSM	Spain	ESP
Mongolia	MNG	Sri Lanka	LKA
Montenegro	MNE	Sudan	SDN
Morocco	MAR	Suriname	SUR
Mozambique	MOZ	Sweden	SWE
Myanmar	MMR	Switzerland	CHE
Namibia	NAM	Syrian Arab Republic	SYR
Nauru	NRU	Tajikistan	TJK
Nepal	NPL	Thailand	THA
Netherlands	NLD	Timor-Leste	TLS
New Caledonia	NCL	Togo	TGO
New Zealand	NZL	Tokelau	TKL
Nicaragua	NIC	Tonga	TON
Niger	NER	Trinidad and Tobago	TTO
Nigeria	NGA	Tunisia	TUN
Niue	NIU	Turkey	TUR
North Macedonia	MKD	Turkmenistan	TKM
Norway	NOR	Tuvalu	TUV
Oman	OMN	Uganda	UGA
Pakistan	PAK	Ukraine	UKR
Palestine	PSE	United Arab Emirates	ARE
Panama	PAN	United Kingdom of Great Britain and Northern Ireland	GBR
Papua New Guinea	PNG	United Republic of Tanzania	TZA
Paraguay	PRY	United States of America	USA
Peru	PER	Uruguay	URY
Philippines	PHL	Uzbekistan	UZB
Poland	POL	Vanuatu	VUT
Portugal	PRT	Venezuela (Bolivarian Republic of)	VEN
Qatar	QAT	Viet Nam	VNM
Republic of Korea	KOR	Yemen	YEM
Republic of Moldova	MDA	Zambia	ZMB
Romania	ROU	Zimbabwe	ZWE
Russian Federation	RUS		
Rwanda	RWA		
Saint Kitts and Nevis	KNA		
Saint Lucia	LCA		
Saint Vincent and the Grenadines	VCT		
Samoa	WSM		

Table 2. List of countries and ISO codes - Part II

Description and list of features

List and brief description of variables used as node attributes (see also Table 3).

- Topological indicators
 - *Node in-degree*¹. It is the number of incoming arcs that are directed towards a specific node in a network, often used as a simple measure of centrality of a node within a network.
 - *Node out-degree*¹. It is the number of outgoing arcs from a specific node in a network.
 - *Node in-strength*¹. It is the sum of the weights of all incoming arcs directed towards a specific node in a network. It measures the total flows that are directed towards a particular node within the network
 - *Node out-strength*¹. It is the sum of the weights of all outgoing arcs from a specific node in a network. It measures the total flows that are going out from a particular node within the network
 - *Local directed and weighted total clustering*^{2,3}. Clustering in directed networks is a measure of the extent to which nodes in a network tend to form groups or clusters of interconnected nodes with arcs. It is measured by calculating the fraction of all possible directed triangles, properly weighted, that are present in the network. Clustering in directed networks can help identify patterns of connectivity and level of interconnections within the network.
 - *Local directed and weighted in-clustering*^{2,3}. It considers only "in" triangles, i.e. triangles in which the neighbours of a node i point to the node and they are also connected each other.
 - *Directed and weighted out-clustering*^{2,3}. It considers only out-triangles, i.e. triangles in which two neighbours of a node i are connected by an incoming arc from the node i and they are also connected each other.
 - *Hub centrality score*⁴. The hub centrality score is based on the idea that important nodes in a network should have many connections to other nodes that are themselves well-connected. Nodes with high hub centrality scores are those that are connected to many nodes with high authority centrality scores, suggesting that they act as important hubs or connectors in the network.
 - *Authority centrality score*⁴. The authority centrality score identifies nodes that are highly connected to by nodes with high hub centrality scores. In other words, nodes with high authority centrality scores are those that are frequently pointed to by other well-connected nodes in the network.
- Macro-Economic indicators based on FAO data⁵
 - *Gross Domestic Product (GDP)* (US dollars). It is a measure of the total value of all goods and services produced within a country's borders during a given period of time, usually a year. It includes all final goods and services produced for consumption, investment, government, and exports, and is used to measure the size and growth of an economy.
 - *Gross Fixed Capital Formation* (US dollars). It refers to the total amount of investment made in fixed assets, such as machinery, buildings, infrastructure, and equipment, during a particular period of time. It is an important indicator of the level of investment in an economy, as it reflects the total amount of resources that are being allocated towards the production of capital goods, which are essential for increasing the productivity and capacity of an economy in the long run.
 - *Gross National Income (GNI)* (US dollars). It is a measure of the total income generated by a country's residents, both domestically and abroad, during a given period of time, usually a year. It is calculated as the sum of all incomes earned by a country's residents, including wages, salaries, profits, and property income, minus any taxes and subsidies paid to foreign entities. Therefore, it measures the total value of all goods and services produced within a country's borders. However, while GDP only includes income generated within a country's borders, GNI includes income earned by its residents abroad, such as profits from foreign investments or remittances sent by workers living abroad.
 - *Global Agriculture, Forest and Fishing Value Added* (US dollars). It refers to the total economic value generated by these three primary industries in a given country. It represents the contribution of these sectors to the overall GDP and it is calculated by subtracting the cost of intermediate inputs from the total output.

- *Global Total Manufacturing Value Added* (US dollars). Value added of the manufacturing industries.
- Population and employment indicators based on FAO data⁵
 - *Total Population* (thousands). It considers the United Nations population estimates based on the World Population Prospects.
 - *Rural Population* (thousands). Rural population refers to the proportion of a country or region's population that resides in rural areas, which are defined as areas outside of urban centres with a lower population density and a lower degree of economic and social development. Rural areas can include farmland, forests, small towns, and villages. Data are based on World Urbanization Prospects of the United Nations.
 - *Urban Population* (thousands). Urban population refers to the proportion of a country's population that resides in urban areas, which are defined as areas with a high population density and a high degree of economic and social development. Urban areas can include cities, towns, and other densely populated settlements. Data are based on World Urbanization Prospects of the United Nations.
 - *Share of employment in agriculture, forestry and fishing in total employment* (percent). This indicator is calculated by dividing the number of people employed in agriculture, forestry and fishing by the total number of people employed in the economy.
- Climate and Sustainability indicators based on FAO data⁵
 - *Emissions* (kilotonnes). The domain includes methane (CH₄) nitrous oxide (N₂O) and carbon dioxide (CO₂) emissions. Data have been collected following the Tier 1 methods of the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National greenhouse gas (GHG) Inventories
 - *Mean surface temperature change* (Degree Celsius). Data are based on the publicly available GISTEMP data, the Global Surface Temperature Change data distributed by the National Aeronautics and Space Administration Goddard Institute for Space Studies.
 - *Water Use Efficiency* (US dollar per cubic meter). It is a measure of the economic value generated per unit volume of water used. It is calculated by dividing the total economic output generated by a particular sector or activity by the total volume of water used for that activity. Water use efficiency is an important indicator of sustainable water management, as it can help identify opportunities to increase the economic value generated from a given volume of water, and to reduce water use where possible.
- Food security and nutrition based on FAO data⁵
 - *Prevalence of severe food insecurity in the total population* (percent). The prevalence of severe food insecurity in the total population refers to the proportion of people in a given population who experience severe food insecurity. Severe food insecurity is defined as a condition where people lack access to sufficient quantities of food or are unable to acquire food in socially acceptable ways, which results in a significant risk of hunger, malnutrition, or other adverse health outcomes. It belongs to the Suite of Food Security Indicators defined by the Committee on World Food Security Round Table on hunger measurement.
 - *Prevalence of obesity in the adult population* (percent). It refers to the proportion of adults (18 years old and older) in a given population who have a body mass index of 30 or higher, indicating that they are severely overweight and at increased risk for a variety of health problems.
 - *Prevalence of undernourishment* (percent). It is a measure of the proportion of the population in a given area that is unable to acquire enough food to meet their daily energy requirements. It is defined as the percentage of the population whose dietary energy intake is below the minimum level needed to maintain an adequate level of physical activity and a healthy body weight. It belongs to the Suite of Food Security Indicators defined by the Committee on World Food Security Round Table on hunger measurement
- Geographic coordinates
 - *Latitude*

- *Longitude*
- Investments and Production based on FAO data⁵
 - *Credit to Agriculture, Forestry and Fishing* (US dollars). It is based on the Credit to Agriculture dataset that considers national data on the amount of loans provided by the private/commercial banking sector to producers in agriculture, forestry and fishing, including household producers, cooperatives, and agro-businesses.
 - *Share of Credit to Agriculture, Forestry and Fishing* (percent). It considers the share of credit to agricultural producers with respect to the total credit.
 - *Agriculture orientation index* (AOI). The AOI for credit normalises the Credit to Agriculture, Forest and Fishing by dividing it by the share of agriculture in gross domestic product. As such, it can provide a more accurate indication of the relative importance that banking sectors place on financing the sector. An AOI lower than one indicates that the agriculture sector receives a credit share lower than its contribution to the economy, while an AOI greater than one indicates a credit share to the agriculture sector greater than its economic contribution.
 - *Gross Production Index in Agriculture*. It is an economic indicator that measures the level of production of agricultural goods within an economy. It is a subset of the overall Gross Production Index that measures the level of production of all goods and services within an economy.
- Other indicators based on FAO data⁵
 - *Political stability and absence of violence and terrorism*. It is an index that measures perceptions of the likelihood that the government will be destabilised or overthrown by unconstitutional or violent means, including politically-motivated violence and terrorism.
 - *Indicator of Food Price Anomalies*. It is an economic indicator used to identify unusual or extreme changes in food prices. It is calculated by comparing the current Consumer Food Price Index, which measures the average change in prices of food products consumed by households, to its historical average or trend. If the current index value is significantly above or below the historical average, this suggests the occurrence of a food price anomaly.

Type	Attribute	Code
Investments and Production	Agriculture orientation index	AOI
Topological indicator	Authority centrality score	AUT
Investments and Production	Credit to Agriculture, Forestry and Fishing	CRE_AFF
Population and employment	Share of employment in agriculture, forestry and fishing in total employment	EI_AFF
Climate and Sustainability	Emissions	EMI
Food security and nutrition	Prevalence of severe food insecurity in the total population	F_INS
Others	Indicator of Food Price Anomalies	FPA
Macro-economic indicator	Gross Domestic Product	GDP
Macro-economic indicator	Gross Fixed Capital Formation	GFCF
Macro-economic indicator	Gross National Income	GNI
Topological indicator	Hub centrality score	HUB
Topological indicator	Local Directed and weighted in-clustering	InCL
Topological indicator	Node in-degree	InDEG
Topological indicator	Node in-strength	InSTR
Geographic coordinates	Latitude	LAT
Geographic coordinates	Longitude	LON
Food security and nutrition	Prevalence of obesity in the adult population	OBE
Topological indicator	Local Directed and weighted out-clustering	OutCL
Topological indicator	Node out-degree	OutDEG
Topological indicator	Node out-strength	OutSTR
Investments and Production	Gross Production Index in Agriculture	PI_A
Population and employment	Total Population	POP
Others	Political stability and absence of violence and terrorism	PS
Food security and nutrition	Prevalence of undernourishment	PUN
Population and employment	Rural Population	RP
Investments and Production	Share of Credit to Agriculture, Forestry and Fishing	SHA_CRE
Climate and Sustainability	Mean surface temperature change	TC
Topological indicator	Local Directed and weighted total clustering	TotCL
Population and employment	Urban Population	UP
Macro-economic indicator	Global Agriculture, Forest and Fishing Value Added	VA_AFF
Macro-economic indicator	Global Total Manufacturing Value Added	VA_TM
Climate and Sustainability	Water Use Efficiency	WUE

Table 3. List of attributes and codes used in the related Figures

References

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