Development Blocks in Innovation Networks. The Swedish Manufacturing Industry, 1970-2007

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Abstract The notion of development blocks suggests the co-evolution of technologies and industries through complementarities and the overcoming of imbalances. This paper studies groups of closely related industries and their co-evolution in the network of Swedish product innovations, by combining statistical methods and qualitative data from a newly constructed innovation output database, SWINNO. The study finds ten sets of closely related industries in which innovation activity has been prompted by the emergence of technological imbalances or by the exploitation of new technological opportunities.

Keywords Development Blocks · Community Detection · Network Analysis · Technological imbalances

1 Introduction

The 'systemic', aspects of technology shifts have been stressed in a variety of empirical and theoretical accounts (Dahmén, 1950; Rosenberg, 1969; Gille, 1978; Hughes, 1987; Carlsson and Stankiewicz, 1991; Nelson, 1994; Bresnahan and Trajtenberg, 1995; Helpman, 1998; Freeman and Louça, 2001; Perez, 2002; Lipsey, Carlaw, and Bekar, 2005). The received literature proposes that technological change takes place by way of strong mutual interdependencies between some industries, sometimes geographically localized, and that innovation activity is profoundly shaped by these interdependencies. The concept

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of *development blocks* emphasizes the co-evolution in large or small systems of technologies. In this view, strong incentives to develop new technologies are provided by the complementarities and sequences of imbalances that arise as development blocks evolve (Dahmén, 1950, 1991; Schön, 1991, 2010). This paper argues that development blocks can be approached empirically by studying two facets of innovation activity: i) the flows of innovations across sectors and the relatedness between industries, ii) the problems and opportunities that spur innovations. Using a new literature-based database on over 4,000 Swedish innovations (Sjöö, Taalbi, Kander, and Ljungberg, 2014; Sjöö, 2014; Taalbi, 2014), the aim of this study is to describe interdependencies in the network of Swedish product innovations, 1970-2007. This description aims both to delineate subsystems of innovations and to analyse the impulses to innovation that emerge from imbalances and complementarities within development blocks. This is achieved by combining recently developed statistical techniques for community detection, with analysis of biographic information on the problems and opportunities that have spurred innovations.

Three aspects of the network of innovations are studied:

- *Are there subsystems in the network of innovations?* The community structure of the network of innovations is explored to delineate closely interdependent industries.
- *What roles do industries have in innovation networks?* The hierarchical structure of the network of innovations is explored statistically to describe the roles of industries as suppliers and users of innovation.
- *How have opportunities and imbalances provided incentives to innovations?* The qualitative character of innovation as response to problems and opportunities is explored by way of innovation biographies available from the SWINNO database.

By answering these questions the structure and character of technological interdependencies between industries can be described, arguably approaching Dahménian development blocks.

The outline of the paper is as follows. Section 2 discusses how sectoral interdependencies between technologies are posited to affect innovation activity according to previous literature and discusses major differences between the notion of development blocks and related notions such as GPTs and technological systems. Section 3 introduces the literature-based innovation output database SWINNO and the construction of the network of Swedish innovations. Section 4 explains the network and community detection analysis and presents the results from statistical analysis of the network of innovations and then discusses the qualitative character of problems and opportunities that have spurred innovations. Section 5 concludes.

2 Analyzing technological interdependencies

Historical studies tell us that innovations come about in bunches and as parts of broader technology shifts in which technologies *co-evolve*. The dynamics of broader technology shifts as arising by way of a series of co-evolving technologies has been discussed in terms of general purpose technologies (Bresnahan and Trajtenberg, 1995; Helpman, 1998; Lipsey et al, 2005), technological styles (Perez, 1983; Tylecote, 1994) and techno-economic paradigms (Freeman and Louça, 2001; Perez, 2002), "Macro" versus "Micro" inventions (Mokyr, 1990; Allen, 2009), technological systems (Hughes, 1983, 1987) and development blocks (Dahmén, 1950, 1991).

These concepts embody different views on the driving forces of innovation. One central difference between these perspectives is the varying emphasis put on positive and negative interrelations in the evolution of industries. In the theory of General Purpose Technologies, interdependencies between supply industries and user industries emerge when user sectors improve and enhance the key input (Bresnahan and Trajtenberg, 1995; Lipsey et al, 2005). Innovation may also be strongly induced by opportunities and problems generated in the activities of other firms or in user sectors. In numerous accounts (for instance Schmookler, 1966; van Duijn, 1983; von Hippel, 1988; DeBresson et al, 1996) innovations are considered demand-led, induced by customer-producer interactions and following patterns of demand for goods. As it were, existing interdependencies between firms, or sectors of economic activity, provide strong opportunities for innovation.

By contrast, other approaches have stressed the inertia in technological development. Despite a swift development of faster and better computers during the 1980s, the lack of productivity effects puzzled many economists. Robert Solow famously phrased this 'paradox' in the words "We can see the computers everywhere but in the productivity statistics" (cited in David, 1990). These other approaches have stressed that technology shifts evolve not only by the downstream improvement of new technologies, but by the solution of *imbalances* and techno-economic problems that appear throughout the life cycle of new technologies (Hughes, 1983; Dahmén, 1950, 1991). The diffusion of new technologies simply takes time and requires the overcoming of numerous obstacles. These obstacles may be technical, economic, social and institutional in character. It has been claimed that this type of problems is one of the most important sources of innovation. Nathan Rosenberg (1969) noted that "The history of technology is replete with examples of the beneficent effects of this sort of imbalance as an inducement for further innovation" (Rosenberg, 1969, p. 10). A very similar view has been offered by Thomas Hughes' (1983; 1987) analysis of 'sociotechnical systems' that evolve through the emergence of 'salients' and 'reverse salients'. Reverse salients are backwards, underperforming components of the sociotechnical system, that hamper the development of the sociotechnical system as a whole. The situation is resolved by the identification and resolution of 'critical problems', problems that hinder the technological expansion. In the view of Hughes, "[i]nnumerable (probably most) inventions and technological development result from efforts to correct reverse salients" (Hughes, 1983, p. 80).

The notion of *development blocks* emphasizes the importance of both positive and negative interdependencies between industries or firms. Development blocks are *complementary economic activities that are stimulated by innovations.* The central dynamics of a development block is provided by the fact that new technologies or innovations require and stimulate investment and development efforts in other firms or industries. As it were, innovations create complementarities, or dependencies between firms, technologies, industries or institutions. In this process obstacles and imbalances appear that require the alignment of the technological frontier in other fields, or new innovations that solve technological problems. Development blocks are, put in a more involved manner, complementarities that appear sequentially as agents overcome obstacles or imbalances.[1]

On a fundamental level, co-evolution between parts of a system may thus be understood in both positive and negative terms. Positive interdependencies may arise due to increasing returns, positive externalities and path dependence in technology choices (Young, 1928; Kaldor, 1981; David, 1985; Arthur, 1989, 1990, 1994; David, 2001). On the basis of positive externalities and increasing returns between agents of a system, structures of strongly interdependent agents, institutions and industries may emerge. On the other hand, precisely because of interdependencies, technological development typically requires the coming into place of other components. The lack of such components may become obstacles to further development and create *imbalances* that must be resolved.

Several previous empirical studies have employed the notion of development blocks or conducted empirical analysis inspired by it (Schön, 1990; Carlsson, 1997; Enflo, Kander, and Schön, 2008). Complementarities between economic activities or technologies and technological imbalances are however typically difficult to study empirically in a systematic manner. The current study proposes a new method to shed light on interdependencies and development blocks by combining textual evidence on innovations that respond to technological imbalances, and a quantitative approach to delineate related industries, using recent contributions to network analysis. It is possible to argue that the localization of development blocks requires us to address two issues: *i)* establishing boundaries of groups of closely related industries, *ii)* establishing the character of innovation interdependencies as creating complementarities or resulting from attempts to close technological imbalances.

The first issue concerns the analysis and description of intersectoral interdependencies in terms of *subsystems.* Previous research has employed a wide set of approaches to analyse and describe economic, knowledge and technological interdependencies in terms of subsystems. The classical analysis of economic interdependencies has departed from Input-Output matrices of economic flows in which interdependencies could be analysed as the "dynamic inverse", or in models of vertically integrated sectors (von Neumann, 1945; Leontief, 1941; Goodwin, 1949; Pasinetti, 1973, 1983). Sraffa (1960) and Leontief (1963) discussed the problem of finding subsystems in such economic flows. Leontief for

[1] Dahmén described the notion of a development block as "a sequence of complementarities which by way of a series of structural tensions, i.e., disequilibria, may result in a balanced situation" (Dahmén, 1991, p. 138).

instance proposed a block partition of non-zero elements in the Input-Output framework.

Previous empirical research has studied intersectoral interdependencies in many ways. Similar in aim to the current study, Enflo et al (2008) employed cointegration analysis between industrial production volumes in Sweden (1900 - 1970) to approach sets of closely related sectors, indicating development blocks. Studies in economic geography have measured industry relatedness by measuring the coproduction of different products on the plant-level (Neffke and Svensson Henning, 2008; Neffke, Henning, and Boschma, 2011). Mappings of the patterns of production and use of inventions or innovations have been constructed since the 1980s (see Los and Verspagen, 2002 for an overview), employing patent data (Scherer, 1982; Verspagen, 1997; van Meijl, 1997; Nomaler and Verspagen, 2008; Fontana et al, 2009; Nomaler and Verspagen, 2012) and innovation output data (DeBresson and Townsend, 1978; Robson, Townsend, and Pavitt, 1988; DeBresson, Andersen et al, 1996). The so-called technology flow matrices constructed with patent data have in general been used to measure the intersectoral spillover effects of knowledge. Robson et al (1988) used a matrix of the number of innovations produced and used in industries, to draw conclusions about the location of innovative activity in Great Britain. These studies were for instance underlying Pavitt's 1984 seminal study and taxonomy of innovation. Recent research (McNerney, Fath, and Silverberg, 2013; Garbellini and Wirkierman, 2014) has suggested that subsystems in economic flows may be analysed by way of network analysis and the detection of *communities*. This analysis can be extended to the case of innovation flows. A *community* is then a set of industries that form close connections in terms of the flow of innovations.

Following these lines of inquiry, the current study examines the overall interdependencies and flows of innovations between industries by mapping the number of innovations in a product group to the respective sectors of use. The resulting "Object Matrix" (Archibugi and Simonetti, 1998), informs us of in what sectors innovations were produced and used, and may be considered a measure of the linkages between product groups and sectors of economic activity. The raw statistics of the Innovation Flow Matrix can be used to describe what sectors were salient sectors of supply and use of innovations, and how these patterns have changed during the period 1970-2007. An analysis of related industries can be carried out in a statistical approach using network analysis and community detection.

The second issue to be addressed is to what extent the co-evolution of innovations takes place by way of the exploitation of technological opportunities and downstream improvement of key inputs or rather by way of overcoming hurdles. There is a somewhat extensive literature of innovation or industry case studies attempting to assess the role of technological imbalances or reverse salients in innovation (Rosenberg, 1969; Hughes, 1983; Dedehayir and Mäkinen, 2008, 2011). However, this issue has been much less studied systematically and in relation to statistical macro-evidence of technological interdependencies. Fortunately, the SWINNO database also gives a rare opportunity to jointly study these two central facets of technology shifts: the response to technological imbalances, and innovation as the response to and downstream improvement of technological opportunities.

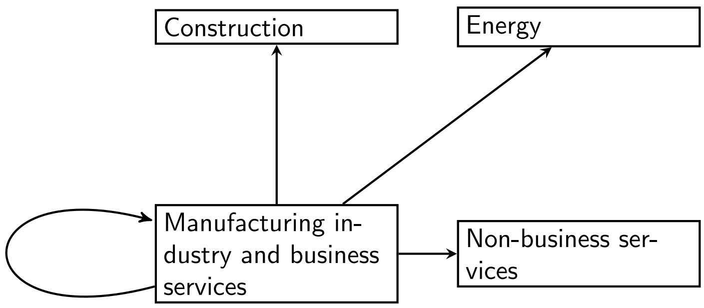
In sum, Dahmén's concept of development blocks can be understood as sets of complementarities that appear sequentially as economic agents solve technological imbalances. Combining statistical and qualitative analysis communities of closely related industries may be said to reflect *development blocks* if innovations create complementarities within the communities, or if innovations are "gap filling", i.e. respond to technological imbalances by supplying missing components or factors in a relation of complementarity. Thus, communities indicate development blocks *if* the qualitative character of interdependencies can be assessed as creating complementarities or supplying complementarities by solving imbalances.

3 Data

SWINNO (Swedish innovations) is a recently constructed database containing extensive information about single product innovations commercialized by Swedish manufacturing firms between 1970 and 2007 (Sjöö et al, 2014). SWINNO is an unprecedented source of information about Swedish innovation in combining depth and width; the database contains detailed information about more than 4000 innovations, to which come more than 500 inventions or projects that had, so far (by end of 2007), not been commercialized. Previous databases capturing inter-sectoral flows of innovations have been either patent based (Scherer, 1982; Verspagen, 1997; van Meijl, 1997; Nomaler and Verspagen, 2008, 2012) or innovation output based, employing expert opinions as sources of data (Townsend et al, 1981; Pavitt et al, 1987). The underlying approach of the SWINNO database is the literature-based innovation output method (LBIO) (Kleinknecht and Bain, 1993) enabling a consistent micro-based long-term analysis of innovation output. The database was constructed by scanning 15 trade journals covering the manufacturing industry, for independently edited articles on product innovations. The available information has enabled classifications of product types (ISIC codes), user industries (ISIC codes) as well as the factors that have spurred innovation activity.

The latter involves a classification of the factors that have spurred innovations in two main classes: opportunities and problems (see Taalbi, 2014). The classification into problem-solving and opportunity driven innovations has departed from information available in the trade journal articles. The classification was based upon direct textual evidence of descriptions of the innovation. An innovation was considered problem-solving if the development of the innovation was explicitly described as aiming to overcome an obstacle or problem, that may be of economic, social or a technological character. An innovation was considered to exploit technological opportunities if the journal articles explicitly mentioned a technology, which contributed to or enabled the development of the innovation.

Fig. 1: The flows studied



3.1 Data coverage

This study covers product innovations launched in the manufacturing industry and business services (including softwares, supply of telecommunication network services and technical consultancy). A product innovation is in the SWINNO database defined as any innovation that is being traded on a market, in contradistinction with process innovations, defined as innovations being withheld from markets and applied in-house only (Sjöö et al, 2014). Figure 1 illustrates the inter-sectoral flows of product innovations that are studied. Clearly, since innovations in construction, energy and non-business service are not studied systematically these sectors are almost exclusively recorded as users of innovation.

3.2 The construction of the Innovation Flow Matrix

To analyse the innovation networks across industries, categorizations of the supply and user industries were constructed based on the information available from trade journal articles. The product innovations found in the journal articles were categorized in the Swedish Industrial Classification system 2002 (SNI 2002) corresponding to ISIC Rev 2 (henceforth referred to as ISIC). The variable "User" describes the sectors in which the innovation is used or explicitly intended to be used according to the trade journal articles. An innovation is allowed in the database to have up to eight different user sectors. The User sectors were classified at the lowest industry-level possible. The level of classification thus may vary. Whereas most user sectors are specified on a three or four digit ISIC level, some innovations are directed towards broader sectors corresponding better to two digit ISIC levels.

Apart from the given user industries two auxiliary categories have been registered: final consumers and general purpose. The former category refers to innovations for private use. The latter category refers to innovations for use in almost any sector (frequently including final consumption).

The innovation flow matrix is an analytical tool that allows one to picture and analyse the supply and use of innovations and the linkages between industries. It is constructed by mapping the innovations developed in industry i that are used in sector j, for final consumption, or are of general purpose character. In matrix notation this can be expressed as a $N \times N$ matrix $\mathbf{W}$ expressing intersectoral supply and use of innovations, together with $1 \times N$ vectors $\mathbf{FC}$ and $\mathbf{GP}$, expressing innovations for final consumption and general purpose:

$$(\mathbf{W}, \mathbf{FC}, \mathbf{GP}) = \begin{pmatrix} W_{11} & W_{12} & \dots & W_{1N} & FC_1 & GP_1 \\ W_{21} & W_{22} & \dots & W_{2N} & FC_2 & GP_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ W_{N1} & W_{N2} & \dots & W_{NN} & FC_N & GP_N \end{pmatrix} \quad (1)$$

In theory, the flow matrix can be constructed by counting the number of innovations of type i that are directed towards user sector j. We then obtain a matrix, mapping the number of times an innovation in the database is found to be of product group i and used in sector j.

However, in practice we observe that an innovation may however have several user sectors. Depending on the purpose of the analysis one may either count all observed linkages between sectors or counting each innovation only once by applying a weighting procedure. In the first case an innovation with two user sectors is counted as two observations. This method gives a relatively large weight to innovations that are used in many different sectors. The first method could be preferred if the study aims to analyse the economic impact or diffusion of innovations in the economy.

By contrast, the second method implies that the more user sectors an innovation has, the *weaker* the linkage between two specific sectors of supply and use. If an innovation has two different user sectors, each of these linkages is given a weight of 1/2, ascertaining a total sum of 1. The second method is suitable for studying the strength of technological linkages between certain sectors, which is the purpose of the analysis in this study. Though not essential for the current analysis, the second method is also consistent with a probabilistic treatment of the flow of innovations, as the calculation of the probability that an innovation is used in a certain sector is straightforward.[2]

This study follows the second method. Thus, each linkage between a supply and a user sector has been weighted by the inverse of the innovation's total number of observed user sectors. The innovation flow matrix W is constructed by taking the sum of all weighted linkages between industry i and industry j. The elements W_{ij} of the matrix are thus weighted sums and will not be integers. However, since each innovation is only counted once, the row sums W_i will be equal to the count of innovations supplied. Formally, given a set of N innovations indexed by $k \in \{1, 2, ..., N\}$, each innovation has a number of

[2] This e.g. makes possible the analysis of the IFM matrix as a stochastic Markov process where the matrix $W_{ij}/\sum_j(W_{ij})$ is the transition matrix. Compare e.g. DeBresson and Hu (1996).

observed user industries U. The weight w for a linkage of innovation k is then $w_k = (1/U_k)$. Assigning each weight to its respective supply and user industry, i and j respectively, we obtain the innovation flow matrix W with elements $W_{ij} = \sum_k (w_{ijk})$. In what follows, all following statistics on the supply and use of innovations refer to weighted sums calculated according to this method.

The treatment of general purpose innovations is an exception from the weighting procedure that merits explanation. General purpose innovations could in principle be counted by giving a (small) weight to each user industry (e.g. signifying a small probability that the innovation would be used in a certain industry). However, as general purpose innovations do not inform of particular relations among industries, general purpose innovations have been retained as a separate category and not part of the inter-industry flows. Innovations that are recorded as general purpose innovations are thus counted separately and do not enter the weighting procedure.

4 The structure of the Swedish innovation network

This paper is concerned with three aspects of the network of innovations:

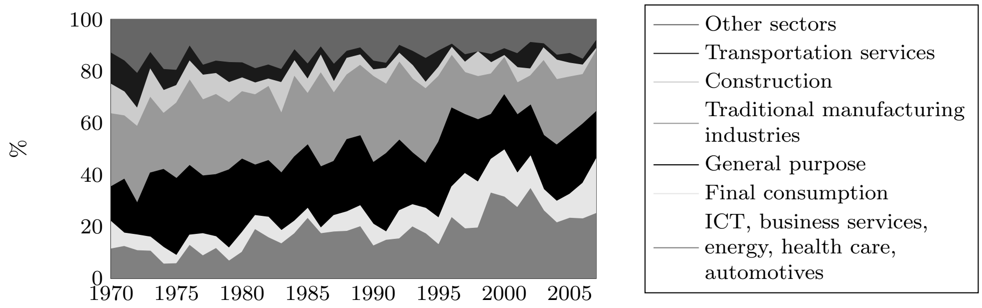
- The community structure of the network, i.e. the relatedness of certain industries in development blocks,
- The hierarchical structure of the network of innovations, i.e. the structural position of industries as suppliers or users of innovations,
- The character of innovative interactions, i.e. if innovations within development blocks are driven by techno-economic problems or exploiting new technological opportunities

4.1 Supply and use of innovations

Table 1 presents the supply and use of innovations at the aggregated level for the period 1970-2007. Clearly, most innovations were aimed for use in other production and service activities. Innovations for use in manufacturing purposes corresponded in total to roughly a third of the total count, throughout the period (36.5% in 1970-1989, 38.48% in 1990-2007). Innovations for use in services (ISIC 50-93) corresponded in total to 18.66% during the period. General purpose innovations accounted for 22.3% of the total count of innovations. Electricity, gas and water supply (ISIC 40-41) and Construction (ISIC 45) corresponded to small shares (1.9% and 6.08% respectively). Table 1 also shows that for most supply industries the majority of innovations was used in other manufacturing industries (abbreviated D). Exceptions were wood and wood products (DD, i.e. ISIC 20) and other metallic mineral products (DI, i.e. ISIC 26) that found used in construction, and chemicals and chemical products (DG, i.e. ISIC 24) that to a very large extent found use in health care.

Figure 2 shows the count of innovations by user destination and year of commercialization over the period studied. The count of general purpose innovations were rather constant throughout the period. Almost half (407 out of

Fig. 2: Innovations by user industries, final consumption and general purpose, 1970-2007. Share of innovations in total annual count (%).



891) of the innovations for general purposes were hardware electronic equipment (ISIC 30-33). Innovations for final consumption were not a large share of the total count (8.8%) but increased during the 1990s, concomitant with an increase in the supply of telecommunication equipment innovations and final customer oriented software innovations. In the beginning of the period a large share of the innovations were aimed to be used in the traditional manufacturing sectors, including foodstuff, pulp and paper, chemical, basic metals and the engineering industries. Their importance decreased somewhat during the period, focus instead shifting from the 1990s towards ICT industries, business services, energy production, health care and automotives.

These patterns appear to reflect structural changes in the Swedish industrial landscape, where the traditional manufacturing sectors have declined and development in ICT and business services have come to the fore.

In Table 2 stronger linkages between manufacturing industries are highlighted. The table allows a broad comparison between the main types of innovation, basic metals and fabricated metal products (ISIC 27-28), machinery (ISIC 29) and hardware ICT products (ISIC 30-33). The main user industries of ICT products were health care (ISIC 85), other business activities (ISIC 70-74) and aimed for internal use or other parts of the hardware ICT sector (ISIC 30-33). By contrast, the principal user industries of machinery innovations were traditional manufacturing industries, e.g. the pulp & paper and printing industries (ISIC 21-22), fabricated metal products and basic metals (ISIC 27-28), foodstuff (ISIC 15-16), and the construction (ISIC 45) and agriculture and forestry sectors (ISIC 01-05). User industries of basic metals and fabricated metal innovations were construction (ISIC 45), transport equipment (ISIC 34-35). A large portion was aimed for internal use or other parts of the metals sector.

Table 1: Aggregated Innovation Flow Matrix, Total economy, 1970 - 2007.

Sector	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	FC	GP	Total supply
A	1.5	0	0.33	0.66	0	0	0	0.5	0	0	0	0	0	0	0	0	0	3
C	1.5	0	0	2	0	0	0	0	0	0	0	0	0	0	0.5	1	0	5
DA	1	0	0	13	0	0	1.5	8.83	1	0	0.33	0	0	0	0	43.33	1	70
DB - DC	1.5	1	0	9	0	2	0	0	0	0	0.5	2	0	1	2	5	3	27
DD	1	0	0	13	1	33	0	0	1.5	0	0	0	0	0	1	6.5	8	65
DE	1	0	0	33.99	1	5	1.5	0	3	0	0	0	0	0	0	4.5	12	62
DF	0	0	0	1	3	2	0	0	0	0	0	0	0	0	0	1	1	8
DG	8	0	2	56.51	0.5	9.7	1	0	2	0	3	0	0	39.75	7.5	11.03	16	157
DH	4.5	1	2.83	90.66	3	22.33	3.08	0	14.17	0	1.25	7	0	3	2	14.17	19	188
DI	0	0	0	12	0	17.25	0	0	0.25	0	0	1	0	0	0	1.5	3	35
DJ	2.5	1	10.73	162.21	7.5	44.49	0.33	2	17.2	1	0.7	4.5	0	3	1.5	20.33	38	317
DK	61	2	35.4	527.9	19.58	59.03	14.43	3.25	51	1	9.85	21.7	1.83	9.33	31.28	57.42	248	1154
DL	6.93	1	13.96	358.25	33.53	23.81	12.82	2.68	72.85	5.45	71.23	29.87	2	88.13	12	132.5	407	1274
DM	4.17	1	4.5	83.71	1	5.33	1.33	0	56.2	0	3.33	26.33	0	2	5.33	15.75	19	229
DN	0.5	0	0	10.5	0	2	0	0	0	0	0	1	0	0	0.5	8.5	17	40
E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
F	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	1	7
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
I	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	4	7	14
J	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
K	4	0	5.7	119.04	6.5	13.5	4	0	11.17	3	29.92	5	2	9	11.33	22.83	90	337
N	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2
Total use	99.1	7	75.46	1493.48	76.62	245.45	40	17.26	233.33	10.45	120.11	98.4	5.83	156.21	74.95	353.37	891	3998

A = Agriculture, hunting and forestry, B = Fishing, C =Mining and quarrying, DA = Food products; beverages and tobacco, DB = Textiles and textile products, DC = Leather and leather products, DD = Wood and wood products, DE = Pulp, paper and paper products; publishing and printing, DF = Coke, refined petroleum products and nuclear fuel, DG = Chemicals, chemical products and man-made fibres, DH = Rubber and plastic products, DI = Other non-metallic mineral products, DJ = Basic metals and fabricated metal products, DK = Machinery and equipment n.e.c., DL = Electrical and optical equipment, DM = Transport equipment, DN = Manufacturing n.e.c., E = Electricity, gas and water supply, F = Construction, G = Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods, H = Hotels and restaurants, I = Transport, storage and communication, J = Financial intermediation, K = Real estate, renting and business activities, L = Public administration and defence; compulsory social security, M = Education, N = Health and social security, O = Other community, social and personal service activities, FC = Final consumption, GP = General purpose

Table 2: Innovation flow matrix of innovations used in manufacturing industries, 1970-2007.

Sector	DA	DB-DC	DD	DE	DF	DG	DH	DI	DJ	DK	DL	DM	DN	Total supply 15-37	Total supply
A	0	0.33	0	0.33	0	0	0	0	0	0	0	0	0	0.66	3
C	0	0	0	0	0	0	0	0	2	0	0	0	0	2	5
DA	10	0	1	0	0	1	0	0	0.5	0.5	0	0	0	13	70
DB-DC	0	3	0	2.5	0	1.5	0.5	0	0	0.5	0	0	1	9	27
DD	0.5	1	6.5	0	0	0	0.33	0	0	0	0	0	4.67	13	65
DE	9.5	0	3.33	14.33	0	1	1.83	0	1.17	1.33	0	1.5	0	33.99	62
DF	0	0	0	0	0	0	1	0	0	0	0	0	0	1	8
DG	3	3.25	4	9.83	0	7	6.33	0	5.33	1.12	8.05	5.57	3.03	56.51	157
DH	36.08	0.83	4	2.75	0	4.08	5.17	3.33	3.14	11.23	1.93	16.29	1.83	90.66	188
DI	0	0	0	0	0	0.5	0.5	2	3.75	1.75	0	3.5	0	12	35
DJ	9	1.5	11.08	2.75	0	2	4	1	51.1	28.77	12.88	32.54	5.59	162.21	317
DK	63.32	29.17	49.3	104.09	1.92	35.77	21.72	3.26	89.44	38.77	19.83	60.11	11.2	527.9	1154
DL	22.09	1.83	25.57	63.34	4.64	28.12	6.1	1.55	49.39	20.47	84.74	50.41	0	358.25	1274
DM	0.7	0	1.83	0.58	0.25	0.2	0.5	0	1	3.67	0.4	74.58	0	83.71	229
DN	0	0	0	3	0	0	0	0	5.5	1	0	1	0	10.5	40
E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
J	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
K	3.5	1	4	34.53	0	9.83	8.53	1.2	13.74	11.43	14.45	13.33	3.5	119.04	337
N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Total use	157.69	41.92	110.62	238.05	6.8	91	56.52	12.35	226.07	120.52	142.28	258.83	30.83	1493.48	3998

A = Agriculture, hunting and forestry, B = Fishing, C =Mining and quarrying, DA = Food products; beverages and tobacco, DB = Textiles and textile products, DC = Leather and leather products, DD = Wood and wood products, DE = Pulp, paper and paper products; publishing and printing, DF = Coke, refined petroleum products and nuclear fuel, DG = Chemicals, chemical products and man-made fibres, DH = Rubber and plastic products, DI = Other non-metallic mineral products, DJ = Basic metals and fabricated metal products, DK = Machinery and equipment n.e.c., DL = Electrical and optical equipment, DM = Transport equipment, DN = Manufacturing n.e.c., E = Electricity, gas and water supply, F = Construction, G = Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods, H = Hotels and restaurants, I = Transport, storage and communication, J = Financial intermediation, K = Real estate, renting and business activities, L = Public administration and defence; compulsory social security, M = Education, N = Health and social security, O = Other community, social and personal service activities

4.2 Network analysis of intersectoral patterns of innovation

In Table 1 the Innovation Flow Matrix has been presented at a fairly aggregated level. The full detail Innovation Flow Matrix however is a 100×100 matrix, with 10 000 possible entries (including innovations for general purpose or final consumption). A detailed description of the flow of innovations requires the use of more complex descriptive statistics due to the complexity and size of the data.

Using network analysis, patterns of supply and use of innovation can be described in terms of industries which are *related*, or to be precise: industries that have more innovation interactions between each other than to other industries. The vehicle of analysis is network analysis and community detection.

A network, or a graph, is formally defined as $\Gamma = (V, E)$, where V is a set of vertices and E is a set of edges $E \subset V \times V$. The Innovation Flow Matrix can be understood as a directed weighted network with the sectors as vertices (industries) and with the weighted number of innovations between industry i and industry j as its edges. This means that both the count of innovations and the direction of the connections between industries matter. For a directed weighted network, each edge from vertex $i \in V$ to another vertex $j \in V$, has a weight $W_{ij} \in \mathbb{R}_+$.

Graphs may to a greater or lesser extent be possible to subdivide into subgroups, called communities. In a graph, in which all nodes are connected there is a weak community structure. In a graph in which some nodes are connected but not to all other nodes, there is a stronger community structure. Recent developments in network theory make it possible to find subgroups within a system of economic or technology flows (see Fortunato 2010; Malliaros and Vazirgiannis 2013 for reviews of community detection approaches in directed networks and Garbellini 2012 for an overview of methods applicable to economic input-output data).

There are many approaches to divide social, technological or other networks into subgroups. The approach employed here employs the concept of modularity, which is a descriptive statistic designed to measure the strength of division of a network into communities. The modularity of a network Q is defined as the sum of share of edges that fall into communities minus the expected shares of such edges:

$$\begin{aligned} Q = &(\text{share of edges within communities}) \\ -&(\text{expected share of edges within communities}) \end{aligned} \tag{2}$$

Formally, in our directed innovation network W_{ij}, the modularity is calculated as

$$Q^{dir} = \sum_{ij} \left(\frac{W_{ij}}{k} - \frac{k_i^{out} k_j^{in}}{k^2} \right) \delta_{c_i c_j} \tag{3}$$

$\frac{W_{ij}}{k}$ is the actual shares of flows between industry i and j, where k is the sum total of flows in the network. The expected shares of flows from industry i to j is calculated as the product of the share of innovations supplied by i, k_i^{out}/k, and the share of innovations used by j, k_j^{in}/k. The expected share of innovations assuming a random distribution is $\frac{k_i^{out}k_j^{in}}{k^2}$. $\delta_{c_i c_j}$ (the so-called Kronecker delta) assumes values 1 if $c_i = c_j$ i.e. if i and j belong to the same community, and 0 otherwise.

The value of modularity lies between −1 and 1, being positive if the number of edges or weights within groups exceeds the number of edges or weights expected. Modularity approaches 1 when no edges flow between communities and all edges flow within communities. Conversely, modularity approaches -1 when no edges flow within communities but only between communities. According to Clauset et al (2004, p. 2) "in practice it is found that a value above about 0.3 is a good indicator of significant community structure in a network."

The problem of finding a community division that maximizes modularity is technically non-trivial. While attaining the same end-goal, there are several algorithms proposed to solve the problem, each with merits and limitations. Since there is no algorithm that finds the community division that maximizes modularity *a priori*, the results section compares three similar community detection algorithms that are suitable for weighted networks. Newman (2004) proposed an efficient "greedy search" algorithm, in which vertices are joined into the same groups if they achieve the largest increase in modularity. Here the improved algorithm by Clauset et al (2004) is used. The algorithm proposed by Clauset et al (2004) is efficient and widely used but limited to undirected weighted networks. Thus, only the total count of innovations flowing between two industries are taken into account, but not the direction of the flows.

A spectral bisection algorithm for detection of community structures in weighted *directed* networks was suggested by Leicht and Newman (2008), generalizing the suggestions of Newman (2006) to directed networks. The task of the algorithm is to yield a subset of vertices which maximize the modularity, by way of a process of repeated bisection (i.e. subdivision into two partitions). The algorithm arrives at communities which are further indivisible, i.e. any further division into new communities does not improve modularity.[3]

The first algorithm was applied using the igraph package (see Csardi and Nepusz, 2006) in software environment R. The two latter algorithms for weighted undirected and directed graphs were executed by the author in software environment R, following Leicht and Newman (2008) and the fine tuning algorithm described in Newman (2006).

During the period studied there are stable patterns in the supply and use of innovations. The results are summarized in Tables 3 and 4. The results first

[3] A drawback with the modularity approach in general is however, that the communities are not allowed to be overlapping, i.e. a sector of product innovations is only allowed to belong to one community. Nicosia et al (2009) have considered an extension of the approach proposed by Leicht and Newman (2008) but at this date there is no algorithm that allows for the identification of overlapping subgraphs that maximize the modularity of a given graph.

Table 3: Summary statistics of partitions for IFM 1970-2007.

	Fast greedy	Leading eigenvector (undirected)	Leading eigenvector (directed)
Modularity	0.3430	0.3067	0.3424
N. communities	10	10	11
NMI fast greedy	1	0.6440	0.7672
NMI leading eigenvector(undirected)	0.6440	1	0.6713
NMI leading eigenvector (directed)	0.7672	0.6713	1

Normalized mutual information (NMI) compares the similarity between the partitions of networks into communities.

of all indicate the existence of a strong community structure. With all three methods, the network partitions result in a modularity above 0.3, which indicates a significant community structure.[4] The highest modularity is yielded by the fast greedy algorithm (Clauset et al, 2004), suggesting ten communities in the Innovation Flow Matrix for the period 1970-2007. The other two algorithms suggest ten and eleven communities but have slightly lower modularity. The importance of the proposed community structure is assessed by the modularity statistic. The modularity of the community is 0.34 for the whole period. The innovations flowing within the communities found capture 45% of the total count of innovations. Moreover, the results from the three different community detection algorithms are similar. An indication of the robustness of the partitions may be obtained by calculating the NMI (Normalized Mutual Information), which compares the similarity between the proposed partitions (Danon et al, 2005). The similarities between partitions is reported in Table 3. The statistic ranges between 0, if the partitions are disjunct, and 1, if the partitions are identical. The lowest found NMI is 0.6440, whereas the NMI between the partition suggested by the fast greedy and leading eigenvector algorithm for directed networks is 0.7672.[5]

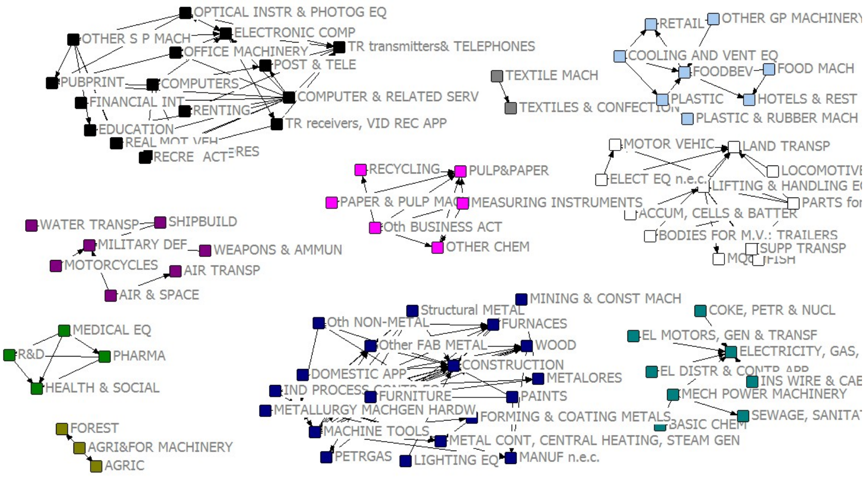
While the results are similar, the fast greedy algorithm finds the best partition.[6] The communities suggested are described in Table 4, where they have been labelled according to the most significant sector of supply or use.

[4] To recapture: The modularity ranges between -1 and 1. If modularity is positive the weights within communities are larger than the expected values of weights were generated by a random process. According to Clauset et al (2004) a modularity above 0.3 indicates a significant community structure.

[5] Following Danon et al (2005) the normalized mutual information (NMI) is calculated as $\frac{-2\sum_{ij} N_{ij} ln(N_{ij}N/N_i N_j)}{\sum_i (N_i ln(N_i/N)) + \sum_j (N_j ln(N_j/N))}$, where N_{ij} is the number of nodes found in community i of the first partition and community j of the second partition.

[6] This decision is based upon the modularity statistic only. The second best alternative suggested by the leading eigenvector algorithm for the directed network differs in one notable aspect. It distinguishes a separate block of innovations focused on transport and storage (ISIC 630) and lifting and handling equipment (ISIC 29220). In the best partition, these

Fig. 3: Communities suggested by fast greedy algorithm.



The communities are from the upper left: ICT innovations (black), Textiles and clothing (gray), Food products and packaging (light blue), Shipbuilding, aircraft and military defence (lilac), Pulp and paper (pink), Automotive vehicles and land transportation (white), Medical (green), Forestry (brown), Construction, metals and wood (dark blue), Electricity (turquoise)

The communities are depicted as networks in Figure 3, which highlights flows of innovations within the communities. Clearly, some communities encompass a large number of industries, while some consist of a smaller number of industries. The revealed community structure is to a large extent consistent with previous research on Swedish innovation activity and previous descriptions of important interindustry linkages and interdependencies. These results thus corroborate previous notions of technological subsystems. Community 3 and 5 correspond to ICT and medical equipment and biotechnology respectively. Community 3 in Tables 4 consists of all ICT industries. It can be understood as composed by three components. ICT innovations were developed for use in electronic components (ISIC 321) and telecommunication services (ISIC 640) during the second half of the period. These innovations were strongly connected to the deployment of Internet and telecommunications. During the first half of the period a development block surrounding factory automation was expanding, consisting of computer innovations (ISIC 30020), control systems (ISIC 333) and electronic components (ISIC 321) (Carlsson, 1995). The community also reveals that, during this period, a large share of computer innovations (ISIC 30020), among with office equipment (ISIC 30010) was aimed for applications in publishing and printing (ISIC 220).

industries are contained within the community centered on automotive vehicles and land transportation (see Table 4).

Community 5 spans medical equipment innovations, pharmaceuticals, health care and the research and development sector. This community corresponds well to what has been referred to as the medical and biotechnology "cluster" or "technological system" in previous research (Stankiewicz, 1997; Backlund et al, 2000). However, biotechnology innovations also include parts of the foodstuff and agricultural innovations.

A broad and important community of innovations (Community 7 in Table 4) was formed around the construction and mining sectors and materials for construction purposes, e.g. wood products, metals and fabricated metals, rubber and other non-metallic mineral products. This community also involves machinery for construction and mining, machine-tools and machinery for the processing of wood products and metals.

The remaining communities found were made up of supply industries more or less concentrated to one or two specific user industries: the pulp and paper industry (Community 1), food products (Community 2), automotive vehicles and land transportation (Community 4), Forestry (Community 6), Shipbuilding and Military defence (Community 8), Electricity production and distribution (Community 9) and Textiles and clothing (Community 10).

4.3 Supplier and user industries in the network of innovations

Our second interest lies in the hierarchical structure of the innovation flow matrix. The roles of industries as suppliers and users of innovations can be studied by comparing the out-strength of industries with the in-strength of industries. The former is defined as the column sums of the innovation matrix

$$k_i^{out} = \sum_j W_{ij} \tag{4}$$

and the latter as the row sums

$$k_j^{in} = \sum_i W_{ij} \tag{5}$$

An overall comparison of the out- and in-strength of industries is presented in Figure 4. The distribution of industries display a towards the vertical and horizontal axes rather than clustering along the line $k_i^{out} = k_i^{in}$, indicating a strong asymmetry among the industries. This suggests a strong hierarchical structure of the network innovations, implying that supplier industries are not typically also user industries to an equal extent, and the converse.

This result also holds within the ten communities detected, that appear to be composed by a set of relatively strong supplier industries supplying innovations to a set of user industries. To formally distinguish between supplier and user industries within communities, the out and in-strengths within communities are employed, calculated as

$$\sum_j \left(k_i^{out} - k_i^{in}\right) \delta_{c_i c_j} \tag{6}$$

Fig. 4: In-strength and out-strength of innovations in 101 industries, 1970-2007

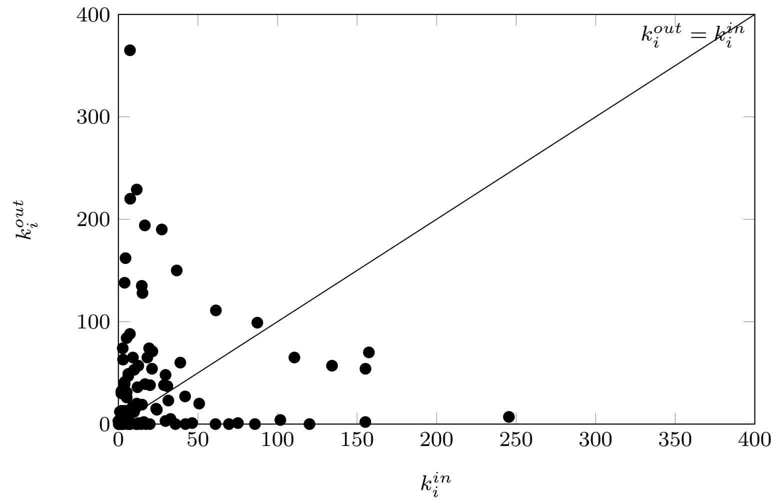
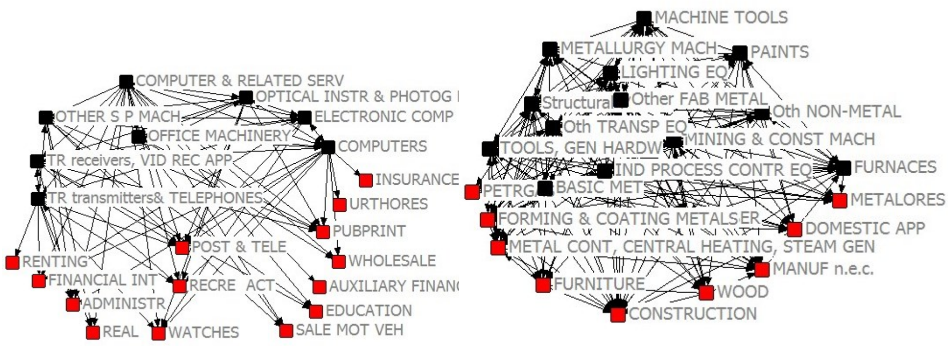
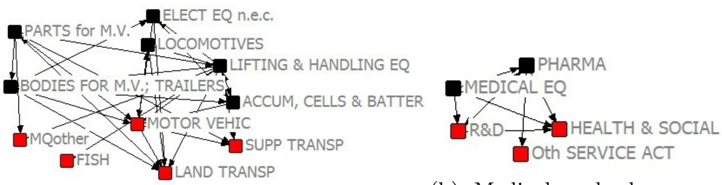


Fig. 5: Supply and user industries in the ICT and construction communities



(a) ICT (b) Construction and wood

Fig. 6: Supply and user industries in the automotive and medical equipment communities



(a) Automotive and land transportation (b) Medical and pharmaceuticals

Table 4: Description and summary statistics of communities suggested by the fast greedy algorithm for IFM 1970-2007.

Brief description of community	Sum of weights within	Count of innovations involved[a]	Total count of innovations involved (including GP and FC)[b]
1. Pulp and paper	134.82	187	324
2. Food products and packaging	129.81	151	303
3. ICT innovations	219.04	268	715
4. Automotive vehicles and land transportation	155.56	202	329
5. Medical	120.11	128	135
6. Forestry	47.67	50	55
7. Construction, metals and wood	404.88	451	642
8. Shipbuilding, aircraft and military defense	50.34	57	69
9. Electricity	48.61	82	172
10. Textiles and clothing	30.69	34	44
SUM	1341.51	1610	2788
Total IFM[c]	2743.63	3998	3998

[a] Count of innovations for which there is at least one linkage within the respective communities.
[b] Total count of innovations for which there is at least one linkage within the respective communities, including innovations for general purpose and final consumption.
[c] In the first row, the total refers to the total sum of weights in the IFM 1970-2007, when innovation for general purpose and final consumption are excluded. In the second and third column these are included for comparison with the count of innovations involved in communities.

In Figures 5-6, the color red indicates industries for which in-strength is less than out-strength and black indicates industries for which out-strength exceed in-strength. The ICT community consists of a set of supplier industries, notably hardware electronic equipment, such as computers, softwares, telephones and electronic components supplying innovations to a broad set of user industries, reflecting the generic diffusion of ICT technologies. The construction and wood community likewise consists of a set of supplier industries, notably machine tools, basic metals, paints and industrial process and control equipment, supplying innovations to the construction, wood and furniture industries. In smaller communities the hierarchical structure of innovation flows is even more apparent. Strong forward links exist between suppliers such as automotive parts, accumulators and batteries and lifting and handling equipment and user industries motor vehicles and land transportation. Medical equipment and pharmaceuticals are the main suppliers to R&D and health and social services.

Table 5: Count of innovations involved in communities (including innovations for final consumption and general purpose) divided by origin in problem-solving (PS) and technological opportunities (TO).

Community	TO	PS	TO and/or PS	Total count
1. Pulp and paper	148	114	213	324
2. Foodstuff	70	96	144	303
3. ICT	378	206	480	715
4. Automotive	90	116	176	329
5. Medical	93	35	104	135
6. Forestry	7	29	33	55
7. Construction	154	233	345	642
8. Military Defence and shipbuilding	21	8	27	69
9. Electricity	55	68	100	172
10. Textiles	13	15	24	44
Total	1029	920	1646	2788

4.4 Development blocks in the Swedish manufacturing industry

What do the communities found convey about evolving interdependencies between industries and technologies? I have argued that communities may be understood as Dahménian development blocks when incentives for innovation arises from complementarities and the resolution of technological imbalances and obstacles that emerge in technological development. Table 5 gives an overall view of the qualitative character of the interdependencies in communities. Some of these communities have been more centered on the exploitation of opportunities and others more on the solution of techno-economic problems. Table 5 shows the count of innovations exploiting new technological opportunities and problem-solving innovations, by community. The table counts all innovations involved in the community, including innovations for final consumption and general purpose innovations. Some communities consist to a greater extent by innovations exploiting technological opportunities. In particular this applies to the ICT community and the community centered on medical equipment and pharmaceuticals, where technological opportunities arising from advances in microelectronics, automation, computerization and digitalization or advances in medical sciences and biotech have been salient driving forces to innovation.

Four communities emerge as more focused on techno-economic problems: the forestry community, the community centered on construction and metal and wood production, the community centered on automotive vehicles and land transportation, and the community centered on electrical apparatus and energy distribution.

Table 5 thus shows that in most of the communities found, innovation activity has been spurred not only by the exploitation of new technological opportunities but also by problems. I proceed by summarizing the technologi-

Table 6: Innovations centered on solving imbalances, 1970-2007.

Development block	Contained in community (no)	Critical problems (summary)
Chlorine free bleaching processes	1. Pulp and paper	Replacement of chlorine
Quick-frozen food	2. Foodstuff	E.g. bacteria in thawing, temperature in distribution
Automated guided vehicles	3. ICT	Insufficient capacities of control systems
Laminate for electronic components	3. ICT	Under-etching
Secure payment and secure identification	3. ICT	Security issues in Internet networks
Telecommunication and Internet networks	3. ICT	Capacity requirements of network standards
Emission control technology	4. Automotive	Availability of unleaded fuels, Technical problems in catalytic converters
Electric and hybrid electric cars	4. Automotive	Weight and energy density of batteries
Pharmaceuticals and drug screening	5. Medical	E.g. slow drug screening, incapacity to deal with vast amounts of data
Forestry deforestation methods	6. Forestry	Unprofitability, obstacles to rational production methods
Occupational noise	7. Construction	Technical difficulties in reducing vibrations
Offshore exploitation of resources in the North Sea	8. Military defense and shipbuilding	Rough climate, Maintenance of oil rigs
Nuclear power	9. Electricity	Security
Speed control of AC motors	9. Electricity	Speed control
Solar power (solar collectors and solar cells)	Several	Limited sun exposure e.g., cost structure
Heat pumps	Several	Technical construction problems

cal imbalances that have provided incentives to innovation, in order to discuss the the underlying dynamics in Dahménian development blocks.

The technological imbalances found vary in character across industries and over time (see Taalbi 2014 for an in-depth description and industries not discussed in the present work.) The imbalances and problems found by a qualitative analysis are summarized in Table 6. Many of the communities found can be broadly understood as related to two macro-economic problem complexes: 1) imbalances emerging in the ICT technology shift, and 2) imbalances emerging in the attempts to deal with the adverse environmental and societal effects of oil based technologies and production systems.

4.4.1 ICT

The first type of imbalances is most notably found in factory automation during the 1970s and 1980s and numerous telecommunication innovations that were aimed to resolve capacity bottlenecks in the emerging telecommunication networks during the 1990s. These development blocks were primarily contained in the ICT community.

Similar to the cases of the steam engine, the dynamo and electricity, the breakthrough of microelectronics was preceded by several decades of discovery and improvement of electronic components and computers. Major breakthroughs in electronics were made with the digital computer (1945), the transistor (1947) and integrated circuits (1961). These innovations resulted from attempts to overcome bottlenecks, rising complexity of transistor-based systems, what has been called the "tyranny of numbers" and high assembly costs.

Thus, in the early 1970s an imbalance had been and was being resolved by the exploitation of micro-electronics. Though Sweden was not a large supplier of electronic components, a small number of innovations can be observed aiming to solve critical problems in the production and use of electronic components during the 1970s, such as under-etching, problems in detecting manufacturing errors due to overheating, and overcoming bottlenecks in the production of electronic components, such as the manufacturing of masks. Meanwhile, a development block surrounding factory automation emerged, primarily driven by the exploitation of new opportunities from the now unleashed capacity of microprocessors. In Sweden this was a strong development block involving a large set of actors producing micro-computer based control systems, industrial robots, machine tools and automated guided vehicles (Carlsson, 1995; see also Taalbi, 2014, pp. 101-106). Examples of innovations aimed to compete and reach new areas of application by improving the performance of control systems and automation equipment are abundant in the SWINNO database.

Not only technological opportunities, but also technological imbalances have however occasionally emerged between the capacity of control systems and the requirements of applied technology. In these cases the development of micro-electronics enabled the solution of technological imbalances in the 1970s. The introduction and further development of automated guided vehicles (AGV) can be described in this way. The first AGV was commercialized by the US company Barret Electronics in the 1950s. A hampering factor in the development of AGVs was however the limited capabilities and bulkiness of the control systems for the guidance of the vehicles. The solution to these problems was made possible by the advancement of integrated circuits and microelectronics. The Swedish firm, Netzler and Dahlgren (NDC) emerged as one of the pioneers in the development of AGV control systems when it became involved in a Volvo project, which was the first installation of AGVs in Sweden.[7] The further development of AGVs has also been characterized by the

[7] In 1972 NDC developed the control system for Volvo's carriers. As a result of the project Volvo developed and commercialized its carrier technology, for instance at Tetra Pak. NDC was also involved in developing the computerized control system in this project. A subsidiary

overcoming of critical problems. The guide paths were perceived as inefficient and expensive when the users wanted to modify the trucks' movement patterns. Several innovations were developed during the 1980s and 1990s aiming to attain flexibility in this way, by e.g. using laser navigation technologies.

The major imbalances observed in the broader ICT development block have been the many technological obstacles that appeared in the deployment of Internet and telecommunication networks during the 1990s and 2000s. A primary driving force in the development of telecommunications and in the deployment of Internet technology has thus been the emerging imbalances between network components, such as circuits and switches, and the network requirements. Innovations solving critical problems in the deployment of Internet and Telecommunication networks include transmission systems and transmission technologies, network switches and electronic components for data and telecommunication networks. Most of these innovations can be understood as responding to obstacles in the introduction of new communication technologies, such as broadband access technologies DSL (Digital Subscriber Line) and the telecommunication transmission standard, ATM (Asynchronous Transfer Mode) or in the later introduction of Voice-over-IP (VoIP). For example, the development of ADSL technology (Asymmetric Digital Subscriber Line) commenced internationally to address a capacity bottleneck (Fransman, 2001, pp. 125-126). Moreover, when Swedish Telia was the first in the world to transmit high resolution TV images using VDSL (Very high speed digital subscriber line) it was noted that modems and network components were necessary for a commercially functioning technology. In 1999 Telia Research could launch a series of chips adapted for VDSL, developed together with the French chip manufacturer ST Microelectronics. Similarly, ATM (Asynchronous Transfer Mode) was developed to fulfil the requirements of broadband, enabling digital transmission of data, speech and video and to unify telecommunication and computer networks. For this technology, fast circuits were needed. Ericsson developed an ATM circuit, AXD 301 for broadband networks aimed to increase performance and fulfil security requirements. Netcore (later renamed Switchcore) launched a circuit that could handle both ATM and IP technology. With increased traffic, the data switch was a capacity bottleneck, but with Netcore's circuit it became possible to build faster and cheaper switches.

Other imbalances can also be found. Internet and data communication security was an imbalance that spurred innovation activity, in particular during the 1990s and 2000s. For example, the breakthrough of "e-commerce" was considered to be hampered by the problem of attaining secure transactions. Other firms developed systems for secure identification on-line or in mobile phones, selling their services to banks.

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to Volvo, ACS (AutoCarrier System) was formed in 1976, based on a guided carrier, the so-called Tetracarrier.

4.4.2 Innovations pertaining to environmental imbalances

The second set of imbalances are found in the automotive and pulp and paper communities and concerning the production of energy.

Following the oil crisis of the 1970s, search *en masse* for new energy technologies was initiated. Some examples of energy technologies developed during this period were heating pumps, innovations for the use of biomass (e.g. wood and forest residue) and peat, innovations for the use of solar power or wind power. These were all technologies characterized by their own obstacles. Such obstacles have frequently focused the direction of innovations. Several innovations were developed aiming to overcome techno-economic obstacles to the use of various forms of bio-energy, e.g. forest residue, peat and recycled biological waste, aimed to break oil dependency. Wood and forest residue was one of the main alternative fuels during the 1970s and 1980s. An urge to make better use of wood material was occasioned by a wood shortage during the 1970s, but also the growing demand for chips for energy production. This led to the development of new methods and machinery that aimed to overcome obstacles to attain profitability in the processing of forest residue. Other alternative energy sources were also increasingly explored from the 1970s by solving critical problems. For instance, obstacles to the use of solar energy, spurred innovation activity from the 1970s. Technologies were developed in order to enable seasonal and long term storage of summer excess energy. While advances were made, chemical energy storage was still by the end of the period a problem that together with renewed interest in solar-power, induced Swedish innovations.

Another set of innovations has been aimed towards dealing with negative externalities and industrial waste. The alleviation of the paper and pulp industry's environmental problems has involved not only new production processes, but also new paper and pulp machinery, measuring apparatus and new chemicals. Swedish firms have been pioneers in producing biofuel from residue from the pulp and paper industry. These innovations have both aimed to solve environmental problems and to reduce production bottlenecks, such as the costly recovery boilers. A set of innovations were aimed to produce biofuel from residue from the pulp and paper industry. For instance, the Chemrec process (developed by a firm with the same name) was aimed to replace the recovery boilers and enable increased energy efficiency.

Another set of innovations were developed to replace traditional chlorine bleaching processes, also induced by regulation. With the Swedish Environmental Protection Act of 1969, efforts were directed towards emissions and developing new processes for bleaching of pulp residue. So it was that during the 1970s oxygen bleaching processes were developed in Sweden (e.g. by firms MoDo and Kamyr). Main chlorine free alternatives were oxygen bleaching and chlorine dioxide bleaching. From the end of the 1980s the industrial emissions of absorbable organic halogens (AOX) were regulated, which meant a push into technology development. For example, as a response to environmental regulations of AOX, Eka Nobel developed its Lignox method, a chlorine free bleaching process, based on hydrogen peroxide.

The unsatisfactory treatment and the adverse effects of emission and vehicle exhaust form an imbalance at the core of the community centered on automotive engines, batteries, automotive vehicles and land transportation. One may point at two parts of this development block. The first part, encompassing a larger number of innovations, is centered on emission control technology and innovations introduced to decrease vehicle exhausts for gasoline driven vehicles. The development of catalytic converters and emission control technologies can be described as characterized by the successive overcoming of technical problems, frequently developed in response to the introduction of exhaust requirements and legislation.[8] Examples in point relate to EGR (Exhaust Gas Recirculation) that was developed in the US as a response to stricter NO_x limits during the 1970s. Swedish firms have since integrated the technology into cars. Towards the 1990s and 2000s some Swedish innovators have developed the technology further, spurred by continued sharpening of the emission limits. A critical problem with EGR has been that the exhaust gases have a lower pressure than the fresh air, which leads to increased fuel consumption. This problem was solved by two inventors starting up a new company Varivent, later bought by Haldex.

A set of stronger incentives to eliminate obstacles to the diffusion or exploitation of a new technology, have characterized the development of electric and hybrid automotive vehicles. Much effort has been aimed at reducing automotive emissions and increase fuel efficiency. The development of hybrid and electric cars and trucks, and the complementary development of automotive engines, batteries and battery stations is a part of the development of more fuel efficient and environmentally friendly cars and transport vehicles. The increased oil, fuel and energy prices in the 1970s forced the automotive industry to concentrate efforts in this direction. Costumer-demand, environmental awareness and sharpened legislation has since then also driven technological development in this direction (Elsässer, 1995). The development of hybrid and electric cars have prompted other complementary innovations. The difficulties in developing sufficiently light and energy-dense batteries with sufficient life length have been salient critical problems that have hampered the commercialization of electric and hybrid cars for decades. Several Swedish innovations were aimed at appeasing or solving such problems, among other things batteries with longer life length, charging stations and hybrid technologies (see Taalbi, 2014, pp. 220-224 for further examples).

4.4.3 Pharmaceuticals and drug screening

Other imbalances are indicated by a set of cases in the medical community. Innovations in the community centered on medical equipment and health care were for the most part driven by advances in microelectronics or scientific advances in biotechnology and medicine. The community however contains a

[8] For instance in response to US regulations, Saab-Scania and Volvo separately developed three-way catalytic converters (TWC), introduced in new car models for the US market in 1976 (Elsässer, 1995; Bauner, 2007, pp. 254-255).

set of innovations centered on pharmaceuticals and drug screening that have been spurred by a sequence of technological imbalances. According to Nightingale (2000) and Nightingale and Mahdi (2006), there were three main imbalances in the development of pharmaceuticals. One of the main imbalances was the slow screening of molecules, which was overcome by the introduction of throughput screening in the 1990s. Up until then a number of innovations were developed in Sweden exploiting the advancement of microelectronics to enable faster screening. The overcoming of the slow screening bottleneck however created a new imbalance in the synthesis of chemicals. The pharmaceutical companies could not develop new interesting substances at a sufficiently fast rate and were therefore deploying resources into finding automated processes for chemical synthesis. One Swedish example was Pyrosequencing that developed a process for DNA sequencing based on a new method developed at the Royal Institute of Technology. Cellectricon's innovations attacked similar critical problems in drug screening and development of new drug candidates. Cellectricon's "Dynaflow" process automated the drug screening process by way of a "micro-shower" for cells.

The introduction of automated synthesis of large amounts of chemicals however also created a new imbalance in the inability of firms to handle the large amounts of data. During the second half of the period the advances made in computer programming could be exploited to solve technical problems in areas such as pharmaceutical production and genetic engineering. An example is Visual Bioinformatics that responded to the problem of handling large amounts of experimental data by developing an analysis program to analyze and visualize data.

4.4.4 Forestry

Some non-negligible problem complexes, were characterized by a strong negative pressure during the structural crisis of the 1970s. Problems in the forestry sector became severe when an acute wood shortage broke out during the 1970s when both production shrank and prices were kept low despite high demand. In 1974 the yearly deforestation level of the forestry industry reached the maximum level allowed by Swedish legislation. These conditions influenced a number of forestry machinery innovations aimed to enable better wood usage per tree felled. These innovations can be understood as a block of innovations aimed to make profitable culling and handling of wood and to eliminate obstacles hindering the introduction of rational production methods, such as whole tree deforestation.

5 Conclusions

Using a combination of quantitative techniques and qualitative information on innovation biographies from a new innovation database, SWINNO, this study has explored the interdependencies in the Swedish network of innovations, 1970-2007. In doing so, the study contributes with a new empirical methodology to study development blocks and technological interdependencies and subsystems. By studying simultaneously interdependencies from quantitative and qualitative data, this article is also able to assess aspects of technological systems that previously have mostly been studied in case studies or employing larger numbers of examples.

The empirical analysis reveals how innovation activity has co-evolved in ten communities, or plausible development blocks. The Swedish network of innovations displays a highly hierarchical and asymmetrical structure as regards the supply and use of innovations. Moreover, the community and hierarchical structure of the network indicates that linkages between industries to a large extent can be understood in terms of vertical relations between suppliers and users. The statistical and qualitative analyses reveals that several of the communities found were focused on resolving technological imbalances, either under a pressure to transform, as in the pulp and paper or forestry industries, or a positive situation, as in the telecommunications industries during the 1990s. In these cases the innovations involved were parts of smaller or broader development blocks centered on the exploitation of new technologies or the overcoming of technological imbalances. Supplier industries have then typically solved problems emerging in user industries, stressing as have many before me, an empirically important dynamic element of co-evolution in the development of technological systems.

A Industrial nomenclature

Table 7: Industrial nomenclature at the level of detail used in the Innovation Flow Matrix, description and code in ISIC Rev 2.

ISIC Rev 2	Text
10	Agriculture and hunting
20	Forestry, logging and related service activities
50	Fishing
100	Mining of coal and lignite; extraction of peat
110	Extraction of crude petroleum and natural gas; service activties incidental to oil and gas
120	Mining of uranium and thorium ores
130	Mining of metal ores
140	Other mining and quarrying
150	Food products and beverages
160	Tobacco products
170-190	Textiles, wearing apparel and leather
200	Wood and wood products, except furniture
210	Pulp, paper and paper products
220	Publishing, printing and reproduction of recorded media
230	Coke, refined petroleum & nuclear fuel
241-242	Basic chemicals, pesticides and other agro-chemical products
243	Paints, varnishes and similar coatings, printing ink and mastics
244	Pharmaceuticals
245-247	Other chemical products (including soap and detergents etc and man-made fibres)
251	Rubber products
252	Plastic products
260	Other non-metallic mineral products
270	Basic metals
281	Structural metal products
282-283	Metal containers; central heating radiators; steam generators
284-285	Forming and coating of metals; general mechanical engineering
286	Cutlery, tools and general hardware
287	Other fabricated metal products
291	Machinery for the production and use of mechanical power, except aircraft,
29210	Furnaces and furnace burners
29220	Lifting and handling equipment
29230	Non-domestic cooling and ventilation equipment
29240	Other general purpose machinery n.e.c.
293	Agricultural and forestry machinery
294	Machine-tools
29510	Machinery for metallurgy
29520	Machinery for mining, quarrying and construction
29530	Machinery for food, beverage and tobacco processing
29540	Machinery for textile, apparel and leather production
29550	Machinery for paper and paperboard production
29561	Machinery for plastic and rubber processing
29569	Other special purpose machinery n.e.c.
296	Weapons and ammunition
297	Domestic appliances n.e.c.
300	Office machinery and computers
311	Electric motors, generators and transformers
312	Electricity distribution and control apparatus

313	Insulated wire and cable
314	Accumulators, primary cells and primary batteries
315	Lighting equipment and electric lamps
316	Electrical equipment n.e.c.
321	Electronic valves and tubes and other electronic components
322	Television and radio transmitters and apparatus for line telephony and line
323	Television and radio receivers, sound or video recording or reproducing apparatus
331	Medical and surgical equipment and orthopaedic appliances
332	Instruments and appliances for measuring, checking, testing, navigating and other
333	Industrial process control equipment
334	Optical instruments and photographic equipment
335	Watches and clocks
341	Motor vehicles
342	Bodies (coachwork) for motor vehicles; trailers and semi-trailers
343	Parts and accessories for motor vehicles and their engines
351	Building and repairing of ships and boats
352	Railway and tramway locomotives and rolling stock
353	Aircraft and spacecraft
354	Motorcycles and bicycles
355	Other transport equipment n.e.c.
361	Furniture
362-366	Manufacture n.e.c
370	Recycling
400	Electricity, gas, steam and hot water supply
410	Collection, purification and distribution of water
450	Construction
500	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel
510	Wholesale trade and commission trade, except of motor vehicles and motorcycles
520	Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods
550	Hotels and restaurants
600	Land transport; transport via pipelines
610	Water transport
620	Air transport
630	Supporting and auxiliary transport activities; activities of travel agencies
640	Post and telecommunications
650	Financial intermediation, except insurance and pension funding
660	Insurance and pension funding, except compulsory social security
671	Activities auxiliary to financial intermediation
700	Real estate activities
710	Renting of machinery and equipment without operator and of personal and household goods
720	Computer and related activities
730	Research and development
740	Other business activities
751	Administration of the State and the economic and social policy of the community
752	Provision of services to the community as a whole
800	Education
850	Health and social work
900	Sewage and refuse disposal, sanitation and similar activities
920	Recreational, cultural and sporting activities
930	Other service activities

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