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Broadening the scope for reporting on the technological competitiveness of the Federal Republic of Germany

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Diskussionspapiere
Discussion Papers

Discussion Paper No. 100

**Broadening the Scope for Reporting on
the Technological Competitiveness of the Federal
Republic of Germany**

by

Dieter Schumacher and Florian Straßberger

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Deutsches Institut für Wirtschaftsforschung

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Broadening the Scope for Reporting on the Technological Competitiveness of the Federal Republic of Germany

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This paper reports on a current DIW research project aiming to develop a concept for giving broader scope to reporting on the technological competitiveness of the Federal Republic of Germany in the international context.¹ The paper concentrates first on providing a basic outline of the report's general conception and second on calculation of sectoral "R&D-capital stocks", plus an analysis on this basis of sectoral technology producer-user relations. This introduces two central propositions of the concept, namely to quantify technology-related knowledge as a component of the intangible capital of a national economy, and to take account of the systemic nature of innovative activity.

1 Fundamentals of Reporting

1.1 Point of departure

Our point of departure is a number of empirical observations most of which show that the Federal Republic of Germany (by which we always mean the former West Germany) has a strong economic position in comparison with other OECD countries, and one which has further strengthened over the past three decades; some indicators, however, point to weaknesses as well:

- Per-capita income is above average. According to the OECD, West German GDP per capita measured in terms of purchasing-power parity was surpassed by only the United States, Switzerland, and Luxembourg in 1992. The lead enjoyed by the USA and Switzerland has narrowed considerably.
- The absolute increase in per-capita income kept pace with labour productivity per hour in West Germany over the past three decades. Thus the increase in national labour productivity per hour for these three decades was calculated at DM 12 to DM 13 per decade (at 1991 prices).
- The share in West German GDP taken by exports of goods and services was double the OECD average. Compared with 1970, the export ratio increased far more than in all large OECD countries.

¹ A comprehensive treatment of the topic will appear in late 1994 in the DIW *Strukturhefte*. Besides elaborating the theoretical basis of the envisaged indicator system, the data preconditions for empirical application are examined. The relevance of the various indicators is underpinned with the aid of the literature and time series analyses of our own, as well as by intersectoral and international cross-section analyses. A pattern for important elements in the reporting system is elaborated with the help of concrete figures, existing deficiencies are noted, and suggestions for step-by-step improvement are advanced. The empirical base relates only to West Germany, because longer time series are available only on this territory. East Germany is to be included as the data situation improves.

- The West German share of total OECD exports of goods and services was subject to considerable fluctuation, primarily reflecting changes in the value of the mark against the dollar; but the trend has been upwards. At constant prices and rates of exchange, the West German share has remained almost unchanged over the past thirty years. West German exporters were thus able to obtain considerable price increases for their products.
- In the eighties, West German companies used the scope for price increases to augment earnings. Income distribution in the Federal Republic of Germany shifted more strongly in favour of profits over this period than was the case in other OECD countries.
- The Federal Republic has meanwhile considerably increased its assets abroad. According to the Bundesbank, total foreign assets in mid-1992 amounted to about DM 1.8 trillion, including direct investment of almost DM 200 billion. In international terms, however, this is a low figure, and particularly so if one considers the export strength of the German economy.
- As in Japan, the share of the manufacturing sector is especially high in the Federal Republic of Germany; mechanical engineering, electrical engineering, motor vehicle construction, and chemicals dominate to a greater degree than in other OECD countries. The structural shift that occurred in the seventies and eighties from food-processing and consumer-goods industries towards capital-goods industries and chemicals was particularly marked in West Germany.
- On the other hand, an international comparison points to the relatively low share of the service sector and the high proportion of elderly people in the Federal Republic. Among other weak points mentioned were microelectronics and an inefficient educational system.

The reasons for (West) German competitiveness are to be considered against this background. Developing fundamental determinants will permit to estimate the future economic power of the Federal Republic of Germany, taking into consideration the integration of East Germany, and the future German position on world markets.

1.2 Fundamentals

Studies on technological competitiveness have hitherto concentrated on R&D expenditure, the analysis of patent data, and the situation with regard to technology-intensive branches of the

economy (the share of such branches in production, employment, and investment), or product categories (relative share of export markets and export-import ratios).² According to these indicators, the more technical knowledge — measured in terms of patents and technology-intensive products — a country produces, the more favourably it is assessed.

The role of real income as a comprehensive indicator of performance has hitherto not been addressed. Broad-scope reporting should be geared precisely to this end. Thus, other things being equal, higher imports of technology-intensive goods diminish the RCA value (relative ratio of exports to imports), and are judged negatively from the point of view of specialization in high-tech production. On the other hand, higher imports increase the domestic stock of knowledge and consequently technology intensity where the imports are utilized. Where human capital is adequate, this can thus contribute to higher labour efficiency in the economy as a whole. More comprehensive reporting should accordingly watch developments not only in (already) technology-intensive areas but also investigate technological intensification in other areas of the economy.

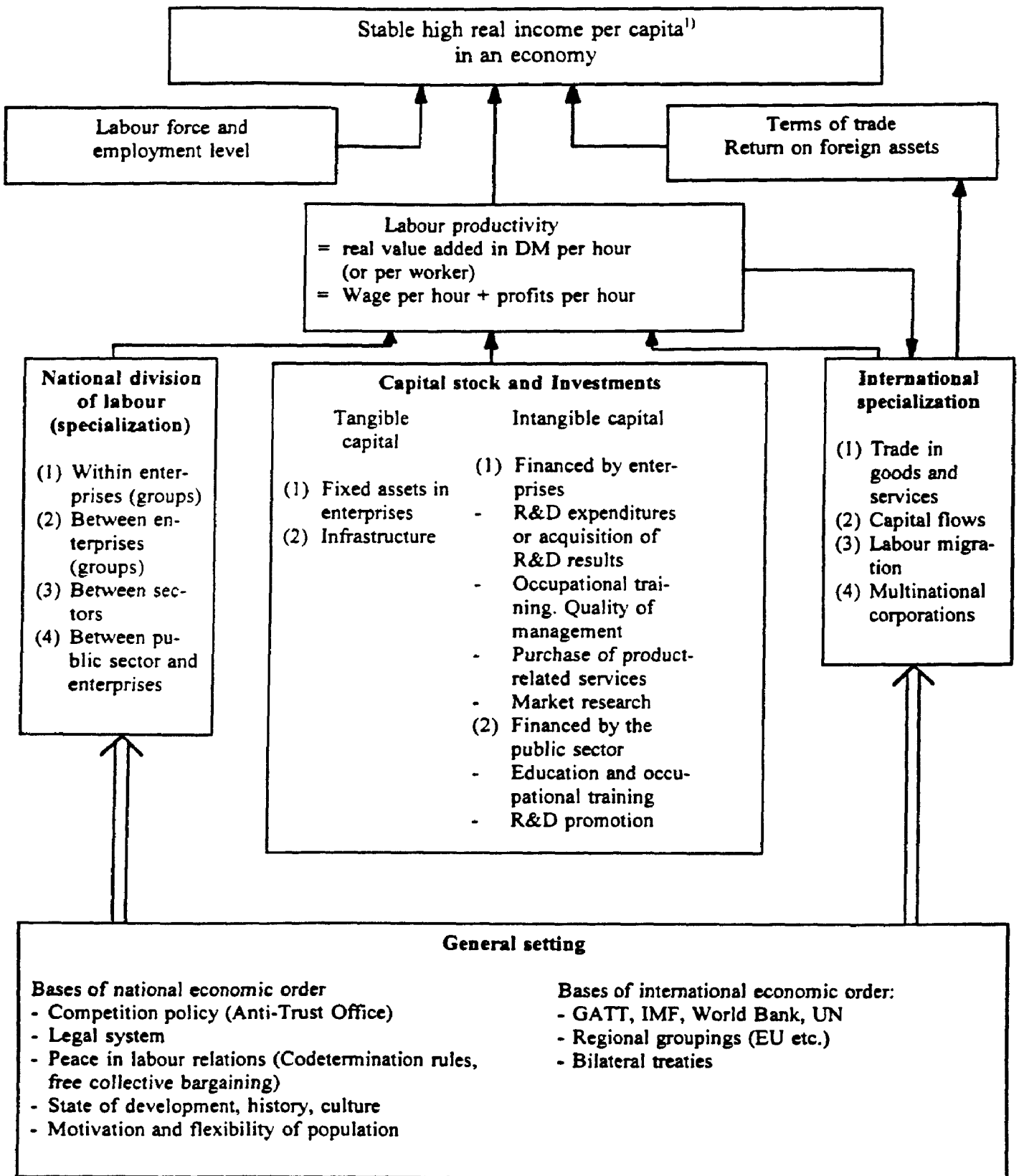
Our concept of technological competitiveness is consequently a broader one. From an overall economic perspective, "technology" includes all knowledge (techniques, organization, marketing) concerning the most productive possible linkage of inputs and outputs and the efficient production of inputs. What is important from the point of view of the economy as a whole is not only technical efficiency but also market performance. Diagram 1 provides an outline of our approach. An economy is "technologically competitive" if it disposes of a high level of knowledge, which it also applies, thus attaining high real income per head of the population. The summary criterion is accordingly a high income level, and this requires high labour productivity.³ Labour productivity in its turn depends on capital resources and the efficient division of labour in both the domestic and international context if it is to exploit specialization advantages.

In this regard, exports also constitute indirect production, which finances the import of cheaper or better goods or capital exports, which in their turn generate income. The crucial issue is thus not how high the current account balance or the share of the world market are and how they change, but whether, within prevailing limitations, an economy constantly obtains the highest real income

² For the Federal Republic of Germany see in particular the NIW and ISI studies commissioned by the Federal Ministry of Research and Technology; e.g. Legler, Grupp, Gehrke und Schasse (1992) as well as Gehrke and Grupp (1994).

³ See also the reports of the Competitiveness Policy Council in the United States, which also define "competitiveness" as the ability to attain a high real income.

DIAGRAM 1
DETERMINANTS OF REAL INCOME



¹⁾ Or lasting high level of consumption.

or rises in income possible. However, integration into the world economy is important for a country. This must on the one hand be assessed in terms of the impact it has on improving productivity; on the other hand, the level and structure of foreign trade depend on changes in productivity.

In considering technological competitiveness, the contribution technology makes to optimum labour efficiency must be scrutinized. At a given level of labour productivity, the level of employment has an important overall impact on real income, but this is not the focus of our attention. Where demand is constant, increasing labour productivity leads to lower employment. On the other hand it exercises a positive influence on employment to the extent that it contributes to greater demand through lower prices, better quality products or higher wages. Important for technological competitiveness is the level of qualification demanded of the workforce.

1.3 Tangible and Intangible Investment

Investments are the decisive factor affecting the level of labour productivity. This is true not only with regard to investments shown in national accounting, which covers only tangible capital; what must also be considered are intangible investments such as R&D expenditure and spending on education and initial and further occupational training. In traditional statistics, however, these are predominantly shown as intermediate and consumer demand.

When it comes to assessing the future competitive position, it is thus essential for all spending in the nature of investment to be reported as such. Unfortunately, there is no generally accepted definition for intangible capital or intangible investment nor a definitive concept for measuring them. One has therefore to begin with approximate values, and attempt gradually to eliminate deficiencies in the statistical record.

If we compute a number of central data on intangible investment in West Germany for the late eighties/early nineties, we obtain the following per annum figures:

Total R&D spending	DM	60 - 70 billion
Education, occupational training		
- Public sector	DM	90 - 100 billion
- Industry	DM	60 -70 billion
		<hr/>
Total	DM	210 -240 billion

This is almost half the figure for tangible investments (averaging about DM 500 billion annually for the period 1989 to 1991). This rough estimate is intended simply to document the dimensions of the issue. Apart from current R&D expenditures and R&D labour costs, the figures include spending on buildings and equipment, thus overlapping with data on tangible investments. On the other hand, they include neither public-service occupational training nor Federal Labour Office (Bundesanstalt für Arbeit) training schemes. Considerably improved and more detailed calculations could be carried out by evaluating existing data and in co-operation with the Federal Statistical Office.

Although the new United Nations' system of national accounts treats the development and purchase of software as investment, this is still not the case for R&D expenditure and for all expenditure by the public sector, business, and private households on occupational training. However, the new system of national accounts provides not only for the functional classification of individual final demand components as hitherto, but also introduces a subclassification by category for company expenditures. On the basis of these data, satellite accounting is possible for R&D and educational expenditure, treating these items entirely or partly as investments.

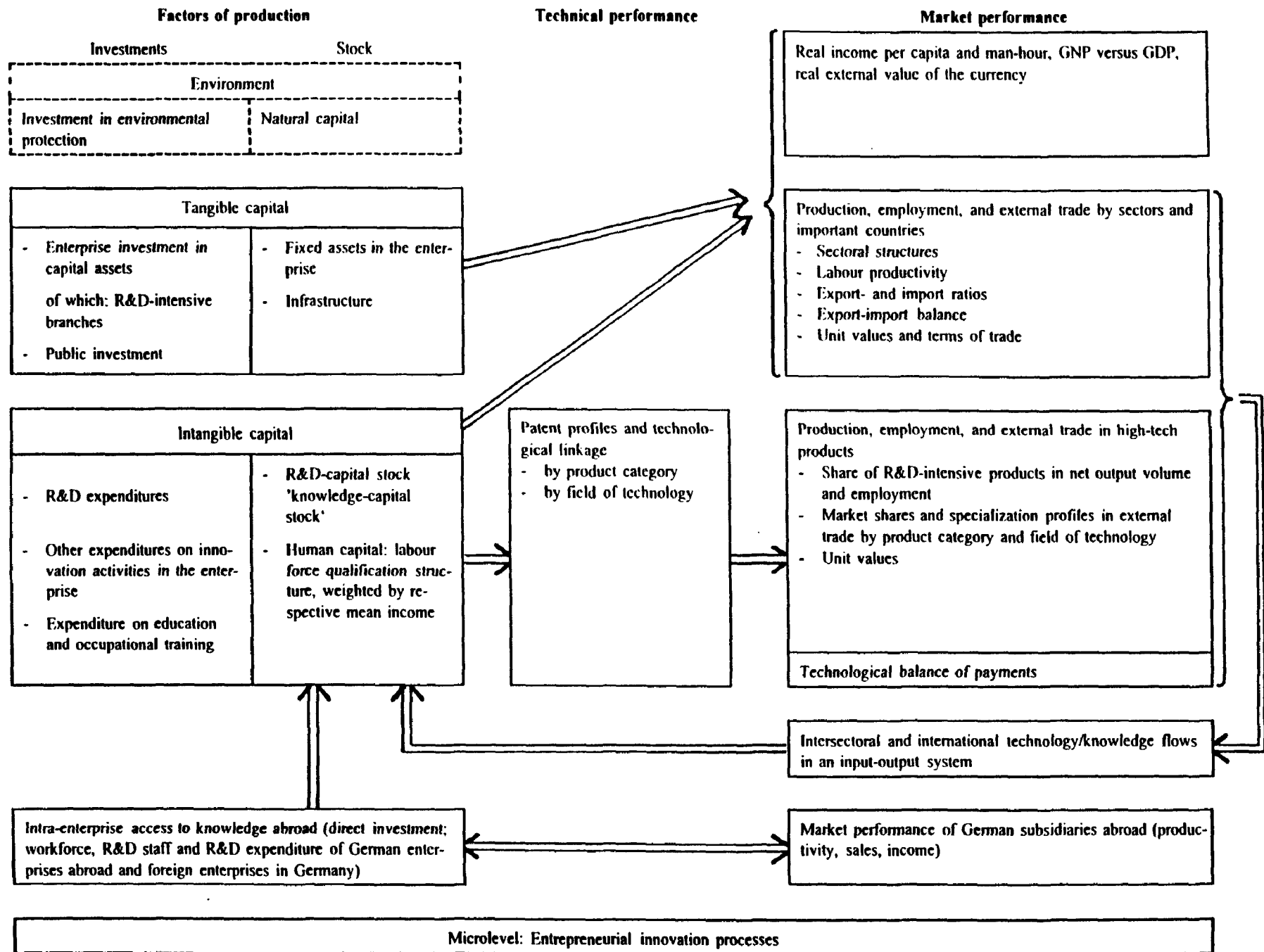
The development of such satellite accounts can draw on the experience of a series of other studies. Thus in France not only the calculation of intangible investments but also the elaboration of R&D satellite accounting is well advanced thanks to work done at the INSEE (Minder, Rubel and Muller 1989). An R&D satellite accounting approach has also been pursued in Japan (Karabayashi and Matsudi 1989). At the Statistical Office of the Netherlands, extensive conceptual work on R&D satellite accounts has been done (Bos, Hollander and Keunig 1992), but due to staffing shortages this has not yet been implemented in concrete computations. At the German Federal Statistical Office, too, conceptual work has been done on elaborating satellite systems, especially for R&D activities (Stahmer 1986). They also take into account a subclassification by industry or by product category, i.e. they use the input-output analysis concept. In principle, the procedure can be oriented on the structure of input-output analysis for environmental protection.

1.4 Principle Elements in Broad-Scope Reporting

Diagram 2 shows the principle elements in more comprehensive reporting and the links between the various parts. The cause-effect flow runs initially from left to right, i.e. from production factors⁴

⁴ The production factor "environment" is included here only for the sake of completeness. It can be taken into account quantitatively only at a later stage in broad-scope reporting.

DIAGRAM 2
PRINCIPAL ELEMENTS IN REPORTING



via technical performance to market performance. The resources from market performance used for investment raise the stock of tangible and intangible capital, thus contributing to the improvement of technical and market performance. The decisive factors are labour productivity in value terms, together with R&D intensity and human-capital intensity. An economy is to be positively assessed if:

- It achieves high labour productivity in value terms,
 - It disposes of large R&D-capital resources and invests heavily in R&D,
- and
- It has built up a large stock of human capital, which continues to grow.

High wage levels are possible in such an economy, which then promotes structural change in the direction of R&D and human-capital intensive production. Investment is thus the decisive indicator for future technical and market performance.

With respect to technological aspects, the point of departure is expenditure on R&D. Together with imported knowledge, these influence the technical performance, which with the aid of patent data can be characterized in terms of product categories and technology fields. The market performance thus achieved becomes apparent in the ratio of technology-intensive branches of industry to total production and employment, and in the specialization in technology-intensive products in foreign trade.

When considering the application of technical knowledge, both home-produced and imported knowledge must be taken into account. This can be documented by analysing technology producer-user linkages, which culminates in quantification of a total "R&D-capital stock". Together with tangible and human capital, R&D capital is the source of labour productivity in both the economy as a whole and in individual sectors. Human capital is crucial to the production and application of technical knowledge, but it is a factor frequently neglected when considering technological performance. It is the precondition for creating new knowledge, for advancing existing knowledge, and for adopting knowledge from elsewhere. The larger and also more differentiated the stock of knowledge in an economy, the more chance it has to sustain a leading position in technological competition. Analysing structure, accruals, and depreciation of a stock of knowledge provides important information for interpreting annual investments in knowledge, and is therefore an important component of reporting.

In addition to knowledge traded on markets, attention must be paid to intra-enterprise access to knowledge from abroad. If one considers that four fifths of all industrial research activities take place in enterprises employing more than 1,000, which as a rule maintain a high level of transnational relations, it is clear that taking a purely national view is insufficient in evaluating the domestic knowledge available. The transborder technology conduct of enterprises must also be evaluated by analysing foreign direct investment and surveying multinationals on a regular basis.

2 Technological Competitiveness as a Systemic Phenomenon

Whereas traditional neo-classical theory regards technical change as an exogenously predetermined factor, evolutionary economic literature has promoted the notion that the diffusion of technical knowledge is a path-dependent process, and by no means free of charge. While technical change results from more or less purposive investment in tangible and intangible capital, the environment in which economic activity occurs exerts a cardinal influence on the entrepreneurial potential for innovative behaviour. This environment is specific to each location.

Since the second half of the eighties, this insight has made the description of national innovation systems an important subject of economic research.⁵ The point of departure for these studies is the question of the extent to which individual institutions as such and in interplay with the other institutions of an economy strengthen the innovative capacity of domestic enterprises. Important components of a national innovation systems are, for example:

- The system of occupational training,
 - The higher educational system and other research facilities,
 - The general political setting (tax system, regulatory requirements, licensing procedures, etc.),
 - The financial system, which imposes either short-term or longer-term planning horizons,
 - Interaction between industry and research institutions
- and
- Technological exchange relations between enterprises and sectors.

Since it is generally not possible to measure the impact these factors have in promoting or inhibiting innovation, analysts frequently pay scant attention to them. It can nevertheless scarcely be denied that the characteristics of an innovation system considerably influence the ability of an economy to

⁵ See Lundvall (1988), Dosi and Soete (1988), Pavitt and Patel (1988), Porter (1990), Keck (1993), Patel und Soete (1994) and Fagerberg (1993).

generate and apply innovations. In this section we will be looking at an important subelement of a national innovation system, namely intersectoral technological exchange relations.

In his noted study (1990), Porter emphasised the importance of national clusters of industries for the international competitiveness of enterprises: traditional competitive advantages, derived from the availability of raw materials or the development of special technical competence, provide competitive advantages not only for the relevant product category, but also for upstream and downstream products. A company forming part of such an information network has close relations with companies on the same level or consecutive levels in the production process. This allows technological challenges or changes in demand behaviour to be tackled more effectively than would be possible for a company acting in isolation.

The competitiveness of a cluster of industries and its persistence require precisely the same special advantages that companies within the cluster enjoy in exchanging technical information among themselves. An important hypothesis in this regard states that the exchange of information among the enterprises of a country operates better than transborder exchanges. According to this hypothesis, geographical proximity and a common language, as well as a common cultural background facilitate communication among the enterprises of a country (Fagerberg 1993).

In cases where the development of new technologies requires purposive co-operation between producers and users, effective communication can be decisive for the technological effectiveness of the sectors of a cluster. This is particularly true for technologies subject to complex and rapid change, where special adjustment to user preconditions must occur. For standardized methods of production, where technical development can be regarded as largely mature, an exchange of information over great distances can be effective (Lundvall 1988).

For the modern economy of an industrialized country, technology producer sectors are of particular importance. As a rule, relatively high wages are paid by such sectors themselves. Since such knowledge-intensive sectors need especially well-trained and qualified production and research personnel, highly developed economies generally offer locational advantages for companies in these sectors. Furthermore, the technical knowledge accumulated in producer sectors also benefits enterprises in other sectors. This in its turn enhances the ability of these user sectors to deploy highly productive methods of production and technology-intensive intermediate inputs, thus enabling them to pay high wages.

For competitiveness as a future-oriented concept, the existence of specific technology interrelationships within a national economy is also very important, since such historically evolved networks are often difficult to imitate. However, the difficulties imitability poses, to which highly developed national economies probably in the final resort owe their competitiveness, are subject over time to changes influenced by at least two factors:

- Fundamental technological innovations can reduce the economic potential of the knowledge accumulated in traditional networks;
- Improved communication, also over long distances, modifies the locational pull of certain production processes and their linkage with research divisions and scientific institutions.

Sectoral technology linkages in a country in terms of producer and user sectors is ascertained empirically either with the aid of patent data⁶, or detailed innovation surveys⁷, or by examining the knowledge transfer via intermediate inputs and capital goods⁸. The approach we have chosen to describe technology producer-user interaction is based on transfers of knowledge tied in with the supply of intermediate and capital goods that can be reconstructed with the aid of input-output tables and investment matrices. It will be briefly presented in the following section.

3 Sectoral Technology Producer-User Linkages

3.1 R&D-capital stocks

The technical knowledge available in an enterprise accumulates over a number of years to form a stock of knowledge that can be utilized in the current period. Thus not only the expenditures on expanding knowledge in a given year or period are relevant, but also the entire stock of knowledge available at the time in question. Among the most important investments in the expansion (or replacement) of the stock of technical knowledge is expenditure on construction and product design, initial and further occupational training, as well as on research and development, which can be subsumed under the heading innovation expenditure.⁹ Spending on R&D is thus not the only component of innovation expenditure, though a particularly important one. Since relatively long and

⁶ For example, Scherer (1982), Griliches and Lichtenberg (1984). See the overview articles by Mohnen (1990) and Hanel (1993).

⁷ See Pavitt (1984), Patel and Soete (1988), Sterlacchini (1989).

⁸ See Terleckyj (1980), Sterlacchini (1989), Goto und Suzuki (1989), Meyer-Krahmer and Wessels (1989), Sakurai, Wyckoff and Papconstantinou (1993), as well as Wolff and Nadiri (1993).

⁹ See Harhoff, Licht and Smid (1994).

internationally comparable time-series are available only for R&D expenditure, we cannot consider overall innovation expenditure in our account. Instead, we will attempt to compute an R&D-capital stock in analogy to tangible capital, to allow us to determine and evaluate the stock of technical knowledge produced within an industry itself.

In analogy to tangible capital, the respective current stock of technical knowledge is worked out as the sum of relevant "investments" in the knowledge field, taking account of depreciation due to decline in economic usefulness. Annual expenditures on R&D expand the stock of knowledge just as current investments in tangible capital increase the stock of fixed assets. However, part of the investment in intangible capital, too, serves merely to replace obsolete knowledge. A certain proportion of annual expenditures on R&D is thus needed simply to sustain the existing level of knowledge. High spending on R&D therefore brings an increase in the innovative capacity of an enterprise only if the expenditure goes on more than simply replacing obsolete knowledge. For instance, industries subject to rapid technical change, where existing knowledge therefore becomes obsolete relatively soon, need to spend relatively high sums on R&D merely to maintain their knowledge capacities. In other sectors, where existing technical knowledge ages at a lower rate, a high proportion of annual R&D expenditures can be appropriated to expand existing technical knowledge.

Evaluating the utility of an existing stock of technical knowledge depends strongly on the perspective taken. From the point of view of a company, it is an advantage to keep internal technical knowledge confidential as long as possible in order to reap the benefits of monopoly. From the point of view of the economy as a whole, by contrast, the fastest and broadest possible diffusion of the relevant knowledge is desirable, at least within the national economy. This is why private rates of depreciation differ from social ones.¹⁰ The rate at which existing technical knowledge depreciates depends on several factors:

- ° *Ease of imitation:* Among the factors influencing the value of technical knowledge is the ease with which it can be acquired by competitors and appropriately implemented for productive purposes. Imitability depends on, among other things, product and industry-specific characteristics and the particularities of the production method. If, for example, reverse engineering can provide easy access to the technical properties of a product, and if the production method makes no elaborate demands in the way of tangible or intangible capital equipment, it is difficult to sustain national competitive advantages. This is

¹⁰ See Griliches (1979 and 1992).

particularly so if experience (tacit knowledge) is not specially important for the abilities to be acquired.

- *Market structure and competitive situation:* Market structure and the situation of the respective technology proprietor embedded in this structure are also important factors determining how long a lead in knowledge can confer benefits (appropriability). A monopolist can realize benefits even from technically easy to imitate products if his market power enables him to keep up the barriers to market entry.
- *Technical innovations:* Technical innovations can alter the importance of existing technologies. Particularly comprehensive changes in an economy's stock of knowledge result from the advent of new cross-section technologies. They can generate new demand for products and individual qualifications, while others decline in economic value because products, methods, or human qualifications are no longer needed or are replaced by others. Fundamental process or product innovations are irregular phenomena, the impact of which on the technical knowledge of an enterprise or industry have to be taken into account in the form of (onetime) accelerated depreciations or possibly expansion.
- *Exogenous factors:* Exogenous factors such as changes in factor-price ratios, changes in demand behaviour, or in the social acceptance of certain technologies can lead to a reassessment of existing technical developments. In so far as the value of the knowledge accumulated in connection with the relevant fields of technology declines, these reductions in the value of knowledge assets must be taken into account in the form of accelerated depreciation.

Both current and extraordinary depreciation rates for knowledge stocks can differ extremely from industry to industry and from technology field to technology field. Appropriate correction is therefore needed if sound findings on the knowledge-intensity of economies or industries are to be derived. A production method is thus knowledge-intensive, even if relatively little is spent per annum on R&D or innovation, if the accumulated stock of technical knowledge available within the sector is very resistant to obsolescence. In sectors such as mechanical engineering, special knowledge is often needed that is acquired through a well-established system of initial and further occupational training and in-house research over a longer span of time, and which is difficult to imitate, not least of all because of the systemic nature of the experience gained.

In other industries characterized by rapid technical change, high annual expenditures on R&D are likely to be confronted with high depreciation rates. Where product generations succeed one another rapidly, the obsolescence rate of the knowledge relating to each generation is correspondingly high. Companies that hold a leading position for one product generation need not necessarily enjoy advantages for the coming generations of products.

How the technical efficiency of an economy and its persistence in the future are to be assessed is an issue that consequently depends on the sectoral specialization profile and the respective obsolescence rates for technical knowledge. Competitive advantages that are based on products with a short life and low learning-curve effects are comparatively vulnerable, because the technical knowledge involved in producing these products becomes obsolete relatively fast. A country specialized in such products or technologies therefore has to spend comparatively large sums on R&D simply to sustain the state of its technological performance. If, on the other hand, a current competitive advantage is based on predominantly long-term technical knowledge with relatively low obsolescence rates, comparatively less will have to be spent on R&D to permit the competitive position as a whole to be considered relatively secure even where innovative activity is rather low.

3.2 Sectoral Technology Linkages

The measurement of technical knowledge available in an enterprise or industry is often based, as in our account so far, on the activities carried on within the enterprise or industry. This cannot take into account the extent to which external sources influence technical knowledge within an industry. While the R&D activities taking place in an industry are a principal source of the sector's technical knowledge and are often the precondition for a company gaining access to outside knowledge¹¹, at least two further sources of knowledge external to the company are to be distinguished, namely embodied and disembodied knowledge-transfer.

The distinction between embodied and disembodied forms of transferring technical knowledge (embodied and disembodied technical change) is drawn with reference to whether the knowledge transfer is based on the supply of goods or not.¹² Transfers of embodied knowledge are connected with supplies of intermediate inputs and capital goods. The R&D intensity of the final product depends on the involvement of research-intensive intermediate products, or to the extent to which

¹¹ In this regard it should be noted that a certain amount of own R&D is an important precondition for the capacity to absorb external technical knowledge. Cohen and Levinthal (1989 and 1990) refer to the "absorptive capacity" of a company.

¹² See Stoneman (1983) and Bollmann (1990).

the production process involves capital goods produced at high R&D expense. Disembodied knowledge-transfer, by contrast, is not connected with the supply of goods but reaches the recipient via other channels. We can, for example, speak of disembodied knowledge-transfer where the available knowledge has largely become a public good, and is easily accessible to interested companies, for instance via academic periodicals. If an enterprise disposes of an appropriately skilled workforce and research staff, parts of the external disembodied knowledge can be utilized for company production purposes. The precondition is a certain degree of technical competence in the company, with the aid of which the acquired knowledge is integrated into the in-house stock of knowledge.

Analyses of sectoral technological linkages provide answers on a series of issues:

- *National innovation systems.* Technology producer-user interaction is an important characteristic of national innovation systems. An account of intersectoral transfers of technical knowledge gives insight into the underlying division of labour in an economy. With the aid of such an account, it is possible to describe networks in industries that are particularly closely interlinked in the technological field. Comparison with sectoral technology interaction in other countries can allow the national characteristics of the various innovation systems to be determined.¹³
- *The sectoral importance of embodied knowledge transfers:* Industries that engage in little R&D of their own are often classified as unpromising fields of activity for a highly developed economy. In view of the high export ratio of so-called "low-tech" industries, this seems to be short-sighted. The situation is rather that there are industries doing little R&D of their own but profiting considerably from the research done in other sectors, and whose end products consequently gain in technology-intensity. This is not given expression in accounts of their own R&D intensity, but becomes clear only through analysis of technology producer-user relations.
- *International division of labour:* Because of the trend towards ever greater specialization, individual economies are becoming more and more dependent on the import of knowledge-intensive goods from other countries. Such imports should not automatically be interpreted as a competitive disadvantage, since they expand the stock of domestic knowledge, and, as in the case of the Federal Republic of Germany, promote the country's own exporting

¹³ See Lundvall (1988).

capacity. Sectoral embedding in the international division of labour can be reconstructed empirically by taking account of transborder transfers of R&D capital.

- *Change in technology producer-user structures over time:* Technical change also modifies the importance of producer industries for user industries in the course of time. Comparisons between producer-user structures at various points in time can show this. Changes relating to the embedding of individual sectors in the international division of labour can provide important indications for the future development of the national specialization pattern.
- *Explanation of sectoral productivity:* International studies show that transfers of embodied knowledge are significant in explaining productivity ratios.¹⁴ These results, which are available for other countries, and which can be verified for Germany, indicate that in explaining sectoral productivity it is important to look not only at intra-industry R&D but also at transfers from external sources.

The approach we have chosen attempts to take not only the production but also the application of technical knowledge into greater account. The following calculations for the Federal Republic of Germany are limited to the transfer of embodied technical knowledge. This is not intended to imply that other forms, such as the intersectoral transfer of disembodied knowledge or the spillover of university research to industry are to be neglected. Numerous recent empirical and conceptual studies substantiate the importance of these sources of spillovers.¹⁵ There is reason to hope that the various approaches will together provide more precise information on the knowledge available within the individual sectors.

3.3 Empirical Results¹⁶

Locational ties

The first results presented here are based on simplified assumptions and estimates, and are only the first step in a differentiated account of sectoral technology linkage. Our findings and conclusions are accordingly provisional.

¹⁴ See, for example, Wolff and Nadiri (1993), Goto and Suzuku (1989), and Sterlacchini (1989).

¹⁵ See Grupp and Schmoch (1994) and the literature cited there.

¹⁶ See Straßberger and Stäglin (1995) for a more comprehensive account of the methodological and statistical fundamentals.

In 1987, the stock of R&D capital generated in the Federal Republic of Germany by own R&D activities¹⁷ amounted to just under DM 300 billion (in 1990 prices). For the trial calculation, a 3 year lead period for research and development was assumed. With the help of the input-output table and an investment matrix for 1990, this R&D-capital stock was attributed to the recipient sectors.

The total R&D-capital stock available within an industry is composed of R&D capital accumulated from own R&D spending and transfers of external R&D capital from domestic and foreign sources. The weight that individual product categories have for the recipient of R&D capital transfers depends on the structure of goods supplies to recipient sectors and the "knowledge intensity" of the products from the sectors of origin. Information on the locational ties of domestic sectors can be obtained in answer to the following questions:

- How important are domestic supplies of R&D capital as measured against own accumulated R&D capital?
- From which domestic areas of production do the most important transfers of R&D capital originate?
- What role is played by the individual domestic areas of production as technology producers?
- How salient are foreign sources of knowledge as a whole and with respect to individual sources of supply?

Domestic Linkage

More than 40 per cent of R&D capital transfers were to the benefit of production sectors, two-thirds going to manufacturing (Table 1). By direct transfer, i.e. taking into account only the first stage of intermediate inputs linkage, just under one tenth of R&D capital goes to private consumption. More than a third of R&D capital goes abroad. This points to the significance of knowledge-intensive products in German foreign trade. Capital goods contain DM 36 billion (12.5 percent) of R&D capital, two thirds of which is transferred to areas other than manufacturing.

¹⁷ To estimate sectoral rates of depreciation, specific depreciation rates were taken for the individual components of R&D expenditures (labour costs: 1 percent; current expenditures: 25 percent; investments: 15 percent). The depreciation rates accordingly vary from sector to sector depending on the structure of R&D spending. The aggregate price increase was used as deflator.

TABLE 1

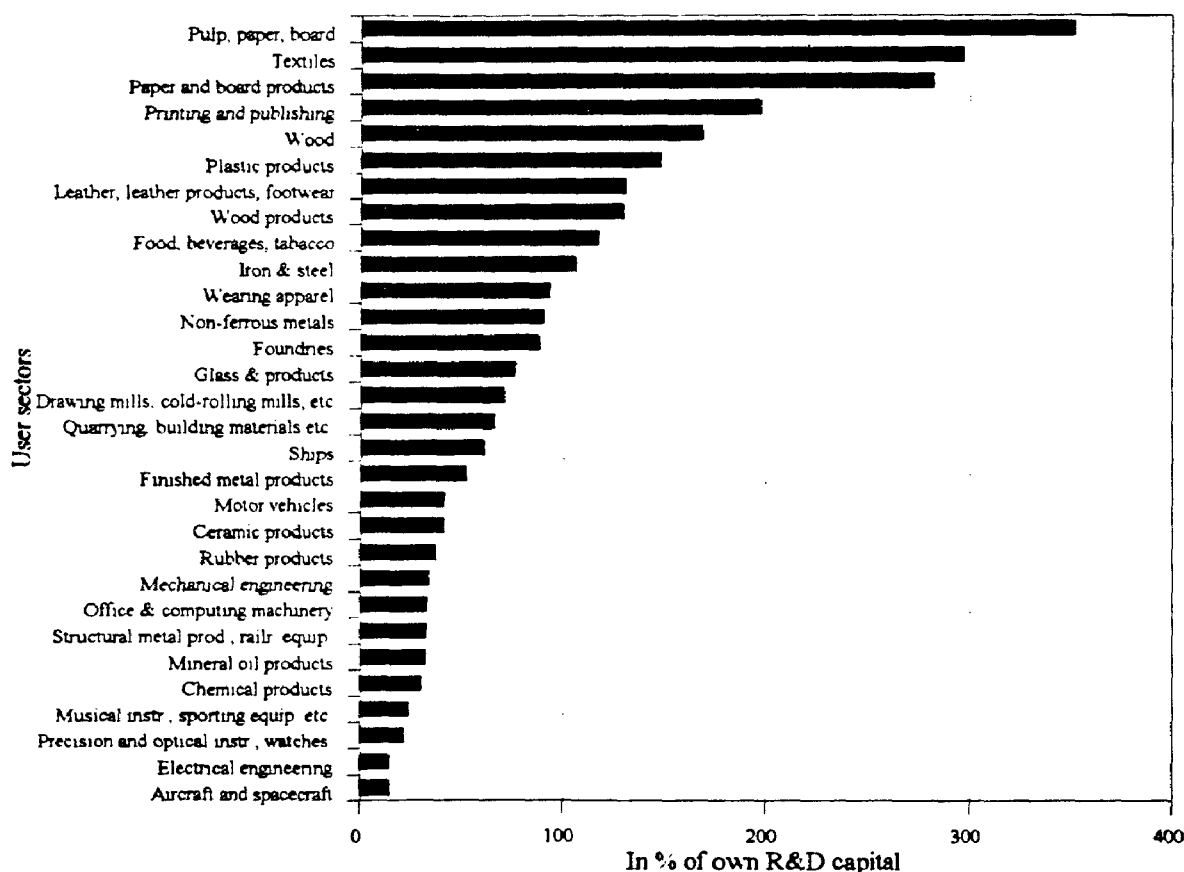
**TRANSFER OF R&D CAPITAL STOCKS TO PRODUCTION
AND FINAL DEMAND SECTORS IN 1990**

Sectors	Direct transfers from ...				Direct transfers from ...			
	dom. sources		abroad		dom. sources		abroad	
	interm. inp.	inv.	interm. inp.	inv.	in- term. inp.	inv.	interm. inp.	inv.
	- Mrd. DM -				- Mrd. DM -			
Intermediate demand								
Energy supplies and mining	6	4	1	1	1.9	12.0	1.7	6.1
Chemical products	19	2	3	0	6.5	4.4	6.9	4.5
Mechanical engineering	11	1	1	0	3.9	3.6	3.0	2.7
Motor vehicles	14	2	2	0	5.0	6.1	5.1	4.0
Aircraft and spacecraft	2	0	1	0	0.8	0.2	2.6	0.2
Electrical engineering	10	2	2	0	3.6	5.1	4.6	3.9
Other manufacturing	23	6	6	1	8.1	16.2	11.9	12.5
Construction	7	1	1	0	2.3	2.2	1.4	1.3
Trade and Transport	5	8	1	4	1.6	21.3	2.1	33.3
Services	8	7	2	3	2.8	19.9	3.6	24.0
Agriculture, public sector, priv. org.	13	3	3	1	4.5	9.1	6.1	7.6
Total intermediate demand	118	36	24	11	41.2	100.0	48.9	100.0
Final demand								
Private consumption	28	--	7	--	9.8	--	14.0	--
Public consumption	0	--	0	--	0.0	--	0.0	--
Machinery and equipment	32	--	11	--	11.3	--	21.8	--
Construction	4	--	0	--	1.4	--	0.4	--
Changes in inventories	1	--	1	--	0.2	--	2.5	--
Exports	103	--	6	--	36.0	--	12.4	--
Total final demand	169	--	25	--	58.8	--	51.1	--
Total	287	--	48	--	100.0	--	100.0	--

Sources: Stifterverband für die deutsche Wissenschaft, OECD, Federal Statistical Office, Ifo-Institute, DIW calculations.

R&D transfers have a varying impact on the various production branches of the manufacturing sector. If one compares transfers of R&D capital — via intermediate inputs and capital goods — with R&D capital generated within a sector by own R&D expenditure, a broad spectrum becomes apparent: whereas transfers to sectors with a high level of own R&D-capital stock are relatively low (aerospace, electrical engineering, precision engineering and chemicals), the volume of transfers to other areas (pulp, textiles, paper and board) were even markedly higher than own R&D-capital stock (Diagram 3). It is precisely in these areas that the error of looking only at own R&D activities is particularly significant.¹⁸

DIAGRAM 3
TRANSFERS OF R&D CAPITAL FROM DOMESTIC SOURCES



Sources: see Table 1.

¹⁸ We give no account of results for areas other than manufacturing. The method presented here can in principle describe an analysis of knowledge transfer in the service industries just as well as in manufacturing.

Even after transfers have been taken into account, the large knowledge-intensive product categories such as electrical and chemical products, motor vehicles, mechanical engineering products, and aircraft and space vehicles, show the largest total R&D-capital stocks. There are, however, shifts in rank among sectors that profit from high transfers of knowledge: for example, whereas the R&D-capital stock of plastic products ranked twelfth if own R&D alone was taken into account, it improved its position to rank sixth when transfers were considered (Table 2).

As far as domestic knowledge transfer is concerned, the crucial importance of technology producer sectors is once again substantiated: it is thus apparent that transfers of R&D capital from the chemical industry, mechanical engineering, and electrical engineering are especially important for numerous domestic product categories. The importance of the large technology producer sectors becomes even clearer if one looks at their relative importance in knowledge transfer to individual industries. Domestic chemical products supply almost three quarters of domestic R&D transfers to German plastics manufacturing and textiles. German electrical engineering products supply knowledge especially for mechanical engineering and office and computing machinery, as well as for precision engineering and optics. Domestic mechanical engineering has a higher than average importance in knowledge transfer to metal-processing industries, finished metal products, paper production, and food, beverages and tobacco products within the German economy.

For almost all user sectors, more than half the transferred R&D capital comes from the three R&D-intensive product areas chemicals, electrical engineering, and mechanical engineering. Only for iron and steel, motor vehicles, and aerospace is the importance of intrasectoral transfers so great that the three principal producer sectors supply less than 50 per cent. This also applies with respect to wearing apparel, where, however, intrasectoral transfers play less of a role, the lion's share of domestic knowledge transfer being attributable to the textiles used there.

The great importance of intrasectoral technology linkage is particularly apparent. According to our findings, these intrasectoral links are eminently important especially for capital goods, but to a lesser degree also for products of the basic goods sector. Thus, almost ninety per cent of the embodied technical knowledge that flows into chemical products originates from intermediate or capital goods from the same sector; and for aerospace products, electrical engineering products, and the iron and steel industry the source of more than half of domestic knowledge transfers lies within the respective sector. For these sectors, interaction with enterprises in the same sector appears to be an important component of the national technology network. As a rule, this locational cohesion based on intrasectoral technology transfer is relatively weak for consumer goods.

TABLE 2

RANKING OF SECTORAL R&D CAPITAL STOCKS BY ABSOLUTE SIZE

Sectors	Rank of absolute sectoral R&D-capital stock including...		Change in rank through inclusion of transfers
	only own R&D	own and transferred R&D	
Plastic products	12	6	6
Textiles	22	17	5
Printing and publishing	24	20	4
Food, beverages and tobacco	13	9	4
Paper and board products	27	24	3
Iron & steel	10	7	3
Non-ferrous metals, n.-f. semifinished products	17	15	2
Pulp, paper, board	28	26	2
Wood	29	28	1
Wood product	20	19	1
Aircraft and spacecraft	5	5	0
Motor vehicles	3	3	0
Leather, leather products, footwear	30	30	0
Electrical engineering	1	1	0
Drawing mills, cold-rolling mills, etc.	16	16	0
Quarrying, building materials etc.	14	14	0
Chemical products	2	2	0
Mechanical engineering	4	4	0
Mineral oil products	11	12	-1
Wearing apparel	26	27	-1
Office & computing machinery	9	11	-2
Glass & products	23	25	-2
Foundries	21	23	-2
Finished metal products	8	10	-2
Precision and optical instruments, watches & clocks	6	8	-2
Rubber products	15	18	-3
Musical instruments, toys, sporting equip. etc.	18	21	-3
Watercraft	19	22	-3
Ceramic products	25	29	-4
Structural metal products, railroad equipment	7	13	-6

Sources: Stifterverband für die deutsche Wissenschaft, OECD, Federal Statistical Office, Ifo-Institute, DIW calculations.

Imports of R&D Capital

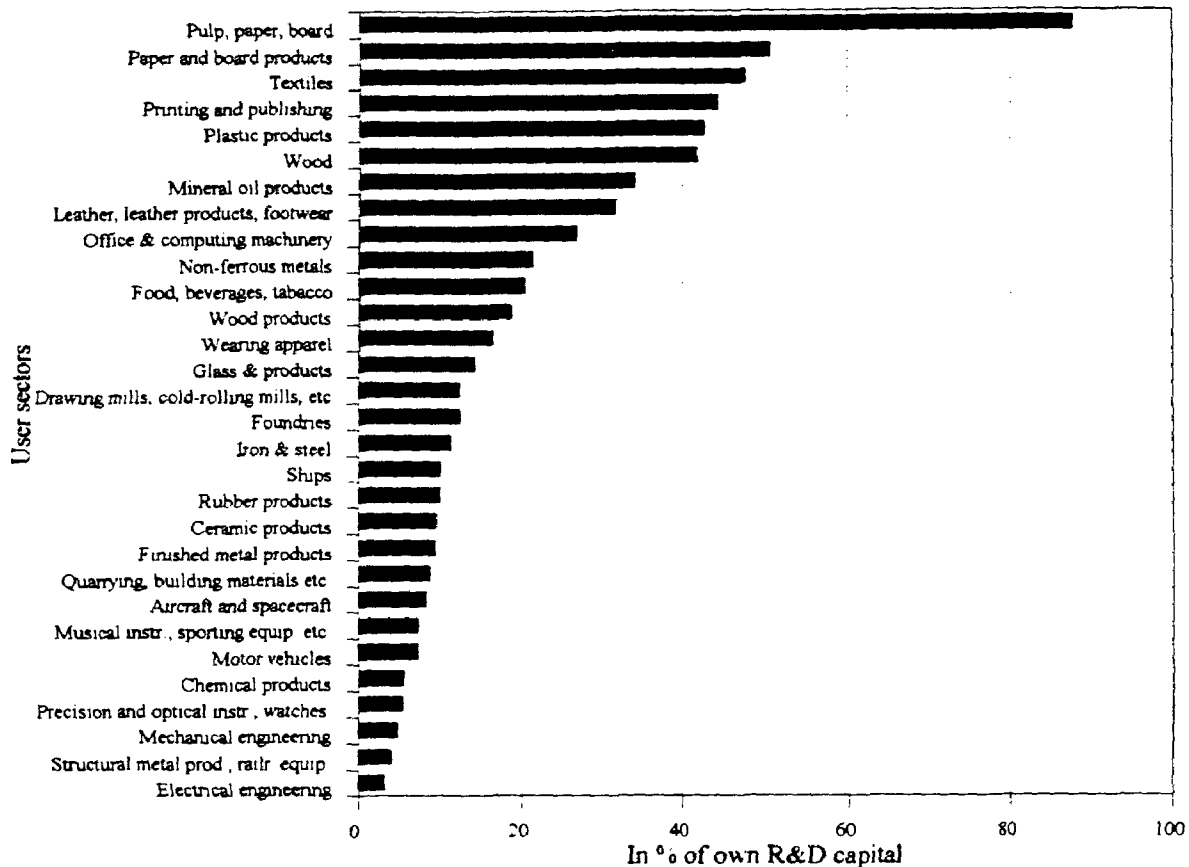
The stock of knowledge available within the Federal Republic of Germany is considerably enlarged by imports. R&D capital to the value of DM 50 billion entered the country in this way in 1990. Half went to production and half to final demand. Transfers from abroad thus represented about a quarter of the R&D capital from domestic transfers for production, and about one seventh for final demand (see Table 1). These R&D capital imports are a sign of the close integration of the Federal Republic in the international division of labour. To the extent that R&D capital imports weaken internal locational cohesion, structural change is induced, which might well be desirable as a means of increasing competitiveness. However, if such structural change meets with notable resistance, it can be to the disadvantage of a country's competitive position.

The trend is for sectors strongly dependent on domestic transfers to import a high proportion of R&D capital. R&D capital imports by the mineral oil and office and computing machinery sectors are above average. What is particularly noteworthy with these two product categories is that, in contrast to other sectors, imported R&D capital is almost as important as domestic transfers. This confirms the higher than average technological dependence of German office and computing machinery manufacturers on foreign sources (Diagram 4).

Domestic user sectors can make use of either domestic or foreign sources of knowledge. With regard to the locational cohesion of a sector, it is interesting to analyse this bilateral linkage, and to identify areas where domestic sources of knowledge supply dominate: the reciprocal locational pull between two sectors is presumably especially strong when the relevant transfers of embodied technical knowledge from individual product categories originate at home.

Moreover, the dependence of a production sector on a specific location presumably tends to be low if the structure of foreign knowledge supplies (by sectoral source) does not strongly differ from that of domestic knowledge supplies. This suggests that user sectors are comparatively indifferent to whether the knowledge they acquire is from domestic or foreign sources. Textiles and plastics come under this heading. In chemicals and aerospace, too, the structure of domestic supplies of R&D capital is hardly different from the structure of foreign supplies. In both of these areas, however, strong intrasectoral linkage points to a relatively high degree of locational cohesion.

DIAGRAM 4
TRANSFERS OF R&D CAPITAL FROM FOREIGN SOURCES



Sources: see Table 1.

For other product categories, by contrast, the sectoral structure of home and foreign sources of technical knowledge transfer is quite varied. Among this group of product categories we find, for example, office and computing machinery, precision and optical instruments, or food, beverages, and tobacco products. For these categories of product, locational ties must play a relatively big role, since the underlying production processes are generally difficult to relocate. Whether the domestic location offers advantages over the foreign one depends in its turn on the special character of intersectoral and intrasectoral technology linkage.

Domestic transfers of R&D capital to German industry as a whole originate primarily from two categories of product, chemicals and electrical engineering. Each of these sources contributes 30 per cent of transfers to German manufacturing (Table 3). With respect to imports, too, these product categories are by far the biggest technology suppliers. But while the amount of R&D capital imported via mechanical engineering products is disproportionately low in comparison to domestic sources, transfers via aerospace products and especially office and computing machinery is predominantly foreign in origin. German companies seek to obtain the technical knowledge that is transferred via these two product categories predominantly from abroad. Domestic sources are relatively insignificant.

TABLE 3

STRUCTURE OF R&D TRANSFERS IN SELECTED SOURCE SECTORS

Technology producers	Transfers to German industry from ...		Transfers by German industry to abroad
	dom. sources	abroad	
	- structure in %	- structure in vH -	- structure in vH -
Chemical products	31.0	31.6	24.8
Electrical engineering	28.0	24.7	26.2
Mechanical engineering	15.6	8.5	16.2
Motor vehicles	8.5	7.4	16.6
Iron & Steel	2.6	1.3	0.6
Aircraft and Spacecraft	2.3	8.3	6.6
Plastic products	1.6	0.8	0.7
Finished metal products	1.2	0.7	0.9
Structural metal products, railroad equipment	1.1	0.2	0.6
Drawing mills, cold-rolling mills, etc.	1.1	0.4	0.2
Non-ferrous metals, n.-f. semifinished products	1.0	1.7	0.5
Office & computing machinery	1.0	9.5	1.2
Rubber products	0.8	1.1	0.6
Precision and optical instruments, watches & clocks	0.6	1.1	1.6

Sources: Stifterverband für die deutsche Wissenschaft, OECD, Federal Statistical Office, Ifo-Institute, DIW calculations.

Foreign sources contribute close to a fifth of total transfers of R&D capital to German industry from home and abroad. In some product categories, however, foreign countries as principal technology producers strongly dominate the corresponding domestic sectors of origin (see Table 3, column 2).

In the case of office and computing machinery, this dominance of foreign sources is apparent across the board for all German user sectors. About two thirds of total R&D capital transfers via office and computing machinery to individual German industrial sectors come from abroad. The salience of foreign R&D capital transfers is just as marked in aerospace. Besides the fields already mentioned, mineral oil processing as well as plastics and rubber processing and precision engineering and the optical industry evidence a higher than average dependence on knowledge transfers from foreign sources.

The Export of R&D Capital

Foreign countries also profit from the R&D capital accumulated by German industry via the export of knowledge-intensive products. Exports of R&D capital are dominated by the four large R&D-intensive product categories chemicals, electrical engineering, mechanical engineering, and motor vehicles, which together represent about five sixths of total R&D capital exports. Especially the last two product classes named are much more strongly involved in exports than in domestic transfers. R&D capital transferred via products of the German precision engineering and optical industries and the German aerospace sector is proportionately more strongly represented on foreign markets than in domestic transfers. In the case of aerospace products, the transborder exchange of knowledge in both directions accordingly appears to play an important role. By contrast, knowledge transfers abroad by German office and computing machinery manufacturers is distinctly underrepresented (Table 3, column 3).

3.4 Refining the Approach

The studies done on the transfer of R&D capital so far (see among others Meyer-Krahmer and Wessels 1989, Sakurai, Wyckoff and Papaconstantinou 1993) assume, like the calculations presented here, that R&D transfers occur in proportion to the supply of goods. No differentiation in terms of user sectors is made. Gerstenberger (1991) has already pointed out that this assumption is unsatisfactory. If we take the example of ceramic products, it seems obvious that products for private consumption (porcelain, etc.) are relatively low in R&D intensity, whereas ceramic materials used in electrical engineering or motor vehicle construction are highly research-intensive. Traditional attribution methods overestimate the transfer of R&D capital to private consumption while underestimating transfers to manufacturing.

In order to eliminate this problem, both input-output tables and R&D statistics would have to provide a breakdown in greater depth. Gerstenberger's criticism thus concerns a general aggregation

problem. A first possible approach to eliminating the rigid proportionality assumption is to analyse the output structure of R&D-intensive and less R&D-intensive subcategories of a product class. If, for example, the particularly technology-intensive output of a sector flows into intermediate and capital goods rather than into private consumption, this must be taken into account in the transfer of R&D capital among user sectors. Kaiser and Münzenmaier (1995) show that the output structure of R&D-intensive areas of important sectors greatly differs from the output structure of less technology-intensive areas. This provides empirical confirmation for Gerstenberger's criticism and an important pointer towards improvement of the traditional approach. However, this method permits only more precise distribution to the intermediate inputs sector as a whole and to the three final demand components private consumption, investments and exports.

Within intermediate inputs linkage, information on the technical distance between sectors can be used as further pointers on the way to refining the sectoral transfer of technical knowledge. Jaffe (1986) uses this concept to weight R&D expenditures to form knowledge pools, which can then be used to measure unembodied knowledge transfers. The technological activities of a sector throw light on a technology profile reflecting the commitment of the sectors in various areas of application. If two sectors have very similar technology profiles, it can be assumed that the technical knowledge of one sector is particularly relevant for the other.

A variant of the concept of technical distance can be used as an additional weighting factor for embodied knowledge transfers: if the innovation activities of a source sector i concentrate on applications of the user sector j , the embodied knowledge from i is presumably of above-average relevance for j . Knowledge transfers from i to j must be more strongly weighted than is the case where proportionality is assumed.

Information on the (potential) application areas for sectoral innovation activities can be derived from patent data or special surveys on sectoral innovation behaviour. A patent matrix based on detailed analyses is available for the year 1983 (Greif and Potkowik 1990), which classifies patents by areas of origin and application. With the aid of such matrices, an approximate picture can be obtained of the spectrum of technological fields of activity in a sector.

A further important source of data for future studies of technological linkage is the innovation survey at present being conducted for the Federal Ministry of Research and Technology (see Harhoff and Licht 1993, Felder, Harhoff, Licht, Nerlinger, and Stahl 1994). The survey questionnaire contains a detailed section on technology transfer issues. Among other things, the significance of

various sources of technical knowledge (capital goods, intermediate inputs, foreign markets) are covered. However, information on the sectoral origin of the transferred knowledge is lacking.

4 Summary

The empirical findings on West Germany for the past decades are at first glance contradictory. High increases in real income per man-hour and high R&D expenditures in proportion to GNP confront declining specialization — measured against RCA or RWA values¹⁹ on high-tech products in foreign trade and a declining patent ratio. From a more comprehensive point of view, the contradiction is resolved: the application of high technology in all sectors of the economy also strengthens competitiveness in product categories not appearing on the list of technology-intensive products. This becomes clear only by taking account of intersectoral technology linkages. With the rise in technology intensity, these sectors also become stronger exporters, so that their still relatively low RCA and RWA values rise. In the case of West Germany, the consequent "levelling off" of the RCA and RWA pattern is likely also to mean that exporting strength is spread over a broader range of products accompanied by the use of low-priced imports.

On the whole, the technological performance of West Germany in the past is assessed as relatively good. This is particularly true when measured against important economic performance data such as income and productivity developments and terms of trade. It is, however, worrying that in recent times the Federal Republic has been slackening in its efforts to make provision for the future. Spending on R&D and education is declining in proportion to GNP, and the share of predominantly structure-conserving subsidies in total support continues to be high in comparison to subsidies affecting technology and structure innovation. These developments could mean that the Federal Republic of Germany is living increasingly on its capital and that its still comparatively good performance is gradually deteriorating, since such omissions in the field of technology make themselves felt at only a very late date. On the other hand, by restricting the study to West Germany, the nascent modernization in East Germany has been left out of account. This process provides an opportunity for increased competitiveness for the whole of Germany.

The proposed broad-scope reporting on technological competitiveness can offer a central orientation aid for long-term policy based on promoting investment in R&D and human capital, thus addressing the real basis for sustained growth. The dilemma that always presents itself from the short-term

¹⁹ Revealed Comparative Advantage values (relative export-import ratios) and Relative World Trade Advantage (relative export market shares).

perspective could thus be resolved. In phases of economic downturn, structural deficits become apparent, but it is difficult to mobilize the means to eliminate them. In periods of upswing the means could be more easily made available, but precisely in such times attention turns away from structural problems.

References

- Bollmann, P. (1990)
 Technischer Fortschritt und wirtschaftlicher Wandel. Eine Gegenüberstellung neoklassischer und evolutorischer Innovationsforschung (Wirtschaftswissenschaftliche Beiträge 20), Heidelberg.
- Bos, F., Hollanders, H., und Keuning, S. (1992)
 A Research and Development Module Supplementing the National Accounts, International Association for Research in Income and Wealth, 22nd General Conference, Flims, Switzerland, 1992.
- Cohen, W.M., und Levinthal, D.A. (1989)
 Innovation and Learning: The Two Faces of R&D, in: *The Economic Journal* 99, pp. 569-596.
- Cohen, W.M., und Levinthal, D.A. (1990)
 Absorptive Capacity: A New Perspective on Learning and Innovation, in: *Administrative Science Quarterly* 35.1, pp. 128-152.
- Dosi, G., und Soete, L. (1988)
 Technical change and international trade, in: Dosi, G., Freeman, C., Nelson, R., Silverberg, G., und Soete, L. (eds.), *Technical Change and Economic Theory*, London.
- Fagerberg, J. (1993)
 User-Producer Interaction, Learning and Comparative Advantage, NUPI-Working Paper Nr. 490, Oslo.
- Gehrke, B., und Grupp, H. (1994)
 Innovationspotential und Hochtechnologie. Technologische Position der Bundesrepublik Deutschland im internationalen Wettbewerb, Heidelberg.
- Gerstenberger, W. (1991)
 Zum Stellenwert von Technologieverflechtungsmatrizen, in: Oppenländer, K.-H. (ed.), *Beschäftigungswirkungen moderner Technologien*, Berlin, S. 99-109.
- Goto, A., und Suzuki, K. (1989)
 R&D Capital, Rate of Return on R&D Investment and Spillover of R&D in Japanese Manufacturing Industries, in: *The Review of Economics and Statistics* 71.4, pp. 555-564.
- Greif, S., und Potkowik, G. (1990)
 Patente und Wirtschaftszweige. Zusammenführung der Internationalen Patentklassifikation und der Systematik der Wirtschaftszweige, Köln.
- Griliches, Z. (1979)
 Issues in assessing the contribution of research and development to productivity growth, in: *The Bell Journal of Economics* 10.1, pp. 92-116.
- Griliches, Z. (1992)
 The Search for R&D Spillovers, in: *Scandinavian Journal of Economics: 1992 Supplement*, pp. 29-47.
- Griliches, Z., und Lichtenberg, F. (1984)
 Interindustry Technology Flows and Productivity Growth: A Reexamination, in: *Review of Economics and Statistics* 66.2, pp. 324-329.

- Grubel, H. (1977)
International Economics, Homewood, Ill.
- Grupp, H. (1994)
Spillover Effects and the Science Base of Innovations Reconsidered: An Empirical Approach, in: Journal of Evolutionary Economics (to be published).
- Grupp, H., und Schmoch, U. (1992)
At the crossroads in laser medicine and polyamide chemistry. Patent assessment of the expansion of knowledge, in: Grupp, H. (ed.), Dynamics of Science-Based Innovation. Berlin, Heidelberg.
- Hanel, P. (1993)
Interindustry flows of technology: An analysis of the Canadian patent matrix and input-output matrix for 1978-1989 (Paper presented at the International Input-Output Conference, Sevilla, March 29 - April 2, 1993).
- Harhoff, D., und Licht, G. (1993)
Das Mannheimer Innovationspanel, ZEW Discussion Paper Nr. 93-21.
- Harhoff, D., Licht, G. und Smid, M. (1994)
Innovationsverhalten der deutschen Wirtschaft. Ergebnisse der Innovationserhebung 1993, Mannheim.
- Kaiser, M., und Münzenmaier, W. (1995)
Technologische Verflechtungsstrukturen in Baden-Württemberg. Möglichkeiten und Grenzen eines Einbaus von FuE-Informationen in regionale Input-Output-Tabellen, in: Schnabl, H. (ed.), Technologische Verflechtung und wirtschaftlicher Wandel (to be published).
- Karabayashi, Y., und Matsuda, Y. (1989)
A Satellite Account Approach Applied to Research and Development: Japanese Data, Beitrag für die 21. Generalkonferenz der International Association for Research in Income and Wealth, Lahnstein, 20.-26. August 1989.
- Keck, O. (1993)
The National System for Technical Innovation in Germany, in: Nelson, R. R. (ed.), National Innovation Systems: A Comparative Analysis. New York, Oxford, pp. 116-157.
- Legler, H., Grupp, H., Gehrke, B., und Schasse, U. (1992)
Innovationspotential und Hochtechnologie. Technologische Position Deutschlands im internationalen Wettbewerb (Wirtschaftswissenschaftliche Beiträge 70), Heidelberg.
- Lundvall, B.A. (1988)
Innovation as an interactive process: From user-producer interaction to the national system of innovation, in: Dosi, G., Freeman, C., Nelson, R., Silverberg, G., und Soete, L. (eds.), Technical Change and Economic Theory, London.
- Meyer-Krahmer, F., und Wessels, H. (1989)
Intersektorale Verflechtung von Technologiegebern und Technologienehmern: Eine empirische Analyse für die Bundesrepublik Deutschland, Jahrbücher für Nationalökonomie und Statistik 206.6, S. 563-582.
- Minder, J.F., Rubel, N., und Muller, P. (1989)
The Research Account in France and its integration in the National Accounts, Paper presented at the 21st General IARIW-Conference, Lahnstein, Germany.

- Mohnen, P. (1990)
New Technologies and Interindustry Spillovers, in: STI-Review 7, pp. 131-147.
- Patel, P., und Pavitt, K. (1994)
The nature and economic importance of national innovation systems, in: STI-Review 14, pp. 9-32.
- Patel, P., und Soete, L. (1988)
Measuring the economic effects of technology, in: STI-Review 4, pp. 121-166.
- Pavitt, K. (1984)
Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory, Research Policy 13, pp. 343-374.
- Pavitt, K., und Patel, P. (1988)
The international distribution and determinants of technological activities, in: Oxford Review of Economic Policy 4.4, pp. 35-55.
- Porter, M.E. (1990)
The Competitive Advantage of Nations, London u.a.
- Sakurai, N., Wyckoff, A.W., und Papaconstantinou, G. (1993)
Technology Diffusion: Tracing the Flows of Embodied R&D in Eight OECD Countries, Paper presented at the International Input-Output Conference, Sevilla, March 29 - April 2, 1993.
- Scherer, F.M. (1982)
Inter-industry Technology Flows in the United States, in: Research Policy 11, pp. 227-245.
- Stahmer, C. (1986)
Integration der Input-Output-Rechnung in die internationalen Systeme Volkswirtschaftlicher Gesamtrechnungen, in: U.-P. Reich, C. Stahmer u.a., Internationale Systeme Volkswirtschaftlicher Gesamtrechnungen. Revision und Erweiterungen, Bd. 4 der Schriftenreihe Forum der Bundesstatistik, hrsg. vom Statistischen Bundesamt, Wiesbaden, S. 92-110.
- Sterlacchini, A. (1989)
R&D, innovations, and total factor productivity growth in British manufacturing, in: Applied Economics 21, pp. 1549-1562.
- Stoneman, P. (1983)
The Economic Analysis of Technological Change, Oxford.
- Straßberger, F., und Stäglin, R. (1994)
Zur Ermittlung von Technologiegeber- und Technologienehmerverflechtungen für die Bundesrepublik Deutschland, in: Schnabl, H. (ed.), Technologische Verflechtung und wirtschaftlicher Wandel (to be published).
- Terleckyj, N.E. (1980)
Direct and Indirect Effects of Industrial Research and Development on the Productivity Growth of Industries, in: Kendrick, J. W., Vaccara, B. N. (eds.), New Developments in Productivity Measurement and Analysis (Studies in Income and Wealth 44), Chicago and London, pp. 359-386.
- Wolff, E. N., und Nadiri, I.M. (1993)
Spillover Effects, Linkage Structure and Research and Development, in: Structural Change and Economic Dynamics 4.2, pp. 315-331.