Are Preferential Agreements Significant for the World Trade Structure? A Network Community Analysis

Carlo Piccardi* and Lucia Tajoli†

1. INTRODUCTION

The decision of a group of countries to selectively lower or eliminate tariffs (and possibly other trade barriers) against imports from group's members, forming a Preferential Trade Agreement (PTA) has been discussed in trade policy debates for a long time.[1] Many works in the international trade literature show the increasing trend of preferential trade agreements since the 1990s, but there is no conclusive evidence on the actual effects of these treaties (Pomfret, 2007; Baier and Bergstrand, 2007). In the literature, among the many still open issues, there is very little agreement on two points in particular: the actual impact of PTAs on the trade flows between members, and the possible distortion produced on trade flows with non-members. The first of these points has been addressed in the empirical literature relying mainly on the gravity model framework,[2] but this approach raises a number of concerns, especially because of the likely endogeneity of PTAs (Baier and Bergstrand, 2004; Baier et al., 2008; Wolf and Ritschl, 2011).

The second issue deals with the possibility that PTAs give rise to isolated groups of countries, highly integrated among them, but separated from the rest of the world (i.e., possible "stumbling blocs" on the way to multilateralism, according to Bhagwati(1991)), and considers how PTA formation interacts with global trade (e.g., Westhoff et al., 1994; Ornelas, 2005; Saggi and Yildiz, 2010). This issue was addressed empirically less often in econometric models (e.g., Fukao

* DEIB, Politecnico di Milano, Italy

† Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Italy. (Corresponding author. Address: Via Lambruschini 4B, Milano 20156, Italy. Tel (+39) 02 2399 2752, Email lucia.tajoli@polimi.it)

1. In this work we adopt a broad definition of preferential trade agreements, following Deardorff (2011), thereby including in the definition free trade agreements, custom unions and common markets between two or more partners. Our definition of PTAs is equivalent to what the World Trade Organization also calls Regional Trade Agreements.
2. The empirical literature testing the effects of PTAs through gravity models is very large and it is becoming increasingly sophisticated. For a recent survey, see e.g. De Benedictis and Salvatici (2011).

et al., 2003; Magee, 2008), and mainly by building measures of regionalization of trade patterns, but all the proposed indices have potential drawbacks (De Lombaerde et al., 2011), leaving open the discussion on the effects of PTAs.

In this paper, we address these issues using a different methodological approach, the network analysis of international trade flows. Among the many real-world networks studied in the literature, the World Trade Network (WTN) received increasing attention in the last decade because of a number of interesting features (see De Benedictis and Tajoli (2011)). It is quite natural to represent international transactions among countries as a network, where countries are the nodes and the connecting edges are the international trade flows between them, giving rise to an intricate system of exchanges affecting all the countries. The specific economic motivations driving international trade flows shape this network, that consequently displays characteristics that are relevant for their economic implications, as well as for the network analysis in itself.

Network analysis has been used to examine the formation of PTAs by Goyal and Joshi (2006) and Furusawa and Konishi (2007). In particular, Furusawa and Konishi (2007) address the issue of PTAs as "building or stumbling blocs", looking at whether PTA formation is a process that will eventually lead to a complete network (with all countries linked to each other through preferential agreements) achieving global free trade. In this paper instead, we don't look at the process of creation of preferential trade linkages, but we analyze empirically the structure of the trade network to better understand how preferentiality (as opposed to randomness) in choosing trade partners impacts on the overall world trade network, and whether it leads to an open connected system rather than a sum of closed blocs.

In order to analyze the impact of PTAs on the structure of world trade, we look for the possible existence of *communities* within the WTN. Searching for communities in the WTN requires to examine the matrix of all the existing trade links, considering the world trading system as a whole, rather than assessing preferential trade on a bilateral basis. The possible effects of trade creation and trade diversion are therefore fully taken into account, considering the existing interdependencies for all countries. If the signed agreements significantly affect the geographical pattern of trade flows, by increasing trade between members and possibly by reducing trade with non-members, community structures should emerge in the WTN. In fact, in general terms, a significant network community is a set of nodes with strong internal connections, much stronger than those with the remaining nodes of the network (Newman, 2006; Fortunato, 2010). What defines a community in this context are strong, above-average commercial ties (relative to the rest of the world) rather than imposed partitions of the network, or common individual characteristics of the nodes. Community analysis applied to the WTN should then discover – without pre-imposing any preferential link or structure – groups of countries with privileged relationships, originated by geographical vicinity, common language or religion, traditional partnerships, and of course preferential trade agreements, if they indeed do affect trade patterns. Instead, in a "globalized" or "multilateral" world, with no exclusive PTAs, we do not expect communities to be significant, as countries can be connected through trade to nearly any country in the world with similar ease.

First, we look for communities in the WTN in the period between 1962 and 2008, allowing the presence of preferential trade patterns to emerge endogenously from the world trade dataset, and we compare different methodologies to search for communities in networks, introducing also a measure of their significance, in order to verify the robustness of the results that we obtain. All the different methods applied here base the search for a community on the identification of a group of countries sharing a disproportionate amount of trade among them when compared with that they have with the rest of the world. The second type of analysis, instead, starts from exogenously defined clusters based on the existing PTAs, and aims to assess their significance as communities within the WTN structure.

Both approaches shed many doubts on the existence of relevant communities in the WTN, whether endogenously emerging or exogenously defined: the results show that the WTN is increasingly connected and PTAs (or other factors) do not split countries into *significantly* defined cohesive groups because of the presence of strong inter-group connections keeping the system together. Some "weak" communities emerge, but the countries involved are generally not much more connected among them than with the rest of the world, so that they do not form truly privileged or exclusive relationships. Put it differently, in international trade globalization seems to prevail over regionalization or preferentiality, in spite of the high heterogenity of the countries.

2. THE ROLE OF PREFERENTIAL TRADE

The number of signed trade agreements increased very rapidly since the 1990s, and in 2014 over 350 such agreements were in force. Currently, all countries of the world are members of at least one trade agreement, with the only exception of Mongolia. According to the World Trade Organization (WTO, 2011), the value of trade between members of PTAs has grown faster than the world average in the past decades, increasing the share of PTA trade to world trade from 18% in 1990 to 35% in 2008. This remarkable coverage in terms of countries and its increase in time, however, overstates the extent of trade that actually takes place on a preferential basis. The number and scope of PTAs in fact is not fully conveying the effectiveness of these agreements in promoting trade among its members and, potentially, in diverting trade to non-members. What matters most is the actual preferential reduction in tariffs and other trade barriers put forth by a PTA, and in many ways, the multiplication of PTAs reduces the exclusivity of a trade agreement, possibily watering down its effects.

The eagerness to form PTAs orginated a large body of literature trying to understand the causes and the effects of this phenomenon.[3] At the basis of the interest both for economists and policy-makers are the potentially important welfare implications of preferential agreements, which can be positive or negative, as discussed since Viner (1950). Most concerns on the increasing number of PTAs are related to the possibility that such agreements might distort patterns of trade by granting selective preferential treatment, thereby affecting the choices of trading partners (e.g., Bagwell and Staiger , 1997; Bond et al., 2004). In spite of many modeling differences, most works agree in showing that the potential negative welfare effects depend on the trade diversion and the terms-of-trade distortions that can be created by such arrangements (Krueger (1999)).[4] Therefore, the extent of the actual "preferentiality" is a relevant issue.

A problem in assessing the extent of preferentiality is that both theoretical and empirical recent work in international trade emphasizes that PTA membership should be treated as an endogenous choice, thereby making it difficult to isolate is own impact: Chen and Joshi (2010) and Baier et al. (2014) highlight the role of countries' interdependencies when analyzing PTAs. But it is not straightforward to deal empirically with this point, and a relatively small numbers of works do it explicitely (Magee, 2003; Egger et al., 2011). The community analysis performed on the WTN, by allowing the existence of countries' blocs to emerge endogenously, can address directly this issue, providing additional insights on the effects of PTAs on trade.

So far, very few studies analyzed communities, or clustering, within the WTN (Reyes et al., 2009; Barigozzi et al., 2011), possibly because of the many open issues still existing in the methodologies for community analysis, making the intepretation of the results quite problematic (Fortunato, 2010). A direct reference to PTAs when looking for communities in the WTN is made by Reyes et al. (2009), using as a benchmark the groups of countries that signed regional trade agreements, finding that over time the formation of communities follows an irregular pattern. The above-mentioned studies define and detect communities in the WTN in distinct ways, but in all cases the main problem is that it is difficult to assess the significance of the partitions that emerge. This is the specific issue we address in what follows.

3. Frankel (1998) is an example of the analyses undertaken when the current wave of regionalism began.
4. The crucial role of trade diversions is often neglected in the empirical work, as it is not easy to capture. A recent exception is Magee (2008), explicitely considering in a gravity equation not only the PTA effect, but also the effect of not partecipating to a PTA. In his work, the analysis is performed at the level of bilateral trade flows between countries, as the gravity framework suggests. This specification allows to conclude that the relevance of the diversion effects is very modest, but it does not consider more complex interactions between countries.

3. THE WORLD TRADE NETWORK

The WTN is here modeled as a directed, weighted network composed of N nodes corresponding to countries ($\mathbb{N} = \{1, 2, \ldots, N\}$ is the set of nodes) and L edges connecting countries, representing the trade flows among them. We denote by $W = [w_{ij}]$ the $N \times N$ *weight matrix*, where $w_{ij} \geq 0$ is the value of the trade flow from country i to country j. The *connectivity matrix* $A = [a_{ij}]$ is the $N \times N$ matrix where $a_{ij} = 1$ if $w_{ij} > 0$, i.e., if there exists the edge $i \rightarrow j$, and $a_{ij} = 0$ otherwise.

Data for our analysis come from the Direction of Trade Statistics published by the International Monetary Fund (IMF) and from the dataset made available by the Center for International Data at UC Davis, constructed from United Nations trade data by Feenstra et al. (2005), known as NBER-UN Trade Data. We use annual bilateral imports for the years 1962, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000, 2005 and 2008 (in the paper we mostly display results for the first and last year of our sample, but the full, detailed set of results is available from the authors). A number of important events affected the patterns of world trade in the period considered: the end of colonial links, changes in the exchange rate regime, removal of many barriers to trade, increasing role of emerging countries in the international markets, and – as mentioned – a rising trend in the number of PTAs signed. Our observation period stops before the outbreak of the financial crisis affected international trade, which was still growing by 15% in value in 2008 before the dramatic drop recorded in 2009.

We use directed aggregate flows received by an importing country from any given exporting country (import data are generally more reliable and complete than exports), measuring the value in U.S. dollars at current prices. Here we are not concerned with the change in prices over time, as we do not make any time series analysis, but we consider the existence of communities in each year separately.

The main topological properties observed by past analysis of the WTN are confirmed by this dataset, indicating that this network is *disassortative* (countries with few trade links tend to be connected to countries with a large number of links), with a high *clustering* coefficient (the trade partners of a given country are often trade partners themselves), and a number of *small-world properties* (the average distance in terms of steps required to move from one node to another is small) (Serrano and Boguñá, 2003; Garlaschelli and Loffredo, 2005; Fagiolo et al., 2008). These properties are accompanied by (and partially arise from) the high heterogeneity of countries as traders, the diversity of geographical distances, and the complex structure of trade costs (Abbate et al., 2012). The evolution of the WTN over time is slow, but it is in line with the so-called 'globalization' process, showing an increasing connectivity between nodes.

Being the network directed, for each node i we distinguish between the in-degree $k_i^{in} = \sum_j a_{ji}$, the out-degree $k_i^{out} = \sum_j a_{ij}$, and the total degree $k_i = k_i^{in} + k_i^{out}$, and we denote the average degree by $\langle k \rangle = \sum_i k_i / N$. Analogously, we define the in-, out-, and total strength of node i as $s_i^{in} = \sum_j w_{ji}$, $s_i^{out} = \sum_j w_{ij}$, and $s_i = s_i^{in} + s_i^{out}$, respectively, and the total weight of the network edges as $w = \sum_{ij} w_{ij}$.

A network is *strongly connected* if, for every pair (i, j) of distinct nodes, there exists an oriented path from i to j (e.g., Barrat et al., 2008). If the network is not connected, the set $\mathbb{N}$ of nodes can be partitioned in components $\mathbb{K}^1, \mathbb{K}^2, \ldots, \mathbb{K}^m$ having, without loss of generality, $N_1 \geq N_2 \geq \ldots \geq N_m > 0$ nodes, respectively ($\sum_i N_i = N$). Each component is a maximally strongly connected sub-network (i.e., it is strongly connected and it is not part of a larger connected sub-network). In our study, given the increase in international trade and in the number of trading partners for most countries, we will find that the largest component $\mathbb{K}^1$ is actually a *giant component*, i.e., it has a dimension N_1 which has the same order of magnitude as N and, on the other hand, it is much larger than all the other components. Network components can be identified by means of standard algorithms of graph analysis.[5] In 1962, the strongly connected component includes 145 countries, and it keeps slowly increasing until 1985 when it jumps to 165. From 1995 onward, the giant component is composed of 180–182 countries, including the new countries born from the dismantling of the former Soviet bloc. In the analysis of the following section we will consider the giant component only.

In our sample, the total value of world imports $w = \sum_{ij} w_{ij}$ increases from about 126 billion in 1962 to 15760 billion in 2008 (all amounts in U.S. dollars). The value of imports in our dataset represents approximately 95 per cent of total world imports in 2008 and slightly lower amounts in the previous years.[6] Not only the trade value but also the number of edges L registers a remarkable increase, passing from 7870 in 1962 to 21123 in 2008. The average in-strengh of each node also increases correspondingly, but average values in this network are not especially relevant, as nodes and edges (in our case, countries and trade flows) are very heterogeneous.

5. A common measure of overall connectivity in networks is *density*, given by $d = L/(N(N-1))$, i.e., the actual number of edges divided by their maximum allowable number. The overall density of the WTN is high compared to many other real world networks, being above 0.50 in recent years, but not all the countries in our sample are connected in every period. In fact, even if the cases in which a country does not trade at all are really exceptional, in our database a country can appear not connected in a given year for a number of reasons. For example, some countries did not report their data to the IMF in a given year.
6. Our dataset does not cover all trade flows registered in a given year because some exchanges are covered by secrecy for security or similar reasons (e.g., arms trade) and the origin and/or destination of the flow are not recorded.

4. COMMUNITIES IN THE WORLD TRADE NETWORK

Consider now a directed, weighted, strongly connected network (or, if not connected, its giant component). Roughly speaking, a subset $\mathbb{C}_h \subset \mathbb{N}$ is called a *community* if the total weight of the edges internal to $\mathbb{C}_h$ is much larger than that of the edges connecting $\mathbb{C}_h$ to the rest of the network. In other words, community analysis looks for non-random distributions of links between nodes, generating groups of nodes more tightly connected than the network average. In our WTN, a community arises if a subset of countries is trading relatively more (in a sense specified below) among them than with the rest of the world. This can occur for a number of reasons, but it is the effect that we expect to observe if a PTA is indeed promoting trade among its members, and trade within the PTA is indeed preferred to trade with the rest of the world, being more economically convenient. The advantage of using network community analysis is that there is no need to define *ex-ante* the countries' groups, but the data structure itself will reveal them, if any. At the same time, the internal cohesion (or "preferentiality") of these groups and their relevance can be measured taking simultaneously into account the strength of all the bilateral linkages within the group and outside the group, and their structure. In fact, the measures used to assess the significance of candidate communities are influenced not only by relative weight of internal versus external links of the community itself, but also by the relative relevance of the links of outside countries with community members, thereby capturing the possible role of trade diversion.

The community analysis of a given network with nodes $\mathbb{N}$ consists therefore in finding the "best" partition $\mathbb{C}_1, \mathbb{C}_2, \ldots, \mathbb{C}_q$ (i.e., $\bigcup_h \mathbb{C}_h = \mathbb{N}$ and $\mathbb{C}_h \cap \mathbb{C}_k = \emptyset$ for all h, k), according to some criteria (for simplicity, we do not consider possibly overlapping communities), namely the "best" grouping of countries that are close trade partners. Despite a huge amount of contributions in the network analysis literature (Fortunato, 2010), there is not consensus, however, on formal criteria for defining communities and for testing their significance. This is why we will use three different approaches to analyze communities in the WTN.

4.1. Modularity optimization

Finding the partition that maximizes a quality index called *modularity* is by far the most popular method for finding communities in a given network. Originally proposed by Newman and coauthors (Newman and Girvan, 2004; Newman, 2006), this approach has found plenty of applications in diverse areas and has been extended in many directions.

In the case of a directed and weighted network, the modularity Q associated to the partition $\mathbb{C}_1, \mathbb{C}_2, \ldots, \mathbb{C}_q$ is given by

$$Q = \frac{1}{w} \sum_{h=1}^{q} \sum_{i,j \in \mathbb{C}_h} \left[w_{ij} - \frac{s_i^{out} s_j^{in}}{w} \right], \qquad (1)$$

which is the fraction of network weight internal to communities, minus the expected value of such fraction in a random network that has in common the in- and out-strengths with the original one. Thus Q is large (i.e., it tends to 1, due to normalization) when the weight density internal to the sets $\mathbb{C}_h$ (the communities) is large with respect to a random distribution of weights.

Although the best partition (i.e., the one with $Q = Q_{\max}$) cannot be found by exhaustive search even in rather small networks, for computational reasons, many efficient algorithms are available for obtaining a presumably "close to optimal" solution (Fortunato, 2010). We use the aggregative, hierarchical method devised by Blondel et al. (2008), which is considered very effective both in terms of $Q_{\max}$ (i.e., in the capability of finding a partition with high modularity) and in computational requirements (Lancichinetti and Fortunato, 2009).

The results of modularity optimization for all the years of our WTN dataset are in Table 1.[7] In 1962 we obtain $q = 4$ communities with $Q_{\max} = 0.225$. The communities count 55, 44, and 42 countries, plus a very small community formed by only 4 countries. The largest communities essentially coincide with most of Europe and Africa, America, and Asia plus Oceania, respectively. This last community also includes UK and Ireland, still strongly linked to Commonwealth countries. From 1970 onward, the results show $q = 3$ with a similar grouping of

Table 1

World Trade Network statistics in the 1962–2008 period, and the results of the max-modularity community analysis. N: number of countries of the giant component; $\langle k_i^{in} \rangle$: average number of import partner countries; $\langle s_i^{in} \rangle$: average import value (million US dollars); $Q_{\max}$: max modularity; # comm.: number of communities, and number of countries for each community (The composition of each community is available from the authors on request)

.

year	N	$\langle k_i^{in} \rangle$	$\langle s_i^{in} \rangle$	$Q_{\max}$	# comm.
1962	145	54.2	870	0.225	4 [55,44,42,4]
1965	145	64.4	1197	0.223	4 [48,43,40,14]
1970	150	74.1	1949	0.244	3 [51,50,49]
1975	151	80.8	5528	0.238	3 [75,40,36]
1980	151	76.9	12322	0.232	3 [75,42,34]
1985	165	69.2	11383	0.282	3 [70,64,31]
1990	163	78.7	20330	0.260	3 [74,70,19]
1995	182	92.7	26315	0.281	6 [77,73,18,8,4,2]
2000	180	106.7	34432	0.290	3 [76,61,43]
2005	181	113.6	56024	0.294	3 [70,65,46]
2008	181	116.7	87056	0.296	3 [68,66,47]

7. The composition of each community is available from the authors on request.

countries (possibly with the exception of African countries, that tend to become more scattered across communities), and with UK and Ireland shifting to the European community, following their membership of the EEC in 1973. In this case, we see in the change of the community composition the possible effect of joining a PTA.

The number of communities temporarily increases in 1995, when trade flows for the new countries formed by the dismantling of the Soviet bloc start to be recorded, and indeed one of the communities is formed essentially by this group. Over time, the strong ties between these countries loosen up, as they appear no longer as a separate group, but mostly in the large Europe-based community. In 2008 the communities contain 68, 66, and 47 countries, but the largest cluster is now associated to Asia/Oceania, confirming the rapidly increasing role of Asia in international trade. This clustering by continents is very much in line with the large body of literature showing that geographical proximity still matters for international trade and for the formation of trading blocs (e.g., Egger, 2008).[8] A slightly larger modularity appears over time, reaching $Q_{\max} = 0.296$ in 2008, but this cannot be immediately seen as an increase in the relevance of our communities, as max modularity generally grows if the size of the graph increases.

The problem we face now is the significance of the obtained network partitions. Maximizing the modularity obviously yields some "best" partition, but this does not imply that the network is actually structured in significant clusters. In our analysis, what emerges in most cases is a partition of the WTN into three (almost continental) blocs, which is the number that many observers expected to emerge "naturally", but that was also seen as a welfare-minimizing situation (Krugman, 1991). This could be a worrisome conclusion, but in fact what really matters for the welfare effects is the extent of intra-bloc preferences (Frankel et al., 1998). If the three blocs are scarcely significant in terms of relevance of intra-bloc trade with respect to inter-bloc trade, welfare implications would be very different. This is why assessing the significance of the partitions is relevant.

Although a large value of $Q_{\max}$, *per se*, should reveal that the network has a modular organization (as it measures a kind of "dissimilarity" between the network and its randomizations), a large value of $Q_{\max}$ can even be obtained in random (i.e., Erdős-Rényi) networks, which instead are expected to have no community structure by construction (Reichardt and Bornholdt, 2006). In addition, the values of $Q_{\max}$ we obtain can hardly be considered to be large (compare, e.g., with the results reported by Newman (2006)). So, finding the partition that maximizes Q by no means concludes the community analysis of the network (Fortunato, 2010). For undirected, unweighed networks, some methods have

8. We also note that, in terms of the number q of communities, our results are qualitatively consistent with Barigozzi et al. (2011), where a value of q ranging from 2 to 4 is reported for the period 1992–2003 (no modularity value is reported, however, in that paper).

been proposed for complementing the max-modularity approach with a test of statistical significance. These methods, however, have some features that make their use problematic in our case. No straightforward extensions exist in the case of weighted, directed networks, for which the definition of randomized models and of suitable perturbation schemes is absolutely not trivial (see Piccardi et al. (2010) for some proposals). For these reasons, in the next sections we will move to completely different approaches for testing the existence and significance of communities in the WTN.

4.2. Cluster analysis

Standard data clustering is aimed at organizing objects into "homogeneous groups", trying to maximize at the same time the intra-group similarity and the inter-group dissimilarity. This needs defining a suitable *distance* among data. When we move to *graph clustering*, i.e., grouping the nodes of a network, which distance should be used is by no means obvious.

We adopt the notion of similarity/distance among nodes proposed in Piccardi (2011), which is based on *random walks*. An N-state Markov chain can straightforwardly be associated to the N-node network[9] by row-normalizing the weight matrix W, i.e., by letting the transition probability from i to j equal to

$$p_{ij} = \frac{w_{ij}}{\sum_h w_{ih}} = \frac{w_{ij}}{s_i^{out}}. \tag{2}$$

The resulting transition matrix $P = [p_{ij}]$ is a stochastic (or Markov) matrix, i.e., $0 \le p_{ij} \le 1$ for all i, j, and $\sum_j p_{ij} = 1$ for all i.

It is important to note that modeling the WTN by (2) corresponds to moving from *absolute* to *relative* trade values, since the flow from i to j is now normalized by the total export flow from country i. This allows to control for countries' different economic weight, and the consequence is that communities, if any, will not necessarily be composed of groups of countries related by large trading, but instead by countries with privileged partnership, namely whose trading is important in relative terms. As mentioned, this can be due to different factors, but certainly it should arise in presence of trade agreements that promote trade between members more than trade with non-members because they give rise to a preferential treatment. Since we expect such communities to be composed of a

9. The study of many problems in network science benefits from some sort of Markov chain approach (e.g., epidemic spreading, navigation, etc. – see, e.g., Barrat et al. (2008); Newman (2010)). Community analysis is one of them, and several contributions have already been published along this vein – we recall Pons and Latapy (2005); Piccardi (2011) among others. See again Fortunato (2010) for a comparative survey.

mixture of large and small economies (Whalley, 1998; WTO, 2011), the use of relative trade values appears to be more appropriate, as absolute measures would *a priori* obscure the position of medium-small countries.

In defining a distance among nodes, we describe the global behaviour of a large number of walkers (a "fleet") started from each node i, and we propose a similarity σ_{ij} between nodes (i, j) defined by

$$\sigma_{ij} = \sigma_{ji} = \sum_{t=1}^{T} \left(\left[P^t \right]_{ij} + \left[P^t \right]_{ji} \right), \tag{3}$$

Then the distance $d_{ij} = d_{ji}$ between nodes (i, j) is defined by complementing the similarity and normalizing the results between 0 and 1:

$$d_{ij} = d_{ji} = 1 - \frac{\sigma_{ij} - \min \sigma_{ij}}{\max \sigma_{ij} - \min \sigma_{ij}}. \tag{4}$$

The rationale underlying the definition of σ_{ij} and d_{ij} is to assign nodes (i, j) a large similarity if a numerous fleet of random walkers started in i makes a large number of visits to j (and viceversa) within a sufficiently small time horizon T.[10] The notion of community induced by this metric, therefore, is that of a subnetwork where a random walker has a large probability of circulating for quite a long time, before eventually leaving to reach another group.

Then a standard hierarchical, aggregative cluster analysis (e.g., Everitt et al., 2011) is used to explore the possible existence of communities. More precisely, a binary cluster tree (dendrogram) is computed by initially defining N groups each containing a single node, and then by iteratively linking the two groups with minimal distance.

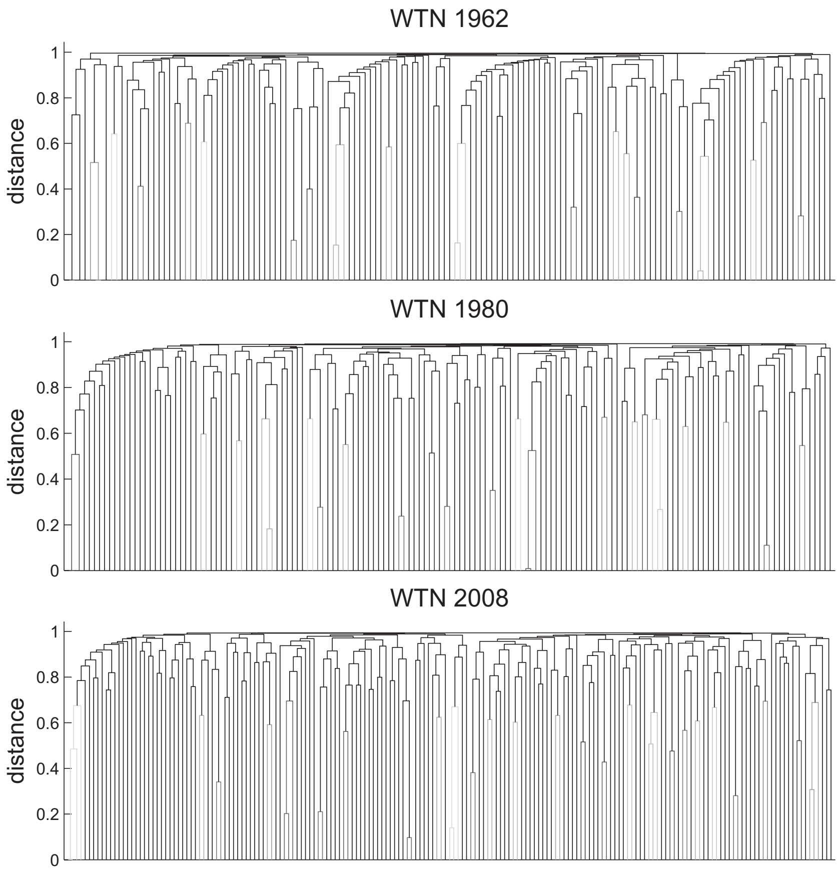
The dendrograms obtained for the WTN in 1962, 1980, and 2008 (i.e., the two extremes of the time window of our dataset, plus an intermediate year) are displayed in Fig. 1 (the full set of dendrograms with the indication of the countries is available from the authors). In the dendrograms, each vertical line corresponds to a node (a country). Horizontal lines ("links") connect two groups of nodes, and the height of the link (as read on the y-axis) is the distance between the two groups.

A clear, visual indication of a clusterized network structure would be the existence of long vertical segments or, equivalently, of links (i.e., horizontal segments) whose height is largely different from the heights of the links below them. In fact, this situation arises when the distance between the two groups joined by the link is much larger than the distance among the nodes forming the two groups – this exactly means that there are clusters in the network. The situation appears to be markedly different in the WTNs' dendrograms: no long

10. See Piccardi (2011) for the technical details on the derivation of similarities.

Figure 1

Three dendrograms obtained by the hierarchical cluster analysis. Vertical lines correspond to countries. Horizontal lines ("links") connect two groups of nodes, and the height of the link (as read on the y-axis) is the distance between the two groups. The absence of long vertical segments denotes weak clusterization



vertical segment is shown and only few distinct groups appear, and they are mostly composed of few countries. Moreover, there seems to be no significant structural differences through the years, possibly with a diminishing visual distance between groups over time.

In all years, some expected patterns can be observed: United States and Canada form one of the closest pairs; France is strongly connected to some of its former colonies; Germany is close to other European countries. Some of these links are very large both in absolute and in relative terms (e.g., between US and

Canada), others are important in relative terms (e.g., over one third of the imports of New Caledonia come from France). Often very small countries are connected to much larger ones, confirming the disassortativity already observed in the WTN (Fagiolo et al., 2008). These links tend to be small in absolute terms, given the small economic size of the countries, but they are very important in relative terms, as they show a strong preference for a given partner.

As pointed out above, the visual analysis of the dendrograms leads us to claim that the WTN, through the years, does not display a significant community structure.[11] In summary, the results of the cluster analysis (although based on the visual evidence only) denote the absence of a strong evidence of the existence of a significant community structure in the WTN. Together with the small modularity level (Sec. 4.1), this is a further clue of a mild community structure of the WTN.

4.3. Persistence probabilities

The final search on the existence of significant communities in the WTN is performed by extracting other quantitative indicators, namely the *persistence probabilities* of the communities. Starting from the N-state network, a given partition $\mathbb{C}_1, \mathbb{C}_2, \ldots, \mathbb{C}_q$ induces a q-state meta-network, where communities becomes meta-nodes. At this scale, the dynamics of a random walker can be described by a q-state *lumped* Markov chain (Kemeny and Snell (1976)) with $q \times q$ stochastic matrix U.[12] Under appropriate assumptions, the entry u_{cd} of U is the probability that the random walker is at time $(t + 1)$ in any of the nodes of community d, provided it is at time t in any of the nodes of community c. We define *persistence probability* of the community c the diagonal term u_{cc} of U. Large values of u_{cc} are expected for significant communities. In fact, the expected escape time from $\mathbb{C}_c$ is $\tau_c = (1 - u_{cc})^{-1}$: the walker will spend long time within the same community if the weights of the internal edges are comparatively large with respect to those pointing outside. The analysis of the persistence probabilities induced on a network by a given partition has recently been proved to be an effective tool for testing the existence and significance of communities (Piccardi, 2011).

For directed networks, the persistence probability u_{cc} turns out to be equal to:

$$u_{cc} = \sum_{i \in \mathbb{C}_c} \frac{\pi_i}{\Pi_C} \sum_{j \in \mathbb{C}_c} p_{ij}, \tag{5}$$

11. We also verified that this result is neither specific to our particular choice of node distance, nor to the choice of considering relative trade values.
12. See Piccardi (2011) for details.

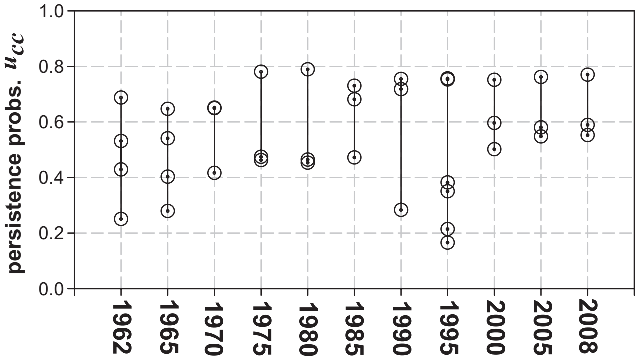
where π_i is the stationary state probability of node i (which satisfies $\pi = \pi P$, e.g., Meyer (2000)), and $\Pi_C = \sum_{i \in \mathbb{C}_c} \pi_i$ is the aggregate over community $\mathbb{C}_c$. Recalling that, in our WTN model, $p_{ij} = w_{ij} / s_i^{out}$, we see that u_{cc} is a convex combination (i.e., a weighted average) of the relative trade flows that the nodes of $\mathbb{C}_c$ direct within the community. Notice that the coefficients of the convex combination are proportional to π_i, which is a well-known measure of centrality (i.e., importance) of node i (e.g. Newman, 2010). From (5), it straightforwardly follows that we obtain $u_{cc} \geq \alpha$, for given $0 \leq \alpha \leq 1$, when all countries of $\mathbb{C}_c$ direct at least the fraction α of their export within $\mathbb{C}_c$. However, we may have $u_{cc} \geq \alpha$ even if $\sum_{j \in \mathbb{C}_c} p_{ij} \leq \alpha$ for some countries i, provided that these countries are those with low centrality.

The measure of cohesion of a community provided in (5) is therefore based on the proportion of trade flows directed within the community (as opposed to the flows directed outside), $\sum_{j \in \mathbb{C}_c} p_{ij} = \sum_{j \in \mathbb{C}_c} w_{ij} / s_i^{out}$, similarly to other standard measures of regionalization of trade flows. But differently from the traditional indices, through π_i it takes explicitely into account the structure of the whole WTN, how the nodes (countries) belonging to the community interact with it, and the relevance of their outside connections for the structure of the community.

We compute the persistence probabilities u_{cc}, $c = 1, 2, \ldots, q$, of the WTNs in the 1962–2008 period for the partition corresponding to the maximum modularity (Sec. 4.1): the results are in Fig. 2. If we individually analyze each single

Figure 2

The persistence probabilities of the World Trade Network from 1962 to 2008. For each year, the circles denote the persistence probabilities of the q communities obtained via modularity optimization (vertical straight lines are for visual aid only). None of the partitions from 1962 to 2000 has all persistence probablities larger than 0.5 (a baseline requirement of significance), whereas this takes place, although with a small slack, in 2005 and 2008. Overall, this denotes a very mild clusterized structure of the WTN over time



community, we discover that most of them turn out to be scarcely significant, as revealed by the small persistence probability. Indeed, let us define a community as meaningful if, for example, $u_{cc} \geq 0.5$: as discussed above, roughly speaking this means that members of community $\mathbb{C}_c$ prefer to trade with other members of the same community at least half of the times. It is a very mild requirement: nonetheless, none of the partitions obtained from 1962 to 2000 fulfills it with all communities, whereas the requirement is met, although with a small slack, in 2005 and 2008, providing a clear indication that the WTN had over time a very mild clusterized structure.

Yet, some important information is conveyed by the analysis of Fig. 2. Even if, in most instances, the partition of the WTN is scarcely significant as a whole, we notice that there is in each case (at least) one community with rather large persistence probability, both in absolute terms, and comparatively with respect to most of the other u_{cc}'s. It turns out that it is a large community which always includes the entire set of European countries, plus a number of minor non-European partners (partially varying from year to year), mainly from North Africa, Near East, and the Asian republics of the former USSR. Up to 1995, there is also another large community with high persistence probability, which includes the entire North America and most of Central and South America, plus China, Australia and many others. Since 2000, however, the community partition dictated by the max-modularity suggests a different arrangement, with North and South America in a community and China and Australia in another one. Notably, both these new communities have a definitely smaller persistence probabilities than before, denoting less exclusive intra-community partnerships.

The evidence emerging from this analysis is partially in line with what can be expected looking at the existence of trade agreements between countries. Most European countries form the European Union (EU), the oldest and deeper custom union in the world, and the persistence of their ties is confirmed by the data. But this analysis also suggests that the EU is not a group of countries separated from to the rest of the world: indeed the observed community includes non-EU members, and the not-too-high persistence probability suggests that trade links with other countries are also important (in 2008, over one third of the European Union imports were coming from non-EU countries). The reported evidence also captures the new active role of China, which became a major player in many areas of the world, less dependent from the US market.

Overall, we can conclude that, as well as the other methods above presented, the evaluation of the persistence probabilities confirms the absence of a strong clusterized structure in the WTN, when considered as a whole. However, the capability of the persistence probabilities of assessing the quality of each single community, differently from the other tools of analysis, puts forward the existence of some significant cluster of countries with privileged intra-community partnerships.

4.4. Testing the significance of PTAs

In a world where international trade takes place according to well-defined preferential partnerships, we would expect to observe a world trading system formed by separated, clearly identified groups of countries, intensely trading within each group, and trading relatively less among each other. If PTAs indeed foster trade between members *and* discourage trade with non-members, significantly distorting trade flows, communities should emerge in the WTN. The evidence presented in the previous sections indicates that the world trading system does not have such a structure. The communities analyzed, arising endogenously from the bilateral trade data, appear mostly weak and scarcely significant in shaping the structure of world trade.

As a further test of the role of PTAs, we computed the persistence probabilities for the communities formed by the existing PTAs, rather than the ones suggested directly by the trade data. In other words, we exogenously impose a partition to the WTN, as defined by the PTAs, and we assess its significance by computing the persistence probability of each group of countries. The existing PTAs and the countries belonging to them were taken from the WTO database (WTO (2011)). Even if many countries are members of more than one trade agreement, and grant some kind of preferential treatment to different group of countries, the list used here includes only plurilateral preferential trade agreements regionally based, so that each country appears at most in one group.[13] The PTAs considered are listed in Table 2, together with the respective persistence probabilities' values in 1990 and 2008.

From Table 2 it is possible to observe that most PTAs have a very low persistence probability, generally lower than the values found for the endogenous partitions, i.e., they do not form significant communities from the point of view of the network structure. If we were again to choose a 0.5 threshold for the persistence probability to define a meaningful community, only the EU would satisfy this criterion, and NAFTA would only come close, but stay below the threshold. Not surprisingly, the values for the African and Asian communities are generally extremely low: it is acknowledged that the trade agreements between these countries are not very effective. The EFTA displays the lowest value, as for its members trade with other European countries is much more important. These results can be due to the fact that, as mentioned, many of these agreements are not exclusive. The EFTA countries, in fact, even if not belonging to the EU, have trade agreements also with the EU.

13. According to these criteria, only four plurilateral agreements listed by the WTO in 2008 are left out of our partition: the Asia-Pacific Trade Agreement, the Economic Cooperation Organization, the Pan-Arab Free Trade Area, and the Global System of Trade Preferences.

Table 2

Persistence probabilities of the communities in the World Trade Network formed by the existing PTAs in 2008. These PTAs were taken from the World Trade Organization database (http://rtais.wto.org/UI/PublicMaintainRTAHome.aspx), where their composition is also listed
.

PTA	*N*	1990	2008
EU	27	0.677	0.671
NAFTA	3	0.397	0.459
ASEAN	10	0.183	0.240
CACM	5	0.129	0.202
CIS	8	n.a.	0.195
MERCOSUR	4	0.075	0.151
ECOWAS	15	0.069	0.122
CARICOM	13	0.078	0.106
COMESA	17	0.048	0.084
ANDEAN	4	0.030	0.070
GCC	6	0.049	0.063
SAFTA	6	0.026	0.049
EFTA	3	0.009	0.006

In any case, the evidence confirms that the existing trade agreements forming PTAs are not giving rise to significant trade diversion, and they do not isolate the member countries from the rest of the world, as they limit the links of non-members to members in a very mild way. The persistence probabilities have increased over time for nearly all PTAs, suggesting that over time international trade has become slightly more regionalized, but never to the extent of showing that regional trade is prevailing. This result is fully in line with the previous results of the paper, that could hardly identify communities in the WTN without pre-imposing any partition. Overall, the results show that most trade agreements do not affect significantly the general structure of world trade as a whole.

5. CONCLUDING REMARKS

In this paper we used different approaches to analyze communities in the WTN. These methods are actually able to identify communities in directed-weighted networks, but in the case of the WTN, all the approaches led to similar conclusions: there is no significant evidence on the existence of a strong community structure in the WTN. The eligible communities found in the data are reasonable, but they are not very significant according to any of the criteria adopted. Even if there is not a single robust measure to identify communities in the WTN, the convergence of results from all the approaches strengthens the robustness of this conclusion. Also the significance of communities formed by the existing PTAs turns out to be very weak, confirming the general result.

The configuration of the WTN therefore suggests that PTAs probably contributed to the general reduction of trade barriers and to the rapid increase of trade links among countries, but many PTAs were not effective in creating special ties between group's members, and generally the element of preferentiality of the agreements did not prevail. This might have occurred for two reasons: the elimination of trade barriers within groups occurred simultaneously with the creation of new trade links across groups because of multilateral liberalizations, and the higher involvement of emerging and developing countries in the WTN. Secondly, the proliferation of the PTAs eroded the effect of exclusivity, and while stronger trade links were created within members of a given PTA, additional strong trade links were created by another agreement with a different group, breaking the cluster in the network. Therefore, in this respect, the effects of the PTAs on trade patterns appear to be weak, and not introducing significant distortions in trade flows.

While globalization of trade in terms of aggregate flows is quite plausible, much stronger community ties could emerge considering trade in specific sectors, where the effect of removing trade barriers can be sizable. Future developments of this work could focus on trade flows between countries in particular commodities, using these aggregate results as a benchmark.

ACKNOWLEDGEMENTS

Lucia Tajoli gratefully acknowledges financial support from PRIN Research Project "The international trade network: empirical analysis and theoretical models".

REFERENCES

Abbate, Angela, Luca De Benedictis, Giorgio Fagiolo and Lucia Tajoli (2012). The International Trade Network in Space and Time, LEM Working Paper 2012/17.

Baier, Scott L. and Jeffrey H. Bergstrand (2004). Economic Determinants of Free Trade Agreements, *Journal of International Economics.* 64: 29–63.

Baier, Scott L. and Jeffrey H. Bergstrand, (2007). Do Free Trade Agreements Actually Increase Members' International Trade?, *Journal of International Economics.* 71: 72–95.

Baier, Scott L., Jeffrey H. Bergstrand, Peter Egger and Patrick A. McLaughin (2008). Do Economic Integration Agreements Actually Work? Issues in Undertanding the Causes and Consequences of the Growth of Regionalism, *The World Economy.* 31: 461–497.

Baier, Scott L., Jeffrey H. Bergstrand and Ronald Mariutto (2014). Economic Determinants of Free Trade Agreements Revisited: Distinguishing Sources of Interdependence, *Review of International Economics.* 22: 31–58.

Bagwell, Kyle and Robert W. Staiger (1997). Multilateral Tariff Cooperation during the Formation of Free Trade Areas, *International Economic Review.* 38: 291–319.

Barigozzi, Matteo, Giorgio Fagiolo and Giuseppe Mangioni (2011). Identifying the Community Structure of the International-Trade Multi-Network, *Physica A – Statistical Mechanics and its Applications.* 390: 2051–2066.

Barrat, Alain, Marc Barthélemy and Alessandro Vespignani (2008). *Dynamical Processes on Complex Networks*. Cambridge: Cambridge University Press.

Bhagwati, Jagdish (1991). *The World Trading System at Risk,* Princeton: Princeton University Press.

Blondel, Vincent D., Jean-Loup Guillaume, Renaud Lambiotte and Etienne Lefebvre (2008). Fast Unfolding of Communities in Large Networks, *Journal of Statistical Mechanics – Theory and Experiment*. P10008.

Bond, Eric W., Raymond G. Riezman and Constantinos Syropoulos (2004). A Strategic and Welfare Theoretic Analysis of Free Trade Areas, *Journal of International Economics.* 64: 1–27.

Chen, Maggie X. and Sumit Joshi (2010). Third-country Effects on the Formation of Free Trade Agreements, *Journal of International Economics.* 82: 238–248.

Deardorff, Alan V. (2011). *Terms of Trade. Glossary of International Economics*. World Scientific.

De Benedictis, Luca and Luca Salvatici (2011). *The Trade Impact of European Union Preferential Policies. An Analysis through Gravity Models.* Berlin: Springer.

De Benedictis, Luca and Lucia Tajoli (2011). The World Trade Network, *The World Economy.* 34: 1417–1454.

De Lombaerde, Philippe, Renato G. Flores, P. Lelio Iapadre and Michael Schulz (2011). *The Regional Integration Manual: Quantitative and Qualitative Methods*. Routledge.

Egger, Peter (2008). On the Role of Distance for Bilateral Trade, *The World Economy.* 31: 653–662.

Egger, Peter, Mario Larch, Kevin E. Staub and Rainer Winkelmann (2011). The Trade Effects of Endogenous Preferential Trade Agreements, *American Economic Journal: Economic Policy.* 3: 113–43.

Everitt, Brian S., Sabine Landau, Morven Leese and Daniel Stahl (2011). *Cluster Analysis, 5th ed.*, John Wiley & Sons.

Fagiolo, Giorgio, Javier A. Reyez and Stefano Schiavo (2008). On the Topological Properties of the World Trade Web: A Weighted Network Analysis *Physica A – Statistical Mechanics and its Applications.* 387: 3868–3873.

Feenstra, Robert C., Robert E. Lipsey, Haiyan Deng, Alyson C. Ma and Hengyong Mo (2005). World Trade Flows: 1962–2000. National Bureau of Economic Research Working Paper 11040.

Fortunato, Santo (2010). Community Detection in Graphs, *Physics Reports.* 486: 75–174.

Frankel, Jeffrey A., Ernesto Stein and Shang-Jin Wei (1998). Continental Trading Blocs: Are They Natural or Supernatural? in Jeffrey Frankel (ed.), *The regionalization of the world economy*. Chicago: University of Chicago Press.

Frankel, Jeffrey A. (ed.) (1998). *The Regionalization of the World Economy*, Chicago: University of Chicago Press.

Fukao, Kyoji, Toshihiro Okubo and Robert M. Stern (2003). An Econometric Analysis of Trade Diversion under NAFTA, *The North American Journal of Economics and Finance.* 14: 3–24.

Furusawa, Taiji and Hideo Konishi (2007). Free Trade Networks, *Journal of International Economics.* 72:310–335.

Garlaschelli, Diego and Maria I. Loffredo (2005). Structure and Evolution of the World Trade Network, *Physica A – Statistical Mechanics and its Applications.* 335: 138–144.

Goyal, Sanjeev and Sumit Joshi (2006). Bilateralism and Free Trade, *International Economic Review.* 47: 749–778.

Kemeny, John G. and J. Laurie Snell (1976). *Finite Markov Chains*. Berlin: Springer-Verlag.

Krueger, Anne O. (1999). Are Preferential Trading Arrangements Trade-Liberalizing or Protectionist? *Journal of Economic Perspectives*. 13: 105–124.

Krugman, Paul R. (1991). Is Bilateralism Bad in Elhanan Helpman and Assaf Razin (eds), *International Trade and Trade Policy*. Cambridge: M.I.T. Press.

Lancichinetti, Andrea and Santo Fortunato (2009). Community Detection Algorithms: A Comparative Analysis, *Physical Review E.* 80, Part 2: 056117.

Magee, Christopher S. (2003). Endogenous Preferential Trade Agreements: An Empirical Analysis, *Contributions to Economic Analysis and Policy*. 2: Online 1538-0645.

Magee, Christopher S. (2008). New Measures of Trade Creation and Trade Diversion, *Journal of International Economics.* 75: 349–362.

Meyer, Carl D. (2000). *Matrix Analysis and Applied Linear Algebra.* SIAM.

Newman, Mark E.J. (2006). Modularity and Community Structure in Networks, *Proceedings of the National Academy of Sciences of the United States of America.* 103: 8577–8582.

Newman, Mark E.J. (2010). *Networks: An Introduction*. Oxford: Oxford University Press.

Newman, Mark E.J. and Michelle Girvan (2004). Finding and evaluating community structure in networks, *Physical Review E.* 69, Part 2: 026113.

Piccardi, Carlo (2011). Finding and Testing Network Communities by Lumped Markov Chains, *PLoS One.* 6: e27028.

Piccardi, Carlo, Lisa Calatroni and Fabio Bertoni (2010). Communities in Italian Corporate Networks *Physica A – Statistical Mechanics and its Applications*. 389: 5247–5258.

Pomfret, Richard (2007). Is Regionalism an Increasing Feature of the World Economy? *The World Economy.* 30: 923–947.

Pons, Pascal and Matthieu Latapy (2005). Computing Communities in Large Networks Using Random Walks, in Yolum, P., Gungor, T., Gurgen, F. and Ozturan, C. (eds), *Lecture Notes In Computer Science*, Berlin: Springer-Verlag.

Ornelas, Emanuel (2005). Endogenous Free Trade Agreements and the Multilateral Trading System, *Journal of International Economics.* 67: 471–497.

Reichardt, Joerg and Stefan Bornholdt (2006). When Are Networks Truly Modular? *Physica D.* 224: 20–26.

Reyes, Javier A., Rossitza B. Wooster and Stuart Shirrell (2009). Regional Trade Agreements and the Pattern of Trade: A Networks Approach, unpublished manuscript.

Saggi, Kamal and Halis Murat Yildiz (2010). Bilateralism, Multilateralism, and the quest for global free trade, *Journal of International Economics.* 81: 26–37.

Serrano, M. Angeles and Marian Boguñá (2003). Topology of the World Trade Web, *Physical Review E.* 68: 015101.

Viner, Jacob (1950). *The Customs Union Issue*, New York: Carnegie Endowment for International Peace.

Westhoff Frank H., Beth V. Yarbrough and Robert M. Yarbrough (1994). Preferential Trade Agreements and GATT: Can Bilateralism and Multilateralism Coexist?, *Kyklos.* 47(2): 179–195.

Whalley, John (1998). Why Do Countries Seek Regional Trade Agreements? in Frankel, J.A. (ed.), *The Regionalization of the World Economy,* Chicago: University of Chicago Press.

Wolf, Nikolaus and Albrecht O. Ritschl (2011). Endogeneity of currency areas and trade blocs: evidence from a natural experiment, *Kyklos.* 64(2): 291–312.

World Trade Organization (2011). *World Trade Report 2011*, Geneva: WTO Publications.