Technological Interdependence in the Danish Economy - A Comparison of Methods for Identifying Knowledge Flows*

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Abstract

The paper investigates technological interdependencies at the industry level in Denmark, during the period 1979-1991/1992. A mapping of technological interdependencies using a graph theoretical model applying input-output data weighted by different knowledge indicators - R&D expenses, patenting and employees with a technical or natural science degree - is compared to a survey based mapping of interindustrial innovation flows using data from the European Community Innovation Survey.

The minimal flow analysis shows that in the Danish case there are small differences between the interdependencies identified using the three different knowledge indicators. Major knowledge source industries identified with this model are machinery and business services. Among the receiver industries are food, trade and other services.

The comparison between the minimal flow analysis measuring embodied knowledge flows and the innovation flows shows that the input-output based graphs do in fact capture some important technological linkages in the economic system, more specifically the identification of machinery as an important technology source and e.g. food as a major receiver industry. But when there is a need for a more complete picture of how technology, expressed as innovations, flows in the economic system, then the input-output model misses out on some important features. These features are first of all related to the fact that sources of innovation are not necessarily high-tech (knowledge intensive) industries in the traditional sense. Secondly, when it comes to the identification of two-way linkages, then the input-output based method falls short. In the Danish case, two different types of innovative source industries were identified: One type of source industries that are general innovation sources for all or most industries in the system and do not depend to a high degree on user participation in the innovative process (e.g. electronic machinery & apparatus); and source industries that have strong linkages to one or a few receiver industries, with firms in the receiver industries often being active participants in the development process. This type of relation is e.g. found between the paper industry (source) and food (receiver), and the telecommunications (source) and other electronics (receiver) industries.

Thus the paper concludes that input-output based graphs using different knowledge indicators can be very important tools in identifying knowledge flows in an economic system. But if the aim is to identify innovation flows, which are not necessarily the off-spring of high-tech industries in the traditional sense, then there are as yet not sufficient indicators to identify these types of relations, and there is at the present no alternative to innovation surveys.

1. Introduction

The importance of interaction in the process of technological change and innovation is becoming increasingly more recognised. Some more recent references are Lundvall (1985;1990;1992) on user-producer interaction, Smith (1995) on interaction in knowledge systems, DeBresson (1996;1994) on economic interdependence and innovative activity, and Teubal and Zuscovitch (1997) on product differentiation and learning in networks, just to mention a few. But also Pavitt's (1984) empirically based taxonomy recognises the - sector specific - importance of external relations in the innovative process.

The main assumption behind the present paper is that knowledge intensive interindustry linkages play a crucial role for technological development and economic performance. This builds on a perception of the economy as an interdependent system where interaction is a decisive factor for economic existence. Linkage analysis is closely related to the analysis of economic systems, as a system has its own structural peculiarity or "identity" where the relevance of a single unit to a large degree lie in the interactions with other units (Leoncini et al., 1996, p. 416). As such there are also close relations to network theory.

By comparing different methods for identifying knowledge flows the paper investigates technological interdependencies at the industry level in Denmark during the period 1979-1991/1992. The knowledge flows express the interindustrial interdependencies, mainly seen as a one-way relation from producer to user, but as illustrated below, the second step of the analysis will also include the role of the user in the innovative process (feedback to the innovative process).

The first step of the analysis is a mapping of the technological interdependencies between industries on the basis of input-output tables, building on a graph theoretical model (a minimal flow analysis). This model mainly refers back to Schnabl (1994;1995). The analysis uses a variety of technology indicators: R&D expenses, patenting and employees with a technical or natural science degree.

The second step supplements the analysis of technological interdependencies based on input-output statistics with an analysis of "actual" interdependencies, as they were expressed in the

Danish part of the Community Innovation Survey. The Community Innovation Survey was carried out in 1993 and covers the period 1990-1992. Drawing on questions concerning the sales of innovative products (means of production, raw materials or intermediate goods) to firms in other industries, and concerning the active participation of firms in other industries in the innovative development process, patterns of innovation and information flows respectively are identified and compared with the input-output based graphs.

The paper ends up with considerations about the policy relevance of identifying knowledge flows and intersectoral technological relations.

2. The importance of technological interdependence

Viewing the economy as a circular system, economic interaction is a decisive factor for economic existence. The perception of the economy as a circular system goes back to Quesnay's Tableau Economique (18th century), but more recent analyses of economic production as a circular process can be found in Sraffa (1960), and in Pasinetti (1981), who is inspired by Sraffa's model of production of commodities by means of commodities. The empirical focus on economic interaction in terms of flows of physical goods and services dates back to Leontief's input-output analysis (see e.g. Leontief, 1941;1953;1965).

The notions of interdependence and innovation do not relate to a well defined and thoroughly developed theoretical framework. That does not imply though, that theoretical considerations are ignored in the analysis.

The paper deals with three concepts which are all related to economic development: knowledge, technology and innovation. Technology and innovation are often used in a somewhat synonymous way, but it is important to bear in mind that innovation includes novel products, processes, organisational forms etc., which do not necessarily imply technological change. Technology is defined as knowledge, in particular knowledge about scientific and technical processes, i.e. technology is a sub-element of knowledge.

Knowledge is a prerequisite for innovation. Kline & Rosenberg stresses the importance of accumulated knowledge in the process of innovating. Knowledge is defined as the stock part of science, while research is the flow part, which creates new knowledge to add to the accumulated knowledge of the system (Kline and Rosenberg, 1986). It is the use of accumulated knowledge which is essential to modern innovation, not as much in the initiating step as in the whole process of innovation ("central-chain-of-innovation" in the terms of Kline & Rosenberg).

Knowledge in the Kline and Rosenberg sense is accumulated in the system. But in a more narrow sense, knowledge can also be accumulated in a given end-product.

When knowledge is used in the production of a product *a*, this knowledge will be embodied in product *a*. If the product *a* is used as an input in the production system, the embodied knowledge will flow through the system. Even though the user of product *a* does not acquire the total amount of knowledge embodied in the product, he or she will make use of/build upon the knowledge in his or her further processing of product *a* into product *b*. The knowledge embodied in product *b* will be the accumulation of knowledge used in sector A (the sector that produces product *a*) and in sector B (the sector producing product *b*). The amount of knowledge embodied in an end-product will, according to this line of thought, consist of the knowledge accumulated through the process of production.

The accumulation of knowledge described above differs from the knowledge accumulation described by Kline & Rosenberg in dimension - the stock of knowledge in the Kline & Rosenberg sense is the continuous accumulation of knowledge over time *in the whole system*, while the knowledge accumulated in a given end-product is accumulated through a process or flow elements in describing a national system of innovation. An analysis of knowledge flows has important policy implications: a thorough mapping of knowledge flows that uncovers major sources for the spread of knowledge in the economic system can point out which sectors have a widespread effect on the whole system through the diffusion of knowledge in the economic system as a result of transactions between sectors.

When analysing technological change and innovation, a specific element of interaction becomes of importance: The linkages through which sectors not only “transmit” new technology and knowledge throughout the system, but also interact in the creation of new knowledge.

Andersen (1996) presents an evolutionary model for the function of innovative linkages between firms in two different industries. The model starts from a given set of interrelated industries since the growth of some industries depends on the growth of other industries (Andersen, 1996, p. 341). In a complex and relatively stable sectorally composed economic system that has evolved through repeated applications of a specialisation procedure, innovation may take two very different forms. First process innovation may take place without influencing the specifications of products exchanged between firms and industries. In the second form, product innovation will influence the interfaces between firms and industries. In this case innovative activities are the outcome of a match between technological possibilities in the supplying sectors and specific needs in the user sectors. This is where interdependence in the form of technological and innovative linkages becomes of crucial importance: The user needs the supplier in order to get the innovative input, and the supplier needs the demand (and input to the innovative process) from the user.

Moving to empirical considerations, Marengo and Sterlacchini (1989) examines two families of methodologies for quantifying patterns of technological change among sectors. The first group of methodologies uses input-output analysis based on vertically integrated sectors in a focus on embodied (indirect) technology transfers. The second methodology has as its main contribution Scherer’s (1982a;1982b;1984) study of direct technology flows focussing on disembodied technology transfers (identified through patent information). Marengo and Sterlacchini points to the need of an integrated approach that combines direct and indirect methodologies in the analysis of technology transfers since embodied and disembodied transfers are strictly connected as parts of one process of innovation and diffusion. The processes take place through a sequence of stages: indirect technology transfer is likely to be, at least partly, fed by direct transfer and follow it at a later stage of the diffusion process; and finally the overall accordance of the empirical results obtained by different methods suggests that combined procedures are likely to yield empirically relevant results (Marengo and Sterlacchini, 1989, p. 12).

The two methods presented in the present paper supplements each other as the first method strictly deals with embodied transfers, while the second method has a broader view where also the interactive element of innovation and diffusion is included.

2.1. The difference between technological interdependence and spillovers

An analysis of technological interdependence in the sense it is presented in this paper can - somewhat mistakenly - be perceived as a spillover analysis. Spillovers are basically externalities occurring when the actions performed by one entity affects another entity in a positive or negative way without a full compensation being payed for this effect.

According to Langlois and Robertson, (1996, p. 11-12), spillovers can take three forms:

1: Spillovers may result from increases in *consumer surplus* if buyers do not have to pay for the full benefit that they receive from an innovation embodied in a good or service that they have purchased.

2: Spillovers may result from *competitors* of the innovator acquiring the new knowledge at less than the full costs of R&D, that the originator had to pay.

3: Spillovers may result from firms in *other industries* acquiring the knowledge at less than full cost of R&D.

Los and Verspagen (1996) distinguishes between pure knowledge spillovers and rent spillovers. Rent spillovers are obtained through the purchase of innovated products, and corresponds to the first type of spillovers in the Langlois and Robertson definition above. According to Los and Verspagen, rent spillovers are not true spillovers, since they largely are due to “mis-measurement”, in the sense that conventional price index systems are not able to account for quality changes, making price increases, which could be due to improved efficiency, be interpreted as inflation. Knowledge spillovers on the other hand are not embodied in traded goods and this type of spillovers do not, according to Los and Verspagen, occur in relation to market transactions. In stead pure knowledge spillovers occur when information is exchanged during conferences, when an R&D engineer moves from one firm to another, or when a patent is disclosed (Los and Verspagen, 1996, p. 4).

Spillovers of the above kind have been argued to prohibit “efficiency” due to the fact that investment returns are not fully appropriable, resulting in a situation where markets provide an insufficient incentive for the investment in knowledge (e.g. Grossman and Helpman, 1994). In relation to the Langlois’ definition, this would primarily be the case in relation to the second type of spillovers, which involves competitors.

Eliasson (1996) states that spillovers mainly occur through the movement of people and the formation of *integrated complexes of consultants and subcontractors*. Even though Eliasson is convinced that spillovers are true *micro* market phenomena, he does acknowledge that they can be established econometrically on macro data (Eliasson, 1996, p. 126). Technology diffusion and spillovers are not distinguished by Eliasson: the main idea behind his argument is that competence blocks of advanced firms operate as “technical universities” and “research institutes” which *unintentionally* provides free education and research services to other agents in the market. The spillovers are unintentional.[1] The knowledge flows dealt with in this paper, and the sectoral interdependencies which are represented by these flows, are not the unintentional outcome of market imperfections. They are rather a necessary condition for a successful technological and economic development. According to Rosenberg (1982, p. 76) extensive interindustrial technology flows are an important characteristic for advanced industrial societies. Rosenberg actually takes the argument further by suggesting that technology flows have reshaped industrial boundary lines radically, and that interindustry flows merely are expressing that we are working with an outmoded concept of an industry. Whether this is the case or not, Rosenberg states that:

> .. even though only a few industries are research-intensive, the interindustry flow of new materials, components, and equipment may generate widespread product improvement and cost reduction throughout the economy. (...) Industrial purchasers of such producer goods experiences considerable product and process improvement without necessarily undertaking any research expenditure of their own.
> (Rosenberg, 1982, p. 76).

A defendant of the spillover approach would probably argue, that what Rosenberg describes is just the very core of a spillover process, but an important aspect is ignored here: To what extent are the technology sources dependent - also technology wise - on the purchasers? We will come back to this question about technological interdependence in section 4. First section 3 will present the mapping of embodied technology flows and identify the main technology sources and receivers in the Danish economy.

3. A graph theoretical analysis of knowledge flows

Schnabl (1994;1995) presents an input-output based method to analyse interdependences/linkages in an economic system: The minimal flow analysis (MFA).[2] Innovative expenditures weighted by

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1 The less orthodox perception that spillover generation can be intended can e.g. be found in Grupp (1996) who defines technological spillovers as sharing of knowledge with other bodies performing R&D without reimbursement.

2 Other examples of minimal flow analysis can be found in Torre (1992), who decomposes input-output matrices into quasi-autonomous subsets - the so-called ‘filieres’ - which characterise the internal structure of the productive system; and in Cassetti (1995) who uses minimal flows analysis to study

input-output coefficients expressing the economic interdependence between industries are used as expressions of embodied technology flows between industries. I.e. it is assumed that the embodied technology flows are proportional to the innovative expenditures in the innovating industries, as well as to the quantitative extent of the flows of intermediate goods and services between the user and producer industries. The advantage of this method is that it captures the combined effect of innovative activities and the structure of the production system in which these activities are transported, through intermediate commodity flows, from their sources to their final use.

The model identifies embodied technology flows whether these flows are the result of a direct link from one industry to another (e.g. if the paper industry supplies packing material to the food industry) or the flows are indirect via other industries in the system (e.g. if the above mentioned deliverance is supplied through a wholesaler or a similar agent in the wholesale or retail sector). This implies that the technology flows are "screened" for possible intermediate links between the observed industries, and thus it is not possible to distinguish direct from indirect deliverances in the figures.

A minimum value for entries in a transaction matrix is selected. All values exceeding this value are set equal to 1, while all other entries are assigned the value 0. In Schnabl (1995) the method is used for analysing the characteristics of interindustrial technology flows for a national innovation system (Germany 1980-1986). Different technology indicators can be included in the analysis in order to cover different areas of the "innovative landscape". A comparison of the production structure of the German system of innovation in 1980 and in 1986 shows a very stable structure without major changes in the industry structure.

The analysis of technology flows in Denmark uses a slightly moderated version of the model used by Schnabl in the above mentioned analysis. Also, in stead of using innovative expenditures, three different technology indicators are used: R&D expenditures, patenting and employees with a technical or science degree.

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international interindustry linkages.

For a technical description of the model see appendix A.

The graphs are constructed for Denmark for the years 1979 and 1991. Since the model is

3.1. Embodied knowledge flows in Denmark

The analysis only includes national relations. This is due to the lack of information on intermediate flows of goods and services which links information on both source country and industry for a given receiver industry: Information on imports is on the one hand available in the form of imported amount specified on industry and country of origin without any information about which industries might use the imported goods or services as production input; on the other hand as input-output tables where source and receiver industries are identified, but there is no link to source country. This implies that an analysis which includes import relations either must build on the assumption that the level and structure of knowledge is the same in the source country as in Denmark, or, a little more sophisticated, on a pre-determined assumption about the country-composition for a given source industry's deliverances to a receiving industry. As both types of assumptions ascribes a large uncertainty to the outcomes of the analysis, the importance of international linkages will only be dealt with in a general manner in the following.

Construction and trade have a weak dependency on international inputs. But, due to the fact that Denmark is a small open economy, imported inputs to the production play a significant role in all other industries. Textiles, chemical raw materials, the medical industry, telecommunications equipment and instruments are the most important import source industries as compared to their importance as national sources. This implies that a lacking importance of these industries as national knowledge sources can be due to Danish firms in these industries are relatively unimportant knowledge sources. Thus the industries can still be important international knowledge sources even though they do not play an important role in the *nationally bounded* innovation system.

Textiles, chemical raw materials, telecommunications equipment and instruments are also, together with other chemical industry, the iron and metal industry, agricultural machinery, other electronics, transport industry and other services, largely dependent on input deliverances from foreign firms through imports. This illustrates that there is no doubt that knowledge transfers from abroad are of major importance for the technological development especially for a small country like Denmark, and in interpreting the knowledge flows it is important to bear in mind that these transfers are not included in the analysis.

When comparing the flows from the three indicators (figures 1 to 3) a number of common features appear. The patent and research and development indicators both show that machinery is a central knowledge source for a wide range of receivers. Another dominant source of embodied knowledge from the patent indicator is the iron and metal industry.

The two industry groups have the same core set of receiver industries: trade and service industries, construction and food. Iron and metal is also a supplier of embodied knowledge to machinery though, i.e. relations also occur between source industries (these relations are not included in the graph in order to maintain the logic of flows going from left to right). The relations are stable over time, since it is the same industries which are main sources in 1979 and 1991, as it is also largely the same group of industries which are knowledge receivers.

Instruments is a source industry in both periods but with only one receiver (public services in 1979, and the residual group in 1991). From the research and development expenses the medical industry is a source for embodied knowledge in public services in both years analysed. Telecommunication equipment is a knowledge source for construction and public services in 1979, but disappears as a technology source in 1991. This is the case even though the telecommunication equipment industry has increased its R&D intensity during the observed period, i.e. the development is caused by a change in the interindustry trade pattern.

Also using the R&D indicator, construction moves from being a knowledge receiver in 1979 to being a source in 1991, which is due to a considerable increase in the R&D intensity from 0,02% in 1979 to 0,08% in 1991. Even though the R&D intensity increases, construction is among the industries with the lowest R&D intensity during the whole period. But the construction industry has quantitatively large deliverances to other services, which, even though they are weighted by the low knowledge indicator, are large enough to exceed the filter value in 1991.

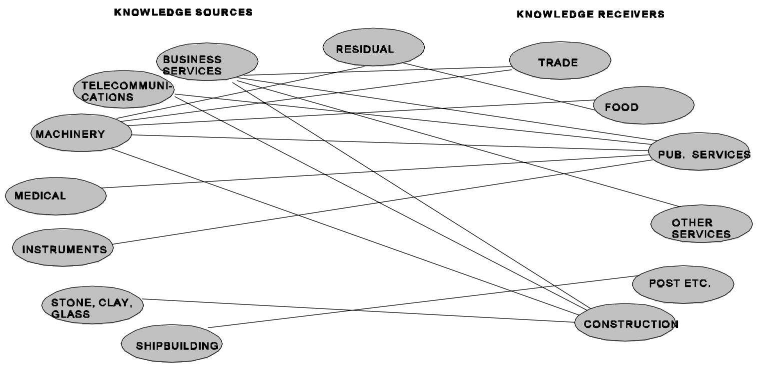
A common feature from the R&D indicator and the education indicator is that business services is a central knowledge source for a number of receivers consisting of other service industries and in 1991 also the food industry.

The education indicator does not identify machinery as a dominating knowledge source. Only in 1991 machinery has knowledge flows to two other industries (food and the residual group). Business services is, as was the case with the R&D indicator, a major knowledge source with several receiver industries. More surprisingly construction is an important knowledge source in both years analysed. This position is due to a medium intensity of technical personnel and quantitatively large deliverances to the other industries in the system. It is doubtful whether construction is in fact a source of knowledge inputs to the production in the receiving industries in all cases. This depends on whether the flows consist of e.g. standardised manual labour services or they consist of specialised engineering services. This illustrates that we are dealing with flows of goods and services that are very heterogeneous with respect to “knowledge content”, and an input-output based analysis cannot capture this heterogeneity.

Also remarkable is the importance of shipbuilding as a knowledge source, but, just as with construction, this industry also has a relatively high intensity of technical personnel compared to the total economy. Chemical industry (excl. chemical raw materials) is a knowledge source for three receiver industries in 1979 (trade, public services and post/telecommunications services etc.), but has lost its importance in 1991.

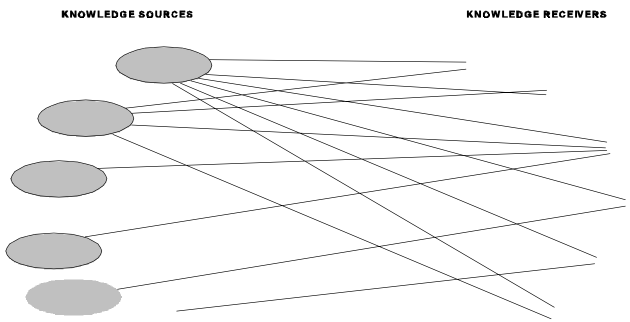
Internally between the knowledge sources flows appear between business services and construction in both years, while stone, glass and clay has flows to construction in 1979, and business services to machinery in 1991.

The graphs show that the overall picture of the knowledge flows between industries is fairly stable regardless of indicator. There is a number of common features regardless whether we are using



OTHER INDUSTRIES OUTSIDE THE CENTRAL FLOWS:

Agricultural machinery	Other transport
Rubber/plastic	Electronics
Chemical rawmaterials	Textiles
Iron and metal	Other chemical

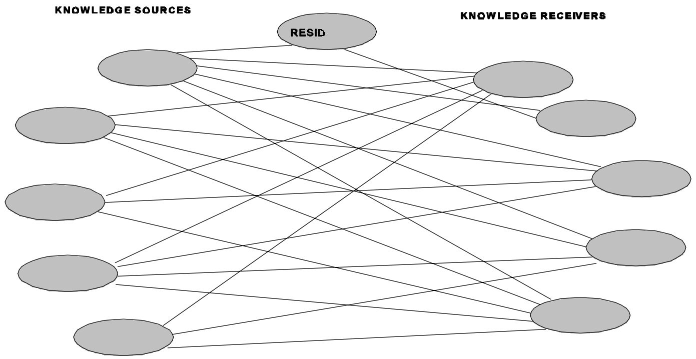


OTHER INDUSTRIES OUTSIDE THE CENTRAL FLOWS:

Agricultural machinery	Other transport
Rubber/plastic	Electronics
Chemical rawmaterials	Textiles
Iron and metal	Other chemical
Stone, clay, glass	Telecomm.

AMONG KNOWLEDGE RECEIVERS FLOWS RUN FROM THE RESIDUAL GROUP TO FOOD

AMONG KNOWLEDGE RECEIVERS FLOWS RUN
FROM POST ETC. TO PUBLIC SERVICES
FROM POST ETC. TO TRADE



OTHER INDUSTRIES OUTSIDE THE CENTRAL FLOWS:

Agricultural machinery	Other transport
Rubber/plast	Telecommunication
Instruments	Chemical raw mat.
Elektronics	Medicial
Textiles	Machinery
Iron and metal	

Combining all three indicators, machinery and business services stands out as general sources of knowledge, since both industries are identified as major sources from two out of three indicators. The role of business services confirms that services not just within the last few years, but for a quite some years, has played a central role as a knowledge source, not just for manufacturing but also for other services. Other important sources, which are only identified from one indicator, are iron and metal as well as construction. The group of users is wider and more stable: Food, trade, public services, the residual group, post/telecommunications etc. as well as other services are identified as knowledge receivers regardless of indicator. This supports the assumption that knowledge production is more concentrated than knowledge use. But three other conclusions can be drawn from these observations:

- An industry that for a long time has been dominating the Danish economy both in terms of volume of production and export, i.e. food, is basically a low technology industry, but the industry is to a large extent an important user of production inputs from high-technology industries, i.e. we are dealing with an industry which has an absorptive capacity for using inputs with embodied knowledge.

- The Danish service industries are, with the exception of business services, low knowledge industries (at least we the presently available knowledge indicators), but the services are, just as the food industry, intensive receivers of embodied knowledge. I.e. we observe a flow of embodied knowledge from a few industries to a broad range of service industries.

- The medical industry, which is the most research and development intensive industry in Denmark, is nationally quite isolated, i.e. being a high-technology industry does not automatically lead to a role as an important knowledge source.

The high degree of stability is an important result, particularly because of the lack of up-to-date input-output data. Few major shifts are observed between 1979 and 1991, which confirms the stability of the results found by Schnabl in his analysis of Germany.

An analysis building on input-output data combined with different knowledge indicators has as its main advantage the possibility of comparing structures over time. But the weakness in only capturing the fraction of intersectoral knowledge flows which are embodied in goods and services cannot be ignored. The assumption that the embodied knowledge from an industry is evenly distributed on all products flowing from this industry is also questionable. In order to assess the credibility of the input-output based analysis, an analysis of flows of product innovation flows between industries in Denmark during the period 1990-1992 is carried out in the following section.

4. Interindustrial innovation flows[3]

Using data from the Danish Community Innovation Survey it is possible to construct graphs of flows of product innovations between firms in different industries, as well as flows of interindustrial information related to the innovative process. The survey data serves two purposes: First it is possible to check whether the hypothesis that embodied knowledge flows estimated from input-output analysis can be used as an approximation of technological interdependencies between industries can find support in actual innovation flow data. Second the survey allows for an analysis of the extent to which the flows are one-way from supplier to user, and to which extent we are dealing with a dependence which is two-way between supplier and receiver of the product innovation - i.e. it is possible to come closer to an answer to the question on the extent of the knowledge sources dependence on the purchasers mentioned in section 2. This relation is the clearest illustration of the difference between technological interdependence and spillovers.

The innovation flows are measured as the fraction of firms in an industry, that identifies firms in another industry as important users of the firm's product innovations. The information flows are measured as the fraction of firms in an industry, which identifies firms in another industry as active participants in the innovative process. In order to be able to compare the innovation flows to the embodied knowledge flows, figures that resembles the graphs of the minimal flow analysis are

[3] The level of aggregation and industry classification differs slightly from the classification used in section 3. This is due to differences in the classification codes used in the I-O tables (ISIC related classification) and the Community Innovation Survey (NACE classification). At the relative high level of aggregation used in the present analysis, these classification differences only cause minor problems for the comparability of results though.

constructed.[4] As opposed to the minimal flow analysis, which only studies the relation from source to receiver, the CIS data supplies information on the flows of product innovations from source to receiver industries as wells as on the flows of information from the receiver industries to the source industries. A two-way relation is marked with a bold line.

From the innovation and information flows two types of innovative industries can be identified:

- Industries which are general suppliers of innovations to a broad range of receiver industries

- Industries which are intensive suppliers to a single or few industries

The first type of industries are suppliers of what can be considered as generic technologies which are of general use in the economy. The second type of industries are, together with their receivers, examples of innovative user-producer relations, in which the role of the users is often crucial for the innovative outcome.

The Danish part of the Community Innovation Survey only covers manufacturing industries, i.e. it is only manufacturing industries which appears as innovation sources, while services, construction and public utilities only appear as receivers.

Figure 4 shows the innovation flows between industries in Denmark during the period 1990-1992. When comparing the innovations flows to the embodied knowledge flows identified in section 3, there is a serious limitation in the lacking coverage of services, i.e. the importance of business services as a knowledge source cannot be checked. When including flows accounting for less than 20 percent of the firms in the source industry, the importance of machinery as a general supplier of knowledge is confirmed from the innovation data.

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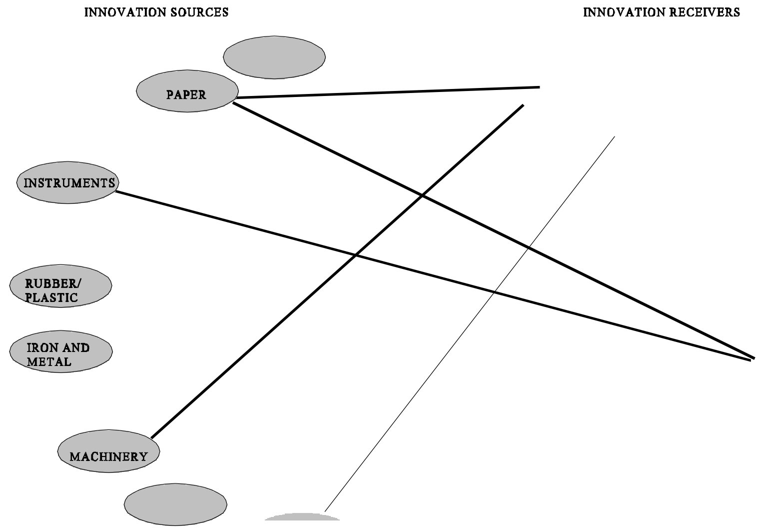
4 The figures only represent part of the complex structures of innovation and information flows. Matrices showing all flows are presented in appendix B.



INNOVATION SOURCES
INNOVATION RECEIVERS
PAPER
INSTRUMENTS
RUBBER/
PLASTIC
IRON AND
METAL
MACHINERY

(a) F

The iron and metal industry, which was identified as a major knowledge source using the patent data, is also a general supplier of innovations.

The most important general supplier of product innovations is electrical machinery and apparatus. No electronics related industry is included in the central knowledge flows with any of the used knowledge indicators, i.e. the importance of this industry is completely ignored when using the input-output based method. Thus an analysis of technological interdependence which was solely based on the I-O method would miss what seems to be the most important supplier of generic technologies in the Danish economy.

Chemicals is another important innovation source to a broad range of receivers. Chemicals has the special feature that information input to the innovative process from the receiver industries is a general feature. This is remarkable since the generic knowledge sources do not seem to rely on inputs from user industries to the same degree as the more specialised source industries. Of the generic knowledge sources, machinery also receive information flows from several receiving industries, while the iron and metal industry and to an even larger extent electrical machinery and apparatus receives information inputs from fewer of their receivers.

The extent of information flows from the receivers of innovations from the chemical industry is underlined in figure 5a, which shows the innovation flows among the innovation sources. The figure shows that the innovation sources have a well developed net of relations amongst each other. In most cases the relations are two-way both in the sense that receivers supply information to the innovation process, and in the sense that most of the industries are sources for each other, e.g. machinery is both an innovation source for rubber and plastic and an innovation receiver from this industry.

There are also cases where innovation flows are *not* coupled with information flows even though we would expect so. This is the case for the relations between electrical machinery and apparatus and office machinery: The industries supply innovations to each other, but even though these two industries would be expected to share a common knowledge base, no innovation related information reportedly flows between them.

The industries in the receiver group (figure 5b) are much less related through innovation flows than the innovation sources. A strong relationship is found between the food industry and the pharmaceutical industry, which is in accordance with an expected overlap in knowledge base. The isolation of the medical/pharmaceutical industry found in section 3 is not as outspoken when looking at innovation flows. But the isolation is obvious when looking at information flows to the pharmaceutical industry, where only other firms in the pharmaceutical industry are identified as active participants in the innovative process. This isolation is probably due to the fact that the knowledge base of the pharmaceutical industry is relatively specific to this industry with relatively few overlaps with other industries except the food industry.

Apart from information flows between firms within the same industry (see the full matrices in appendix B), the most extensive flows are found from receiver industries which are major receivers of product innovations from firms in the source industries. One example of such an interdependence is found between telecommunication and electronics: Between 80 and 100 percent of the firms in the telecommunications industry has supplied product innovations to the electronics industry during the period 1990-1992. At the same time between 20 and 40 percent of the telecommunication firms identify firms in the electronics industry as active participants in the developing process. In this case we are dealing with two high technology industries with overlapping technological competencies explaining the high degree of innovative interdependence between the two industries.[5]

An even clearer example of a user-producer like relationship between innovation suppliers and receivers is the paper and food industry. Between 80 and 100 percent of the firms in the paper industry have supplied product innovations to the food industry during the period analysed, and between 40 and 60 percent of the firms in the paper industry identify firms in the food industry as active participants in the innovative process. The dependence of the food industry on innovations (in packaging) from the paper industry was also found by Christensen et al. (1996).

While the relation between telecommunication and electronics could not be captured in the I-O

[5] The survey did not cover electronics as a source, but only electrical machinery and apparatus, i.e. it is not possible to check the extent of innovation flows from electronics to telecommunication and the corresponding information flows.

analysis, the relation between paper and food, at least indirectly, could be seen from the graphs based on both R&D expenses and technical and science personnel, since paper is included in the residual group of industries.

Thus the survey based data both confirms some findings from the input-output analysis, and reveals some features which were not captured in the input-output analysis. In particular the survey based data illustrates that when it comes to technological and innovative relations between industries, we are most often faced with relations that express a true two-way interdependence where both source and receiver is dependent on the other party in the relation.

Another important finding when comparing the input-output based flows with the innovation flows is that economic relations, as expressed by flows of intermediate goods and services, seems to be followed by flows of innovations. This is illustrated in the way that the innovation flows in most cases confirms the findings from the minimal flow analysis. But the fact the innovation flows also can appear between industries without extensive trade relations illustrates that the causality does not run in the opposite direction. A possible explanation of this observation is that two industries might have overlapping technology bases even though they are not closely related in an economic sense.

5. Concluding remarks

The aim of this paper has been twofold: To compare methods for identifying interindustry knowledge flows, and to increase our knowledge of the extent of technological two-way interdependencies at the industry level.

Regarding the first aim, the two applied methodologies show that an innovation survey provides a more complete picture of the dynamics of the economic system, as input-output based analyses using different knowledge indicators are not able to capture dynamic relations which do not stem from economic relations in the form of flows of goods and services between industries. But the input-output analyses of knowledge flows have their large advantage in the possibilities they provide for comparing structures across time. Innovation surveys only started emerging in the late

1980's, i.e. it is not possible to go back in time and study changes, and furthermore innovation surveys are both expensive and time-consuming, thus putting limits on the frequency by which they can be repeated in the future.

A certain overlap between the embodied knowledge flows and the innovation flows have been found above, making input-output based analyses a good supplement of the sparse innovation surveys.[6] Furthermore the comparison of embodied knowledge flows and flows of product innovation reveals information as to which extent - and in which industries - knowledge flows are quite closely related to economic relations, and to which extent knowledge flows are largely independent of economic interdependence. As a general rule (to the extent data were available), the input-output based flows revealed in the graphs were confirmed by the innovation flows, i.e. embodied production related flows seem to be matched by innovation flows, while innovation flows are not always dependent of production flows.

The innovation survey used in the present analysis has some severe limitations though. The fact that only manufacturing industries are surveyed is a major problem. If it is actually the case that embodied knowledge flows are matched by innovation flows, then the Danish innovation survey fail to identify an important innovation source in business services, and probably also in construction.

Regarding the second aim, the analysis shows that there is a high degree of industrial interdependence in the Danish economy. A complex web of relations illustrates that looking at the most knowledge intensive industries isolated from the rest of economy is to simplistic an approach as it will not reveal which sectors are central to the utilisation and diffusion of knowledge in the economic and technological system.

The analysis also indirectly confirms the point raised by Marengo and Sterlacchini that embodied and disembodied knowledge transfers are strictly connected in the process of innovation and diffusion: We have shown that a relation exists between on the one side knowledge embodied in

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6 Due to the discrepancies in industry aggregation a statistical test of the correlation has not been performed.

general flows goods and services, and on the other knowledge embodied in product innovations as well as knowledge inputs to the innovative process. This illustrates the benefits from combining methods.

The policy implications of the analysis concern the way technology policy aims at increasing the technological level and the innovativeness of the production system. Following Rosenberg's statement that extensive interindustrial knowledge flows are an important characteristic for advanced industrial societies the analysis reveals a "healthy" Danish system with a large degree of systemic interdependence. If this healthy characteristic is to be maintained and improved, two main policy strategies can be chosen. One is to focus on improving the technological development in the industries which are identified as being important for the knowledge diffusion, i.e. machinery, business services, iron & metal, construction and electrical machinery and apparatus. The other is to aim at improving relations with the high-tech industries which at the present seem quite isolated nationally, e.g. improving the relations between the medical industry and other Danish industries. Regardless of main strategy chosen, an improvement of the general environment for knowledge diffusion through an improvement of the absorptive capacities of the low-tech industries and setting up good framework conditions for collaboration between firms across industries is recommendable.

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Appendix A: The model for the graph theoretical minimal flow analysis

The following model is a slightly modified version of the model presented in Schnabl (1994;1995).

The model starts with a Leontief system, where the total production equals the direct and indirect intermediate flows of goods and services (as expressed in the Leontief inverse) multiplied by final demand. This expresses the total production requirement for producing for the actual final demand:

$X=(I-A)^{-1}\langle y\rangle$, $\langle\ \rangle$ expresses a diagonalisation of a vector.

This system is "normalised" by dividing with the diagonalised vector for final output, thus making all rows summing to 1. Thus we now have relative requirements:

$$S=\langle x\rangle^{-1}(I-A)^{-1}\langle y\rangle.$$

Technology is now introduced through the diagonalised vector $\langle tek\rangle$.[7] This step weights the production requirements by the technology levels in the delivering sectors:

$$X_{tek}= \langle tek\rangle\langle x\rangle^{-1}(I-A)^{-1}\langle y\rangle.$$

Since $(I-A)^{-1}$ by definition equals

$$I+A+A^2+A^3.....$$

the X_{tek} equation can be expressed by the following section of equations:

$X_{1,tek}=\langle tek\rangle\langle x\rangle^{-1}A\langle y\rangle.$

$X_{2,tek}=\langle tek\rangle\langle x\rangle^{-1}A^2\langle y\rangle$

etc.

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7 Three different technology indicators are used: R&D expenditures, patenting (by Danish firms in then US), and the fraction of employees with a technical or science degree.

In order to make the system binary, and thus allowing for the use of graph theoretic methods, the values of the $X_{1,tek}$ matrix, which expresses the direct technology deliverances, are “filtered” through a preset minimal value, thus making cells with a value less than the minimal value equal 0, while cells with a value equal to or larger than the minimal value are given the value 1. Thus we create a new matrix W_{tek}, with cells having the values 0 or 1.

W_{tek} is used for calculating a “dependence” or “reachability”matrix, D:

$$D=\#(W+W^2 +W^3 +W^4 + \ldots +W^{n-1}),$$

where # expresses boolean summation, and n is the number of sectors in the system.

D is used in calculating a “connection” matrix, C:

$$c_{ij}=d_{ij}+[d_{ij}\ d_{ji}]+k_{ij},$$

where $k_{ij}=1$ if there is a relation, regardless of direction, between the sectors i and j, or else $k_{ij}=0$.

K is calculated as

$$K= \#[(I+I') + (W+W') + (W+W')^2+ (W+W')^3+ (W+W')^4+\ldots..],$$

where the summation of the transposed W matrix (W’) and W “dissolves” the direction in the relation between sectors i and j by making the sum matrix (W+W’) symmetric.

The elements of C can take the values 0, 1, 2 or 3 (see e.g. Harary, et al., 1965):

$c_{ij}= 0$: no relation between i and j.

$c_{ij} = 1$: there is a weak relation between i and j, in the sense that i and j both are connected to a 3rd sector, but there are no flows, neither direct nor indirect, between i and j.

$c_{ij} = 2$: there is a one-way-relation from i to j. The direction from i to j is the result of the

Appendix B: Innovation and information matrices

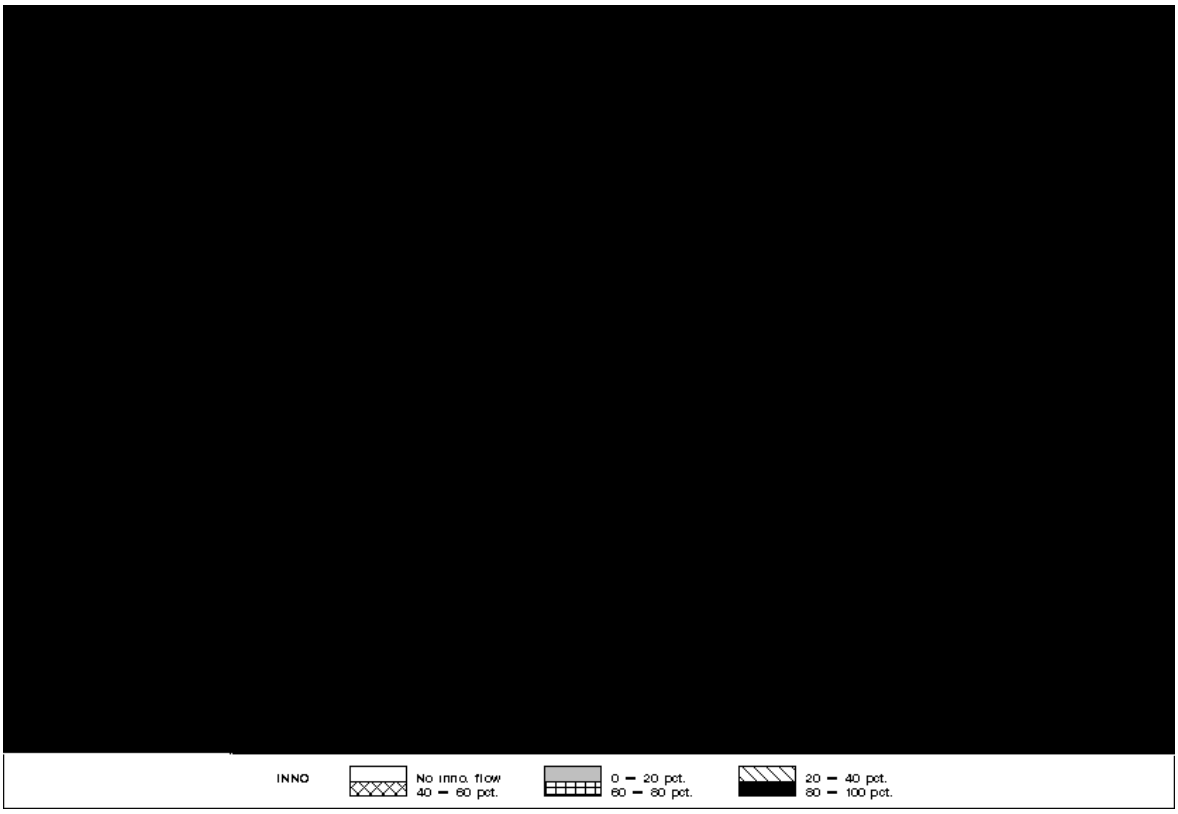

Figure B1: Innovation flows in Denmark, 1990-1992.

1. Food
2. Textile and clothing
3. Leather
4. Wood
5. Furniture
6. Paper
7. Graphical industry
8. Pharmaceutical ind.
9. Chemical industry
10. Mineral oil
11. Rubber and plastic
12. Stone, clay and glass
13. Iron and metal industry
14. Machinery
15. Electronics
16. Electrical machinery and apparatus
17. Office machinery and computers
18. Telecommunication equipment
19. Instruments
20. Transport (manufacture)
21. Raw materials/other manufacturing
22. Public utilities
23. Construction
24. Trade and repair
25. Hotels and restaurants
26. Transport services etc.
27. Finance and insurance
28. Public adm., defence etc.
29. Education
30. Health and welfare institutions

Industries 15 and 22-30 are only included as users, no. 21 is only includes as supplier.

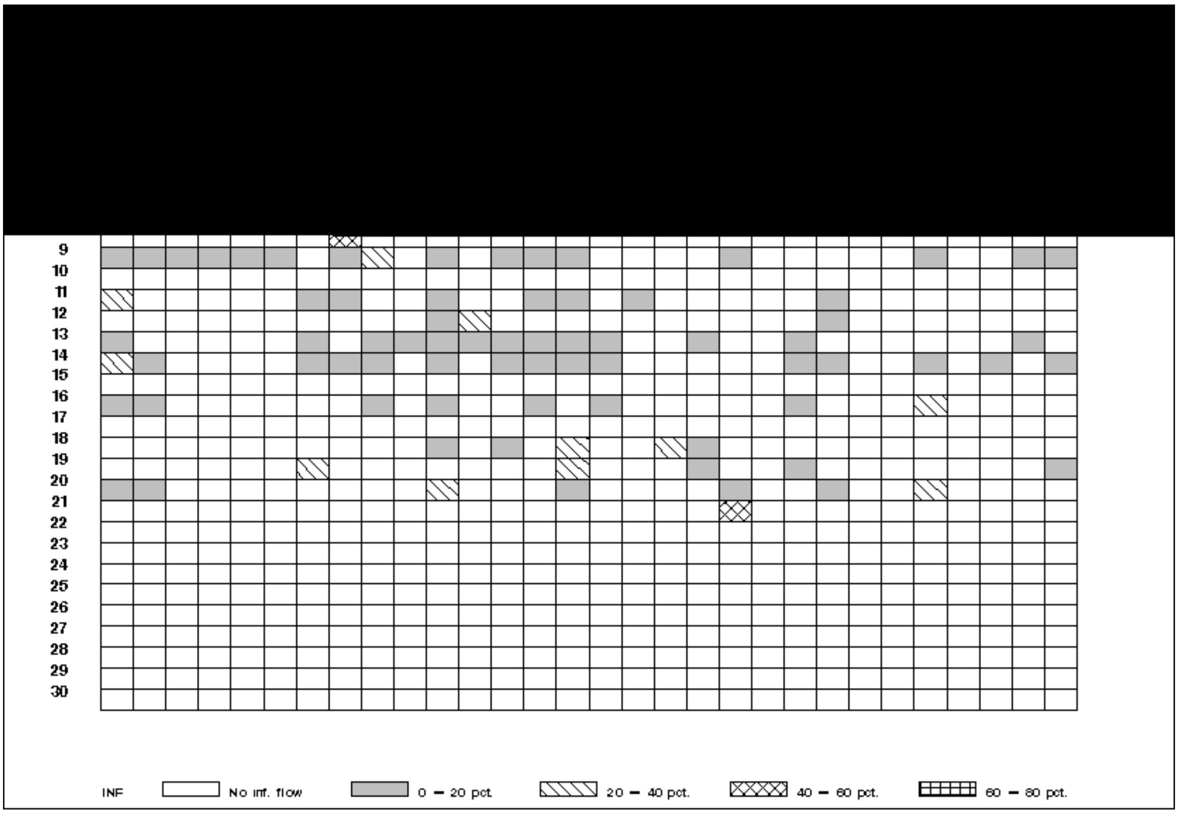

Figure B2: Information flows (active participation in the development process) in Denmark, 1990-1992.

1. Food	11. Rubber and plastic	21. Raw materials/other manufacturing
2. Textile and clothing	12. Stone, clay and glass	22. Public utilities
3. Leather	13. Iron and metal industry	23. Construction
4. Wood	14. Machinery	24. Trade and repair
5. Furniture	15. Electronics	25. Hotels and restaurants
6. Paper	16. Electrical machinery and apparatus	26. Transport services etc.
7. Graphical industry	17. Office machinery and computers	27. Finance and insurance
8. Pharmaceutical ind.	18. Telecommunication equipment	28. Public adm., defence etc.
9. Chemical industry	19. Instruments	29. Education
10. Mineral oil	20. Transport (manufacture)	30. Health and welfare institutions

Industries 15 and 22-30 are only included as users, no. 21 is only included as supplier.

Figures B1 and B2 shows the matrices for interindustrial product innovation and information flows in Denmark during the period 1990-1992. The rows in figure B1 are source industries, while the columns are receiver industries. The different patterns in the cells express the intensity in the flows: The white cells express no flows of product innovation, while the black cells express that between 80 and 100% of the firms in the source industries have supplied product innovations - means of production, raw materials or intermediary goods - to firms in the receiver industry during the period analysed. The gray and hatched cells express flows between 0 and 80 percent in the source industries.

Figure B2 illustrates to what extent other firms have participated actively in the innovative process. The dimensions from figure B2 are maintained in order to be able to compare the two figures directly. This implies that e.g. the gray cell in row 9, column 1 (chemical industry and food) in figure B1 express that between 0 and 20 percent of the firms in the chemical industry have supplied product innovations to firms in the food industry, while the gray cell in row 9, column 1 in figure B2 express that between 0 and 20 percent of the firms in the chemical industry points to firms in the food industry as active participants in the innovative process, i.e. the information flows from food to the chemical industry. This breaks the logic in a traditional matrix where flows always run from rows to columns. The diagonals show that intraindustrial innovation and information flows are a common phenomenon.

Only manufacturing firms were surveyed, i.e. construction, services and public goods are only included as users.