National innovation systems analysed by the SMFA: A comparison between Germany, Japan and the USA for the decade 1980 / 1990

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Abstract:

The paper shows how the National Innovation System of a country can be detected using a tool called Subsystem-MFA (SMFA), an MFA application to so called subsystems. The standard subsystem analysis shows the innovation-spillovers of the relevant innovative sectors of a country which are the basis for compiling a system of interlinked sectors due to the most important innovation flows. This system is then turned into graphical form so that the sectors clustering into this system can be shown like a “molecule“ of sectors, giving the national innovation basis.

The analysis uses the recent input - output - tables of the OECD for Germany, Japan and the United States for the begin, mid and end of the decade 1980 until 1990. The tables offer a good opportunity to compare the above 3 countries as the used table series were made comparable. To discover innovation-spillovers the analysis uses innovation-indicator-vectors, like R&D-expenditures, coming also from the OECD, which had to be transformed into the suitable form of the IO-tables.

The data are aligned into a subsystem approach and deliver an innovation flow matrix of innovation providers and innovation users, which is analysed by a suitable version of the MFA. The results show how the innovation system in Germany, Japan and the United States looks like and how it developed over the decade 1980 to 1990.

The results show that there are specific pattern of national innovation systems which differ to some extent between the given countries. These differences can well be interpreted to be due to the specific economic history of these countries.

1 Introduction

Innovation seems to be the main source of technological progress. However, those innovation effects do not only consist of the innovative activities created by the sector itself, but as well of innovations that are „imported“ from other sectors via intermediary products or investment goods. To analyse these indirect effects we have to regard the direct as well as the indirect innovation activities of sectors.

Mostly, a direct observation of innovation flows is not possible. To answer the question, how much a sector profits of the innovation efforts of other sectors, e.g., included in intermediate goods, a subsystem approach is chosen. As an indicator of the innovation activities of a sector the R&D-expenditures of that sector were used. Besides this indicator of course other possible indicators like innovation expenditures (broader definition), R&D-capital or R&D-personal would be suitable for the analysis but were not available in the data basis. The subsystem approach combined with the innovation indicator and the SMFA identifies technology delivery and technology user sectors and their connections and thus produces a picture of the national innovation systems under analysis.

This paper compares the structure and structural changes of the national innovation systems of Germany, Japan and the USA between 1980 and 1990.

2 The Subsystem - Model

The idea and the concept of a subsystem originated with the work of Sraffa (Sraffa 1976) and Pasinetti (Pasinetti 1973) and became soon an interesting component of the Input-Output-Analyses. A first idea of the subsystem - concept is given by equation (1).

$$Z_j = (I - A)^{-1} y_j \qquad (1)$$

If we use a final demand vector y which, except for one element consists of zeroes and the element $y_j = 1$, the formal multiplication results in Z_j which contains exactly the jth column of the Leontief inverse $(I - A)^{-1}$. This is because the multiplication leaves in each row of the Leontief inverse the jth element c_{ij} (j = 1,...,n). All other elements of the matrix vanish due to the multiplication with zero. The individual element c_{ij} is a so called multi-sector-multiplier. The meaning of such a vector is how much sector i must produce directly and indirectly to help producing one unit of the final product j. Thus, the jth column of the Leontief inverse specifies the contribution of all sectors, leading to the production of one unit of the jth final demand product.

If instead of the described vector y_j a vector with the *absolute* amount of the final demand component *j* will be used for the multiplication, the result matrix Z_j will obtain the *absolute* production requirements of all sectors involved in the production of the final demand y_j. According to Sraffa the so calculated column vector is called a *subsystem* (for the production of final demand component j). It describes all production necessities for the production of the desired final demand.

If we regard all *n* final demand categories simultaneously we have to use a corresponding multiplication formula for all *n* sectors. This is achieved by multiplying instead the final demand y_j with the diagonalised final demand vector $<y>$. If we now finally divide the square matrix Z row by row by the corresponding production value x, we obtain the respective proportional amounts s_{ij} of each subsystem in the production of the total final demand y.

$$S = <x>^{-1} Z = <x>^{-1} (I - A)^{-1} <y> \qquad (2)$$

The left side multiplication of the matrix Z by the corresponding diagonalized production vector $<x>^{-1}$ signifies a norming of the rows, i.e., the elements s_{ij} sum up to 1 in each of *n* rows. This matrix is called the S-Operator (Schnabl 1995). Multiplying again the S-Operator from the left side with a further diagonal matrix of R&D-expenditures, $<R\&D>$, results in the square matrix $X_{R\&D}$.

$$X_{R\&D} = <R\&D> <x>^{-1} (I - A)^{-1} <y> \qquad (3)$$

The result is an imputation of the R&D-expenditures of the sectors to the *n* subsystems. This subsystem approach shows how each sector i „dedicates“ its own

R&D-expenditures to the production of its own as well as the other final demand goods (j) (j = 1..n).

Thus the rows of the R&D-flow-matrix show to which extent a single row sector i will be a technology deliverer to the production of the other final demand goods. The columns however show the contribution of the R&D-expenditures of other sectors to the final demand category of that subsystem. This signifies how much the producer sector of the corresponding good is a technology user. The R&D-flow-matrix $X_{R\&D}$ indicates the „technology flows“ between sectors which are hidden in the intermediate-matrix and are visualised by the use of the R&D-expenditures. Thus, such a subsystem calculation helps to estimate technological interlacing which, at the first glance, is not evident.

The R&D-flow-matrix $X_{R\&D}$ is the basis for the Subsystem MFA (SMFA) which works analogously to the MFA (Schnabl 1994) but is not identical. As in the MFA the Matrix $X_{R\&D}$ will be divided into hierarchical layers according the Eulerian row development of the Leontief inverse. These layers are the basis for deducing the R&D flows.

3 The presentation of the results

The SMFA results obtained will be represented in an ellipse. Sectors not presented are – according to the endogenous filter used – interpreted to be not „relevant“ (enough) for the national innovation system while the represented sectors can be signified on the one hand according to their location and on the other hand according to their links – emphasised by different lines[1].

To obtain the position of an individual sector within the ellipse, a so-called *centrality coefficient* is used. This coefficient is defined roughly as the ratio of input and output flows, maps into the interval [0; 2] and allows a differentiation into source, centre and sink sectors. Centre sectors are emphasised by a bold circle and have roughly as many input relations as output relations. Therefore the ratio is about one. The source-sectors with a centrality coefficient below 1 are the so-called „technology-deliverers“ within the innovation system – their innovation output is higher than their

[1] The structurasation is described at the appendix.

innovation input, whereas the sink-sectors are the „technology-users“ within the system – they have a higher innovation input.

With this arrangement a possible intertemporal change of the sectors within the groups can be noticed and be questioned. A normal innovation flow is represented by an arrow, whereas a bold line denotes bilateral flow connections. Broken lines – whether fat or simple arrows – denote connections given at one filter level *below* the endogenous filter. Thus broken lines can signify „death“ or „birth“ of the corresponding link when analysed in an intertemporal context. The correct interpretation of the development of the structure is achieved by comparing (intertemporaly) successive graphs.

Thus it is possible not only to find the important sectors but also the relevant links (Schnabl 1995/1996). This gives us the facility to realise basic features of structural development and to gather knowledge of potential future development patterns.

4 Database

The data base for the national innovation systems analysis are the OECD publications „Input - Output Database“ (OECD 1995) and the „Basic Science and Technology Statistic“ (OECD 1993). The OECD data are suitable especially for an international comparison because the data have been made comparable for the sectors for different countries by an international expert committee.

4.1 The Input - Output Tables of the OECD

The Input - Output Tables of the OECD are designed for 36 sectors whereby sector 36 is a catch all sector for statistical discrepancies. To ensure compatibility within the database the member countries of the OECD supplied the data according to the International Standard Industrial Classification (ISIC, Rev. 2) because the changes could be only done by the national authorities. This analysis compares the tables of

Germany[2], Japan and the USA for the decade 1980/1990. The sector 36 will not be used in the analyses.

The classification chosen by the OECD was designed to identify technology-intensive and/or trade-sensitive sectors as for example pharmaceutical, computers communication equipment automobiles etc.. Consequently, the manufacturing sector is desegregated more finely than the agriculture, mining or services sectors.

Although the OECD tried to impose consistency in the data, some inconsistencies became apparent resulting from country peculiarities. For Germany it is to notice, that the sector 18 (Radio, TV and Communication equipment) is not given separately but is included in sector 17 (Electrical Apparatus). In order to keep comparability also with respect to our analysis the tables of Japan and the USA were changed so that the sector 18 was also aggregated into sector 17. The rows and columns of sector 18 will then be zero as it was the case for the German table.

4.2 The R&D-Budget vectors

From the OECD „Science and technology indicators“ we used the R&D-Total-expenditures. The R&D-Expenditures had to be fitted to the scheme of the corresponding Input-Output Tables which did not turn out to be a big problem. Only in the case of the service sectors the sector R&D amounts had to be desegregated to several sectors, which has been achieved according the output value of the corresponding sectors of the table.

If in the Input-Output Table some sectors are aggregated for better comparison the R&D total expenditure of course has to be aggregated as well. The data of the R&D total expenditure is sufficiently well prepared for Germany and Japan whereas the R&D data for the USA are only available for the expenditures of the US enterprises (not including government expenditures like the two other countries). The data of the

[2] The German dataset contains the tables of 1978, 1986 and 1990. Therefore an Input - Output Table was aggregated according to ISIC 2 classification for the year 1980 out of the German (58 sectors) Input - Output Table of 1980. For making the table corresponding to the OECD Tables the sector 34 (Government producers) will be added into the final demand. Therefore the columns and rows of the intermediate matrix for sector 34 consists only of zero. Sector 31 (Finance and Insurance) is treated as well separately. The imputed bank service changes are allocated to the sectors according the ratio of distribution of the year 1978.

R&D-Budget spent by the government is highly aggregated. Therefore it seems much more plausible in the case of US to use only the data of the enterprises.

The R&D total expenditure data exist for the diverse countries over the years 1981 to 1990. Thus the time frame of the R&D data not always corresponds exactly with that of the Input-Output Tables. Quite often there exists a time difference of one year. As the R&D expenditures are quite consistent over the years a time difference of one year will not be so important. As well it is supposed, that the R&D structure of the imported goods correspond to the structure of the own country.

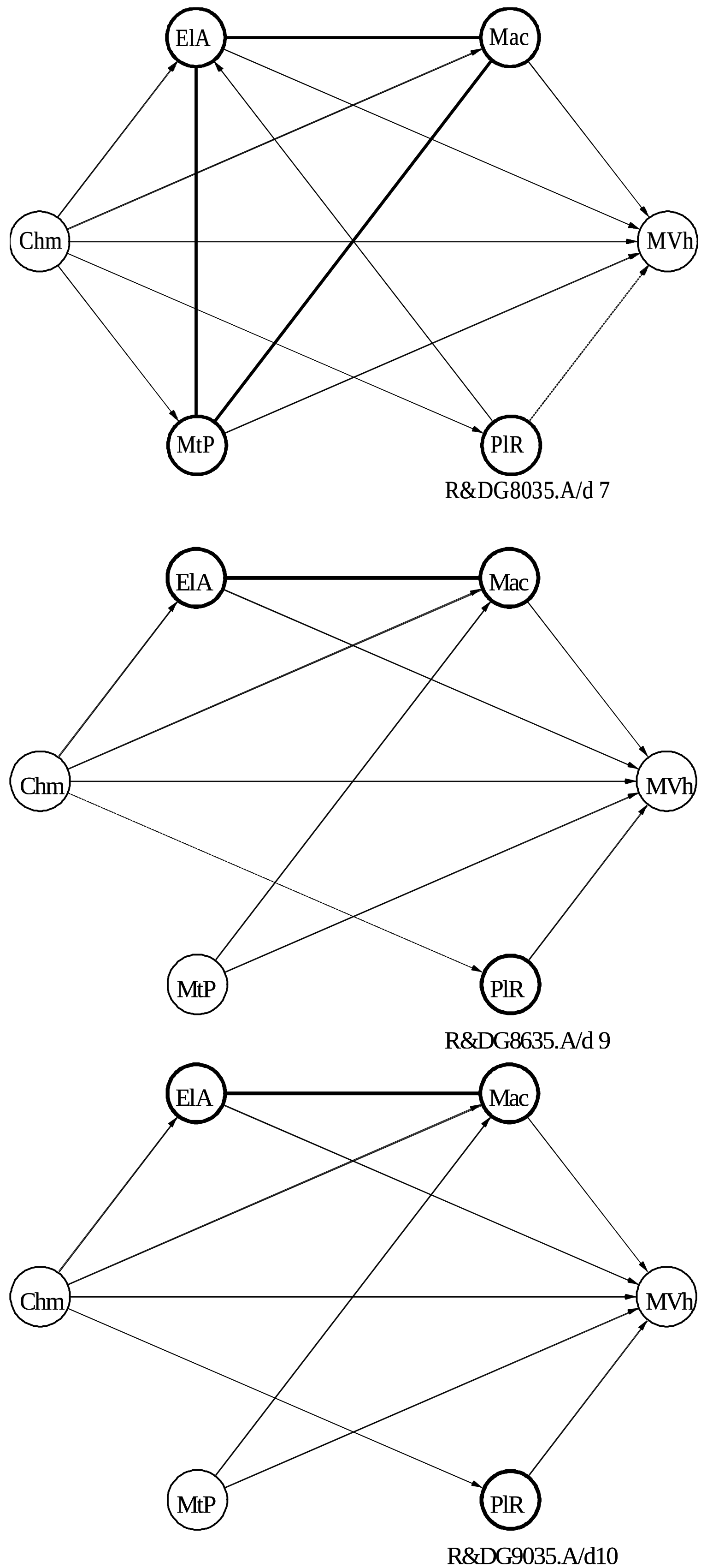
5 Results

According to the SMFA important sectors can be assigned to one of the three groups source, centre and sink sectors for identifying and questioning possible changes between groups. The results of this analyses for the three countries Germany, Japan and the USA concerning the decade 1980 until 1990, with exception of the USA where the first table was given for 1982 and for Germany where the 1986 table was given instead of the 1985 table. The first table corresponds to the beginning, the last table to the end and the second table to the middle of the decade.

In Figs. 1 to 3 the signature at the lower right corner of each graph denotes the type of the table. Thus i.e., „R&DG8035“ denotes, that as an indicator of innovation efforts the R&D-expenditures is used. The G stands for Germany (needless to say that this was West-Germany before unification for all tables) the first two figures (80) indicate the year and the second two (35) the number of sectors of the used table which is the same of course for all tables here.

5.1 The German innovation system, measured by R&D expenditures

Fig. 1: The characteristic innovation flow structure for Germany from 1980 - 1990



The following table shows the distribution of the R&D-sectors for Germany qualified as important by the SMFA according to the three categories source-sectors, centre and sink-sectors.

Tab. 1: Important R&D-sectors Germany 1980 - 1990

Year	source-sectors	center	sink-sectors
1980	Chm	ElA, Mac, PlR, MtP	MVh
1986	Chm, MtP	ElA, Mac, PlR	MVh
1990	Chm, MtP	ElA, Mac, PlR	MVh

At the first glance we can see that the assignment of the sectors to the three categories in the structure of innovations is quite stable over time. The important source-sector of incorporated R&D is sector Chm (Chemicals). In 1986 the sector MtP (Metal Production) changes its place from centre sectors to source sectors. The only stable sink-sector is the sector MVh (Motor Vehicles). The relevant centre sectors are ElA (Electronic Apparatus), Mac (Machinery) and PlR (Plastics and Rubber).

Another interesting point of the innovation flow structure is the development of the bilateral linkages. A bilateral connection of two sectors can be called a „growth dipole“ with respect to interchanged innovations. The innovation growth of one sector stimulates an additonal growth of the other sector which is than reflected back to the first one. So we get a positive feedback and a non-linear acceleration of growth of innovations in both sectors. The bilateral links are the dynamic source of the economy. Over the decade 1980 until 1990 there exists a bilateral connection of the sectors ElA == Mac which form a so-called „bilateral triangle“ with the sector MtP for the year 1980. The sector ElA uses in 1981 approximately 24% and in 1989 nearly 27% of the overall R&D expenditures and the sector Mac requires between 14% and 11%. For Germany this result is not surprising. In a certain sense the graphs of fig. 1 can be interpreted as a picture of the prominent sectors forming the German national innovation system. The structure of this system mainly shows sectors grown after the second World War. Sectors, which are relevant for future development like e.g. RTC (Radio, TV and Communication) do not however show up in the figures because the data are contained in sector ElA of the German Input-Output-Table.

5.2 The Japanese innovation system, measured by R&D expenditures

Fig. 2: The characteristic innovation flow structure for Japan from 1980 - 1990

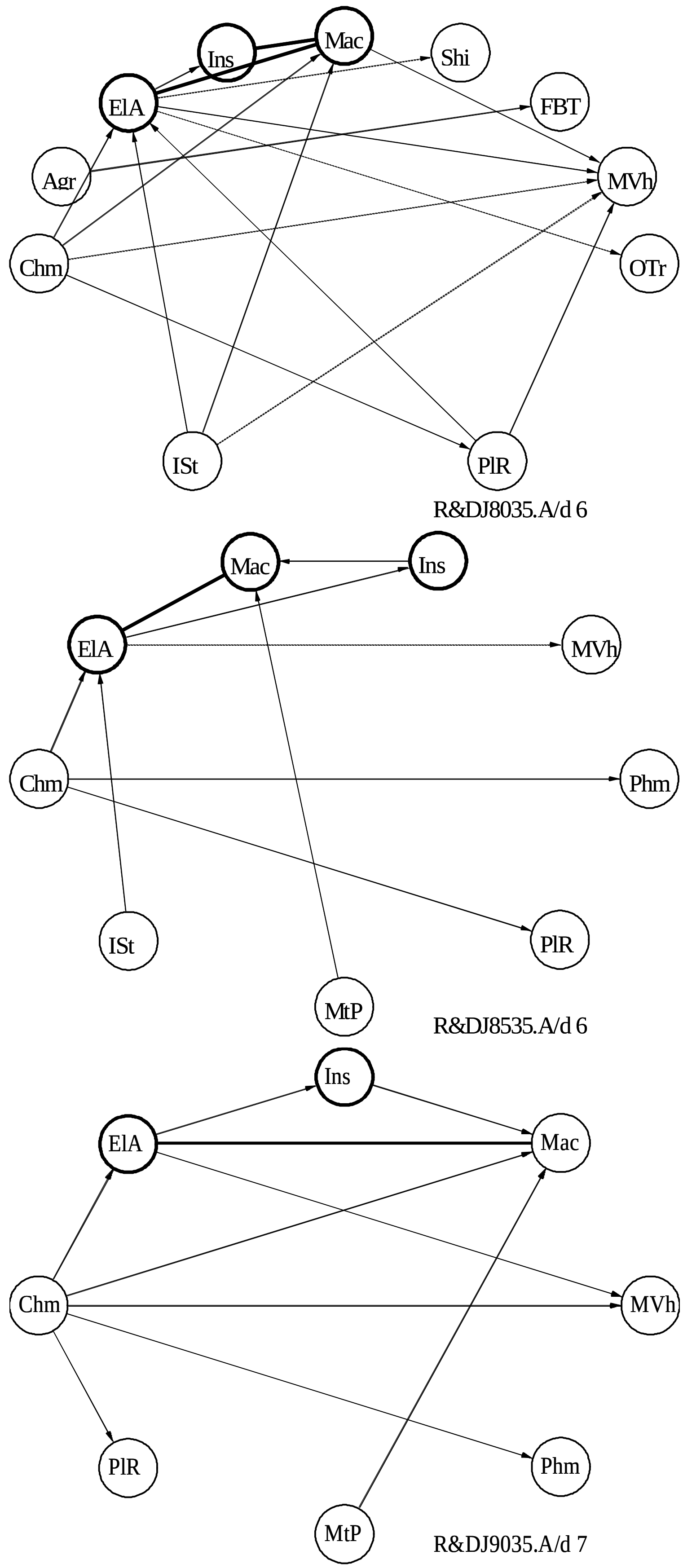


Figure 2 shows the most important sectors of the Japanese innovation system qualified as important by the SMFA according to the three categories source sectors, centre and sink sectors.

Tab. 2: Important R&D-sectors for Japan 1980 - 1990

Year	source-sectors	centre	sink-sectors
1980	Chm, ISt, Agr	ElA, Ins, Mac	MVh, PlR, FBT
1985	Chm, ISt, MtP	ElA, Ins, Mac	MVh, PlR, Phm
1990	Chm, MtP	ElA, Ins	MVh, PlR, Phm, Mac

Similarly to Germany the central source sector of innovations in Japan is sector Chm (Chemicals). The sector Agr (Agriculture) figuring as source in 1980 looses its importance and vanishes together with the sink-sector FBT (Food/Beverages/ Tobacco). The same is true for the sector ISt (Iron and Steel) for the year 1985. The important centre-sectors for the decade 1980 till 1990 are the sectors ElA (Electronic Apparatus) and Ins (Instruments). The centre-sector Mac (Machinery) moves to the group of sink-sectors in 1990 which consists of the sectors MVh (Motor Vehicles) and PlR (Plastics and Rubber) throughout the decade and of Phm (Pharmaceuticals) for the last two years.

The stable *bilateral* link for the regarded decade of the Japanese innovation structure is – like in Germany – the connection of the sectors ElA and Mac. The prolongation of this link into a bilateral chain ELA==MAC==Ins degenerates its Ins-connection from 1985 on to a simple innovation flow from Ins (Instruments) to Mac.

If we look closer at the results of the analyses we have to take into account that the two sectors ElA and RTC are aggregated in the Japanese Input-Output-Table for the purpose of a better comparison with Germany. Those two sectors use about one third of the total R&D-expenditures of which the sector RTC requires almost two thirds. The SMFA-result produced by the original data (i.e. not aggregating sectors 17 and 18) only consists of a bilateral link of only these two sectors. Other connections would not show up due to the overwhelming concentration of R&D to these two sectors in Japan.

The intertemporal comparison of the innovation flows shows that the link of the sectors Agr and FBT vanishes with the year 1985. The sector ISt looses its position as well. This structural development fits well with the Japanese Industry- and Technology-Policy which is strongly influenced by the MITI (Ministry of international Trade and Industry). After the Second World War the aim of the MITI was to establish a new industrial basis. Therefore they imported technological and process innovations to Japan. The primary industries (like i.e. coal, iron, steel, electricity) especially took profit of this policy. The oil crises however, changed the R&D policy in a way, that the Japanese dependency of the imports of primary goods and energy should be diminished. After reaching a technological top position the R&D policy changed (Holzkämper 1995). The main aim no longer was imitation but to develop new technologies trough own R&D activities and to change Japan into a HiTech country. The MITI took and still takes influence with the help of administrative guidance's, which can have a consultative, mediative or regulative character. The administration hopes for the voluntary co-operation of enterprises but it exists as well a latent obligation to participate in the proposals of the administration as it has the power to sanction not obeying enterprises in other businesses. The MITI possesses authority and high reputation in the organisation and co-ordination of R&D cooperations especially in the HiTech sectors (Holzkämper 1995). HiTech enterprises mostly belong to the sectors 17 (Electronic Apparatus) and 18 (Radio, TV and Communication).

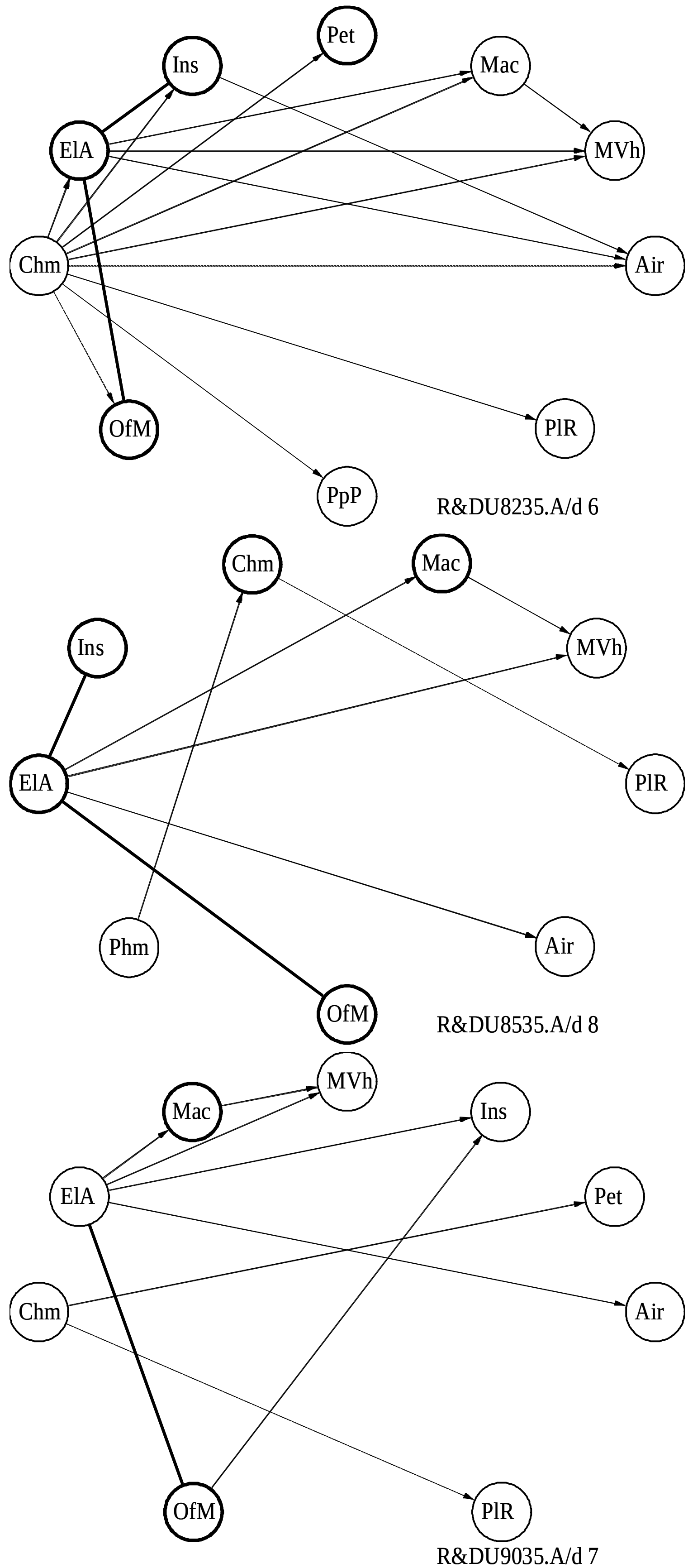
5.3 The US innovation system, measured by R&D of the enterprises

The following table 3 shows the distribution of the R&D-Budget sectors - spent by the enterprises - for the USA qualified as important by the SMFA in figure 3 according to the three categories source sectors, centre and sink sectors over a period of 1982 until 1990.

Tab. 3: Important R&D-sectors for US 1982-1990

Year	source-sectors	centre	sink-sectors
1982	Chm	OfM, ElA, Ins, Pet	MVh, Air, PlR, Mac, PpP
1985	Phm	OfM, ElA, Ins, Mac, Chm	MVh, Air, PlR
1990	Chm, ElA	OfM, Mac	MVh, Air, PlR, Pet, Ins

Fig. 3: The characteristic innovation flow structure for USA from 1982 - 1990



Like in Germany and Japan the stable source-sector of the innovation structure in the USA is the sector Chm (Chemicals) including a short disappearance in the year 1985 where it belonged to the group of the centre sectors. In 1990 the sector ElA (Electronic Apparatus) changes its place from centre to the source. The important sectors within the centre group are OfM (Office Machinery) and Mac (Machinery) for the second half of the decade while ElA (Electrical Apparatus) and Ins (Instruments) take the same position for the first half decade. The consistently relevant sink-sectors are the sectors MVh (Motor Vehicles), Air (Aircraft) and PlR (Plastics and Rubber). The sector Mac moves in 1985 from the sink to the centre position and changes his place in 1990 with the sector Ins.

The interesting point of the American structural evolution is a bilateral chain formed by the centre sectors Ins, ElA and OfM within the period 1982 until 1985. In 1990 it degenerates to the bilateral link ElA==OfM. Unlike Germany and Japan the American structural development shows the sector Air as a sink sector. This peculiarity of the American innovation structure has its cause in non-market events like the Second World War and the then starting arms race. All this led to rising defence- and space budgets with continuously rising governmental R&D-investments (Holzkämper 1995). The technologically selective effect of the American defence- and space expenditures had, with the appearance of spin-off-effects, a lasting influence on the industrial structure.

6 Summary

Looking at the development of the innovation structures of the three countries Germany, Japan and the USA it can easily be seen that the structural patterns of Germany and Japan come closer. The structure of innovation flows of the USA as well shows many similarities with those of Germany and Japan, whereby the American research- and technology policy (R&T) concentrates on the pure research and on intensive military- and space research. With rising spin-off-effects the American R&T-policy influenced as well the civilian production.

Tab. 4: Synopsis of the structural changes of the 3 national innovation systems

Table	source-sectors	centre	sink-sectors
G 1980	Chm	ElA, Mac, PlR, MtP	MVh
J 1980	Chm, ISt,Agr	ElA, Mac, Ins	MVh, PlR, FBT
U 1982	Chm	ElA, OfM,Ins, Pet	MVh, PlR, Air, Mac,PpP
G 1986	Chm, MtP	ElA, Mac, PlR	MVh
J 1985	Chm, MtP, ISt	ElA, Mac, Ins	MVh, PlR, Phm
U 1985	Phm	ElA, Mac,OfM,Ins, Chm	MVh, PlR, Air
G 1990	Chm, MtP	ElA, Mac, PlR	MVH
J 1990	Chm, MtP	ElA, Ins	MVh, PlR, Mac,Phm
U 1990	Chm, ElA	Mac, OfM	MVh, PlR, Air, Pet, Ins

The necessity for Germany and Japan to catch up technologically with USA after WWII was realised by means of special research support. Unfortunately the German support of the communication sector cannot be seen in the structure of innovation flows because this sector is contained in the sector ElA (Electronic Apparatus). Japan has closed its technological gap by means of export support and the co-ordination of private R&D.

The development of the structure of innovation of these three countries indicates, that in global markets the production patterns and their products become more and more similar. Therefore the national innovation systems measured by the R&D-expenditures should become much more similar over the time.

Appendix: The structurization steps of the SMFA

The main principle of qualitative analyses is the binarisation of quantitative flows in relation to a given filter value F. Thus all entries of the analysed interlacing matrices are compared to F. If the entry ij of a given transaction or innovation flow matrix is

$$x_{ij} \geq F$$

then the entry w_{ij} of the corresponding adjacency matrix W constructed in parallel contains the value 1 otherwise zero. Therefore the adjacency matrix consist only of zeros or one's. Thus the filter value F determines the structure of the adjacency matrix. A high filter for example brings a good structuring in the early phase of the analyses whereas a low filter value allows for a deep reaching structure. The relevance of a flow will be checked in each of the k^{th} intermediary stages with k = 1,2,..,n-1. The original matrix $X_{R\&D}$ is taken apart into individual layers, based upon Euler´s row development of the Leontief inverse L:

$$L = (I - A)^{-1} = I + A + A^2 + A^3 ... \qquad (a)$$

If we apply this to the appropriate transformed subsystem equation (3)

$$X_{R\&D} = \langle R\&D \rangle \langle x \rangle^{-1} (I - A)^{-1} \langle y \rangle \qquad (b)$$

this results in a layered decomposition of the subsystem matrix $X_{R\&D}$ as

$$X_1 = \langle R\&D \rangle \langle x \rangle^{-1} A^1 \langle y \rangle \qquad (c)$$
$$X_2 = \langle R\&D \rangle \langle x \rangle^{-1} A^2 \langle y \rangle \qquad (d)$$
$$X_3 = \langle R\&D \rangle \langle x \rangle^{-1} A^3 \langle y \rangle \quad \text{etc.} \qquad (e)$$

in which the first matrices X_k, k = 1,2,..., reflect the layers of the original subsystem matrix $X_{R\&D}$ as a result of the Eulerian row development.

The layers X_1, X_2, X_3,... etc. obtained in this process will then be transformed into the corresponding adjacency matrices W_1, W_2, W_3,... etc. according the chosen filter value F. The W_k-matrices consist of only the economically significant links reflected by the decrease of 1-entries with rising k. Each W_k matrix tells how many deliveries ≥

F exist on the respective intermediary level, but they do not reflect links of greater distance. However, as interesting in an analyses of economic structure are not only the direct connections but as well the indirect links which can be established according to

$$W^{(1)} = W_0 \qquad \text{(f)}$$

and

$$W^{(k)} = W_{k-1}\, W^{(k-1)}\ . \qquad \text{(g)}$$

for k > 1. Equation (g) determines the links within the structure, where the matrix multiplication is done in a Boolean way. The condensation of the product matrices W^k to a so-called dependence matrix D is achieved by using Boole´s addition.

$$D = (W^{(1)} + \#W^{(2)} + \#W^{(3)} + \ldots) \qquad \text{(h)}$$

An individual entry d_{ij} is only 1 if there exists one direct or indirect innovation flow from sector i to sector j. The dependence matrix D is necessary to develop the so-called connexity matrix H, whose general term is given by equation (i):

$$h_{ij} = d_{ij} + d_{ji} \qquad \text{(i)}$$

The connexity matrix H *qualifies* all connections by three indices as i.e. 0, 1, 2. This is an efficient standard graph-theoretical procedure in order to automatically label each sector with respect to its place and the degree of connection with others. The individual values of h_{ij} denote in the following description:

$h_{ij} = 0$ sectors i and j are isolated;
$= 1$ a unidirectional flow exists from sector i to j;
$= 2$ a bilateral relationship between sector i and j exists. The delivery flows between sector i and j have at least the defined minimum.

The further steps of the SMFA to derive the characteristic structure are the same as given by Schnabl (1994) for the MFA.

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