The evolution of trade and scientific collaboration networks in the global wine sector: a longitudinal study using network analysis

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Abstract

Throughout the last three decades the global pattern of wine production has undergone fundamental change, most notably the emergence of New World producers. This study provides a detailed account of the sector's changing global organization by applying network analysis methods to the evolution of international trade and scientific collaboration networks. We argue that there is a strong mutual interdependence of trade and scientific knowledge production, as a result of which we expect the geographical configuration of global knowledge and trade networks to co-evolve. Our results show that over time only a few New World wine producers have developed trade and scientific collaboration networks that resemble those of traditional Old World producers. We also find that structures of trade and scientific collaboration networks are more alike for Old World than for New World producers, which suggests that – contrary to our expectations – it is particularly Old World producers who may have mainly benefitted from participation in international scientific collaboration.

Key words: international trade, scientific collaboration, longitudinal network analysis, wine sector, globalization

1. Introduction

Throughout the last three decades the global pattern of wine production has undergone fundamental change. For centuries, production of wine has been heavily concentrated in a small number of European countries (the so-called 'Old World' (OW) producers of France, Italy, Spain and Portugal). It is only recently that 'New World' (NW) wine producers have taken a more prominent position in the world wine market (Anderson 2004). Both OW and NW producers have invested in the creation of new scientific knowledge in the field of wine production, though motivations differ; while the NW producers aimed at catching-up with the OW producers, the latter strived to renew their capabilities to counter new competition (Cusmano et al. 2010; Giuliani et al. 2011).

This study aims to advance our understanding of the changing global organization of the wine sector. Starting from the premise that it is not only the changing pattern of wine trade that characterizes globalization in this sector, but also developments in global scientific research related to wine, this study addresses the question how patterns of globalization in trade and globalization of scientific knowledge are interconnected. Following earlier exploratory studies of co-authorship in academic publications on wine (Cassi et al. 2011; Glänzel and Veugelers 2006), we investigate the globalization of the wine sector by analysing the evolution of both trade networks and networks of scientific collaboration. On the basis of the existing literature (e.g. Romer 1994, Kline and Rosenberg 1994; Mazzoleni and Nelson 2007) we argue that there is a strong interdependence between science and trade that sets in motion a pattern of interdependent pathways of evolution of the global trade and scientific collaboration networks and their geographical configuration. This implies that we expect that dynamics in one network – for example with regard to the countries that move from the core of the network to its periphery – are mirrored in the other network. This enables us to critically assess, for example, the emergence of NW wine producers and the role of scientific knowledge production and collaboration therein.

To accomplish these aims, this study applies network analysis methods to longitudinal data of international trade and scientific co-authorship. More specifically, through block modelling techniques (structural equivalence), it empirically investigates to what extent these networks exhibit similar dynamics over time. Block modelling partitions countries in a network into groups that are 'structurally equivalent' in that they have strongly similar patterns of relations in the network. Comparing the composition of groups in the trade and scientific collaboration networks – and its dynamics over time –generates insights into mutually interdependent pathways of evolution of both networks. Furthermore, correlating the extent to which a country occupies a core (or peripheral) position in one network with its 'coreness' in the other network at multiple points in time provides clues as to how its position in trade may be a precursor to its position in scientific collaboration or vice versa.

Our study contributes to the literature on globalization in two broad ways. First, to our knowledge, this analysis is one of the first attempts to analyse the joint evolution of trade and scientific collaboration networks. The study elicits the idea that investments in science are not only a precursor to changes in the production and trade of wine (e.g. NW producers use investments in science to catch up with OW producers), but that developments in international trade may at the same time steer and redirect investments and international collaboration in science (e.g. NW producers refocus their science base towards research related to emerging sectors). The results indicate that there is indeed a strong mutual dependence between science and trade that impacts on the way the dynamics of globalization unfold; over time, developments in trade and scientific collaboration networks have increasingly come to run in parallel. Second, the paper further illustrates the value of network analysis as a useful toolbox to assess changing patterns of globalization quantitatively.

The paper is structured as follows. The next section provides the theoretical underpinnings of the argument that trade and scientific collaboration networks co-evolve. Section 3 then describes recent trends in the global wine sector in more detail and Section 4 explains the theoretical foundations of our network analysis methods. Sections 5 and 6 present data and analysis. Section 7 discusses the implications and limitations of our study.

2. Theory: co-evolution of trade and scientific collaboration networks

An import facet of globalization is the increased interconnectedness and interdependence of countries in multiple, overlapping networks (Chase-Dunn and Grimes 1995). In fact, economic globalization can be defined as "*an integrating set of tendencies that operate on the global scale and intensify connections and flows across territorial borders and regions*" (Yeung 2002, p. 288). This conceptualization represents globalization as an *outcome* rather than a *cause;* globalization describes how the global economy is reshaped in response to developments in technology, politics, economy or geography (Yeung 2002). It also explicitly portrays globalization as a set of *multiple* tendencies rather than the mere interconnectedness of countries in trade (Hargittai and Centeno 2001). In the context of our study of the wine sector, it is not only the changing pattern of wine trade that characterizes globalization trends, but also developments in the global production of scientific knowledge related to wine. This raises the question how patterns of globalization in trade and globalization of scientific knowledge production are interconnected. We argue that there is a strong interdependence of science and trade that sets in motion a pattern of mutually interdependent pathways of evolution of global trade and scientific collaboration networks.

First, developments in the global organization of scientific knowledge production impact on global patterns of production and trade. It has long been recognized that access to international scientific knowledge is of utmost importance for the economic catch-up of countries (e.g. Romer 1994; Keller 2004). Since at least the end of the Second World War, science has featured prominently as a main input for economic progress in policy and academic debates. As Vannevar Bush (1945) articulated in a report to the US government, scientific advancement constitutes an essential step to achieve technological innovation and ultimately economic development. This idea is captured in the "linear model of innovation" (see Balconi et al. 2010, for an overview) that suggests that innovation can be represented as a continuum ranging from new scientific discovery to applied research and product development, whereby the former more basic forms of innovation feed into the more applied forms of innovation. Despite that many have cast doubt about how realistic the linear model is (e.g. Kline and Rosenberg, 1986, Mansfield 1991), there is ample evidence that both basic and applied forms of academic research have contributed to the development of technological capabilities across countries and sectors (Mazzoleni and Nelson 2007; Balconi et al. 2010). In fact, several theoretical approaches in the economics of innovation (among others National System of Innovation, Triple Helix, Mode 2 knowledge production) are built around the idea that universities play a key role in economic development by contributing directly to industrial and other forms of applied research (Edquist 2005; Etzkowitz and Leydesdorff 2000).

Following this line of argument, it is argued that a country's science base may steer in which technologies a country develops a stronghold in production and international trade. Thus, countries that aim to enter – or become more dominant in – new sectors would need to set up or enhance the relevant scientific infrastructure and establish international collaborations with places where excellent science is being undertaken (Nelson 2008). In the wine sector, where quality is a major asset for competitiveness, access to and production of scientific research is a key input for product and process upgrading (Archibugi 2007). Along those lines, Aylward (2004) showed that for the Australian wine sector science and innovation were major driving forces for its increasing wine exports. In a comparative study of Chile, Italy and South Africa, Cusmano et al. (2010) showed that scientific and research organizations played a large role in the technological modernization and product standardization of the wine sectors of those countries.

Second, at the same time, developments in global patterns of trade also impact on the organization of scientific knowledge production. Many have challenged the central idea in the linear model that academic research is independent and as such feeds into the development of applications, rather than the other way around. Criticisms (e.g. Kline and Rosenberg 1986, Mansfield 1991) have voiced that technological change is often independent from basic research and in some industries may be an input for – rather than an output of – scientific research. As a result of increased interaction between academia and the world of practice, scientific research tends to take on new research directions in response to demand from practitioners (Gibbons 1994) and may not be as independent from the pressure and needs of industry as the linear model suggests. In the context of the wine industry, Aylward (2006) noted that Australia's R&D agenda was being directed towards region-specific research in response to industry pressures for differentiation and products in higher market segments. This suggests that, countries that aim to enter – or become more dominant in – new sectors would adapt the organization of relevant scientific research towards the needs associated with these ambitions. They may not only invest more heavily in their home base of scientific research for upcoming sectors, they may also show increasing interest in forging stronger connections to worldwide scientific communities, establishing international research partnerships that may provide them access to existing world-class expertise and ongoing research.

Taken together, we take the standpoint that global patterns of production and trade and global patterns of knowledge production and collaboration mutually influence each other. As a result, we expect global networks of trade and global networks of scientific knowledge production to 'co-evolve'. That is, we expect both networks to exhibit similar pathways of evolution over time, most notably regarding changes observed in the countries that are positioned in the core and periphery of both networks. Recent work by Glänzel and Veugelers (2006) showed that trade and scientific outputs in wine appear to be highly correlated, which strengthens us in our expectation that the evolution of trade and scientific collaboration networks may follow similar pathways.

The interdependence of science and technology is by no means limited to high-tech manufacturing sectors. Agricultural sectors increasingly incorporate scientific inputs and, as a consequence, the interaction between academic and industry researchers has become more common and frequent (D'Este and Patel 2008; Fontana et al., 2006; Giuliani et al. 2010). As a result, scientific discoveries and applied research have contributed to augment agricultural productivity (Pardey and Beintema, 2001). In this context, academic research may also more deliberately address the needs of agro-food sectors, where new health and quality standards that producers need to comply with before entering new markets pose technological challenges (Nadvi 2008). The next section zooms into the specific context of the global wine sector, explaining how a framework of co-evolving trade and scientific collaboration network offers a relevant study perspective.

3. Context: the evolution of the global wine industry

Radical changes have been observed in how wine is produced and marketed over the last three decades. This has altered the nature and variety of the actors and their geographical locations. Whereas OW producers (France, Italy, Spain and Portugal) still hold the leadership in production, export and consumption, NW producers (e.g. USA, Australia, New Zealand, Argentina, Chile and South Africa) have gained market share among consumers around the world, up from a mere 2.5% percent of world exports in the early 1980s to more than 35% in 2009 (OIV, 2009). To an increasing extent NW producers have also gained recognition in the high-end segments of the market, which were once dominated by an elite group of OW producers (Anderson et al. 2003). Existing research on globalization in the wine sector has pointed towards two critical developments that may have spurred these developments.

First, the attention of the main OW and NW producers has moved from domestic to international markets (Cusmano et al. 2010). In a situation where, from the early 1980s, domestic markets had to cope with stagnating demand and oversupply, NW producers were quicker to realize that international demand had become essential for the commercial success of wine brands and products (Aylward 2003). Accordingly, in order to operate in a more international, volatile and competitive environment NW producers responded more rapidly by adapting the institutional setting of wine production and marketing. For example, wholesalers, wine experts and oenologists have come to play a greater role in influencing consumption behaviour, in particular of inexperienced consumers in expanding markets like the USA (Gwynne 2008; Lagendijk 2004).

Second, although the wine sector has always been science-based (Unwin 1991), it is suggested that the ‘science behind wine production’ has become a more prominent driver of competitive success in increasingly sophisticated markets (Giuliani and Arza 2009; Morrison and Rabellotti 2007). Since the early 1980s, NW producers have played a major role in establishing and strengthening the emergence of a new paradigm based on a market-driven scientific approach to wine production (Aylward 2003; Cusmano et al. 2010). Universities and public research centres were restructured to adapt to intensified international competition. This new strategy is characterized by academic research priorities being increasingly shaped by market demand, particularly over quality, the only basis for competitiveness in the wine sector (Giuliani et al. 2011). These developments suggest that, since the 1980s, developments in supply, demand and trade of wine have become increasingly interconnected with developments in the production of scientific knowledge about wine. Therefore, this study aims to analyse how NW and OW producers have positioned themselves in international networks of trade and scientific knowledge production, exploring how interdependencies between science and trade may have spurred parallel trends in the evolution of both networks over time.

4. A network approach for studying the evolution of the global wine industry

Starting with the work of Snyder and Kick (1979), the application of network analytic methods to the literature on globalization has brought new and more detailed insights in economic globalization. The application of network analytic methods supports existing descriptive accounts of globalization with empirical evidence. For example, Kim and Shin (2002) demonstrated on the basis of a longitudinal analysis of trade flows between 1959 and 1996 that world trade became increasingly decentralized with increasingly important positions of countries in middle strata. Adopting a similar methodology, Mahutga (2006) showed how a New International Division of Labour has been put in place benefitting a few emerging countries while producing structural inequality for many others.

In general terms, network analysis provides the conceptual and methodological tools to empirically investigate the relational structure among interacting units (Wasserman and Faust 1994). The interest resides in the relationships between actors rather than in the characteristics of actors themselves. A central question is how any specific pattern of relations generates opportunities and constraints for the actors involved. Two broad sets of methods prove useful for this purpose.

First, network structural properties provide measures for identifying cohesion (Kim and Shin 2002), which refers to a group of network properties describing the connectivity and density of a network from the perspective of the network as a whole rather than of its individual actors. In sociology cohesive networks foster the development of trust among its members (Festinger 1954; Coleman 1988). Trust is produced by properties of cohesive networks, via reciprocal, repeated and frequent interactions between the actors who can cross-check information through indirect paths in the network. Further, cohesive networks foster uniformity among nodes in a network, as similar nodes tend to connect to each other and, simultaneously, connected nodes tend to become more similar (McPherson et al. 2001).

Cohesion is also observed in trade, as similar countries (e.g. size, demand patterns) tend to trade more, and develop similar trade patterns over time (Linder 1961, Krugman and Obstfeld 2009). In networks of scientific communities, cohesion is often interpreted as a sign of cognitive lock-in and knowledge decay (Grabher 1993), as nodes in cohesive networks have access to the same information (Burt 1992).

Second, positional analysis identifies patterns of equivalence in the set of relations nodes have in a network. In positional analysis, *blocks* of structural equivalence refer to groups of nodes that "have identical ties to and from identical actors", whereas the term *role* refers to the pattern of relationships within these blocks (Wasserman and Faust 1994, p. 348). In studies of globalization these concepts have proven useful in order to empirically assess theoretical claims such as dependence and unequal exchange in the world economic system. For example, in the literature on world systems (Smith and White 1992) the theory of dependence has been operationalized using the concept of equivalence blocks (e.g. core and periphery), where countries within each block entertain the same relations to the same set of countries.

In our study, we apply the concept of structural equivalence using block modelling techniques to partition all countries in the trade or scientific collaboration networks into groups of countries that have strongly similar patterns of relations in the network. Repeating the analyses at multiple times and comparing the changing composition of groups in the trade and scientific collaboration networks allows for example to analyze whether a NW producer such as Australia has developed patterns of relations in the trade and scientific collaboration networks that have become more similar to each other and more equivalent to the patterns of OW producers.

5. Data and Method

5.1 Data

This paper analyses the dynamics of knowledge and trade networks across countries. The 'scientific collaboration network', includes international co-authorships in wine-related research, whereas trade networks represent international trade of wine.

For the trade network two different sources of data are used; the NBER database (NBER-United Nations Trade Data, 1962-2000) and the COMPENDIUM database (Anderson and Norman, 2006). The former dataset is a generic trade-bilateral dataset reporting data for all the SIC sectors (4 digit), from 1962 to 1999 for all countries. The latter, developed by

Anderson and Norman at the Australian Centre for International Economic Studies, includes a series of national indicators specific to the wine sector and bilateral international trade flows among the main importing and exporting countries between 1994 and 2004. The partial overlap in years between the two datasets allows us to evaluate discrepancies. As shown in Table A1 in the Appendix, COMPENDIUM tends to overestimate the absolute value of traded wine. However, this bias is rectified in our analysis as we use ratios of these values. In order to have a longer time series of data we have merged the two data sources from 1970 until 1993 NBER was used for years 1970-93[1] and COMPENDIUM was used for 1994-2004[2]. We limited our analysis to 24 countries included in COMPENDIUM dataset, and included all countries that were reported at least once over the period 1980-2004 with a yearly share of 1.5% or more traded internationally)[3]. These countries account for more than 95% of the worldwide wine export in 2004 and more than 97% of wine related international collaborations in 2004.

For the scientific collaboration network, we extracted bibliographical data covering 18 years from 1989 to 2006 from the Web of Science edition of the *Science Citation Index Expanded* ™ (SCIE) of the *Institute for Scientific Information* (ISI, Philadelphia, PA, USA). The number of publications is considered an important output measure of research activity (for a critical appraisal see Katz and Martin 1997). As in many similar studies (e.g. Glänzel and Veugelers 2006), we restrict our analysis to the Science Citation Index. In order to select the publication of the research field "wine research" we follow Cassi et al. (2011), who in turn built on Glänzel and Veugelers (2006), combining three search criteria. The first one is lexical, which includes specific search strings applied to keywords, title and abstract of the publication[4]. Second, we have searched all the publications issued in the following three top journals: *American Journal of Enology and Viticulture*, *Australian Journal of Grape and*

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[1] We selected code 1121 of the Standard International Trade Classification.

[2] Since comparison with publication data is possible only for the most recent years (publication data start in 1989) we chose the COMPENDIUM data for the overlapping years of trade data for reasons of coherence.

[3] The selected countries are the following: Argentina, Australia, Austria, Belgium, Bulgaria, Canada, Chile, Denmark, France, Germany, Great Britain, Greece, Hungary, Ireland, Italy, Japan, Netherlands, New Zeeland, Portugal, South Africa, Spain, Sweden, Switzerland, and United States. We excluded former Communist countries (USSR/Russia, FM Yugoslavia, Republic of Moldova, and Czech Republic) for lack of territorial consistency, and some Asian countries (Singapore and Taiwan) were also excluded as COMPENDIUM included only regionally aggregated data.

[4] We used the following search terms: GRAPEVIN* OR WINES OR WINE GRAP* OR WINE PRO* OR RED WINE* OR WHITE WINE* OR WINEMAKING OR ENOLOG* OR VITICULT* OR OENOLOG* OR WINE CELL* OR WINE YEAST* OR WINERY OR WINERIES OR VITIS. In line with Glänzel and Veugelers (2006), we defined and tested the set of search terms. We started our search with the term *wine*, which was however left out as it produced significant noise in the results. Most relevant documents included the term *wine* in title, abstract or as keyword.

Wine Research, and *Vitis*[5]. Third, we excluded publications where at least one of the authors was affiliated to either hospitals or medical schools as these include articles that have no direct relevance to wine production (e.g., research on health benefits of wine consumption). The final dataset contains 12,373 distinct publications.

5.2 Generating the trade and scientific collaboration networks

We developed two networks among 24 countries, the 'scientific collaboration network' based on co-authorship data, and the 'trade network' on the basis of trade flows. While the scientific collaboration network is symmetric and undirected, the trade network is directed and asymmetric. Unlike research on multi-sectoral trade network (e.g. Fagiolo et al. 2008), we treat trade networks as 'directed' for this single sector study. Both trade and scientific collaboration networks are weighted networks indicating the intensity of relationships. For scientific collaboration network, we adopted the Salton index of scientific collaboration widely used in the scientometrics literature (Glänzel and Veugelers 2006). This index measures scientific collaboration between two countries relative to the value of total number of publications. The value of a link between countries *i* and *j* is:

$$v_{ij} = COPUB_{ij} / ((PUB_i * PUB_j)^{1/2})$$

where PUB_i corresponds to the number of publications with at least one author affiliated to one institution of country *i*; $COPUB_{ij}$ counts the number of co-authorships, i.e. the number of publications with, among the affiliations reported, at least one located in country *i* and another one in country *j*. The value v_{ij} ranges from 0 to 1, where v_{ij} is equal to 0 when countries *i* and *j* have no research collaboration, while it is equal to 1 if all the scientific activities done in two countries are in common.

The value of a link between two countries in the trade network has been defined as:

$$v_{ij} = X_{ij} / ((X_i * M_j)^{1/2})$$

where X_i and M_j represents respectively the total value of export of country *i* and import of country *j*, while X_{ij} measures the value of the export of country *i* to country *j* (in dollars of 2000). By construction, we have that $0 \leq v_{ij} \leq 1$ and $v_{ij} \neq v_{ji}$; v_{ij} is equal to 0 when country *i* does not export to country *j*, while it is equal to 1 when country *i* exports only to country *j* and the latter does not import wine from any other countries.

[5] In line with Cassi et al. (2011) and differently from Glänzel and Veugelers (2006), we also included *Vitis,* which is a top field journal.

This measure allows us to measure the growing share of emerging producers in each country. As conventional in research on longitudinal network analysis (e.g. Fleming et al. 2007), we apply a five-year time window procedure from to 1992 to 2004[6].

6. Analysis

6.1 Descriptive statistics

Figures 1 and 2 report trends in terms of international trade and international co-authorships in wine research. Figure 1 shows a steady increase in the total value of worldwide export of wine from 1962 to 2004, and a fourfold increase in the number of international co-authorships between 1994 till 2004. Figure 2 displays a positive trend in the density of both trade and scientific collaboration networks. In the mid-1990s, authors in each country established collaborations with authors in circa one-fifth of all the other countries; five years later this figure doubled. Table 1 reports the share and rank in trade and international scientific collaborations, which indicates that OW producers significantly reduced their share over time, though they still lead the global ranking in export and scientific publications (e.g. France, Italy). In some NW producers, an extraordinary growth in trade has been accompanied by a significant increase in international collaborations (e.g. Australia, Chile, and USA), which suggest that developments in trade and scientific collaboration in wine research may indeed be related[7].

INSERT FIGURES 1 AND 2 AND TABLE 1 ABOUT HERE

6.2 Analysis of the trade network

In this section we investigate the wine trade network using block modelling on the basis of structural equivalence. Block modelling partitions nodes into homogeneous groups of countries that occupy similar positions in terms of hierarchy, power and dependence. That is, the procedure groups those countries that are connected to the same set of countries with similar intensity as expressed by the value of the relationship (Wasserman and Faust, 1994).

[6] In order to make the comparison between the two patterns possible, we normalised each series relative to value in 2000 that it is fixed equal to 100.

[7] It is worth highlighting that many countries, which are not wine producers, do carry out research in wine related fields. This is because international research in wine covers a broad spectrum of disciplines, which have enlarged over time (Cassi et al. 2011; Glänzel and Veugelers, 2006). Therefore universities and research centres might be specialized in scientific fields, such as microbiology, which are relevant for wine but also for a wide range of other applications and sectors. Our interest, however, is geared towards the pattern of collaborations related to wine production.

We apply the block modelling CONCOR algorithm[8], which, by construction, partitions the network into a pre-defined number of groups[9]. Based on the qualitative evidence about globalization in the wine sector (see Section 3), it is fair to assume that the network consists of at least two different groups of producer countries (i.e. OW and NW), plus a group of consumer countries and a remaining group including peripheral countries (either producers or consumers). On the basis of this evidence, we impose a structure of four blocks. As we apply the algorithm at multiple points in time (1974, 1984, 1994, and 2004), we are able to observe the changing composition of blocks, and changing patterns of trade across different blocks over time.

INSERT TABLE 2 ABOUT HERE

Table 2 illustrates the results[10] [11]. Blocks 1 and 2 represent countries specializing in wine production, distinguishing traditional producers, mainly included in Block 2, from emerging exporters in Block 1. Block 4 includes the major international importers, while Block 3 consists of a mixed group of both peripheral producers and emerging importers with little or no production. Accordingly we have labelled these clusters as follows: *core producers* (Block 2), *second-tier and emerging exporters* (Block 1); *core importers* (Block 4) and *peripheral producers/importers* (Block 3).

When zooming in onto the dynamics over time, we observe that Block 2 is composed of a rather stable group of OW producers[12]. Further we observe a relative stable group of importer countries (Block 4) that do not have a significant tradition in wine production.

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8 The software used to compute network indicators and structural equivalence is UCINET VI (Borgatti et al. 2002).

9 CONCOR block modelling clusters countries in 2N groups where N is determined exogenously.

10 Additional partitions at different levels of aggregation (with. three instead of two levels) have been computed also for intermediate periods. This partition identifies eight blocks (the initial four blocks are partitioned in half) and show a stronger fit to a perfect structural block model. This three-level analysis shows results which are coherent with the outcomes of the model with four blocks. For the sake of clarity we report it in the appendix and comment it only when needed (see Table A2).

11 For each year, Table 2 reports a measure of goodness-of-fit, i.e. R^2."The goodness-of-fit of a block model can be assessed by correlating the permuted matrix (the block model) against a "perfect" model with the same blocks (i.e. one in which all elements of one block are ones, and all elements of zero blocks are zeros)" (Knoke 1982; Hanneman and Riddle 2005). The values obtained in our study show reasonable fit and are in line with the values reported in other studies with this kind of analysis (e.g. Salk et al. 2001).However, these results would seem to ask for some consideration of the unexplained variation in the data. For instance, an alternative explanation could be based on a gravity model approach, which could take account also some structural features of the countries, e.g. similarity in size or similarity in demand (usually captured by average income), geographical distance as well as cultural links (e.g language) or historical heritage (e.g. ex-colony).

12 In 1974, also Chile was part of this block of core producers, which may be explained by the colonial legacy that links this country to Spain, as it appears from the 8-block partitioning (see Table A2).

However in some periods, this block also includes important wine producers, such as Germany or the USA.

NW producers are spread over Blocks 1 and 3 in the early observation periods, but, over time, converge into the block labelled emerging exporters (Block 1). In 2004 this block comprises the most prominent NW producers (except the US), which over time have become a more coherent group of countries with stronger similarities in their trade relations. Over time NW producers have developed more intense relations among themselves (within Block 1) and consolidated their position in the main consumer markets (Block 4). However, they have failed to export to emerging markets (Block 3), for which OW producers instead successfully strengthened their trade networks. That is, despite their increasing prominence in terms of export share and market penetration, NW producers still greatly differ in their trade structure from OW producers. Figure 3 displays in greater detail to what extent trade patterns of NW producers have become similar to those of OW producers by plotting the Pearson product-moment correlation over time. Two countries are correlated if they have similar trade patterns, with similar means and variance for the value of the relationships. Over time only Australia – and to a lesser extent Chile and South-Africa – have developed trade patterns similar to the aggregate pattern of OW producers, whereas this development is very marginal for New Zealand and Argentina.

INSERT TABLE 3 AND FIGURE 3 ABOUT HERE

6.3 Analysis of the scientific collaboration network

This section performs a structural equivalence block modelling on the pattern of scientific collaborations (international co-authorships) over the period 1990-2004. In contrast to the analysis of the trade network, we do not have *a priori* evidence pointing to any specific aggregation of countries. Therefore we cannot impose a pre-determined number of blocks, making the CONCOR algorithm less suitable for this analysis. Instead, we analyse structural equivalence in network patterns of countries by computing a Pearson product-moment correlation matrix, which reports the level of structural equivalence of each pair of countries, where two countries are correlated if they have similar patterns of relations with similar means and variance for the value of those relations. This similarity matrix is obtained through a hierarchical clustering procedure (represented by a dendrogram) that partitions the data in a series of successive steps running from a single cluster containing all clusters to a trivial partitioning with each cluster containing a single country. We conduct this analysis for 1994 and 2004. Figure 4 reports the dendrograms that visualize groups of countries according to their similarity in relations in the scientific collaboration network. From left to right, the tree shows partitions with decreasing levels of structural equivalence among the countries (the single country blocks represent maximum structural equivalence).

INSERT FIGURE 4 ABOUT HERE

In 1994, patterns of scientific collaborations differ between OW and NW producers. Roughly three main groups can be identified[13]. The first block, which shows a level of Structural Equivalence (henceforth SE) of 0.44, consists of countries with a high number of publications and strong interconnectedness through international co-authorships. The cluster includes several *core producers* (in particular France, Italy, Spain and Portugal) along with some large importers (e.g. Great Britain, Germany, US, Canada), which are also active players in scientific research related to wine. Small-size OW producers, such as Austria and Greece, form a second block (they reach the highest level of SE = 1). A third block consists of Australia and New Zealand (SE of 1), which, at a less refined level of partitioning, merge with a block of countries including South Africa, Bulgaria and Hungary (SE of 0.5). The remaining two *emerging exporters*, Argentina and Chile, form single-country blocks, as both have very few (internationally co-authored) publications. Overall, the structural features observed in 1994 show little resemblance with trade patterns; instead they resemble the structure found in other scientific fields (Glänzel 2001; Glänzel et al. 1999).

In 2004, the pattern changes with respect to the situation in 1994. *Core producers* form a number of equivalence blocks (e.g. Italy with France – SE = 0.45; Bulgaria with Greece – SE = 0.61; Spain with Hungary – SE = 0.52). Similarly, among *emerging exporters*, Chile forms a block with Argentina (SE of 6.1), South Africa with New Zealand (SE of 0.52) and at higher level of aggregation with Australia (SE of 0.36). Third, wine importer countries form blocks of structural equivalence (e.g. Canada and Japan -SE of 0.61; Belgium and the Netherlands - SE of 0.43; Denmark and Sweden – Se of 0.55). As for the mechanisms driving collaborations, findings seem to suggest that, first, advanced and geographically close economies show equivalent patterns of relations. For example, European countries form a block of neighbouring countries, whereas at the same time economic and scientific leaders,

[13] In order to identify the number of clusters we consulted the measures of cluster adequacy (see Tables A.3 and A.4 in the appendix).

such as the USA and Germany, also form a block. Second, blocks form according to their trade specialization.

Overall, in 2004 we observe a higher similarity between patterns of trade and patterns of scientific collaborations. The trend of convergence in patterns of relations is illustrated in Figure 5, which depicts the similarity in scientific collaboration network relationships of various *emerging exporters* against the pattern of relationships of *core producers,* as evidenced by the Pearson cross-product correlation. Similar to the trends in the trade network, Australia's pattern of international co-authorships has become more similar to that of *core producers.* To a lesser extent we can observe a similar trend for South-Africa, New Zealand, Chile and Argentina.

INSERT FIGURE 5 ABOUT HERE

6.4 Co-evolution of the trade and scientific collaboration network

When comparing developments in the trade and scientific collaboration networks (for 1994 and 2004) we observe that patterns of relations in scientific collaboration do not fully align with those found in trade. Nevertheless, significant overlap in trends between globalization in trade and scientific collaboration networks have become more visible over time, pointing towards a pattern of co-evolution between trade and scientific networks, as discussed in Section 2.

In order to explore these issues further, we compute for each network a measure of *coreness* over the period 1994-2004 (i.e. 11 network observations). 'Coreness' (Borgatti and Everett 1999) refers to the degree of closeness of each node to a core of densely connected nodes in the network. It is worth noting, while all countries in the network's core are highly central as calculated by virtually any measure, the opposite (that central countries are necessarily in the core) is not true. The coreness algorithm, provided in UCINET VI, fits a continuous model of core/periphery structure to the network data, attributing high values to countries in the core of the network and low values to countries in the network's periphery. Subsequently, we calculate a Pearson correlation coefficient for coreness values between knowledge and trade networks for different groups of countries, as reported in Table 4 and displayed in Figure 6. Two main findings emerge from this analysis.

INSERT TABLE 4 AND FIGURE 6 ABOUT HERE

First, wine producing countries, and most notably *emerging exporters* and *core producers*, show a remarkably higher correlation than non-wine producers. This result clearly suggests that access to international scientific sources do matter to competitiveness in the global wine market. However, this simple correlation does not imply that international research is a prerequisite for export success. Following the literature in the field (Aylward, 2003; Glänzel and Veugelers, 2006; Cusmano et al. 2010), we are inclined to think about this positive association in terms of co-evolution between scientific research and trade networks.

The second remarkable finding concerns the different correlation coefficients between *emerging exporters* and *core producers*. Although the increasing role of the 'science of wine' firstly and prominently influenced *emerging exporters*, the group of *core producers* reports a higher correlation coefficient. This suggests that particularly countries in this group may have benefitted from engaging with international sources of knowledge.

7. Discussion

This study has provided a detailed account of the changing global organization of the wine industry. To our knowledge, this study is one of the first attempts to analyse the co- evolution of trade and scientific collaboration networks. By applying network methods to the evolution of trade and scientific collaboration networks in the wine sector it has increased the depth of our understanding of globalization in this sector. More precisely, this study has yielded the following insights.

First, our analysis revealed that there is substantial overlap in trends between globalization in trade and scientific collaboration networks, and that similarities have become stronger over time. However, while trade networks show some neat and rather persisting features (e.g. cohesion, stable blocks) across our observation period (1974-2004), the scientific collaboration network is characterised by a more heterogeneous and volatile structure. In particular, we found that structures of trade and scientific collaboration networks are more alike for OW than for NW producers. That is, scientific collaboration of OW producers tends to take place with the same group of countries they trade wine with. For NW producers, by contrast, scientific collaboration networks are relatively dissimilar to their respective trade networks. Although New World countries have become established wine producers, their patterns of trade and in particular knowledge relations only partly resemble those of OW producers. This suggests that it is particularly OW producers who may have benefitted from participation in international scientific collaboration, even though it was arguably the NW producers which were take the lead in moving towards a stronger market-driven science-based approach to wine production in order to compete in international markets (Aylward 2003, Cusmano et al. 2010). It is also remarkable given that most countries within the group of *Core producers* have been often depicted as locked in old oenological practices and constrained by too rigid institutional frameworks (EU, 2007).

This finding might indicate that, on the one hand, NW producers are still dependent on scientific knowledge produced elsewhere. Indeed, the traditional dominance of OW producers in the production and trade of wine is still strongly reflected in the structure of the scientific collaboration network. OW producers have retained central positions and strong mutual connectedness in the scientific collaboration network. At the same time, it might also suggest that NW countries are building a set of scientific relations of their own, which better fit the needs of their peculiar production system. Our evidence shows the emergence of homogeneous blocks of countries of South-South scientific collaboration (e.g. Australia, South Africa and New Zealand; Argentina and Chile). In this respect, our conclusion differs from Glänzel and Veugelers (2006) who did not find a strong correlation between NW producers' share in world trade and their volume of wine-based scientific research. This may be explained by the fact that their investigation is based on shorter time series running till 2001, whereas the consolidation of NW producers in the global wine community occurred only after 2001.

Second, this study has revealed variation in the role certain countries play and the position they take in the global dynamics of the sector, beyond the description of broad trends, such as the emergence of a semi-periphery or NW wine producers. Despite the fact that for NW producers overall the similarities between knowledge and trade networks are limited, there is strong heterogeneity among the group of NW producers. Over time we observe early signs of a convergence trend between scientific and trade networks only for a few New World wine producers, most notably Australia, which has developed trade and scientific collaboration networks that resemble those of traditional OW producers. On the contrary, Argentina and Chile have patterns of international trade and knowledge relations that are strongly dissimilar from both OW producers and other NW producers. This suggests that NW producers differ from one another in terms of the 'strategy' they adopt in scientific collaboration.

Taken together, this implies that we find some, yet limited support for the idea that international networks of wine trade and international networks of scientific knowledge production related to wine co-evolve. For OW countries, we find that their traditional dominance in the production and trade of wine is strongly reflected in the structure of the scientific collaboration network. Further, for the case of Australia we find that its trade and scientific network structures have developed increasing similarities over time. That is, for this country investment and international collaboration in science may have paved the way for building and intensifying its wine exports into traditional OW-dominated markets, whereas at the same time these growing exports may have been an entry-ticket for increased collaboration in the arena of international scientific knowledge production. However, for most other NW countries, resemblance in the structure and dynamics across trade and scientific collaboration networks is limited. Notwithstanding the widespread view in the literature that investments in science related to wine have played a major role in driving NW producers to catch-up in the worldwide trade of wine, for most countries this was at least not achieved through scientific collaboration with established wine producers or other target countries for wine export. This challenges the view that the role of science has been a major driving factor of the increasing exports in the same way for all NW countries. Future research should therefore have a more detailed look at the mechanisms and boundary conditions that may underlie the different pathways of development among NW countries. Our network approach has yielded new insights into the changing global structure of the wine sector, but qualitative case study research should now guide us to more detailed explanations in order to obtain fully comprehensive understanding of the changing structure of a worldwide wine sector.

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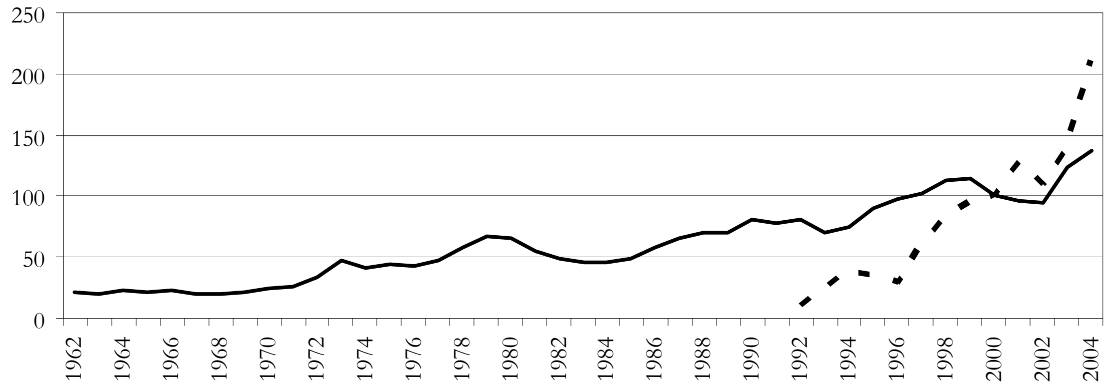
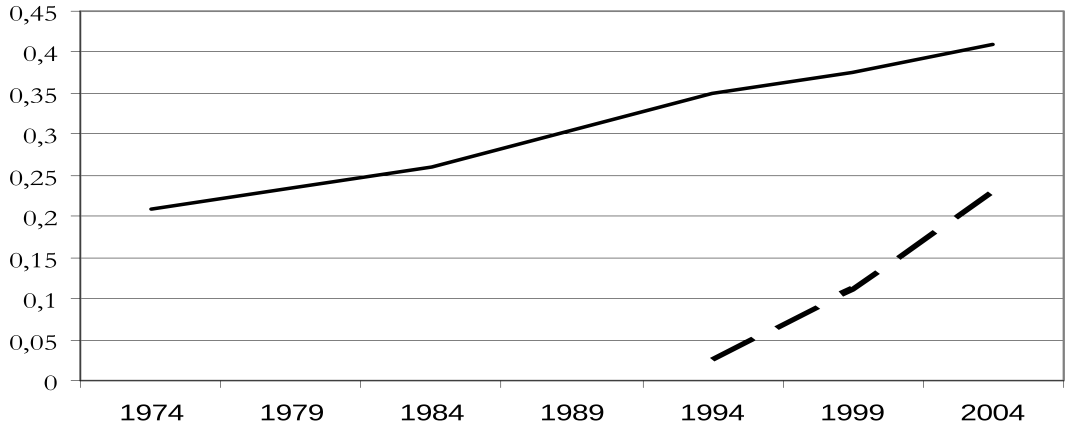
Figure 1: Total amount of worldwide export (continuous line) in constant currency (2000), and total number of international scientific co-publications (dashed line), 2000=100



Source: own elaboration on NBER-COMPENDIUM and ISI data.

Figure 2: Network density of trade network (continuous line), and of knowledge network (dashed line)



Source: own elaboration on NBER-COMPENDIUM and ISI data.

Figure 3: Similarity in trade pattern (Pearson cross-product correlation measure) between *Emerging Exporters* and *Core Producers*

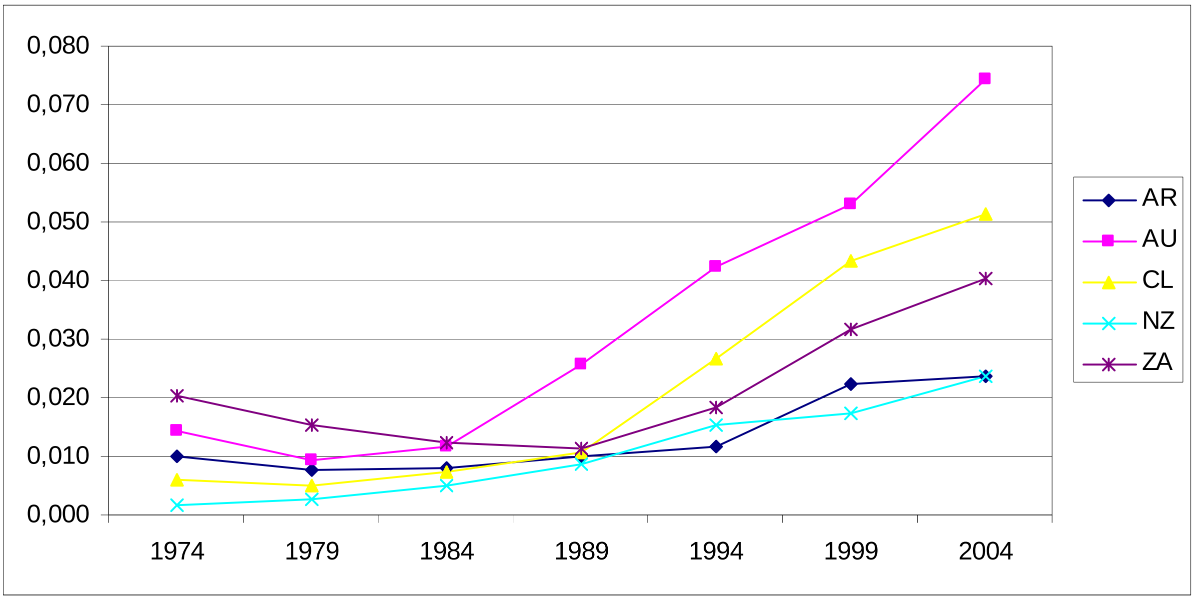
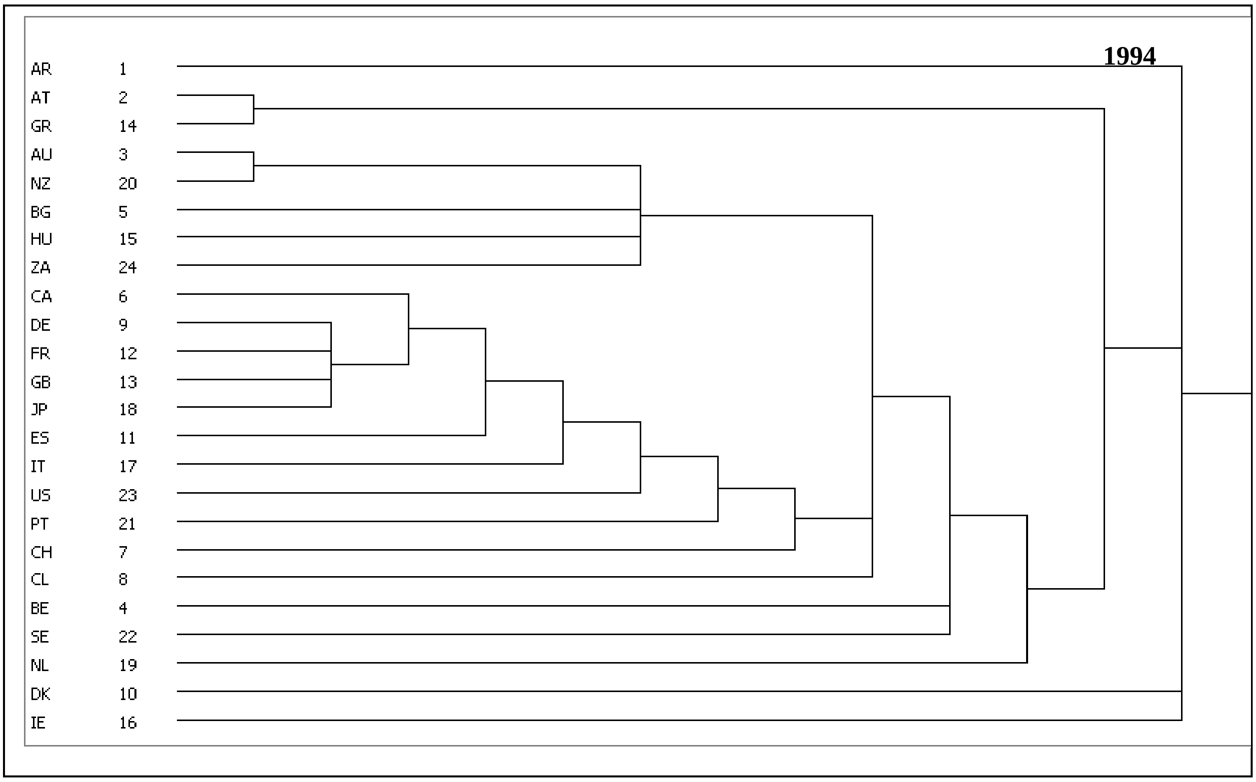


Figure 4: Hierarchical clustering (based on correlation coefficients) expressing similarity in patterns of relations in the Knowledge Network



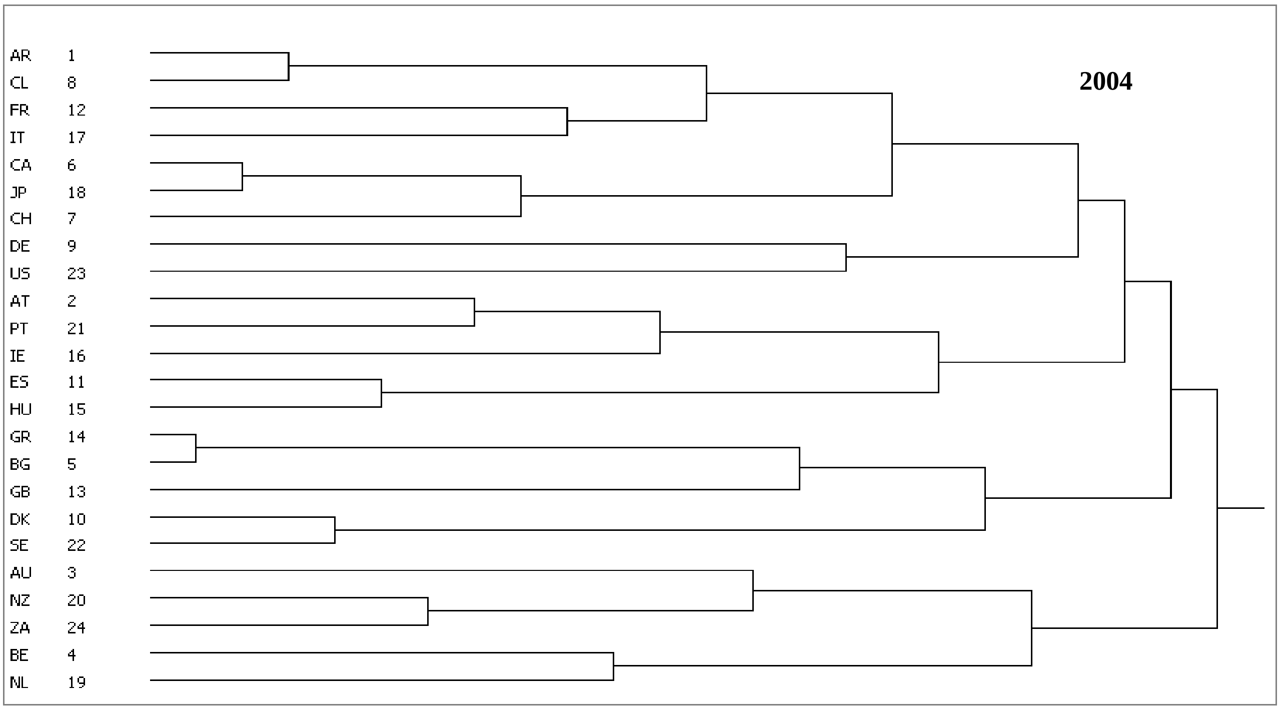


Figure 5: Similarity in pattern of relations in Knowledge network

(Pearson cross-product correlation measure)

between *Emerging Exporters* and *Core Producers*

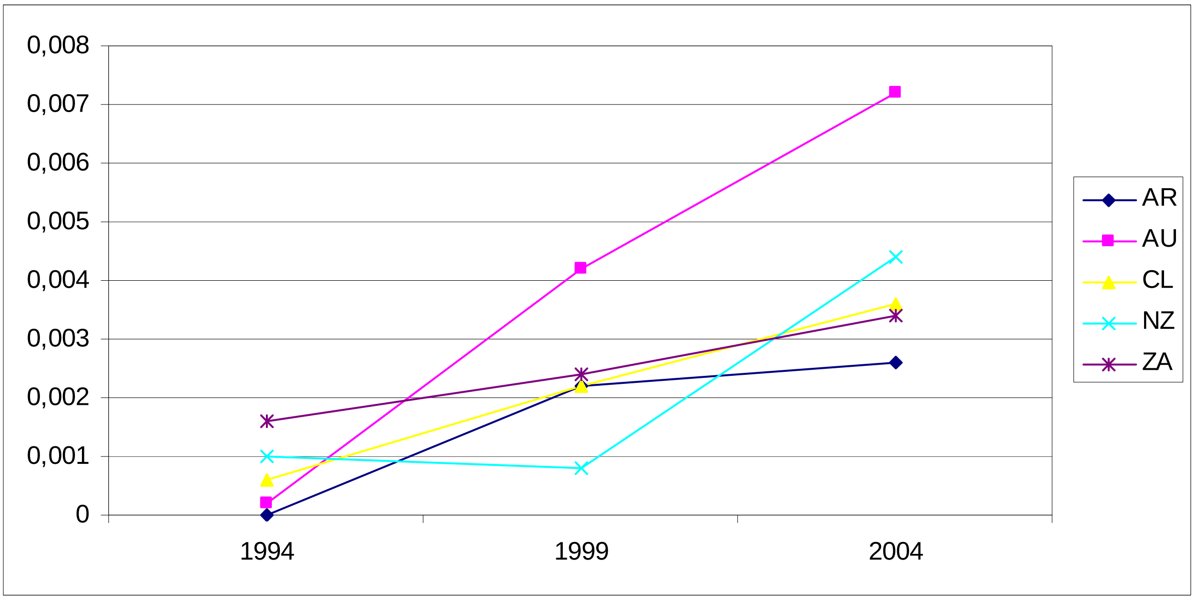
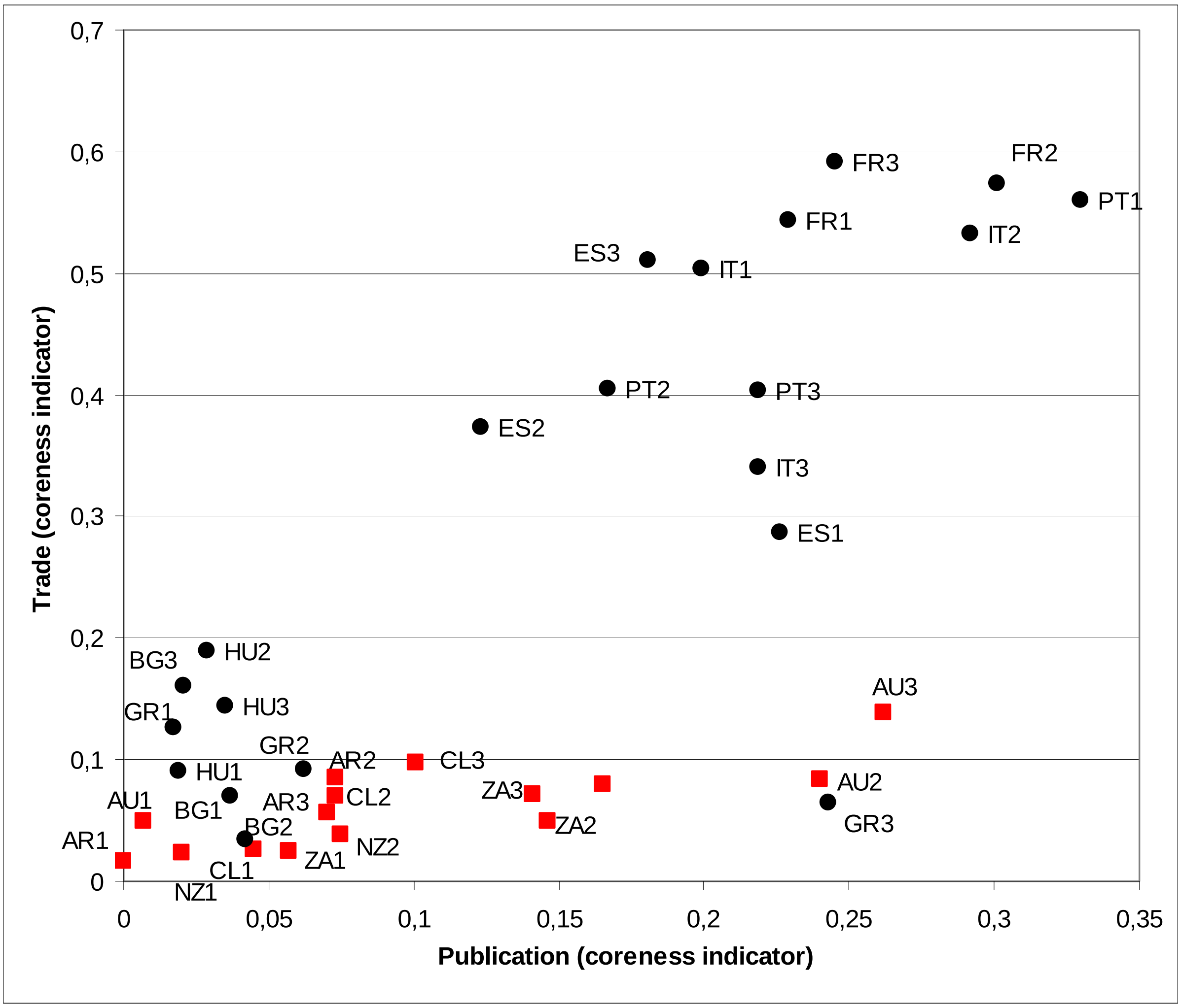


Figure 6: Country-level correlation of coreness values in Knowledge and Trade networks



For each country correlation values are displayed for selected years (1994 (1), 1999 (2) and (3) 2004).
Core producers (black circle) and Emerging Exporters (red square)

Table 1: Descriptive statistics on export and co-publication data

Country	Export average 1990-1994		Export average 2000-2004		Co-Publication average 1990-1994		Co-Publication average 2000-2004	
	Share	WW Ranking	Share	WW Ranking	Share	WW Ranking	Share	WW Ranking
AR	0,35	15	1,07	10	0,00	23	1,17	18
AT	0,29	17	0,41	16	0,47	19	1,32	17
AU	2,40	6	8,26	4	0,93	13	4,78	7
BE	0,41	13	0,66	13	1,40	12	0,97	21
BG	0,77	10	0,47	14	0,93	16	0,51	23
CA	0,01	24	0,07	21	1,86	9	2,03	10
CH	0,13	19	0,15	20	1,86	10	1,88	12
CL	1,30	8	4,65	5	0,47	20	1,17	18
DE	5,75	4	2,97	8	7,91	4	5,19	6
DK	0,06	20	0,31	19	0,47	22	0,92	22
ES	9,01	3	9,26	3	7,44	5	6,97	4
FR	48,47	1	37,58	1	11,63	2	9,66	2
GB	0,38	14	0,97	11	3,72	6	5,80	5
GR	0,81	9	0,40	17	0,47	17	2,09	9
HU	0,71	11	0,44	15	0,93	15	1,53	15
IE	0,01	23	0,01	23	0,00	23	0,41	24
IT	18,64	2	18,10	2	9,77	3	7,12	3
JP	0,03	22	0,01	23	3,26	7	1,98	11
NL	0,30	16	0,40	18	0,93	14	1,68	13
NZ	0,27	18	0,83	12	0,47	21	1,02	20
PT	5,38	5	3,17	7	1,86	8	3,81	8
SE	0,03	21	0,02	22	0,47	18	1,58	14
US	1,82	7	3,85	6	21,86	1	15,82	1
ZA	0,48	12	2,21	9	1,40	11	1,42	16
World	49918 Million of dollars (2000)		71667 Million of dollars (2000)		215 Total number		1966 Total number	

Table 2: Positions of Countries in the Trade Network

	BLOCK 1 *Second tier & emerging exporters*	BLOCK 2 *Core producers*	BLOCK 3 *peripheral exporters and consumers*	BLOCK 4 *core consumers*
1974	Argentina Austria Bulgaria Hungary	Chile; **France** **Greece**; **Italy** **Portugal**; **Spain**	Australia New Zeeland South Africa	**Belgium**; **Canada** Denmark; Germany **Great Britain**; **Ireland** **Japan**; **Netherlands** Sweden; **Switzerland** **United States**
1984	Argentina Bulgaria Chile	Austria; **France** **Greece**; Hungary **Italy**; **Portugal** **Spain**	Australia New Zeeland South Africa	**Belgium**; **Canada** **Denmark**; Germany **Great Britain**; **Ireland** **Japan**; **Netherlands** Sweden; **Switzerland** **United States**
1994	Australia Bulgaria Chile South Africa	**France**; **Greece** Hungary; **Italy** **Portugal**; **Spain**	Argentina New Zeeland Sweden	Austria; **Belgium** **Canada**; Denmark Germany; **Great Britain** **Ireland**; **Japan** **Netherlands**; Switzerland **United States**
2004	Argentina; Australia Chile; New Zeeland South Africa	Bulgaria; **France** **Greece**; Hungary **Italy**; **Portugal** **Spain**	Austria Denmark Germany Sweden	**Belgium**; **Canada** **Great Britain**; **Ireland** **Japan**; **Netherlands** **Switzerland**; **United States**

In bold countries that are stable in one block, all over the period

R2: 0,21(1974);0,12(1984);0,18(1994);0,18(2004)

Table 3: Blocks' features in terms of average export and import share

	BLOCK 1 *Second tier & emerging exporters*	BLOCK 2 *Core producers*	BLOCK 3 *Peripheral exporters/consumers*	BLOCK 4 *Core consumers*
1974				
Average export share (std dev)	0.46 (0.33)	13.63 (14.20)	0.26 (0.22)	0.57 (1.25)
Average import share (std dev)	0.22 (0.35)	2.67 (5.07)	0.24 (0.1)	6.51 (6.17)
1984				
Average export share (std dev))	0.40 (0.24)	11.78 (15.09)	0.21 (0.16)	1 (2.58)
Average import share (std dev)	0.04 (0.02)	1.21 (2.32)	0.31 (0.25)	7.27 (7.08)
1994				
Average export share (std dev)	1.25 (0.85)	13.82 (18.19)	0.21 (0.16)	0.84 (1.7)
Average import share (std dev)	0.12 (0.21)	1.3 (1.86)	0.88 (1.1)	7.35 (6.62)
2004				
Average export share (std dev)	3.36 (3.03)	9.95 (13.87)	0.93 (1.36)	0.78 (1.29)
Average import share (std dev)	0.21 (0.24)	0.9 (1.14)	4.89 (6.01)	7.69 (6.5)

Table 4: Pearson correlation between coreness values of Knowledge Network vs. Trade Network

Prob > |r| under H0: Rho=0

	Observations	**Correlation**
All countries	264	0.30598 (<.0001)
Core Producers countries	77	0.74457 (<.0001)
Emerging Exporter countries	55	0.56075 (<.0001)
Others	132	0.43120 (<.0001)

Appendix

Table A1. Comparison between COMPENDIUM and NBER datasets (export data) overlapping years, 1994-1999 (average value)

Country	COMPENDIUM DATASET		NBER DATASET	
	Millions of dollars (2000)	Percent	Millions of dollars (2000)	Percent
Argentina - AR	118,65	0,93	119,75	0,91
Austria - AT	39,92	0,31	33,91	0,26
Australia - AU	497,85	3,89	568,11	4,33
Belgium - BE	92,35	0,72	65,56	0,50
Bulgaria - BG	137,72	1,08	133,23	1,02
Canada - CA	4,60	0,04	4,02	0,03
Switzerland - CH	27,60	0,22	29,94	0,23
Chile - CL	360,40	2,82	404,79	3,09
Germany - DE	519,55	4,06	538,54	4,11
Denmark - DK	19,09	0,15	8,55	0,07
Spain -ES	1242,12	9,72	1255,15	9,58
France - FR	5406,87	42,29	5467,53	41,72
Great Britain -GB	120,72	0,94	91,90	0,70
Greece - GR	78,43	0,61	77,66	0,59
Hungary - HU	105,39	0,82	93,48	0,71
Ireland -IE	1,80	0,01	3,40	0,03
Italy - IT	2387,59	18,67	2465,74	18,81
Japan - JP	1,96	0,02	3,76	0,03
Netherlands - NL	62,75	0,49	49,36	0,38
New Zealand - NZ	45,84	0,36	61,71	0,47
Portugal - PT	541,20	4,23	545,47	4,16
Sweden - SE	4,73	0,04	4,06	0,03
United States of America - US	371,60	2,91	408,40	3,12
South Africa - ZA	179,86	1,41	195,73	1,49
World	12785,37	100,00	13105,46	100,00

Table A2: Positions of Countries in the Trade Network

	BLOCK 1&2 *Second tier & emerging exporters*		BLOCK 3&4 *Core producers*		BLOCK 5&6 *peripheral exporters and consumers*		BLOCK 7&8 *core consumers*	
1974	Argentina Bulgaria	Hungary; Austria,	France Greece; Italy	Chile; Portugal; Spain	New Zeeland	South Africa; Australia	Belgium; Japan ; Germany; Switzerland	Canada Denmark; Great Britain; Ireland; Netherlands Sweden; United States
1984	Argentina Chile	Bulgaria	Austria; Greece; Hungary	Italy; Portugal Spain France	Australia New Zeeland	South Africa	Belgium;Germany Netherlands Switzerland	Canada Denmark; Japan; Sweden; United States Great Britain; Ireland
1994	Australia; South Africa; Bulgaria	Chile	France; Portugal;	Spain Greece Hungary; Italy	Argentina	Sweden New Zeeland	Austria; Germany; United States	Ireland; Japan Netherlands; Switzerland Belgium Canada; Denmark Great Britain
2004	Argentina; Australia Chile; South Africa	New Zeeland	Bulgaria; Greece; Hungary	Italy; Portugal Spain France	Austria Germany	Sweden Denmark	; Canada Great Britain; Ireland United States	Belgium Japan; Netherlands Switzerland;

R2: 0,41 (1974); 0,35 (1984; 0,40 (1994); 0,41(2004)