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International trade of GMO-related agricultural products

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Abstract This paper examines the international trade of a variety of genetically modified (GM) food products over a 27-year period (1984–2011) with data from the United Nations using the tools of social network analysis. The results indicate that each of the different crops have a distinctive pattern of trade that has changed over time due to a number of different factors. Also, trade in agricultural commodities became more diversified over time, dominated less by the United States and other nations central in the trade networks and trade in the individual GM crops was stable over time. Countries maintained their trading partners for specific crops, despite the adoption of the genetically modified varieties. The economic implications of these results are discussed for specific countries.

Keywords Genetically modified foods · International trade · Social network analysis

1 Introduction

Humanity has been thriving on planet Earth for thousands of years, testifying to the power of the agricultural, industrial, and green revolutions. In recent decades, agriculture has been aided by advances in biotechnology, which have answered the increased demands for abundant and nutritious food from a rapidly growing population. Biotechnology has been applied to genetically modified (GM) food products, which have been subject to continuous debate. Attitudes to such products range from acceptance to strong opposition to their

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production and consumption. Nevertheless, since GM agricultural products became commercially available, the dynamics of global trade has started to change in complex ways.

This study analyses the international trade network of key commodities (grains and other GMO-related products) over a 27-year period. Our findings include a notable growth of most of the trade networks after the release of the first wave of GMOs (1990–2000). There was a growing geographical centralization in most networks, with developing countries becoming more prominent in bridging roles. A few countries (Germany, the US and to a lesser extent, Australia, Canada, China, France, India, Italy, Japan, Mexico, Netherlands, South Africa and Thailand) remained consistently at the top levels of the centrality metrics. Trade flows slowed down after the release of the second wave of GMOS (2000–2010), partly due to the lack of consistent trade agreements between countries. In an increasingly interdependent world, fair political and economic agreements on food commodities should be a priority for both the public and private sectors.

2 Literature review

2.1 The dynamics of global food trade

Broadly speaking, international trade flows are influenced by three factors: location, resources, and politics. North (1955) established the following basic concepts: (1) The unifying cohesion of a region is its development around a common export base; (2) The success of the export base is a determining factor in the region's growth; (3) The importance of the export base is a result of its role in determining a region's income, which in turn influences secondary and tertiary activities, as well as population distribution, urbanization patterns, and social and political attitudes; (4) In a young region, dependence on supplies is reinforced by efforts to reduce processing and transfer costs, subsidization of social overhead benefits, and the tendency for outside suppliers of capital to reinvest in the existing staple base; (5) Some regions have developed an export base for manufactured goods due to location advantages, but this is not a necessary stage for the sustained growth of all regions; (6) The growth of regions tends to be uneven; and (7) The export bases of regions tend to diversify, losing their identity as regions.

Such dynamics have changed considerably over recent decades. Globalization brought liberalization and privatization, which caused: (1) The collapse of the state as head of vertical coordination and control over trade, (2) mobilization of agricultural products from East to West, (3) foreign investment, and (4) an increasing role of developing countries in world trade (Dries and Swinnen 2004). Nearly 35% of the terrestrial ecosystems have been transformed to agricultural lands (Foley et al. 2007). Private coordination systems have emerged and, in the case of global food consumer demand, are growing rapidly, as they are viewed as alternatives that might foster economic growth, rural development, and poverty reduction. There has also been an increase in the share of high-value products (e.g. grains, edible oils and seeds), while developing countries increased their export of such products from 21% in 1980 to 41% in 2000 (Aksoy 2005).

Transportation technology for trade has also developed, but despite the advancements in GPS, containers and faster ships, some vessels are so large that they cannot use the conventional transportation routes, or drop anchor in developing countries ports (Coyle et al. 2001). Distance is another persistent obstacle to bilateral trade (Disdier and Head 2008), which highlights the continuing importance of geographical location in global trade.

Nevertheless, despite these obstacles, the commercialization of food-related products has resulted in a more globalized diet, where consumers in developed countries are offered various food products and ethnic meals all year round.

On the other hand, whole grains and minimally processed vegetable oils are among the healthy foods consistently recommended by experts (Mozaffarian and Ludwig 2010), which suggests they are necessary for humankind. Cereals also represented an important portion of the food budget in developing countries (Regmi et al. 2001). Hence it is important to avoid a lack of such products at the world level. An alternative for increasing food security is biotechnology, as briefly described in the following section.

2.2 The role of biotechnology in food production

Humans select, breed, and grow plants for consumption to the point where they are completely different from their wild varieties. Biotechnology can be broadly defined as the use of living systems to create new products. Its application to edit the genetic information of living beings started with bacteria, which eventually led to modifying crops for human consumption, known as GMOs. Bioengineered crops can be designed to meet specific needs oriented towards the producer or the consumer. In the first category, we find easier growth and management, resistance to precarious environmental conditions, pest resistance and the prolonged shelf life. Crops labelled with the acronyms HT (Herbicide resistant) and BT (Bacillus thuringiensis) belong to this category. The second category includes reduction of naturally present toxins, better digestion, increase of nutritional value, taste and freshness enhancement (Brandt 2003). While experimentation in the first decades of food biotechnology focused on addressing producers' needs, research is now directed towards consumers' demands, occasionally leaving the nutritional value of crops in second place.

From 1985 to 1995, field trials of transgenic crops were conducted in 34 countries on at least 56 crops, mostly in North America and Europe (James and Krattiger 1996). The International Treaty on Plant Genetic Resources for Food and Agriculture was released in 2000, covering several fundamental aspects of the sustainable use of genetic plant resources and international cooperation. The treaty entered into force in 2004 (FAO 2009), which helped to further disseminate R&D on GM crops.

In 2009, Bt maize was grown mostly in the Americas, but it was also planted in South Africa and the Philippines; HT soybeans were grown mostly in the US, Argentina, Brazil, and other South American countries; Bt cotton was grown mainly in India, China, South Africa, Argentina, and Mexico; HT canola was grown mostly in North America; and Bt and HT cotton were employed partly with stacked genes in the US (Qaim 2009). By 2014, 13 of the 28 countries cultivating transgenic produce were in the American continent, 6 in Asia and 5 in Europe; while their portfolio included maize, soybean, cotton, canola, sugar beet, papaya, squash, poplar, sweet pepper, eggplant, potato and alfalfa (James 2014).

2.3 Commercialization of GMOs

China was the first country to release transgenic tobacco and tomato in the beginning of the 1990s (Huang et al. 2002), followed by various commodities in the US and Canada in 1992, and later in the European Union (Finucane and Holup 2005). A second wave of commodities was released in the early 2000s, which involved more developing countries around the world (International Service for the Acquisition of Agri-Biotech applications 2016).

As a result of complex international dynamics and the asynchronous release of GM food products, there is a lack of consistent regulation. The relatively low regulated level of developing countries limits their participation in international markets. Therefore, India adopted GM crops before biosafety approval and China issues permits on a case-to-case basis, while Europe and the US have developed legal bodies for production and testing before releasing GM food products to the public.

Public opinion has also affected GM-related products availability. When the US Food and Drug Administration (FDA) granted permission for release GM food products to the market quickly without labels, Europe had no central regulator and its public was not convinced by the US system, due to the downplay of the mad-cow disease by the UK government (Finucan and Holup 2005). That was the origin of what are essentially two factions: one that believes too much regulation will slow development and diffusion of GMO technology, and other that believes such products should be extensively tested.

According to Qaim (2009), as public opinion tends to be negative, a couple of GM technologies previously developed for food crops either were never commercialized or were withdrawn from the market because of consumer-acceptance and marketing problems (e.g. Bt and virus-resistant potato, and HT wheat). In contrast with these views, there is evidence that GM technology contributed to the reduction of chemical pesticide use by 37%, increased crop yields by 22%, and increased farmer profits by 68% over the last 20 years; although yield gains and pesticide usage reduction are larger for insect-resistant crops, and yield and profit gains are higher in developing countries (Klumper and Qaim 2014).

Stein and Rodríguez-Cerezo (2010) predicted that half the new transgenic food products would be developed by Asian countries (mainly China and India) and Latin America by 2015, with the other half coming from the US and EU. Therefore, the role of developing countries in the international availability of GM-related products will likely continue to grow in importance. A study by the European Directorate General of Agriculture and Rural Development [ARD] (2007) predicted that the economic impact of an interruption of trade on soybean and meat GM products from South America could be serious. Given the global importance of cereals, oils and other related products, it is important to determine the trends in key partnerships and patterns in trade of such commodities. Thus, our research questions are: How have the global trade networks changed through time? And which countries have been key partners on the trade networks?

3 Methodology

Data on the trade value of fixed vegetable oil, processed animal and vegetable oil, unmilled maize, unmilled cereals, cotton, soybeans, cotton seeds, and rape and colza seeds between 198 countries were analysed. The data were based on United Nations trade data, edited by Feenstra and Romalis (2014). Total trade values from the period between 1984 and 2011 were extracted and analysed with R language (R Development Core Team 2008), an open software package for statistical computation and graphics. Network centralities were calculated for each product, where a node represents a country and a path represents its trade relationship with another country. The definitions of the network centralities (based on Kane et al. 2012; Vargas-Meza 2014; Vargas-Meza and Park 2015) are as follows:

- Betweenness Centrality: the number of shortest paths connecting other nodes in a network, passing through a specific node. This implies that the node acts as a bridge.
- Closeness Centrality: the average number of steps to access all the other nodes in a network. This implies fast access to products.
- Degree Centrality: the number of direct connections a node has to other nodes. This implies greater access to products.
- In-degree Centrality: the number of connections directing to a node from other nodes.
- Out-degree Centrality: the number of connections from a node to other nodes.
- Density: the number of existing ties divided by the number of all possible ties within a network.
- Eigenvector Centrality: a measure determined by how well connected a node is overall, and the extent to which it is linked to more central nodes.
- Strength: a measure of the "closeness" and intensity of a relationship, represented by the value of trade for each country.

4 Results

Three visual representations for each commodity were generated with Netdraw, a visualization tool included in the UCINET software package (Borgatti et al. 2002). The representations correspond to 1990 (just before the initial commercial releases of GMO crops), 2000 (before the second wave of commercial releases) and 2010. Each node represents a different country, while the ties between nodes represent tie strength, considered as trade value. The results can be summarized as follows:

4.1 Fixed vegetable oil

The networks were drawn showing ties over $10,000 in trade value. Thailand and the US had relevant role as gatekeepers in 1990. By 2000, the network gained many nodes. Ten years later, Thailand and the US were still important gatekeepers, while the network gained a few more nodes. All in all, it was a centralized network. While betweenness increased practically across all continents, closeness increased slowly, with Japan, Bhutan, African and Middle East countries occupying central positions frequently during the time of analysis. Degree (with the US in the top position) and out-degree (with the US and Thailand in top positions) increased. In-degree increased slowly, with Occidental countries the most central. Density showed a slight decrease in 2011. Eigenvector did not show a clear tendency, with Asian countries (notably Thailand) the most central. Strength increased, with Thailand occupying the central position (Fig. 1).

4.2 Processed animal and vegetable oil

There were several gatekeepers in the network for 1990 (Australia, Canada, Denmark, France, Germany, Netherlands, Qatar, the US, and Yugoslavia). Ten years later, the network gained nodes and the connections increased, while Kazakhstan and South Africa became gatekeepers for countries in their respective geographical regions. In 2010, Egypt and Tanzania also became gatekeepers for African countries. The number of nodes in the network remained similar. Betweenness increased, with Occidental countries occupying central positions frequently during the time of analysis. Closeness did not show a clear

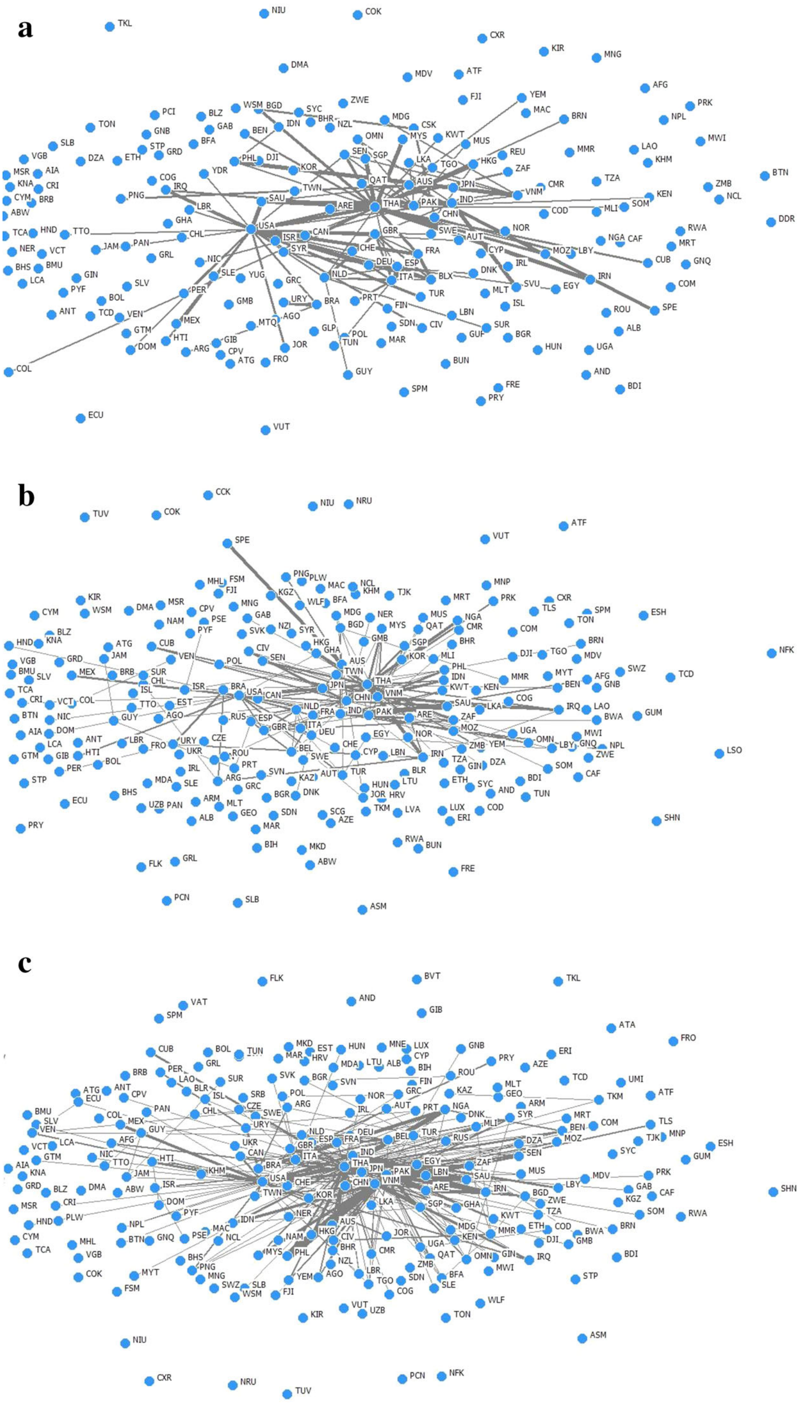

Fig. 1 Trade network for fixed vegetable oil in **a** 1990, **b** 2000, **c** 2010 (Tie strength ≥ 10,000)

tendency. Degree, in-degree and out-degree increased slowly, with mostly European countries occupying the central positions. Density showed a slight decrease in 2011. Eigenvector centrality did not show a clear tendency, with mainly France and Saudi Arabia occupying the central positions. Strength increased, showing France and Saudi Arabia as central once more (Fig. 2).

4.3 Unmilled maize

The ties shown in the graphs represent over $10,000 in trade value. According to the graph for 1990, this was a broadcast network with the US at the center, while France was a gatekeeper for a few countries. Ten years later, the network gained a few nodes, France's role as a gatekeeper covered more countries, and South Africa became a gatekeeper. The network for 2010 showed Canada, Peru and the US close to the center, with no significant increase in nodes. Across time, betweenness and closeness centralities increased, with Asian and Occidental countries; and African, Middle Eastern and Latin American countries the most central. Degree, and in-degree increased but out-degree did not show a clear tendency. The US and Occidental countries were at the center. The network's density increased. While eigenvector centrality increased, strength did not show a significant increase, with the US occupying the most central position (Fig. 3).

4.4 Unmilled cereals

Ties shown in the graphs are over $10,000 in trade value for 1990 and 2010. In 2000, the ties shown are over $100 in trade value. The US was strongly tied to Japan and Mexico in 1990, but overall, the nodes were highly interconnected. There were two central clusters in the network: American and European countries on the right, and African, Asian, and Middle Eastern countries on the left. Ten years later, the network lost a few nodes and clusters based on geographical location are less visible. Trade between European countries had Germany and UK in a central place, although the tie strength was considerably weaker in comparison to the ties between American and Asian countries. South Africa and Sudan became gatekeepers for the African countries. In 2010, the network gained many nodes, and the connections between them increased, although the strength of such connections was weak. This suggests a diversification of the market. Overall, betweenness and closeness increased, with countries from across the world in the first case; and African, American, Asian and Middle Eastern countries in the second case at the top centrality levels. Degree and in-degree also increased, with the US in terms of degree, and Canada, France and Germany at the central position of in-degree. Out-degree showed no clear general tendency, with the US the most central. While density increased, eigenvector centrality and strength did not show a significant increase, both showing Japan and the US at the top (Fig. 4).

4.5 Cotton

The ties shown in the graphs are over $10,000 in trade value. In 1990, the US was the most central node, surrounded by countries from around the world. Ten years later, the network gained a few nodes and ties, with the US surrounded by American countries. In 2010, the network lost a few nodes and the position of the most important nodes remained similar to 2000. Betweenness and closeness centralities increased, with European countries in the

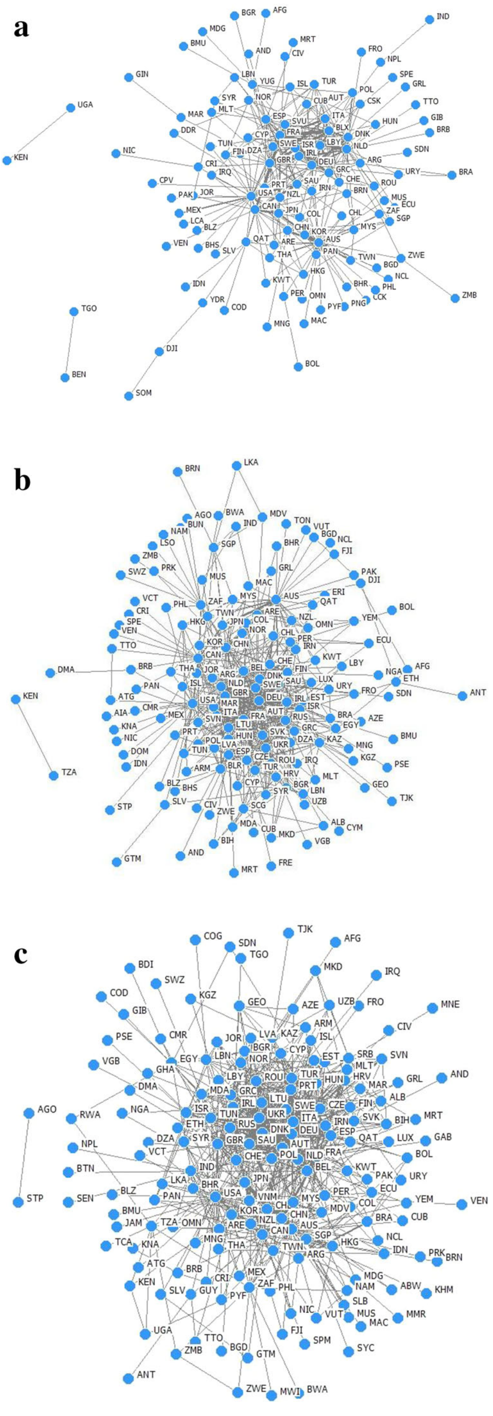

Fig. 2 Trade network for processed animal and vegetable oil in **a** 1990, **b** 2000, **c** 2010

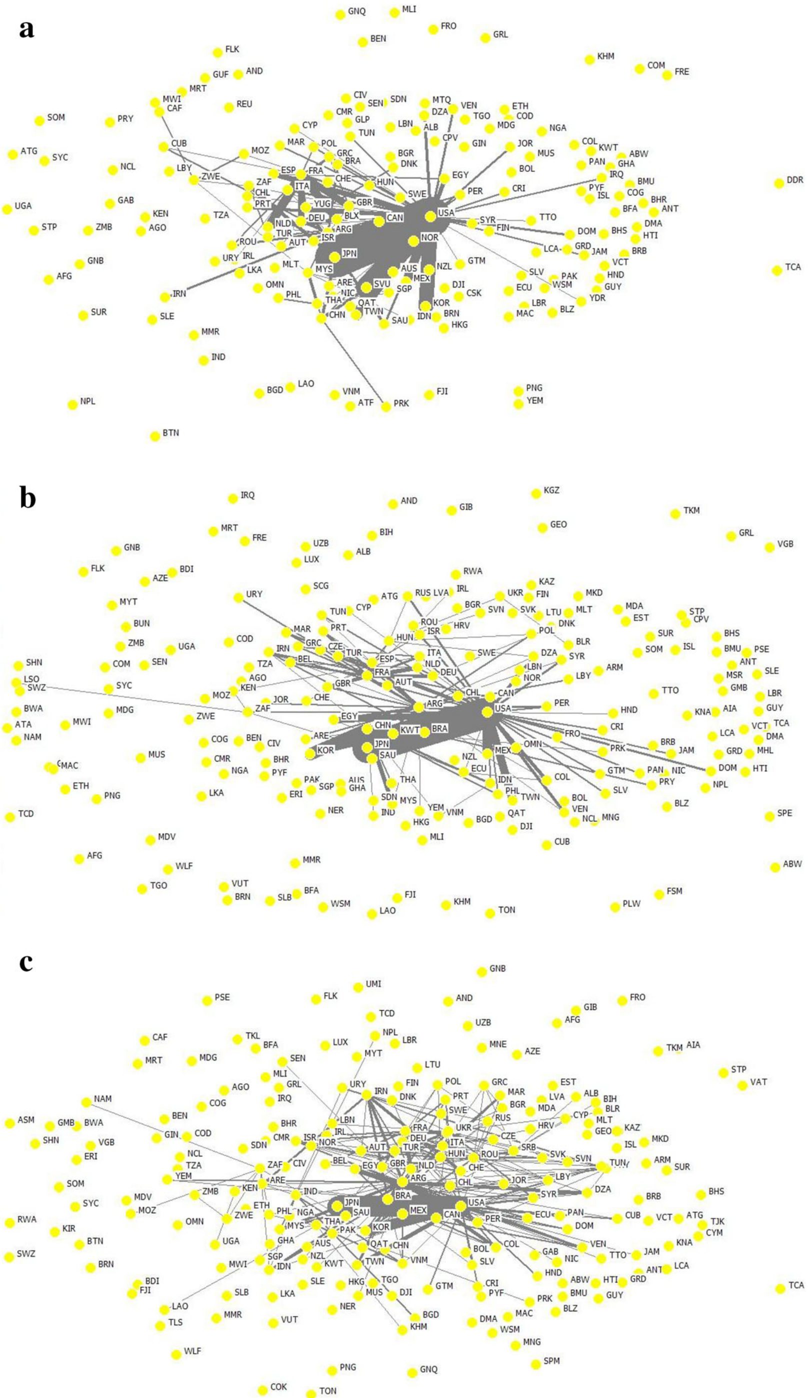

Fig. 3 Trade network for unmilled maize in **a** 1990, **b** 2000, **c** 2010 (Tie strength ≥ 10,000)

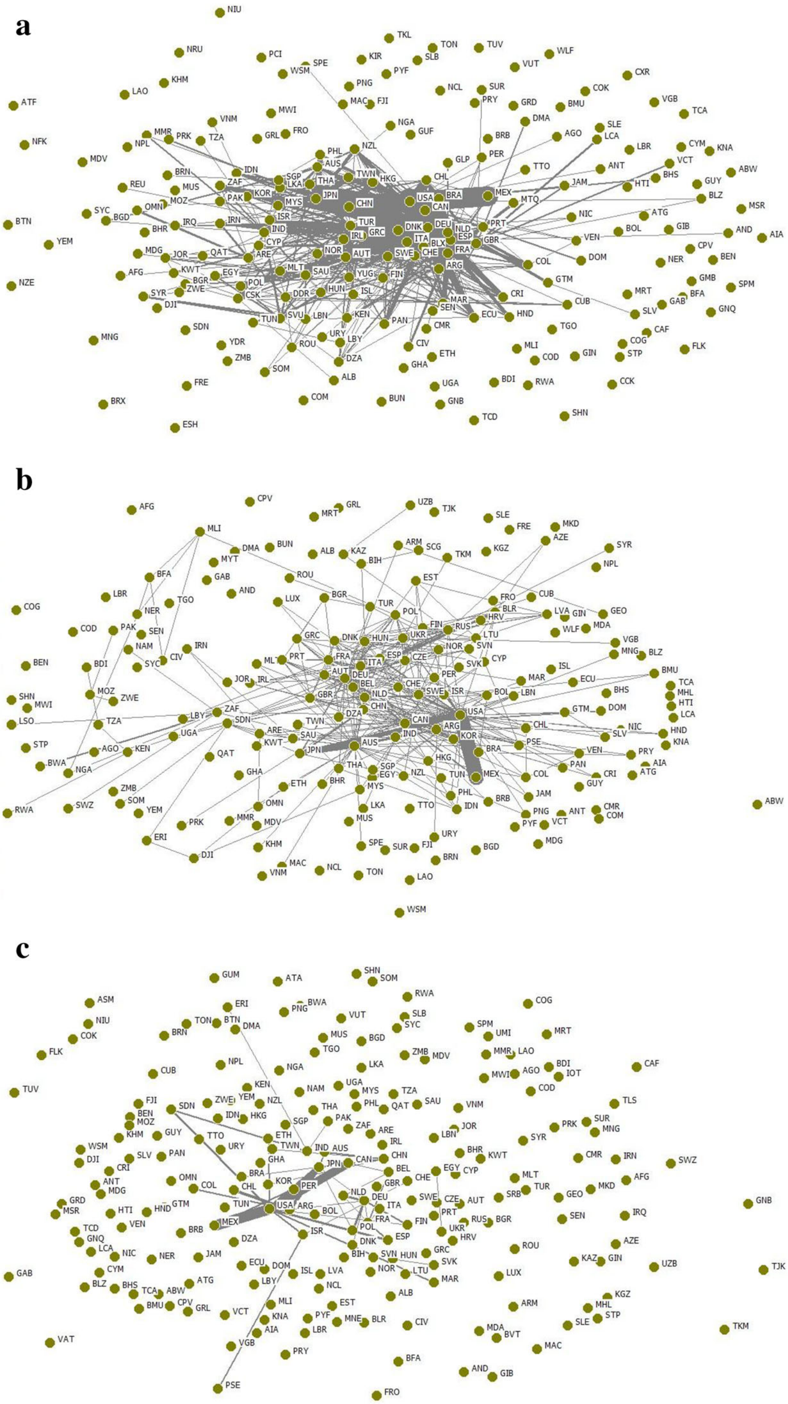

Fig. 4 Trade network for unmilled cereals in **a** 1990 (Tie strength ≥ 10,000), **b** 2000 (Tie strength ≥ 100), **c** 2010 (Tie strength ≥ 10,000)

first case and Asian and European countries in the second case occupying the central positions. The degree centralities did not show a clear pattern, with European countries in degree centrality, Germany and Italy in in-degree centrality, and China and the US the most central. Density did not increase significantly. Eigenvector centrality showed a slight decrease, with China and the US occupying the top positions. Only a few countries increased in strength, with China and the US occupying the strongest positions. These observations suggest a decentralized network for cotton trade (Fig. 5).

4.6 Soybeans

The network for 1990 shows the US at the center and a few countries (Bolivia, China, India and Zimbabwe) as gatekeepers. In particular, commerce between the US and Japan and Netherlands was the most prominent. Ten years later, the network gained more nodes, and China and India gained importance. Tie strength between the US and other countries decreased, while South Africa and Turkey became gatekeepers. In 2010, China, India and the US appeared as broadcasters in the network. They gained a few nodes in ten years. Betweenness centrality increased, with Asian and European countries at the top. Closeness did not show a clear tendency, with African and Middle Eastern countries occupying the top positions in centrality. Degree, in-degree and out-degree centralities increased slowly, with China and the US for the first measure, Germany for the second, and China and the US for the third the most central. While density increased, eigenvector decreased, with China and the US most central. Strength did not increase significantly, with China and the US the strongest. These observations suggest that the soybeans network became more decentralized (Fig. 6).

4.7 Cotton seeds

The network for 1990 showed few nodes. Only Australia and Japan were strongly connected, while main hubs were Italy and the US. Over the next ten years, the network gained more nodes and the strongest ties were between the US, and Australia and Mexico. Important hubs were Benin, India, Italy, Saudi Arabia and South Africa. There also was a small separated cluster of African countries. By 2010, the network gained a few more nodes. The strongest ties were between the US and Greece, Italy, Japan, Korea and Mexico. Betweenness centrality increased, with the US the most central. Closeness did not show a clear tendency, with African, American and Middle Eastern countries occupying central positions. Degree centrality increased, with the US most central. In-degree did not show a clear pattern, with Italy, Japan, Korea and Spain most central. Out-degree increased slowly. Eigenvector did not show a significant increase, with Australia, Japan, Mexico and the US occupying the top positions. Strength increased slowly, with Australia, Japan and the US the strongest (Fig. 7).

4.8 Rape and colza seeds

The graph for 1990 shows a cluster of European countries with Germany at the center. The strongest tied countries were Canada and Japan. Ten years later, the network was centralized with a cluster of European countries. Canada was strongly tied with China and Mexico, while important gatekeepers were Pakistan and South Africa for Asian and Middle Eastern, and African countries, respectively. By 2010, the network gained a few nodes,

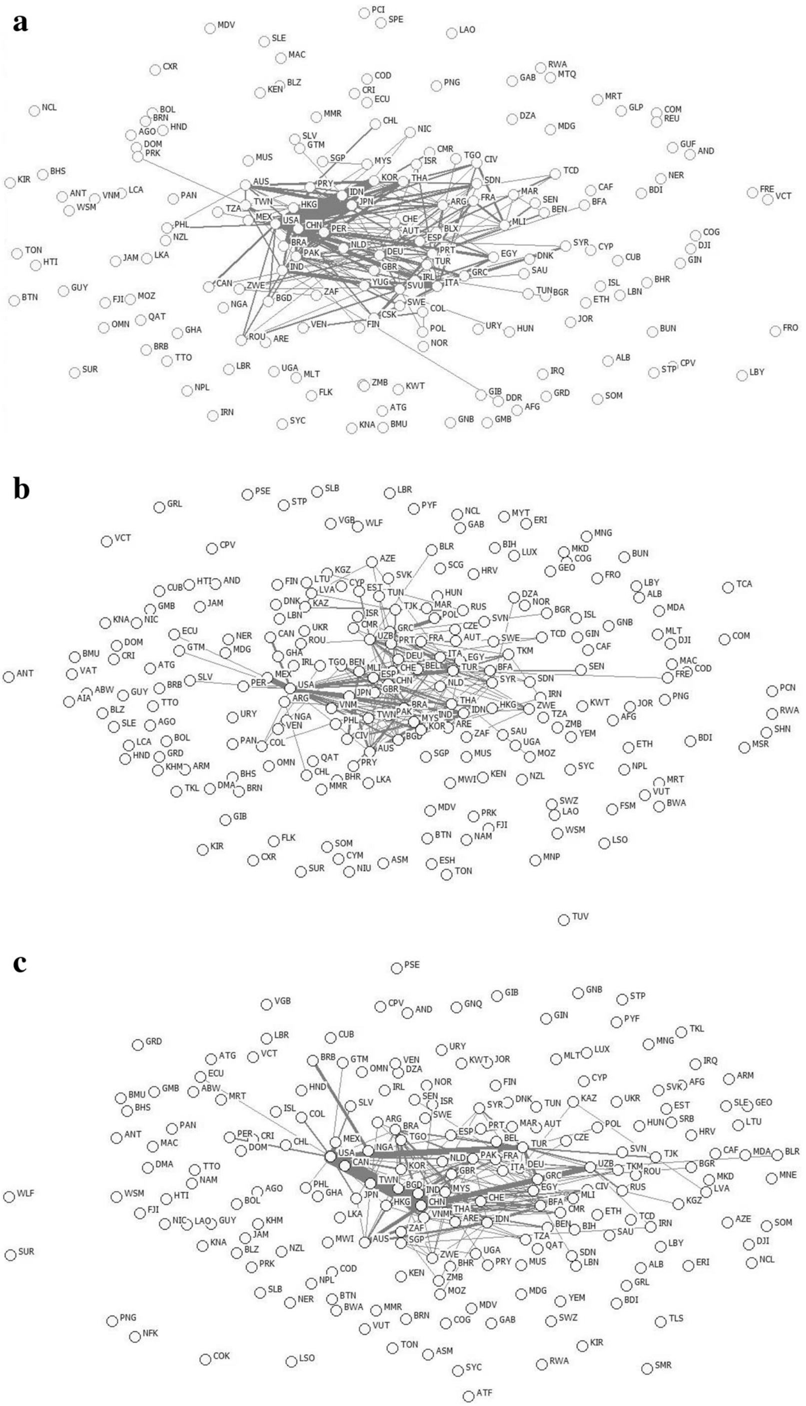

Fig. 5 Trade network for cotton in **a** 1990, **b** 2000, **c** 2010 (Tie strength ≥ 10,000)

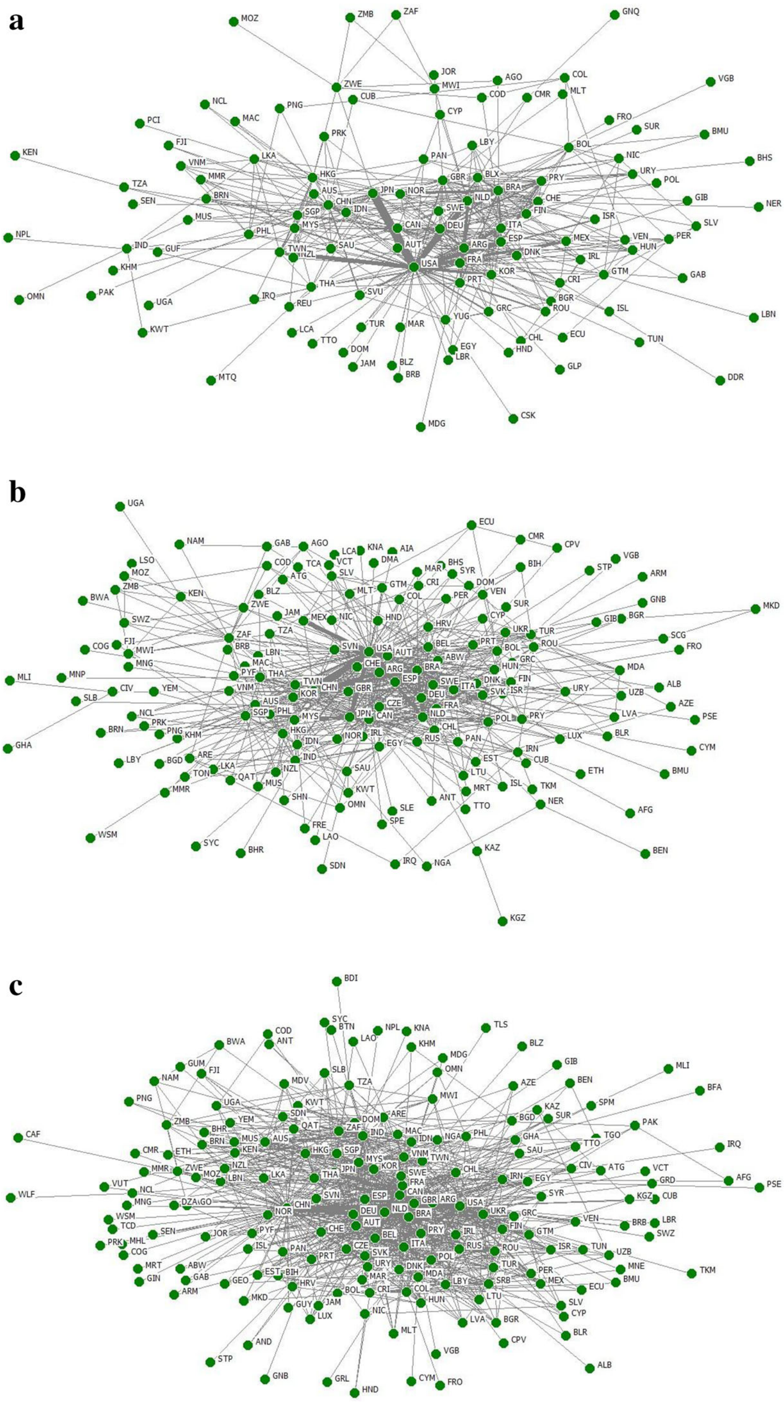

Fig. 6 Trade network for soybeans in **a** 1990, **b** 2000, **c** 2010

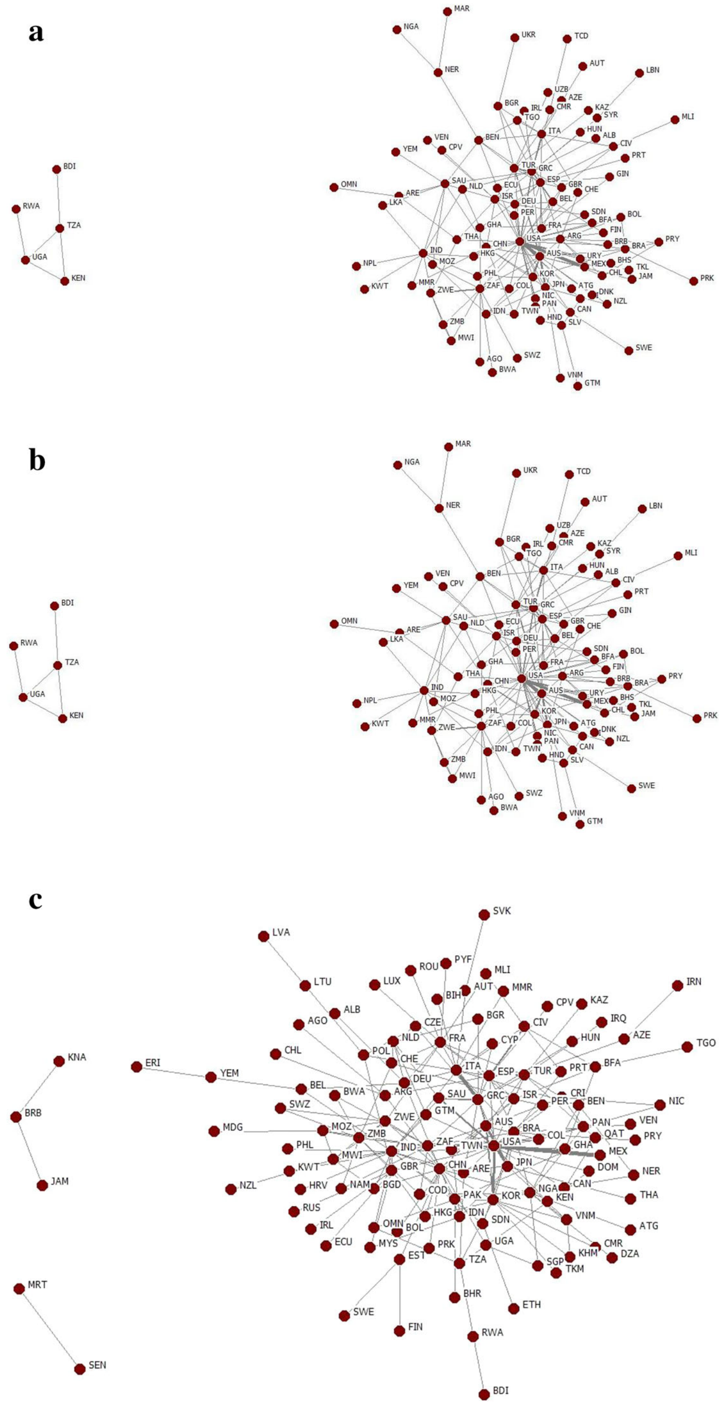

Fig. 7 Trade network for cotton seeds in **a** 1990, **b** 2000, **c** 2010

becoming more centralized. Betweenness increased, with American and European countries the most central. Closeness did not show a clear tendency, with European and Latin American countries occupying the top positions. The degree centralities increased, with France, Germany and Netherlands in degree centrality, Germany in in-degree centrality, and Canada, France, Germany and Netherlands in out-degree centrality occupying the most central positions. Density decreased in 2011. Eigenvector and strength did not increase significantly, with Canada the most central and strongest (Fig. 8).

To examine the overall trends in the trade of agricultural products, each network at each point in time was correlated with all other products at the same point in time, and all products were correlated with themselves at adjacent points in time. QAP correlations were used to control for the lack of independence of the relations among the countries (Dekker et al. 2007). The results indicated that correlations among the products got smaller over time. The average coefficient dropped from the .23–.25 in 1984–5 to .13 in 2011. This suggests that trade in agricultural commodities became more diversified, with less dominance by the US and other nations central in the trade networks. Trade in the individual GM crops was stable over time, meaning that countries maintained their trading partners, despite the adoption of the genetically modified varieties. The over time (1984–2011) correlations ranged from a low of .895 for cotton, to a high of .965 for soybeans. Also, there were no dramatic changes in any product's trade patterns before and after the introduction of GM varieties or any consistent trend resulting from their adoption by individual countries.

5 Discussion

5.1 Network centralities and economic implications

In-degree centrality tended to be higher than out-degree in the networks, suggesting that countries were seeking more imports than exports channels. There was clustering in the networks and an increment in nodes after the release of the first wave of GMO-related products. After the second wave, trade between geographically distant countries grew, while a few products (cotton, soybeans, and unmilled cereals) tended to have less centralized networks. In the last few years, density declined slightly across most of the networks, suggesting less centralization. The importance of the role of non-Western countries increased over time, although a few Western countries' impact on the overall trade networks remains high. Areas growing GM agricultural products are mostly in the South, while the North led the trade networks. Thus, the economic aspects of trade are being primarily managed by countries without large production volumes.

The control of trade by the North can have important implications for southern countries with large shares of GMO products (e.g. Australia, India and Mexico). Nevertheless, there is an important international void in regards to effective tax management, as central countries in terms of GM agricultural trade (e.g. China, France, Germany, Japan and the US) are also among those with the largest trade tax evasion (Johnston 2011).

On the other hand, modern agriculture concentrated in productive soils can contribute to reducing deforestation (Balmford et al. 2005). The cultivation of large yields of soy in Latin America has brought economic benefits through taxes and the ability to provide both national and international populations with cheap and large amounts of calories and proteins, although at the expense of biodiversity (Grau and Aide 2008).

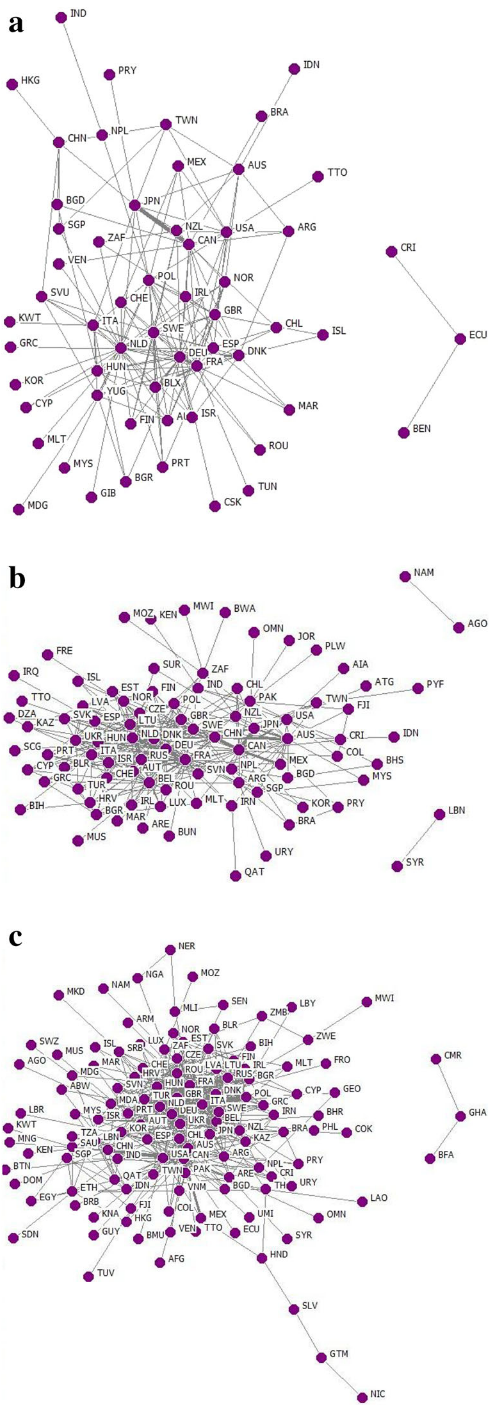

Fig. 8 Trade network for rape and colza seeds in **a** 1990, **b** 2000, **c** 2010

5.2 Patents and GM trade

Four organizations deal with GM crops patents: one located in the US, another in Germany, a third in Japan and the International Patent Cooperation Treaty (PCT). Graff et al. (2003) calculated that 24% of the US agricultural biotech patents granted from 1981 to 2001 were from public organizations (academy and government), compared to 25% in Europe, 14% in Japan and 33% by the Patent Cooperation Treaty, which makes the contribution of the public sector on GM patenting greater than patterns of patenting in other industries. The public sector is mainly focused on new varieties of GMO crops. Nevertheless, the commercialization approvals in industrialized countries have been granted to private sector corporations with the exception of China. As result, Monsanto and DuPont hold 14 and 13% of the patents, respectively, followed by Syngenta with 7%, Bayer with 4% and Dow with 3% (Graff et al. 2003).

The concentration of patents in a few companies is partly due to the complex negotiations required to use the dozens of intermediate technologies required to develop a single GM crop, which involve high transaction costs (Santaniello et al. 2000). Therefore, such factors were partly translated to the networks through the increment of nodes and ties in the first wave of commercial releases of GM crops, followed by a continuous centralization in most of the trade networks.

5.3 The western countries' role in the trade networks

5.3.1 The US

The American legislation of 1954 facilitated the economic assistance to other countries by supplying grain, allowing the United States to dispose of agricultural surplus, triggering other countries to do the same (Obenchain and Spark 2015). This contributed to reshaping the world economy around grain, fostering the development of commercial markets, grain traders and the growth and concentration of agribusiness (Winders 2012). Cargill, an American company, is the largest grain trader in the world, involved in (but not limited to) biofuels, soybeans, cotton, and feed. Thus, the US is also one of the top producers and consumers of soybean oil, employed for industrial purposes and biofuel. Also, it has a large surplus of corn, which is employed in the elaboration of food, beverages and biofuel (ethanol). For environmental and political reasons, the demand for biofuels comes mainly from the developed world although the rise of prices on such products is felt in the developing world (Gunstone 2011). As for cereals, consumer demand might have risen during the period of analysis partly driven by the release of the first Dietary Guidelines for Americans in 1980, which were later modified to stress the importance of whole grains (Kantor et al. 2001). In sum, a large surplus of agricultural production combined with energy, nutrition and trade policies (both domestic and international) have aided the US to become one of the main actors in the analysed trade networks.

5.3.2 Canada

Canola originated in Canada through conventional breeding of rapeseed (Stringam et al. 2003). Because of this commodity's ease of genetic editing, its rapid production and the country's small population, Canada became a relevant exporter of both canola seeds and oil (Gunstone 2004). According to Phillips (2003), although "many innovations in the canola industry have been developed by public researchers and provided at low (or no) cost to producers, most recent developments have occurred in the private sector, protected by enhanced private intellectual property rights and commercialized through increasingly proprietary systems". There has been an increase in the international oilseed trade since 2003 (Carré and Pouzet 2014), reflected in the growth of the processed oil trade network. The development of biodiesel since the mid 2000s has led to an abundant supply of rapeseed meal, which has encouraged its use for feed. Also, there is growing interest in rapeseed food in China, the US and Korea due to its nutritional value (Carré and Pouzet 2014).

5.3.3 Germany, Italy and France

These three countries are each others' main trading partners, so their trade dynamics tended to be similar. Germany's large spending on R&D and openness to export practices have contributed to its role in the processed oil, cereals, cotton, soybeans and rape networks. This contrasts with France's secondary role in cereals and grains networks, and Italy's secondary role in cotton and cotton seeds networks. Nevertheless, according to Felettigh et al. (2006), "the geographical specialisation of Germany and Italy has been more favorable than the French one because German and Italian external trade is more oriented towards fast-growing areas such as the Far East, the United States and Central and Eastern Europe, whereas the French one is more inclined towards the Euro Area and Africa". These three European countries have also been impacted by competition from China and Central and Eastern Europe, due to the low cost of labor related with low technology sectors (Felettigh et al. 2006).

5.3.4 Australia

Indirect trade flows to this country increased tremendously during the mid-2000s, with palm oil being one of the highest trade resources (Dittrich et al. 2012). Thus Australia's relative high relevance in the oil related networks. Nevertheless, due to the its richness of resources, European countries tend to shift the environmental burden of their exploitation to Australia.

5.4 The Eastern countries role in the trade networks

5.4.1 China

The rapidly growing economies of China, India and other South Asian countries have increased the flow of resources and goods to this area of the world. In China, GM crops are supported by R&D facilitated by government research institutes and foreign companies, assisted by efforts from local officials and extension agents interested in the commercialization of bioengineered crops, particularly cotton (Huang et al. 2001). While Europe and America have regulatory bodies to conduct trials in few square meters, China conducts trials on tens of thousands of acres (The Economist 2016). As result, China has become a global player in GM crop commerce, directly competing with Europe and the US. This explains the findings of a decentralization tendency in some of the trade networks. China is a leading country in the cotton trade network, where it has been central since 1986. In the case of soybeans, China has been central since 2003, which roughly corresponds to the second wave of GM crops commercial release. Nevertheless, current views on GM crops in China contrast the need to feed the population and the dependence of foreign imports with public concerns over the safety of bioengineered food (The Economist 2016).

5.4.2 India

Soybeans have grown in importance as oil seed for this country, but they are also processed for industrial use and feed. This partly explains India's leading role in the soybean trade network. Soybean production is concentrated in the state of Madhya Pradesh, but there is no centralized market. Between 1981 and 2004, the annual output of soybeans grew at about 10%, slowing down in later years (Dummu 2009). Western countries biofuel demand has not affected soybeans in India because the law prohibits its usage for non-food products (Gunstone 2011). Soybean production and trade also have the advantage of a system of self-regulated companies at the international level, which avoids market disruption and long-term losses in contrast with GM corn and rice (Gruère et al. 2011).

5.4.3 Thailand

Among the several varieties of vegetable oils internationally available from this country, palm oil has higher production volumes, partly due to its low cost. That is why Thailand was shown to be one of the leaders in the fixed vegetable oil network. Although palm oil can be used as food, it also has attracted attention as an energy crop since the Thai government introduced policy measures to promote biodiesel (Silalertruksa et al. 2012), but due to the high demand for such combustible in western countries, Thailand 's role in the network might increase in coming years. Nevertheless, in order to increase the sustainability of the palm oil industry, there should be improvement on the infrastructure (Silalertruksa et al. 2012).

5.4.4 Japan

The trade network where this country had more impact was cotton seeds. Part of the reasons can be found in the role of the US as opposing force to Russia. Funds to modernize the textile industries and access to American cotton markets were provided in Hong Kong, Japan, Singapore, South Korea and Taiwan in the 1950s and 1960s (Rosen 2002). Japan became the most important bilateral trade customer for Australia around the same time and has remained in this position, as can be seen in the cotton seed network. Nevertheless, the relationship is not limited to this product: Japan accounted for 18 per cent of Australia's exports of goods and services in 2005 (Department of Foreign Affairs and Trade 2006). According to Capling (2008), "through the 1980s and 1990s, Australia and Japan were actively committed to non-discriminatory forms of economic cooperation, globally through the multilateral trade system, and regionally." Such policies contributed to keep the countries afloat in the trading networks despite their lesser role in seeds patenting, compared to the US.

5.5 The role of other developing countries in the trade networks

5.5.1 African countries

Energy and food availability have increased in this region due to increased availability of vegetable oils caused by an increase in fast food consumption and, to a lesser extent, urbanization, income increase and the globalization of media (Golzarand et al. 2012). Thus the growing role of African countries in the processed oil network. South Africa is the only

African country where Bt cotton and Bt maize were grown commercially during the analysis period. The first generation of GM crops were a relatively easy-to-use technology that did not require a large investment or big changes in the patterns of agricultural production, leading to its fast adoption (Ameden et al. 2006). Ayele (2007) described a political will for the adoption and common regularization of GMOs on the African continent, as long as regulatory skills, knowledge of modern biotechnology, and infrastructure for administration, inspection and monitoring are addressed. Nevertheless, social and political factors must not be downplayed, due to the public concern over the adoption of GMOs, as well as cultural and ethnic barriers (Ayele 2007).

5.5.2 Mexico

By 2002, only Mexico and Argentina were producing GM crops for commercial use within Latin America (Ameden et al. 2006). As Argentina was not particularly relevant in the analysed trade networks, this discussion concentrates on Mexico. The science and research infrastructure and funding in Mexico for the adaptation of transgenic crops to local conditions were growing, experience with biosafety was expanding, and seed markets were large enough to attract private sector interest (Traxler et al. 2001). Perhaps the biggest obstacle to GM crops in this country is the rejection of the largest agricultural patent holder (Monsanto) by farmers and the public. Our findings reveal that Mexico was a vital partner in cereals and cotton, but not in maize. The Monsanto controversy in Mexico is largely due to GM maize, viewed as a danger to the rich diversity of native maize species.

6 Conclusions

We can see two tendencies on the global trade policies: while the US and European countries favor bilateral and regional agreements that have long-term negative impacts mostly on Southern countries, Australia and East Asian countries favor multilateral and non-discriminatory trade systems. In the absence of GM-specific trade regulations, adopting a GM crop by developing countries is generally beneficial. This has been confirmed by CGE studies, partial equilibrium models (Gruère 2011), and is also suggested by the cotton and soybeans network analyses.

GMOs have received support and attention from global actors as a food security measure, although this remains a compromised objective if most of the patents are controlled by the private sector. Therefore, governments should consider investing in the public R&D sector. This would permit greater emphasis on diverse local agricultural products (e.g. Lindhout and Danial 2006; BBC 2015) and in bio-remediation (Zimmermann and Porceddu 2006). By targeting the specific needs of countries, other fundamental aspects of GM production that are often overlooked could be addressed more effectively and rapidly, such as soil nutrition replacement, the nature of the produced crops, producers working conditions, and public rejection of GMOs.

Complementary measures can be formulated following the example of other industries that have been threatened with Intellectual Property congestion. Both public and private sectors could form collective rights organizations such as patent pools and royalty clearinghouses that provide freedom to operate with substantial savings (Graff and Zilberman 2006). Information technology could be a powerful tool to enhance collaboration and foster collective intellectual property.

An improvement in corporate and scientific communication targeted at the general public should be another priority. Zimmermann and Porceddu (2006) discuss that most of the regular biosafety concerns related to GMOs can be dealt with knowledge of the biology and the evolution of the species that was modified. Companies should also be more transparent about all their procedures involving the production and trade of GMOs, with a special emphasis on food labelling (Golan et al. 2001). In sum, sustainability in agricultural and trade systems should address micro-, meso- and macro-level issues.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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