Exploring trade-related spillovers: A network approach

Christoph Meister*
&
Bart Verspagen**

* ECIS, Eindhoven University of Technology
** ECIS, Eindhoven University of Technology
& TIK, University of Oslo

c.meister@tm.tue.nl
b.verspagen@tm.tue.nl

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Abstract: This paper suggests a network approach to the analysis of R&D embodied in trade flows. Social network analysis has developed an impressive toolbox of indicators. Unfortunately, most of these have been developed for binary network data only. Also 'qualitative input-output analysis' and 'minimal flow analysis' binarise the available flow data and incur therefore necessarily a loss of information. On the other hand, they provide a powerful body for structural analysis. For that reason we propose to use the quantitive information contained in maximum flow matrices as a starting point and combine these with the further steps of QIOA and MFA.

Keywords: Input-Output Analysis, Network Analysis, R&D, Technology, Europe, United States

JEL: O38, O47, P52

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1. Introduction

At the Lisbon Summit in 2000 the governments of the European Union (EU) agreed on the goal of the EU to become by 2010 "the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion".[1] This overall goal of the 'Lisbon process' has been embedded in a set of policy guidelines that include the following elements:

- Preparing the transition to a knowledge-based economy through better polices for the information society and R&D;
- Stepping up the process of structural reform for competitiveness and innovation and completion of the single market;
- Combating social exclusion and modernizing the European social model by investing in people;
- Sustaining the healthy economic outlook and favourable growth prospects by continuing with an appropriate macroeconomic policy mix and improving the quality of public finance.

To realise these goals, the review of the Lisbon process at the Barcelona Summit in 2002 has explicitly emphasized the importance of Research and Development (R&D). [2] One of its main recommendations calls for an increase in European R&D expenditure with the target to reach 3% of European GDP by 2010, two thirds of this to take the form of business R&D.[3] The main argument behind this target appears to be the concern that even if in the EU knowledge-intensive industries have been partially successful in creating employment over the last decade, productivity developments have been far less favourable (especially if measured against the US). This underperformance is seen as a threat for European competitiveness and economic growth in general and, more specifically, for the achievement of the Lisbon goals and for the growth of national incomes and living standards. A related concern is the fact that the EU performs

[1] Presidency Conclusions, Lisbon European Council, 23 and 24 March 2002, para. 5.

[2] For a broader description and a general assessment of the other goals of the Lisbon process see Dierx and Ilzkovitz (2006).

[3] Cf. Presidency Conclusions, Barcelona European Council, 15 and 16 March 2002 para. 47. For a review of the progress of the Lisbon process up to then see *The Lisbon Strategy. Making Change Happen*, Communication from the Commission to the Spring European Council in Barcelona, COM(2002) 14 final, 15.1.2002.

relatively low in input (business R&D) and output indicators (such as patents) of innovative activity. Public policy, with the aim to promote investment in business R&D, is therefore seen as a key measure to prevent long-term economic decline (European Commission, 2002, Economic Policy Committee, 2002).[4]

In a recent paper (Meister and Verspagen, 2006) we simulated and projected the productivity effects of increased R&D in European manufacturing industries. In our analysis, we took into account not only the direct effect of R&D carried out in a specific sector but also included indirect R&D embodied in intermediate inputs (from both ‚home' suppliers and imports, which included the United States) – for the concept of spillovers see more in the following section. Our results suggest that raising overall European R&D benefits European productivity in many sectors but that it is not a complete solution to the productivity backlog relative to the U.S. We also ran a series of thought-experiments where we targeted specific only. We could show the already 'leading edge' of European sectors gains relatively much as a result of a targeted high-tech impulse. More striking, however, we found that the most dramatic impacts may be expected from raising R&D in so-called low-tech sectors. Surprising that may be, still, this is in line with the analysis by Sandven *et al.* (2005), which stresses the persistent importance of low-tech and medium low-tech sectors in manufacturing output and employment in the OECD economies.

However, what we miss in our analysis is a further examination of these trade-related spillovers. Especially, it is interesting to see how they propagate in the trade network. A better understanding of this propagation helps to address several issues with policy implications. Both 'Qualitative Input-Output Analysis' as well as 'Minimal Flow Analysis' provide instruments for such a structural analysis. Unfortunately, they trade off structuration gains with a loss of information. The paper argues therefore for a modified approach, which uses quantitative information, as a starting point. It starts with a short discussion on the link between R&D and spillovers. Section 3 presents an overview of existing approaches to multisector and multicountry analysis. After a summary of our data, section 5 provides and discusses the results from our analysis. A conclusion sums up the main findings and gives perspectives for further research.

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[4] See also *Productivity. The Key to Competitiveness of European Economies and Enterprises*, Communication from the Commission to the Council and the European Parliament COM(2002) 262 final, 21.05.2002.

2. R&D and spillovers

Economic theorists have accepted the positive link between technological change, productivity and economic growth for a long time. Process innovation provides opportunities for cost reduction. Product innovation enhances either the range of available intermediate inputs for the production process, increasing real output, or increases the availability of consumer products with corresponding welfare gains. Indeed, in modern economies, the inputs of capital and labour alone cannot account for a large part of output growth in modern economies (Solow, 1957). The concept of 'total factor productivity' (TFP) has been widely used as a measure to explain this residual (see Nadiri, 1970).

In a rich empirical tradition of work on productivity growth (e.g., Griliches, 1979), the total factor productivity residual has been related to the accumulation of a 'knowledge stock', which is not accounted for in the measurement of the conventional capital stock but increases output via innovation and technological change. R&D expenditures have been suggested as a way of measuring this knowledge stock, and this has led to a range of works relating R&D expenditures to total factor productivity growth. This is consistent with the notion in 'new growth theory' of non-convexities of R&D and knowledge in output, which results in self-sustaining growth (as in Romer, 1986, 1990).

An important issue in this literature is the idea that R&D not only provides productivity benefits for the firms that undertake it, but also for other firms in similar or somehow related lines of business. This is the notion of R&D spillovers, indicating that the impact of innovation and technology is felt widely rather than being a private pay-off. In this context, Griliches (1979, 1993) pointed to the distinction between knowledge and rent spillovers. Pure 'knowledge spillovers' are externalities arising from the public goods characteristics of technology and research without the need to engage in economic transactions. These externalities can arise from learning, observation and copying such as 'reverse engineering' and 'patenting around'. Other transmission channels result from formal and informal contacts and networks of scientists, professionals, clients and customers, which go beyond market transactions (Mansfield, 1985). Rent spillovers, on the other hand, are defined by a shift of innovation rents from the producer to the user of a certain technology due to competitive market pressures. From the perspective of the whole economy, this constitutes an unwanted measurement error in attributing productivity increases to the wrong entity and can in principle corrected by using adjusted output deflators (Triplett, 1996). Yet for an individual firm, industry or country, such effects result in real benefits with corresponding productivity increases.

Empirically, however, both notions are somewhat difficult to separate, as market interaction can facilitate the exchange of technological knowledge. To reflect the different mechanisms of spillover transmission and absorption the empirical literature uses basically three different weighting schemes to aggregate a stock of indirect, spillover-related R&D. Tansaction-based weights emphasise to some extent the rent spillover component. Usually these are derived from interindustry sales (e.g. van Meijl, 1995), investment flows (e.g. Sveikauskas, 1981) or from a full input-output framework (e.g. Terleckyj, 1974, 1982, Wolf and Nadiri, 1993 or Sakurai *et al.*, 1996). In contrast, weighting by technological distance measures accounts for the fact that the absorption of knowledge spillovers is mediated by the technological proximity between receiver and transmitter. Such distance may be measured by the type of performed R&D (Goto and Suzuki, 1989), the qualifications of researchers (Adams, 1990), the distribution of patents between patent classes (Jaffe, 1986) or patent classifications and citations (Verspagen, 1997a,b). Technology flow matrices in a sense combine the two concepts of technological and 'market' proximity by identifying originators and (potential) users of a technology or an innovation. Scherer's user-producer matrix as well as the Yale matrix have been derived from patent statistics (Scherer, 1982, Putnam and Evenson, 1994). Many empirical studies have found indeed a relatively high influence of R&D and related spillovers to productivity growth but the results depend in some measure on the construction of the spillover variable.[5]

The findings that market transactions and technological closeness matter for productivity imply an extension of any meaningful empirical analysis to the global level, at least to the major trading partners. There is no *a priori* reason why international spillovers should be modelled differently than domestic spillovers. The total technology content of a product or a sector that matters for

[5] See Cincera and van Pottelsberghe, 2001, Mohnen, 2002, and Los and Verspagen, 2003, for recent in-depth reviews of the empirical spillover literature.

productivity contains the R&D performed by itself as well as the technology acquired by inputs from both domestic and foreign sources. For that reason, besides the more static advantages of getting an expanded set of inputs at lower cost (including frontier-technology), international trade is an important source for long-term development and catching-up (Fagerberg, 1987, Abramovitz, 1986). Especially small open economies can benefit disproportionately from international spillovers, not only in a development context (Coe et *al.*, 2002) but also amongst developed countries as shown by Coe and Helpman (1995). In fact it may be argued that the potential of the global R&D stock for catching-up should be *relatively* high for developed economies that already have a high level of absorptive capacities and would yield *comparatively* marginal benefits from investment in education and other social capabilities (Archibughi and Mitchie, 1998).

3. Approaches to multisector and multicountry analysis

Traditional IO analysis

Most of the input-output literature phrases multisector analyses in terms of systems of multiple simultaneous equations (cf. the original work by Leontief, 1936, 1941 or the classic textbooks by Miller and Blair 1985, Schnabl and Holub, 1994 and Schumann, 1968). The basic IO table, as shown in figure 1, consists of three matrices and two vectors. The upper-left quadrant contains the supplying relations between the n sectors of production in the intermediate matrix **Z**. Final demand **Y** on the right contains the domestic components of consumption, investment etc. as well as (net) exports[6]. **Fa** in the lower-left quadrant includes primary inputs like (different types of) labour, indirect taxes and other components of value added. The elements of the two output vectors (i.e. row and column sums) have to be equal for the same sector (that is, $x_i = x_j$ for $i = j$).

[6] If, like in the example table, imports are included as inputs final demand contains total exports. Else imports enter final demand in a negative fashion and contribute to net exports.

	intermediate secors		final demand		
	1	n	domestic	exports	gross output
1	$Z = \{z_{ij}\}$		$Y = \{y_{ik}\}$		$x = \{x_i\}$
n					
primary inputs	$Fa = \{fa_{ij}\}$				
imports					
gross output	$x = \{x_j\}$				

Figure 1 Basic IO table.

By dividing the elements the intermediary relations by output values one obtains coefficients, which describe the technology of production. Depending on the goal of the analysis, one divides either by row sums to get output coefficients $\omega_{ij} = z_{ij} / x_i$ or input coefficients, divided by column sums, $a_{ij} = z_{ij} / x_j$. Especially the latter has been important in the literature – as this coefficient gives the increase in the output of sector *i* that is necessary produce an additional unit of good *j* for final demand. The magnitude of effects in the total economy, which are induced by changes of final demand, is therefore calculated by means of the so-called Leontief inverse, $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$.

From the coefficients it is also possible to identify key sectors which have strong backward and forward linkages in the economy (cf. Rasmussen, 1956, Chenery and Watanabe, 1958; for surveys: Sonis et *al.*, 1995, Dietzenbacher, 2002). The hypothetical extraction method (HEM) is a related yet alternative approach. Basically, it calculates the effects of a sector's hypothetical elimination from the economy (cf. Miller and Lahr, 2001, Los, 2004).

Several studies have linked input-output with innovation indicators to analyse technology flows. DeBresson *et al.* (1994) and the contributions in DeBresson (1996) connect it with R&D expenditure to analyse Italy and other countries. Leoncini *et al.* (1996) link it with R&D employment data to follow technology flows in Germany and Italy. Drejer (1999) links patents and qualifications of (R&D) personal for the Danish economy. The literature of spillover studies using input-output weights has already been mentioned in section two above.

Network approaches

Essentially, any network approach is an application of mathematical graph theory (Busacker and Saaty, 1965). Both fields use, however, a slightly different terminology. Network theory speaks of 'nodes' and 'ties', graph theory speaks of 'vertices' and connecting 'edges'. A directed edge is an 'arc'. While the early theory of networks was developed by mathematicians and social scientists alike, more recent developments were carried out by physicists (Barabási 2002, Buchanan 2002, Watts 2003). Links can be represented in graphs, in a list of ties between nodes or – condensed from the latter – in an adjacency matrix. Given that the intermediate matrix of the IO table represents effectively such an adjacency matrix, it is somewhat surprising that IO analysis rarely resorts to network analytical methods. When doing a literature search we found with Kali and Reyes (2004) only one (and indeed as yet unpublished) paper by economists, which explicitly depicts trade relations in network categories.

On the other hand, the discipline of sociology provides an increasing body of literature, which does just that. It seems that the development of Social Network Analysis by quantitative sociologists (cf. Scott, 1991, Faust and Wasserman, 1994) provided a methodological toolbox for sociologists interested in international political relations and political economy, which has been largely neglected by economists.[7] Much of this literature – starting from the work of Snyder and Kick (1979) – has been based on Wallerstein (1974). Many analyses therefore use trade as one dimension to detect centre-periphery structures in the world system (e.g. Smith and White, 1988, 1992). Others look at globalisation (Krempel and Plümper, 1998, for the motor car sector and Sacks *et al.*, 2001, and Kim and Shin, 2002, with a more general perspective). A third stream examines processes of transition as in the East and central European countries (e.g. Krempel *et al.*, 2001).

Qualitative IO Analysis

Building explicitly on graph theory, Czayka (1972) developed with the so-called 'qualitative input-output analysis' (QUIOA) a branch of IO economics, which has been useful to visualise

[7] Interestingly, business economists interested in organisational issues have been well-aware of network provided by Granovetter and others. And there is, of course, a vast literature on network industries as well as on network externalities.

economic structures. In order to extract important economic linkages QIOA binarises the available IO data. Coefficents or values below a cut-off filter threshold are set to zero; these above are set to one. By exponentiating this binarised adjacency matrix data Czayka calculates linkage matrices for different path lengths. Boolean addition of the latter results in a *dependency matrix* for a given path length. Here, elements are set to one if the sectors are connected to each other, either directly or via intermediary steps. Evaluating these decencies according to the different types of connections (isolated, unilateral linkage and bilateral linkage) Czayka calculates a *connectivity matrix*, which is the starting point for further analysis. By condensing strongly connected sectors into groups and by establishing 'source' and 'sink' sectors QIOA is able to recommend an efficient business cycle policy. It helps to choose a group of sectors which has a relatively small 'input dispersion' to other sectors. By applying a typology of linkages, Czayka is even able to recommend "optimal investment sequences" (ibid.: ch. 5). Jagrič (2004) provides an application with Slovenian data.

The problem with QIOA is clearly the choice of the threshold filter. As a rule of thumb Holub and Schnabl (1994) suggest to set the filter to three times the average transaction value between sectors. For intertemporal analyses Jagrič (2004) proposes to change the filter so that the number of important intermediate flows stays constant over time. Still, the choice is somewhat arbitrary and differing filters lead to different results (Kleine and Meyer, 1982).

'Minimal Flow Analysis' (MFA) was partially developed in response to this criticism. As a more refined rule, Schnabl (1994, 2000, see also Schnabl *et al.*, 1985) calculates connectivity matrices for a set of filter values. These are multiplied and the average is then used for further analysis. In addition, MFA takes into account not only direct linkages like QIOA bit also second- on other higher-round linkages. MFA has successfully employed for the study of national as well as regional economies (e.g. Ghosh and Roy, 1998, for India and Schnabl, 1996, for Baden-Württemberg). Still, even with a refined methodology, MFA relies on binarised data, with the implication of a loss of information from the original available data.

4. Data and methodology

As nodes in the network we have France, Germany, Great Britain and the US. Japan will be included at a later stage. We focus on the manufacturing industry only, which we subdivide into 22 sectors, documented in table 1. The sources of the data are the OECD STAN family of databases as well as the OECD Input-Output database. The newest version of the STAN database, using the ISIC rev. 3 classification, covers the period 1980 – 1999, while the older version of it, using the ISIC rev. 2 classification covers the period 1970 – 1994. Merging these editions and accounting for the different classification schemes we obtain a dataset that covers the period of 1973-1999.

Table 1 Sectors in the analysis.

ISIC rev.2	ISIC rev.2	
15-16	31	Food products, beverages and tobacco
17-19	32	Textiles, textile products, leather and footwear
20	33	Wood and products of wood and cork
21-22	34	Pulp, paper, paper products, printing and publishing
23	353+354	Coke, refined petroleum products and nuclear fuel
24ex2423	351+352ex3522	Chemicals excluding pharmaceuticals
2423	3522	Pharmaceuticals
25	355+356	Rubber and plastics products
26	36	Other non-metallic mineral products
271+2731	371	Iron and steel
272+2732	372	Non-ferrous metals
28	381	Fabricated metal products, except machinery and equipment
29	382ex3825	Machinery and equipment, nec
30	3825	Office, accounting and computing machinery
31	383-3832	Electrical machinery and apparatus, nec
32	3832	Radio, television and communication equipment
33	385	Medical, precision and optical instruments
34	3843	Motor vehicles, trailers and semi-trailers
351	3841	Building and repairing of ships and boats
353	3845	Aircraft and spacecraft
352+359	3842+3844+3849	Other transport
36	39	Other manufacturing

The linking ties are embodied R&D flows. To construct these we get from STAN data for sectoral output, sectoral R&D expenditures as well as bilateral trade flows. The constraining factor is the IO data, which is available for a couple of years only, as given in table 2. Because of that we do not construct complete time series but snapshots for the early 1980s, the mid-1980s and the early 1990s. Data for the mid- and late-1990s will be constructed later from the 'new' OECD IO database. On the plus side, OECD provides separate domestic and imported transaction tables which reference to the potential different use of domestic and imported goods. From the flow data we take 5-year averages around these 'IO years'.

Table 2 Countries in the analysis, available IO data.

	early 80s	mid-80s	early 90s	mid-90s	late-90s
France	1980	1985	1990	1995	
Germany	1978	1986	1990	1995	
Great Britain	1979	1984	1990	1995	
Italy		1985		1998	
USA	1977	1985	1990	1997	
(Japan)	1980	1985	1990	1995	1997

In constructing embodied R&D flows we follow in line with most spillover studies since Terleckyj (1974). Sectoral R&D stocks are constructed by applying the perpetual inventory method, that is

$$\overline{RD}_t = (1-\psi)\overline{RD}_{t-1} + RE_t$$

with *RE* being R&D expenditure, the depreciation rate ψ set to 0.15 and an initial capital stock of 5 times RE_{t+1} (assuming an initial growth rate of 5 per cent).

In order to to attribute the share of R&D undertaken by the supplying sector *i* to the using industry *j*'s technology stock we weigh with ω_{ij} from the IO tables, i.e. the output coefficients, obtained by dividing the cell values through by the corresponding row sums – both from the domestic and imported tables,

$$\omega_{ij} = z_{ij} / x_i$$

> The common idea behind this method is that the 'statistical benefit' industries obtain through R&D embodied in intermediate goods is proportional to the parts of the output of the innovating industry they buy, through rent spillovers. (Los, 2000)

Hence for indirect domestic R&D, we divide the supplier's R&D stock by its output to get intensities and weigh by trade flows and 'domestic' IO coefficients,

$$RD_{ij}^{dom} = \frac{\overline{RD}_i}{x_i} z_{ij} \omega_{ij}^{dom}$$

For indirect imported R&D *from* country *k*, we divide the supplier's R&D stock by its output (in the exporting country) to get intensities and weigh by bilateral trade m^{km} flows and 'imported' IO coefficients,

$$RD_{ij}^{imp} = \frac{\overline{RD_i^k}}{x_i^k} m_{ij}^{km} \omega_{ij}^{imp}$$

5. The R&D-trade network

Overview

As result we get a 110x100 adjacency matrix of intra- and inter-country R&D flows; 5 countries with 22 sectors (table 3).

Table 3 Adjaceny matrix of R&D flows.

	FRA	GBR	GER	ITA	USA
FRA					
GBR					
GER					
ITA					
USA					

Figure 2 presents snapshots of the network on the left-hand side generated by the social network analysis package UCINET (Borgatti *et al.*, 2002). It uses a spring-embedding layout, where the nodes repel each other and the ties, according to their strength, hold the network together. Therefore, 'outliers' have relatively weak ties. With some minor differences (i.e. US 'other manufacturing' is an outlier only in 1985), these pictures do not reveal much dissimilarity. To reveal more details, the right-hand side display different 'layers' of the 1980 network. Obviously, US sectors are grouped much closer together than European sectors. Especially interesting is the strong link between 3825 – computers etc. – and 3832 – telecommunications.

This finding is confirmed in figure 3, which orders the 1980 and 1990 network nodes according to a three-dimensional multi-dimensional scaling algorithm (Kruskal and Wish, 1978). In short,

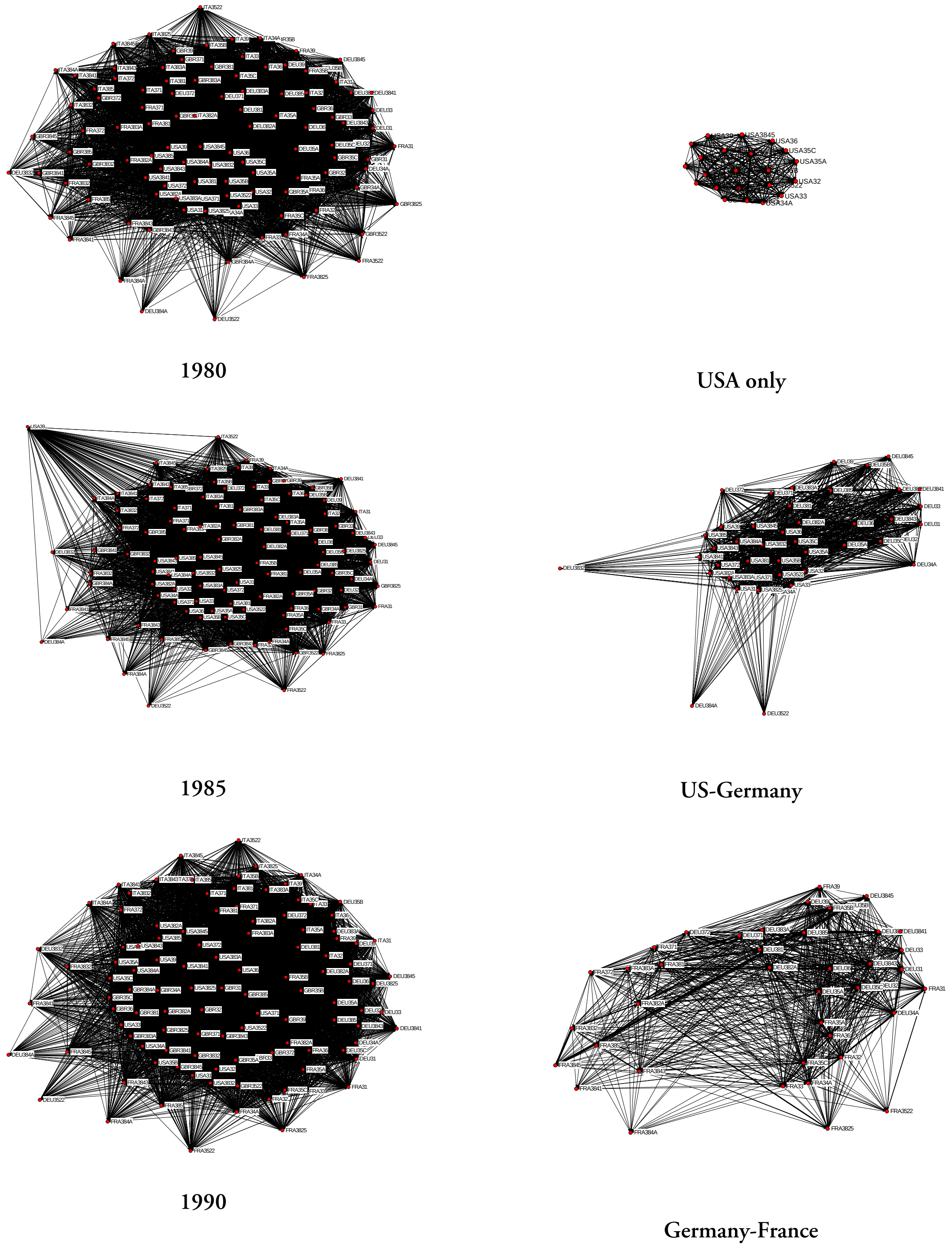

Figure 2 Snapshots of the R&D-trade network.

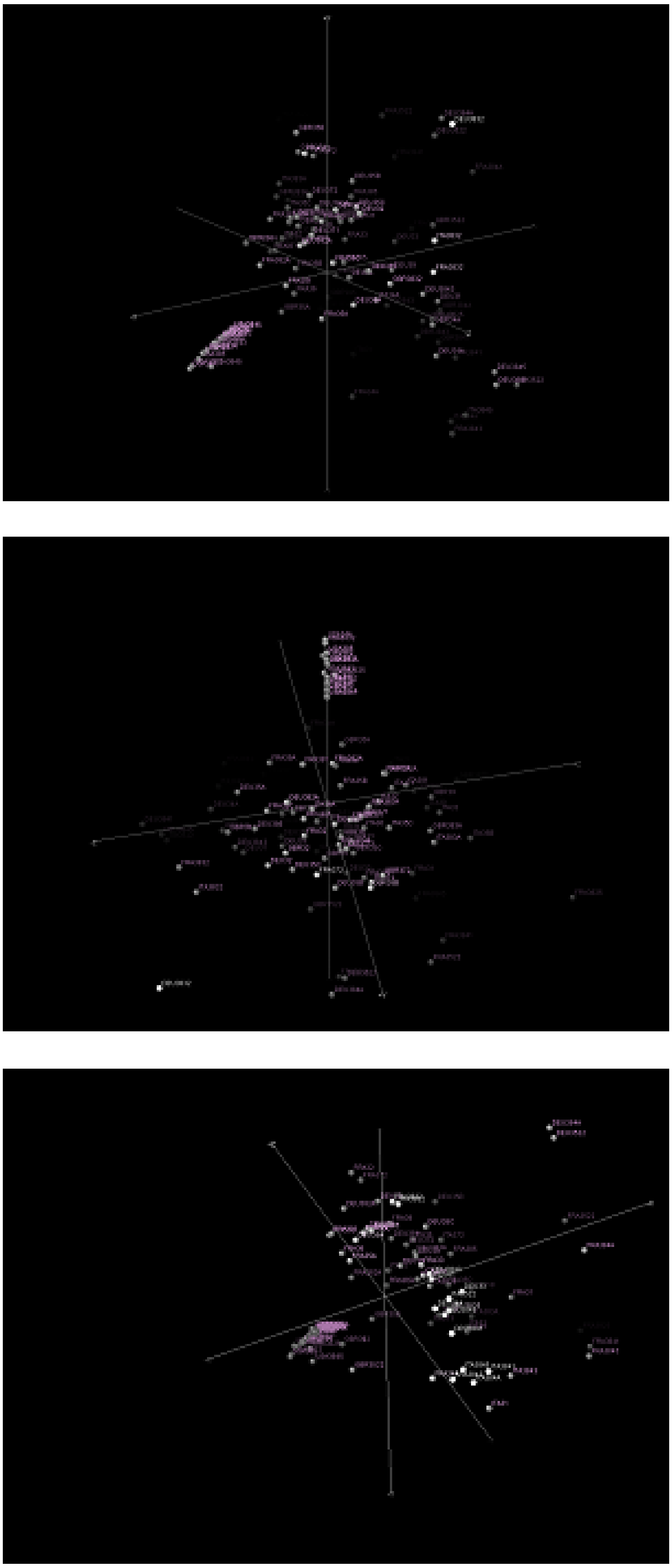

Figure 3 Multi-dimensional scaling: 1980, 1980 turned, 1990.

MDS projects multi-dimensional distances in a lower-dimensional space, while trying to keep the ordering of components intact. Again, American sectors are close together, European sectors are dispersed. This is not an illusion of the three-dimensional representation in a two-dimensional space. A rotation of the image endorses this suggestion (picture in the middle). A comparison of 1980 and 1990 networks (upper and lower picture) seems to propose that the later network has become more compact – nodes have moved closer to each other.

To answer such questions of the overall network structure as well as of the position of individual nodes, social network analysts have developed a plethora of indicators (cf. Scott, 1991, Faust and Wasserman, 1994). Amongst others, measures of density set the realised number of linkages in relation to the potential maximum of linkages possible within the total network. Indegree and outdegree measure the incoming or outgoing linkages of a specific node or give averages for the network. Measures of reach count the accessibility between nodes, both via direct and indirect linkages. They can be refined into measures of centrality, influence or power. It is possible to identify sets of nodes which are tied more closely than others. Combining these indicators has yielded insights on the position and role of specific nodes in the networks as well as on comparative network dynamics (Freeman, 1979). Unfortunately, most indicators have been developed for binary networks only and are not applicable for valued graphs. We therefore propose to use the 'maximum flow' as a measure for connectivity and 'flow betweeness' for centrality.

Maximum flow and connectivity

Issues of flow arise in many directed and valued networks. For instance, in a network of pipes the directed weights can be reinterpreted as capacities of pipes between the individual nodes. Flows in such networks are bounded by two requirements: First, the flow on each tie cannot outrun the tie's capacity. That is, a flow is constrained by bottlenecks in the networks. Second, with the exception of source and sink nodes, the incoming flow has to equal the outgoing flow in each node. The 'maximum flow' between two nodes is thus defined as the flow with the highest possible value amongst all potential flows between them. The example in figure 4 represents a small valued and directed network with one source, one intermediate and two sink nodes. It has thus five possible maximum flows; i.e. $\overrightarrow{1.2} = 10$, $\overrightarrow{1.3} = 8$, $\overrightarrow{1.4} = 10$, $\overrightarrow{2.3} = 8$ and $\overrightarrow{2.4} = 15$. For more complex problems Ford and Fulkerson (1956) provided a first efficient algorithm.

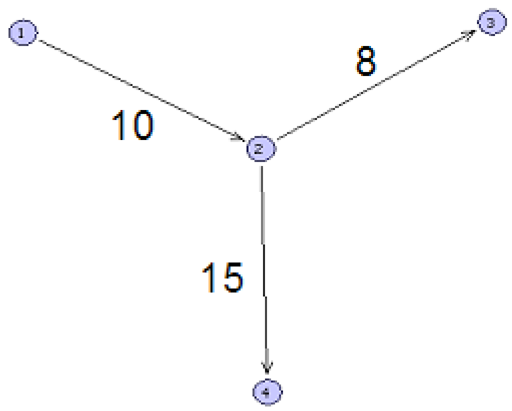

Figure 4 Example flow network.

We use the network analysis package Netminer (Cyram Ltd., 2003) to calculate pairwise maximum flow values between all nodes in our network. The maximum flow matrices for the early 1980s, mid-1980s and early 1990s are given in the appendix. Rank order correlations show strong association between adjacent 'periods', but more structural change between the early 1980s and early 1990s.

Table 4 Rank order correlations.

	mid-1980s	early 1990s
early 1980s	0.95	0.87
mid-1980s		0.92

Given that the maximum flow between two nodes is a weighed measure for their connectivity we propose to replace the binary connectivity matrix of the QIOA approach with maximum flow matrices and use it for further analysis.

6. Conclusion and outlook

In this paper we have suggested a network approach to the analysis of R&D embodied in trade flows. Unlike traditional spillover analysis, which focuses only on the nodes of that network, we think that such an approach can yield additional insights. Social network analysis has developed an impressive toolbox of indicators. Unfortunately, most of these have been developed for binary network data only. Also 'qualitative input-output analysis' and 'minimal flow analysis' binarise the available flow data and incur therefore necessarily a loss of information. On the other hand, they provide a powerful body for structural analysis. For that reason we propose to use the quantitative information contained in maximum flow matrices as a starting point and combine these with the further steps of QIOA and MFA.

We demonstrated some first analyses with data covering the manufacturing sectors of the four biggest European economies as well as the US and for three snapshots from 1980 to 1990. We will extend this further in time. In a second step, a further integration with QIOA and MFA will yield measures of distance and influence between sectors, which are expected to shed more lights on the issue of targeted and broad effects of policy-induced R&D impulses.

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